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Stratix Report

Cost elements in the rollout of 5G networks in the Netherlands

REPORT

Report by Stratix,

in cooperation with
Judge Business School University of Cambridge,
Universidad Politécnica de Madrid,
Rabión Consultancy and Ascolo

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Management Summary in Dutch

De succesvolle introductie van GSM als tweede generatie mobiele netwerken in het laatste decennium van de vorige eeuw markeerde het begin van een snelle evolutie van mobiele technologie, met korte innovatiecycli van ongeveer een decennium per generatie. Na het succes van de vierde generatie (4G) mobiele communicatie (ook wel aangeduid met LTE, Long Term Evolution) die verbeteringen in mobiele breedbandprestaties en verdere globalisering heeft gebracht, staat de mobiele communicatietechnologie van de volgende en vijfde generatie (5G) nu voor de deur. De specificaties van de 5G-technologie zijn nog niet volledig ingevuld, maar de verwachtingen zijn hooggespannen als het gaat om de verbetering in prestaties, radiotoegangsmogelijkheden en efficiëntie en flexibiliteit van de netwerkarchitectuur.

De uitrol van 5G-netwerken vereist extra investeringen in de infrastructuur voor mobiele communicatie, als gevolg van de verdichting van antenne-opstelpunten. Deze verdichting is nodig om de celgrootte te verkleinen en daarmee de lage latency, grootschalige communicatie met machines en verbeterde mobiele breedbandsnelheden die 5G biedt te kunnen ondersteunen.

Van belang voor de uitrol van 5G is dat mobiele netwerkproviders over voldoende spectrumruimte beschikken. Hoewel er in Nederland verschillende frequentiebanden beschikbaar zijn gesteld aan netwerkproviders (450 MHz, 800 MHz, 900 MHz, 1800 MHz, 2100 MHz en 2600 MHz) worden in de komende jaren nieuwe spectrumtoewijzingen verwacht voor de 700 MHz, 26 GHz en mogelijk ook voor de 3,5 GHz-frequentieband (3,4 GHz - 3,8 GHz). Afhankelijk van de uitkomst van de ITU World Radio Conference 2019 (WRC-19) kunnen andere frequentiebanden worden toegevoegd.

Doel van de studie

Momenteel is de kennis en het inzicht in de financiële gevolgen van de uitrol van 5G en de verwachte verdichting van het radionetwerk beperkt. Het doel van deze studie is het in kaart brengen en analyseren van de kostenelementen die relevant zijn voor (passieve) infrastructuur, actieve netwerkelementen en energievoorzieningen voor de uitrol van mobiele netwerken gebruikmakend van mobiele communicatietechnologie van de vijfde generatie (5G). Daarnaast wil deze studie onderzoeken in hoeverre de bestaande infrastructuur voor deze uitrol kan worden gebruikt.

Onderzoeksvragen van het ministerie waren:

1. Hoe zal de verdichting van mobiele netwerken zich tot 2025 ontwikkelen? Besteed daarbij specifieke aandacht aan de ontwikkelingen in de backhaul- en edge-netwerken.

2. Welke regelgeving en procedures gelden voor de uitrol van onder meer small cells? Zijn hier belemmeringen te verwachten? Beschrijf de stappen in het proces om te komen tot plaatsing van small cells of andere vormen van netwerkverdichting. Maak in het bijzonder duidelijk in welke fasen van dat proces afhankelijkheid bestaat van (lokale) overheidsorganisaties of wet- en regelgeving.

3. In hoeverre dienen bestaande netwerken te worden uitgebreid? Geef inzicht hierin door een aantal casussen uit te werken, waaronder in ieder geval in een binnenstad alsook een in een ander gebied waar het verdichten van een netwerk waarschijnlijk is. Maak hierbij onderscheid tussen de netwerken van partijen die een accesnetwerken naar consumenten hebben (Vodafone, Ziggo en KPN) en andere mobiele partijen (Tele2, T-Mobile of een mogelijke toetreder). Beschrijf hierbij ook in hoeverre publieke netwerken kunnen voorzien in bepaalde elementen van de verdichtingsopgave.

4. Beschrijf welke type investeringen tot 2025 benodigd zijn in glasvezel of andere backhaul-technologieën alsook in actieve apparatuur en energievoorzieningen voor mobiele netwerken? Maak een inschatting van de ordegrootte van deze investeringen en ga hierbij in op:

a. Welke investeringen een mobiele netwerkaanbieder moet maken die reeds een vast aansluitnetwerk heeft.

b. Welke investeringen andere aanbieders van mobiele netwerken moeten maken

c. In hoeverre verbindingen van andere netwerkaanbieders (privaat en publiek) in deze behoefte kunnen voorzien. Ga hierbij specifiek in op netwerken die in publieke handen zijn, netwerken van alternatieve aanbieders en netwerken in handen van aanbieders met een vast netwerk.

Het algemene kostenmodel

De studie maakt gebruik van een kostenmodel dat is ontwikkeld door onderzoekers van de Universiteit van Cambridge (Verenigd Koninkrijk) en Universidad Politécnica de Madrid (Spanje). Het model werd eerder succesvol gebruikt om de kosten van de uitrol van 5G voor een hypothetische mobiele operator in het Verenigd Koninkrijk te berekenen, op basis van geografische schattingen van de celcapaciteit en de noodzaak om nieuwe locaties te bouwen. Het maakt gebruik van een combinatie van informatie over bestaande antenne-opstelpunten, gebruikersdichtheid in geografische gebieden, voorspelde gegevenssnelheden per gebruiker en toegewezen radiospectrum. De onderzoekers die aan dit model hebben gewerkt maakten deel uit van het Stratix-team voor de kostenmodelleringsstudie voor Nederland. Het kostenmodel zoals gedefinieerd voor het Verenigd Koninkrijk is aangepast om de uitrolscenario's voor het mobiele netwerk voor Nederland te analyseren.

Op basis van de onderzoeksvragen en de gesprekken met het Ministerie Van Economische Zaken en Klimaat zijn de volgende elementen gemodelleerd en specifiek geanalyseerd voor scenario's voor de Nederlandse 5G-kostenstudie:

1) Een minimale snelheid van 30 Mbps met een geografische dekking van 100%;
2) Een minimale snelheid van 100 Mbps met een geografische dekking van 100%;
3) Een minimale snelheid van 300 Mbps met een geografische dekking van 100%;
4) Verschil tussen een mobile-only provider en een vast-mobiele provider (biedt zowel toegang over vast als mobiel netwerk aan);
5) Beschikbare netwerkcapaciteit afhankelijk van geografische distributie van klanten

Op basis van de berekende uitkomsten van de gemodelleerde scenario's en varianten zijn ook de volgende elementen geanalyseerd en zijn waar mogelijk de kosten geschat:

6) Impact van beschikbaarheid van 3,5 GHz frequentieband (3,4 GHz - 3,8 GHz) voor heel Nederland;
7) Effect op de kosten van dekking van watergebieden zoals Markermeer.

Daarnaast is in parallel een kwalitatieve analyse uitgevoerd. Hierbij is niet specifiek gebruik gemaakt van een kostenmodel, maar waar mogelijk is de analyse wel mede geïnspireerd door ervaringen met de kostenberekeningsmethode voor 5G-netwerken in Nederland, en hielp het anderzijds om het model te checken en te verbeteren.

8) Kwalitatieve analyse van de mogelijkheid om gebruik te maken van backbone-installaties van overheids/gemeentelijke/vervoersorganisaties (variërend van landelijk naar lokaal glasvezelnetwerk langs spoorwegen, snelwegen etc.);
9) Kwalitatieve analyse van de effecten op extra kosten als gevolg van bouwvergunningen, milieuregelgeving, gemeentelijke regelgeving (gebaseerd op de nieuwe Omgevingswet).

Zoals hierboven uiteengezet, hebben operators in gevallen waarin een mobiel netwerk niet voldoet aan de groeiende vraag van klanten naar snelle mobiele dataconnectiviteit, verschillende mogelijke strategieën om hun netwerkcapaciteit uit te breiden. Deze omvatten het inzetten van nieuwe spectrumbanden op bestaande macrocelulaire basisstations, het inzetten van een small cell laag of een hybride strategie die beide opties combineert. Deze strategieen zijn weergegeven in Tabel 1.

Tabel 1: Overzicht van infrastructuurstrategieën

Infrastructuur strategie	Omschrijving
Strategie voor spectrumintegratie	Integreer alle beschikbare spectrum in de banden 700 en 1500 MHz en 3,5 GHz in het brownfield[1] macrocellulair netwerk.
Small Cell strategie	Implementeer een greenfield *small cell*-laag in TDD bij 3,7 GHz[2].
Hybride strategie	Integreer al het andere spectrum in het brownfield macrocellulaire netwerk (700 MHz, 1500 MHz, 3,5 GHz). Implementeer een greenfield *small cell*-laag in TDD bij 3,7 GHz.

De hybride strategie gaat uit van een rationele investeringsaanpak waarbij telecom operators eerst spectrum inzetten en als dit niet aan de capaciteitsdoelstellingen kan voldoen, dan zetten zij een *small cell* infrastructuurlaag op.

[1] Dit houdt in dat elke nieuwe softwarearchitectuur rekening moet houden met en moet bestaan naast live software die al aanwezig is.
[2] In theorie kunnen small cell lagen ook in andere frequentiebanden werken. Op basis van gesprekken met verschillende operatoren werd voor het model de 3,7 GHz-band gekozen als "gangbare praktijk" - benadering. Dit werd ook gepresenteerd en besproken in de workshop met de Nederlandse operatoren.

De Nederlandse telecommarkt

De Nederlandse telecommarkt bestaat uit drie belangrijke afzonderlijke markten: de mobiele markt, de vaste lijn voor consumenten en de zakelijke vaste lijn. Voor dit onderzoek is de mobiele markt de belangrijkste. Het bestaat uit 4 mobiele netwerkoperators: KPN, VodafoneZiggo, T-Mobile en Tele2[3]. Elk van deze operators is ook aanwezig op de markt voor breedband voor consumenten met vaste telefonie. KPN is eigenaar van een landelijk opererend koper- en glasvezelnetwerk met vaste lijnen. VodafoneZiggo is eigenaar van een bijna nationaal dekkend DOCSIS-netwerk. T-Mobile[4] en Tele2 bieden consumenten vaste netwerkdiensten aan op het netwerk van KPN. Daarnaast hebben KPN, VodafoneZiggo en Tele2 belangrijke zakelijke glasvezelverbindingen in het hele land. In de zakelijke glasvezelmarkt zijn er ook andere spelers zoals Eurofiber, Relined (die de glasvezelinfrastructuur van ProRail - het Nederlandse Spoorweginfrastructuurbedrijf- en Tennet- de Nederlandse hoogspanningsnetbeheerder- doorverkoopt), BT, Colt en diverse regionale spelers zoals Trent.
KPN en (de voorloper van) Vodafone waren de eerste twee GSM-aanbieders in Nederland, die in 1994 respectievelijk 1995 netwerken openden. De voorloper van T-Mobile kwam pas in 1998 op de markt als exploitant van 1800 MHz band. De propagatie, dat is de voortplanting van radiogolven, van deze 1800 MHz-band was aanzienlijk lager dan die van de 900 MHz-band. Daarom had T-Mobile met alleen deze band een groot aantal antennelocaties nodig om hetzelfde dekkingsniveau te bereiken. T-Mobile heeft nog steeds het grootste aantal antenne-opstelpunten in het land.

Tele2 betrad de mobiele markt in 2012 toen het een spectrumlicentie kocht. Het was al actief als MVNO, eerst op het netwerk van KPN, later op het netwerk van T-Mobile. Tele2 is ook actief als operator van vaste lijnen op KPN's netwerk en zakelijke glasvezelverbindingen op Tele2's eigen en op KPN's glasvezelnetwerk. Tele2 bouwt het 4G-netwerk uit met als doel een landelijke dekking, deels door sites en antennes te delen met T-Mobile, maar ook met een eigen backhaul en actieve radioapparatuur. Op 15 december 2017 kondigden Tele2 Group en Deutsche Telekom hun voornemen aan om hun respectievelijke dochters Tele2 Netherlands en T-Mobile Netherlands te willen samenvoegen tot één bedrijf.

[3] Terwijl deze studie werd uitgevoerd, kondigden T-mobile en Tele2 hun voorgenomen fusie aan.
[4] T-Mobile heeft de vaste consumentenmarkt in 2012 verlaten door zijn DSL-netwerk te verkopen aan Online. nl en trad in 2016 opnieuw toe tot de vaste consumentenmarkt toen het de vaste activiteiten van Vodafone kocht.

Tabel 2: Huidige spectrumtoewijzing per mobiele netwerkoperator (MNO) in Nederland

Band	KPN	Tele2	T-Mobile	VodafoneZiggo
800 MHz	2x 10MHz	2x 10MHz		2x 10MHz
900MHz	2x 10MHz		2x 15MHz	2x 10MHz
1800MHz	2x 20MHz		2x 30MHz	2x 20MHz
2100MHz	2x 19.8MHz		2x 20MHz	2x 19.6MHZ
2600MHz	2x 10MHz	2x 20MHz	2x 5MHz	2x 30MHz
2600MHz (un-paired)	1x 30MHz	1x 5MHz	1x 25MHz	

KPN, T-Mobile en VodafoneZiggo hebben het grootste deel van het beschikbare spectrum in handen, met name in de banden onder 2600 MHz, terwijl Tele2 slechts 20 MHz in deze banden heeft.

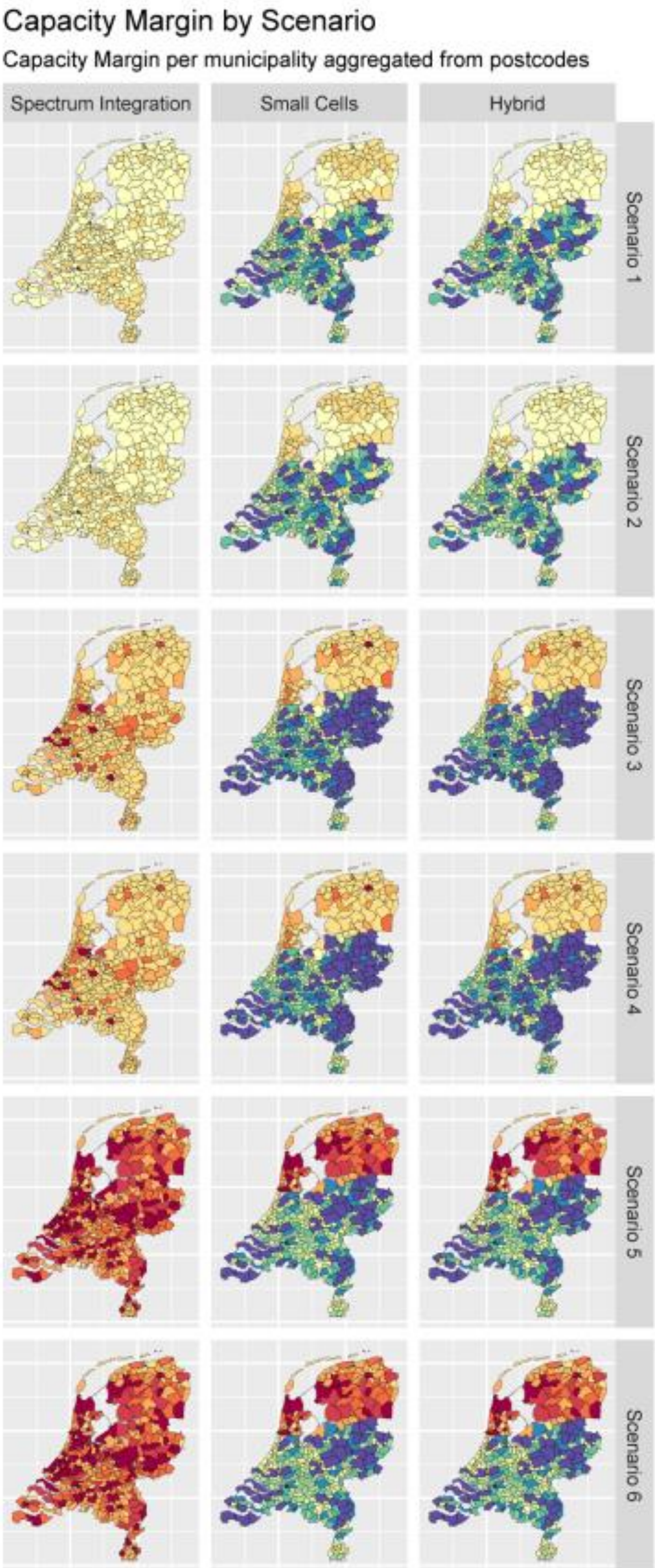
Resultaten en analyse

Het algemene kostenmodel voor 5G dat werd ontwikkeld door de Universiteit van Cambridge en de Universidad Politécnica de Madrid en dat eerder werd gebruikt om mogelijke uitrol scenario's in het Verenigd Koninkrijk te modelleren, bleek bruikbaar in de Nederlandse situatie en kon worden aangepast aan de geografie, de dichtheid van de gebruikers, antenne-opstelpunten en frequentieverdeling in Nederland voor een hypothetische operator. Het kostenmodel werd gebruikt om de investeringen voor 5G uitrol te berekenen volgens de verschillende strategieën die in Tabel 1 worden beschreven, voor 6 verschillende scenario' s. De scenario's weerspiegelen de gewenste landelijke dekking om een bepaalde downloadsnelheid (30 Mbps, 100 Mbps en 300 Mbps) per gebruiker te bieden in alle omgevingen, van zeer stedelijk tot zeer landelijk, voor twee soorten "hypothetische operators": (1) een operator die alleen een mobiel netwerk heeft en (2) een "vast-mobiel" operator die ook eigenaar is van een vast toegangsnetwerk naar klanten. Het bleek echter moeilijk om het verschil tussen een operator voor uitsluitend mobiel en een operator van vaste-mobiele netwerken te modelleren. Er zijn namelijk bij vast-mobiele operators grote verschillen tussen de toegangsnetwerken en hun technische en economische voordelen. Het model biedt slechts beperkte ondersteuning voor de berekening van dit verschil en lokale verschillen zijn moeilijk volledig te integreren in een algemeen model. Tabel 3 geeft een overzicht van de gemodelleerde scenario' s.

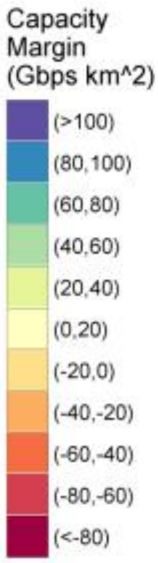
Tabel 3: Scenario overzicht

Scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Snelheid per gebruiker	30 Mbps	30 Mbps	100 Mbps	100 Mbps	300 Mbps	300 Mbps
Type operator	Mobile-only	Mobile-fixed	Mobile-only	Mobile-fixed	Mobile-only	Mobile-fixed

Het model berekent de uitrol van jaar tot jaar, beginnend met de bestaande situatie met betrekking tot antenne-opstelpunten, gebruikte frequentiebanden, etc. Het houdt ook rekening met factoren zoals (gemiddeld) maximaal beschikbare investeringslast per jaar. De resultaten geven inzicht in de technologische en economische implicaties, zoals het niveau waarop de uitrol de capaciteit die nodig is om de gewenste snelheid te ondersteunen voor het aantal gebruikers per km2 dat normaal gesproken in verschillende soorten gebieden aanwezig is, onder- of overtreft. Figuur 1 laat duidelijk zien dat' spectrumintegratie' in het geval van 30 Mbps al voldoende capaciteit biedt, behalve in sommige stedelijke gebieden. Middels de "small cells " en de "hybride" strategie kan in het hele land een aanzienlijke capaciteitsmarge worden bereikt.



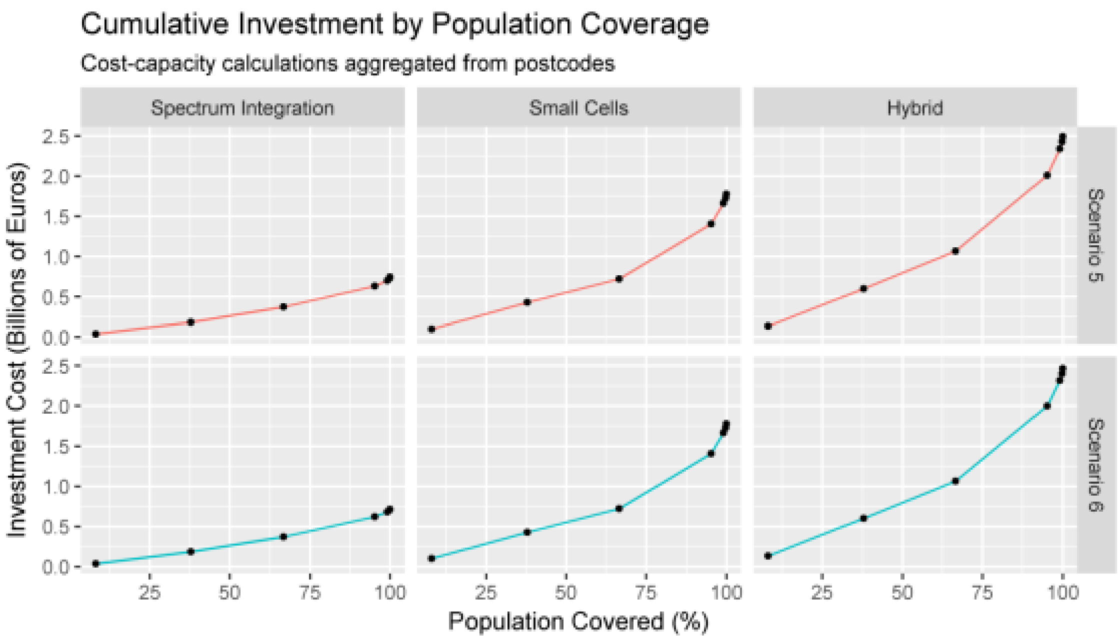
Scenario legend	Speed per user	Type of operator
Scenario 1	30 Mbps	Mobile-only
Scenario 2	30 Mbps	Mobile-fixed
Scenario 3	100 Mbps	Mobile-only
Scenario 4	100 Mbps	Mobile-fixed
Scenario 5	300 Mbps	Mobile-only
Scenario 6	300 Mbps	Mobile-fixed



Figuur 1: Verdeling van de capaciteitsmarge naar scenario en strategie

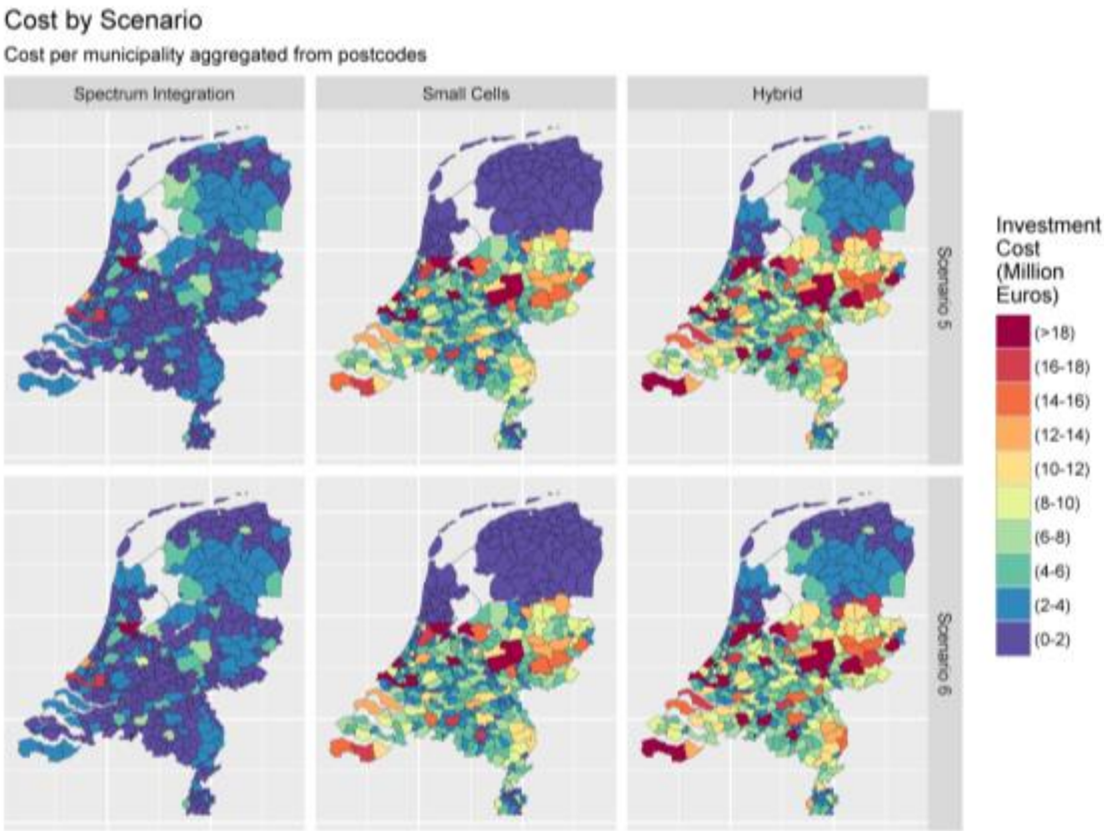
Voor de scenario's 3, 4 ,5 en 6 (100 Mbps en 300 Mbps) is het moeilijker om voldoende capaciteit te verkrijgen door alleen maar nieuw spectrum in de bestaande macronetwerken te integreren ("spectrumintegratie"). Met de "small cells " en "hybride" strategieën kan wél een aanzienlijke capaciteitsmarge worden bereikt door de 3,7 GHz-frequentieband te gebruiken voor de uitrol van "small cells". Voor grotere bandbreedtes is een strategie met small cells echt nodig om de beoogde resultaten te leveren; deze "small cells" dragen meer bij aan de capaciteitsmarge dan spectrumintegratie doet. Dit brengt wel kosten met zich mee.

De grafieken in Figuur 2 tonen de cumulatieve kostencurves over strategieën en scenario's heen. Ze bieden zeer nuttige inzichten om de investeringen te beoordelen die nodig zijn om een bepaald niveau van dekking van de bevolking te bereiken. Merk wel op dat de celcapaciteit sterk kan verschillen per geotype, scenario en strategie. Wanneer we kijken naar de kosten voor het leveren van dit resultaat zien we dat het inzetten van kleinere cellen kostbaar is, vooral bij het aanbieden van dekking voor meer dan 75% van de populatie. Maar we zien ook dat een hybride scenario niet goedkoper is dan een scenario met alleen “small cells” en bijna geen extra capaciteitsmarge oplevert.



Figuur 2: Kostencurves per scenario en strategie voor scenario 5 (300 Mbps, operator alleen mobiel) en scenario 6 (300 Mbps, operator vast mobiel)

Figuur 1 en ook de geografische kostenverdeling in Figuur 3 laten duidelijk een afbakening zien die Nederland in tweeën verdeeld, ruwweg de lijn Amsterdam – Zwolle. Ten noorden van deze lijn is het gebruik van de 3,5 GHz-frequentieband (3,4 GHz - 3,8 GHz) momenteel verboden, wat in het model is meegenomen.



Figuur 3: Geografische verdeling van de kosten per gemeente voor scenario 5 (300 Mbps, operator alleen mobiel) en scenario 6 (300 Mbps, operator vast mobiel)

Overwegingen inzake hergebruik van andere netwerken

Het hergebruik van andere netwerken (nutsvoorzieningen, openbaar en soms particulier) wordt overwogen als een manier om de uitrol om vast en mobiel breedband te bevorderen. De Europese Unie heeft een richtlijn aangenomen om de uitrol van dergelijke netwerken te bevorderen (Richtlijn 2014/61/EU). De richtlijn citerend:

"Deze richtlijn dient niet alleen van toepassing te zijn op aanbieders van openbare communicatienetwerken, maar ook op alle eigenaren of houders van gebruiksrechten, in het laatste geval onverminderd de eigendomsrechten van derden, uitgebreide en alomtegenwoordige fysieke infrastructuurvoorzieningen die geschikt zijn voor het hosten van elementen van elektronische communicatienetwerken, zoals fysieke netwerken voor de levering van elektriciteits-, gas-, water- en rioleringssystemen, verwarming en vervoersdiensten".

Nederland voert momenteel deze richtlijn uit. Het nut van deze 'nutsinfrastructuur' voor breedband en 5G in Nederland hangt echter af van twee elementen. Ten eerste de manier waarop deze infrastructuur beschikbaar is en ten tweede de eigenschappen van 5G. In Nederland is dit soort infrastructuur soms beschikbaar voor vaste en mobiele telecombedrijven. Zo zijn er bijvoorbeeld gevallen geweest waarin telecomoperatoren hun graafwerkzaamheden met Rijkswaterstaat konden coördineren of toegang tot bestaande kanalen konden kopen. Infrastructuren van het Nederlandse spoorbedrijf Pro-Rail en hoogspanningselektriciteitsnet Tennet zijn beschikbaar via commercieel bedrijf Relined. Daarnaast zijn er mogelijkheden geweest voor telecombedrijven om hun antennes te plaatsen op vaste infrastructuren, zoals op portalen over snelwegen.

Voor 5G echter zal dit soort nutsinfrastructuur waarschijnlijk minder nuttig zijn. De benodigde verdichting betekent dat niet zozeer de nationale of regionale backbone, maar de laatste honderd meter, de lokale ringen en uitbreidingen, extra investeringen vereisen. Op dit laatste deel is er geen infrastructuur voorhanden die gemakkelijk kan worden gedeeld. Dit in tegenstelling tot andere EU-landen waar gemeenten of nutsbedrijven betonnen kanalen hebben om elektriciteitskabels, waterleidingen en riolen te huisvesten, die kunnen worden hergebruikt. Als een operator naar een locatie moet uitrollen, betekent dit dat hij toegang moet hebben tot bestaande *ducts* die eigendom zijn van de operator zelf of van zijn concurrenten. Zijn deze *ducts* niet aanwezig, dan moeten ze aangelegd worden. Gemeenten proberen deze werken te coördineren en kunnen eisen dat degenen die willen graven dit in samenwerking doen, zodat in dezelfde straat niet meerdere malen per jaar gegraven wordt. De meeste nutsinfrastructuur is echter al aanwezig en op korte termijn wordt niet verwacht dat er naast telecom ook nieuwe infrastructuur zal worden gebouwd[5].

Dit betekent echter niet dat eigenaren van infrastructuur niet kunnen helpen bij het verdichten van 5G netwerken. Vooral voor “small cell” capaciteit kan hergebruik van lokale vaste objecten zoals straatverlichting en gebouwen nuttig zijn. Er zijn al proeven om antennes te integreren in lantaarnpalen. Andere objecten die in aanmerking kunnen komen zijn bushaltes, verkeerslichten, reclamelocaties, enzovoort. Bushaltes, verkeerslichten en reclamelocaties kunnen gekozen worden vanwege esthetische overwegingen, ze zijn namelijk handig voor het uit het zicht plaatsen van antennes. Dat zal echter niet tot directe kostenbesparing leiden. In vergelijking met het plaatsen van een normale antenne kunnen de coördinatiekosten immers stijgen; wellicht is de vergunningaanvraagprocedure wel weer eenvoudiger.

Overwegingen met betrekking tot regelgevingskwesties

De uitrol van 5G zal een positieve bijdrage leveren aan de digitale connectiviteit in steden en Nederland als geheel en zal daarmee bijdragen aan de positie van Nederland als digitale koploper. Regelgeving kan de uitrol van mobiele netwerken bevorderen of schaden. Het vinden van een locatie om een antenne te plaatsen en het ontvangen van de benodigde vergunningen van gemeenten voor de antenne en het backhaul netwerk zijn een punt van zorg. Regelgeving omtrent straling lijken in Nederland een minder groot obstakel.

Er zijn verschillende nationale wetten die relevant zijn voor de uitrol van een telecomnetwerk. De Nederlandse Telecomwet bevat verschillende artikelen over de aanleg van netwerken. Andere relevante wetten zijn die op het gebied van ruimtelijke ordening, bouw en milieu, aangezien ze invloed hebben op wat, waar en hoe gebouwd kan worden. Ook wetten op

[5] In de toekomst zal er wellicht geïnvesteerd worden in nieuwe vormen van energienetwerken, om gasnetwerken te vervangen ten behoeve van de energietransitie, maar dat zal waarschijnlijk buiten het tijdsbestek van 2025 van dit onderzoek vallen.

het gebied van erfgoed kunnen van belang zijn als een antenne op of nabij historische gebouwen wordt geplaatst of als de plaatsing ervan van invloed is op het zogenaamde "beschermd dorpsgezicht". De twee belangrijkste nationale wetten waarmee bij de uitrol van mobiele netwerkinfrastructuur rekening moet worden gehouden, zijn de volgende:

1. De Nederlandse **Telecommunicatiewet** beschrijft twee elementen van de aanleg van netwerken:

- Aanleg van kabels: Hoofdstuk 5 stelt dat eigenaren van openbare terreinen de aanleg van telecommunicatienetwerken op hun terrein moeten toestaan (gedoogplicht).
- Bouw van antennesites: Artikel 3.24 van de Telecommunicatiewet bepaalt dat exploitanten antennelocaties, indien mogelijk, op verzoek van een andere exploitant moeten delen.

Voor de eigenaren van netwerken biedt dit de mogelijkheid om hun antennesites uit te rollen en garandeert het de mogelijkheid om bestaande antenne-infrastructuren te gebruiken. Voor de aanleg van kabels is nog steeds een vergunning nodig. Voor de bouw van antennes is de vergunningsplicht gebaseerd op de Wet Milieuvergunningen en een het Antenneconvenant tussen de overheid en telecomoperators.

2. De **Wet Milieuvergunningen (Wabo)** regelt de bouw van antenne-opstelpunten hoger dan 5 meter. Onder 5 meter hoog kan gebouwd worden zonder vergunning, behalve als er gebouwd wordt op of rond beschermde historische objecten of beschermd stads- of dorpsgezicht. Om uitrol zo goed mogelijk te coördineren en maatschappelijke zorgen weg te nemen, wordt in het Antenneconvenant aangegeven hoe dit gebeurt.

Hoewel er nationale regelgeving en afspraken zijn over de uitrol van nieuwe antenne-opstelpunten, zijn er nog steeds lokale aanpassingen. Daarnaast hebben gemeenten het recht om specifieke wetgeving aan te nemen met betrekking tot leges, precario, graafdieptes, enzovoort. Dit verhoogt de kosten en vertraagt een grootschalige uitrol van het 5G-netwerk vertraagt.

Wetten die betrekking hebben op gebouwen, monumenten, het milieu, ondergrondse infrastructuur kunnen een effect hebben op de plaatsing van antennes. Er is momenteel een herziening gaande om de wetten inzake milieu en ruimtelijke ordening te herzien. De nieuwe wet is bedoeld om een lappendeken van wetten te vervangen door één uniform regelgevend kader. In de huidige opzet zal de wet 15 bestaande wetten vervangen, waaronder de Waterwet, de Crisis- en Herstelwet en de Ruimtelijke Ordening. De bepalingen van acht andere wetten worden overgebracht naar de Wet Milieu en Ruimtelijke Ordening. Het nieuwe wetsvoorstel is door beide kamers van het parlement goedgekeurd. Het kabinet is nu bezig met het opstellen van inleidende wetgeving. De verwachting is dat de wet in 2021 in werking zal treden.

Twee voordelen van de nieuwe wet die relevant zijn voor de 5G verdichting zijn naar verwachting:

- *Eén loket "voor burgers en bedrijven*
  Als burgers of bedrijven een project willen realiseren, kunnen ze een (digitale) vergunning aanvragen bij één loket. De gemeente of provincie neemt dan een beslis-

sing. Zijn zij beiden verantwoordelijk voor de beslissing? Hoe dan ook, slechts één zal de beslissing nemen. Dit vereenvoudigt de zaken voor de aanvrager en versnelt de vergunningaanvraagprocedure.

- *Bedrijven hoeven minder onderzoeken uit te voeren*
  Om een vergunning te krijgen voor een project op het gebied van ruimtelijke ordening, bouw en aanleg moeten bedrijven onderzoeken uitvoeren (bijvoorbeeld een bodemonderzoek). Met de Wet Milieu en Ruimtelijke Ordening blijven onderzoeksgegevens langer geldig. Dit vergemakkelijkt het hergebruik van gegevens. Bovendien zullen sommige onderzoeksverplichtingen worden afgeschaft en dat betekent lagere kosten.

Men zou verwachten dat dergelijke voordelen door de mobiele netwerk operators worden toegejuicht. Er bestaat echter enige scepsis over de vraag of de wet daadwerkelijk haar belofte van vereenvoudiging zal kunnen waarmaken; de wet laat gemeenten nog steeds veel vrijheid en juist deze individuele aanpak van gemeenten vormt de grootste bron van kosten en complicaties.

Gebouweigenaren kunnen het moeilijk maken om bestaande huurovereenkomsten uit te breiden en nieuwe locaties te vinden, hetgeen momenteel een schaarste aan locaties voor antennes en masten lijkt te creëren. Bovendien zijn sommige gemeenten soms niet erg coöperatief wat betreft de ontwikkeling van meer locaties voor antennes en zendmasten of leggen zij aanvullende en beperkende voorwaarden op, bijvoorbeeld op grond van visuele geschiktheid of gezondheid. Het vinden van de (grote aantallen) locaties die nodig zijn voor de grootschalige uitrol van 5G zal uitdagend zijn, hoewel de trend naar kleinere apparatuur en kleinere antennes op lagere posities deze uitdaging enigszins kan verlichten.

Op basis van het uitgevoerde onderzoek en de uitkomsten van het model kunnen een aantal conclusies worden getrokken:

30Mbps is haalbaar middels spectrumintegratie; voor hogere snelheden zijn aanzienlijke investeringen nodig.

De nieuwe frequentiebanden die in 2020 beschikbaar komen en de huidige antenne-opstelpunten zijn voldoende om 30 Mbps te leveren. Voor het bieden van een bandbreedte van 100 Mbps als doel, is een uitrol van "small cells" nodig om de benodigde dekking en celcapaciteit te kunnen bieden. Een doelstelling van 300 Mbps is alleen te realiseren met een jaarlijks investeringsbudget dat veel hoger ligt dan wat momenteel gebruikelijk is. Ook zou dit doel een uitgebreide combinatie van spectrumintegratie en celverdichting vereisen.

Het model laat zien dat, voor een hypothetische mobiele operator met 30% marktaandeel, het leveren van 30 Mbps op elke locatie in Nederland aan klanten kan worden gerealiseerd door 0,75 tot 1,5 miljard euro te investeren in de uitrol van 5G en bijbehorende integratie van nieuwe frequentiebanden, afhankelijk van de gebruikte uitrolstrategie. Voor hogere doelen (100 Mbps en 300 Mbps) laat het model zien dat het in Noord-Nederland moeilijk is om op elke locatie voldoende celcapaciteit te realiseren. Dit is voornamelijk te wijten aan het feit dat in het noordelijke deel van het land de 3,5 GHz-frequentieband (3,4 GHz - 3,8 GHz) niet kan worden gebruikt terwijl het model deze frequenties gebruikt voor zowel het vergroten van capaciteit in het macro-netwerk als ook de uitrol van small cells. In de rest van Nederland, waar het model ervan uitgaat dat de 3,5 GHz frequentieband (3,4 GHz - 3,8 GHz) wordt gebruikt, zijn de capaciteitsmarges voor de kleine cel- en hybride strategieën voldoende, zelfs voor de hogere doelen (100 Mbps en 300 Mbps). In het theoretische geval dat de 3,5 GHz-frequentieband (3,4 GHz - 3,8 GHz) in heel Nederland bruikbaar zal zijn, waarbij de kosten voor heel Nederland voor een hypothetische operator ruwweg worden geëxtrapoleerd, zou een uitrol van 5G met 300 Mbps aan klanten mogelijk zijn voor ongeveer 5 miljard euro per operator.

Een vast-mobiele operator heeft een beperkt voordeel ten opzichte van een 'alleen mobiele' operator bij het uitbreiden en verdichten van zijn mobiele netwerk.

In theorie beschikken vast-mobiele operatoren over een uitgebreidere backbone en backhaul netwerk dat ze ook kunnen gebruiken voor hun mobiele backhaul netwerk. In Nederland hebben mobiele operators echter een uitgebreid glasvezelnetwerk opgebouwd en daarom zullen slechts voor een klein deel van de locaties backhaul upgrades of de aanleg van meer glasvezelverbindingen nodig zijn. Op de meeste locaties in Nederland bestaat de mogelijkheid om zakelijk glasvezeltoegang te verkrijgen van 'andere vergunninghoudende operators' (other licensed operators of OLO's) om nieuwe locaties en/of "small cells" aan te sluiten. Veel van de bestaande antenne-opstelpunten zijn gedeelde locaties met glasvezelnetwerken. Het is waarschijnlijk dat commerciële glasvezelnetwerken hun netwerken ook zullen uitbreiden tot nieuwe gedeelde antenne-locaties. In steeds meer situaties kunnen nieuwe "small cells" ook gebruik maken van bestaande netwerkaansluitingen voor bedrijven of consumenten, vooral wanneer glasvezeltoegang al aanwezig is. Op basis van de in Nederland geldende toegangsregeling (zoals in de meeste lidstaten van de Europese Unie) kan een antenne-opstelpunt (bijvoorbeeld een "small cell") gebruik maken van het toegangsnetwerk van een concurrerende operator in het pand van een klant door ontbundelde breedbanddienst in te kopen. Als alternatief kan ook een locatie worden aangeboden die "over the top" op bestaande breedbanddiensten kan worden aangesloten. In de toekomst zullen veel factoren van invloed zijn op het relatieve voordeel van de vast-mobiel geconvergeerde operator. Hieronder volgen enkele voorbeelden:

- Lagere prijzen van femto-apparatuur ("small cells');
- Nieuwe methoden voor netwerkplanning;
- Nieuwe methoden om het gebruik van toegangsnetwerken voor 5G backhaul te vergemakkelijken; en
- Discussies, interpretaties of regelgevingstrends met betrekking tot netneutraliteit en waar het demarcatiepunt van een toegangsnetwerk zich zou moeten bevinden.

Belangrijkste kostencomponenten van 5G uitrol onafhankelijk van scenario

De belangrijkste kostencomponenten voor de twee meest verschillende strategieën die in Table 1 worden beschreven zijn:

- **Spectrumintegratie**: ongeveer 80% van de kosten bestaat uit macro RAN-apparatuur, waarbij grote civiele werken slechts ongeveer 20% van de totale kosten uitmaken;
- **"Small cells"**: ongeveer 84% van de kosten zijn "small cells" civiele werken, waarbij het materiaal, de werkelijke "small cells" slechts ongeveer 16% van de kosten uitmaken.

5G-netwerken zullen zo fijnmazig moeten zijn dat de economische voordelen van de uitrol waarschijnlijk niet zullen leiden tot vier volledig overlappende toegangsnetwerken met dezelfde dekking en capaciteit. Het is dus zeer waarschijnlijk dat ten minste de backhaul voor “small cells” zal worden gedeeld of uitbesteed aan bedrijven die gespecialiseerd zijn in het leveren van glasvezel- of mmWave-verbindingen om te dienen als backhaul voor 5G ‘small cells”. Of dit in de praktijk zal gebeuren en of overheidsingrijpen nodig is, is nog onzeker.

De beschikbaarheid van de 3,5 GHz-frequentieband (3,4 GHz - 3,8 GHz) zal voor de volgende generatie mobiele netwerken van groot belang zijn.

Door beperkingen van de overheid maken de “small cells” die al in Nederland worden ingezet over het algemeen geen gebruik van de 3,5 GHz frequentieband (3,4 GHz - 3,8 GHz). Als deze frequentieband in de toekomst niet beschikbaar zal zijn, zal het moeilijker worden om nog meer kleine cellen in te zetten. Zonder deze frequentieband is de enige manier om de bestaande capaciteit te vergroten het verdichten van het macrocell-netwerk. Het kostenmodel dat we gebruiken, bevat dit scenario op dit moment niet, aangezien dit geen aannemelijk scenario is.
Macrocelverdichting stelt ons voor grote uitdagingen omdat het nog moeilijker is om nieuwe locaties voor macrocellen te vinden, mobiele netwerken in West-Europese landen zijn immers al zeer verdicht. Indien door spectrumbeperkingen macrocellulaire verdichting echter de enige beschikbare strategie is om tegemoet te komen aan de vraag van de Nederlandse operators, dan zullen er nog meer inspanningen gedaan moeten worden om de toegang tot locaties te vergemakkelijken die als macrocellocatie kunnen dienen (publieke faciliteiten, etc.). Daarnaast zal het leveren van bandbreedtes van 100 of 300 Mbps per gebruiker in het geval er genoeg macrocell locaties beschikbaar zijn, nog steeds (zeer) uitdagend zijn.

Overheden kunnen de kosten van civiele werken beïnvloeden, maar niet de kosten van Macro RAN.

De kosten voor de upgrade van Macro RAN zijn aanzienlijk, maar de markt voor deze apparatuur is een commerciële en concurrerende markt, zodat overheden deze kosten op beperkte schaal kunnen beïnvloeden. De kosten voor ‘small cells” civiele werken zijn zeer hoog en omdat er geen standaardisering is in de omstandigheden waaronder straatmeubilair toegankelijk is, noch standaardisering van mogelijke extra kosten voor lokale gemeenten, lopen de kosten sterk uiteen.

De beschikbaarheid van andere landelijke netwerken (nutsvoorzieningen, openbaar en particulier) heeft weinig invloed op 5G-investeringen. Het gebruik van regionale en gemeentelijke netwerken is essentieel, maar er zijn ook problemen

De lokale aanwezigheid van bestaande en commerciële glasvezel backhaul netwerken in Nederland is relatief hoog. Slechts in een beperkt aantal gevallen zijn landelijke netwerken aanwezig in gebieden waar andere netwerken niet aanwezig zijn. De kans dat exploitanten van mobiele netwerken gebruik willen maken van andere netwerken is relatief klein. Op lokaal niveau kunnen er gevallen zijn waarin lokale glasvezelnetwerken in overheidsbezit zeer interessant kunnen zijn voor operators van mobiele netwerken, maar economische, organisatorische en procedurele uitdagingen kunnen in de weg staan. In veel gevallen geven operators er de voorkeur aan hun eigen glasvezelnetwerk te bouwen en te implementeren, of Managed Ethernet Services (MES) of Managed Dark Fiber Services (MDFS) te gebruiken die door commerciële operators worden aangeboden.

Versnipperde regionale regelgeving kan grote gevolgen hebben voor de organisatiekosten en de inspanningen van de operators.

De regelgeving voor de uitrol van netwerken is gefragmenteerd. De nieuwe Omgevingswet is gericht op het creëren van een one-stop-shop, wat gunstig is, maar de implementatie blijft echter op lokaal niveau. MNO's (mobiele netwerk operators) zullen nog steeds geconfronteerd worden met gemeenten die geen antennes op de gevels van gebouwen toestaan, verschillen in graafkosten toepassen, verschillende regels voor het herbergen van antennes toepassen en de verlening van de vergunningen door meerdere afdeling binnen de gemeente laten gaan.

De meeste mensen willen een goede mobiele dekking en uitstekende connectiviteit, maar tegelijkertijd willen velen om verschillende redenen liever niet in de nabijheid van mobiele antenne-opstelpunten wonen. Dat is paradoxaal, want kleinere cellen kunnen zelfs een oplossing zijn voor de redenen die mensen noemen. "Small cells" gebruiken over het algemeen lagere elektromagnetische veldsterkten dan grotere netwerkcellen en voor "small cells" kunnen kleinere antennes op lagere hoogten worden geplaatst. Gemeenten spelen een belangrijke rol bij het omgaan met deze afwegingen door de manier waarop zij hun lokale regelgeving voor het plaatsen van antennes structureren.

Management Summary

Since the successful introduction of GSM as the second-generation mobile network in the last decade of the twentieth century, mobile technologies have continued evolving on a decadal basis. After the success of the fourth generation (4G) of mobile communications, also known as LTE, or Long Term Evolution, and following the improvements in mobile broadband performance and the further globalisation this has brought, the next and 5th generation (5G) mobile communication technology is now on the horizon. The specifications of 5G technology have not yet been fully completed, but expectations are high for the improvement that they can deliver in service performance, radio access capabilities and flexibility of the network architecture.

The deployment of 5G networks will require additional investments in mobile communication infrastructure, due to the densification of radio network sites needed to obtain smaller cell sizes and to be able to support the ultra-reliable low latency, massive machine type communication and enhanced mobile broadband rates that 5G will provide.

Of importance for the deployment of 5G is that mobile network providers have sufficient spectrum resources available. While several spectrum ranges have been made accessible to network providers in the Netherlands (450 MHz, 800 MHz, 900 MHz, 1800 MHz, 2100 MHz and 2600 MHz) new allocations of spectrum are expected in the 700 MHz. 26 GHz, and potentially for the 3.5 GHz frequency band (3.4 GHz – 3.8 GHz) in upcoming years. Depending on the outcome of the ITU World Radio Conference 2019 (WRC-19), other frequency bands may be added.

Objective of the Study

Currently, there is limited knowledge and understanding of the financial impacts of the rollout of 5G and the expected densification of the radio network. The objective of the study is to identify and analyse the cost elements that are of relevance in (passive) infrastructure, active network elements and power facilities for the rollout of mobile networks making use of fifth generation (5G) mobile communication technology. In addition, the study aims to analyse to what extent existing infrastructure can be used for this roll out. Questions of the ministry for the study were:

1. How will densification of antenna sites in mobile communication networks progress until 2025, and what will be the developments in backhaul networks and edge networks?
2. Which rules and regulations are applicable for the rollout of small mobile network cells particularly, and which restrictions may be expected? A description should be made of the process and steps towards the deployment of the densified mobile communication network by using small cells or alternative technologies for coverage of the mobile network. It should be addressed specifically which phases in the process of the rollout are depending on law and regulation, and national and municipal authorities.
3. To what extent does the installed base of mobile communication need to be expanded? Several scenarios will need to be investigated including in dense urban areas, and by distinguishing between mobile network providers that are 'mobile only', and mobile network providers that are also deploying access networks to fixed customers. The study should

address to what extent public fibre transmission networks are able to contribute to the densification of the mobile networks for the rollout of the 5G technology.

4. The study should describe the cost elements and the order of magnitude of investments required until 2025 for each of these cost elements (fibre and backhaul technology, active radio equipment, power facilities). This should lead to a range of the level of investments required, whereby specific attention should be paid to:
   a) The investments of a fixed mobile converged network operator;
   b) The investments of a mobile-only network provider;
   c) Whether or not backhaul capacity owned by third parties (public organisations, private (non-telecom?) companies and fixed network providers can be used for 5G rollout and cell densification.

The General Cost Model

The study makes use of a cost model developed by researchers from the University of Cambridge (United Kingdom) and Universidad Politécnica de Madrid (Spain). The model was previously successfully used to calculate the costs of the 5G rollout for a hypothetical mobile operator in the UK, based on geographical estimations of cell capacity and the need to build new sites. It uses a combination of information on existing antenna sites, user density in geographical areas, estimated data rates per user, and available radio spectrum. The researchers that have worked on this model were part of the Stratix team for this cost modelling study for the Netherlands. The cost model as defined for the United Kingdom has been further amended and customised in order to analyse the mobile network rollout scenarios for the Netherlands.

Based on the research questions and the discussions with the Ministry the following elements were modelled and analysed specifically for scenarios for the Netherlands' 5G cost study:

1) A minimum service level of 30 Mbps with a geographic coverage of 100%;
2) A minimum service level of 100 Mbps with a geographic coverage of 100%;
3) A minimum service level of 300 Mbps with a geographic coverage of 100%.
4) Difference between a Mobile-only carrier and a Fixed-Mobile carrier (Fixed and Mobile access);
5) Available network capacity dependent on geographic distribution of customers;

Based on the calculated outcomes of the modelled scenarios and variants, the following elements were also analysed, and costs were estimated where possible:

6) Impact of availability of 3.5 GHz frequency band (3.4 GHz – 3.8 GHz) for the entire geography of the Netherlands;
7) Impact of coverage of water areas such as Markermeer.

Additionally, in parallel, a qualitative analysis of the following elements was carried out. As such not based on a modelling method, but wherever possible linked to and inspired by, the cost calculation method for 5G networks in the Netherlands:

8) Analysis of the opportunity to make use of backbone facilities from government/municipal/transport organisations (varying from countrywide to local fibre network along railways, motorways etc.);

9) Qualitative analysis of the effects on additional costs due to building permits, environmental regulation, municipal regulation (based on the new 'Omgevingswet').

As explained above, in the cases where a mobile network does not meet the growing customer demand for high-speed mobile data connectivity, operators have several possible strategies to expand their network capacity. These include deploying new spectrum bands on existing macro cellular base stations, deploying a small cell layer, or a hybrid strategy combining both options. These strategies are outlined in Table 1.

Table 1: Overview of infrastructure strategies

Infrastructure Strategy	Description
Spectrum Integration Strategy	Integrate all available spectrum in the bands 700 and1500 MHz and 3.5 GHz to the brownfield macrocellular network.
Small Cell Strategy	Deploy a greenfield small cell layer operating in TDD at 3.7 GHz[6].
Hybrid Strategy	Integrate all other spectrum to the brownfield macrocellular network (700 MHz, 1500 MHz, 3.5 GHz). Deploy a greenfield small cell layer operating in TDD at 3.7 GHz.

The hybrid strategy follows a rational investment approach where operators would first deploy spectrum resources, and if this is unable to meet the scenario capacity objectives, a small cell infrastructure layer is delivered.

The Dutch Telecom Market

The Dutch Telecom market can be described as consisting of three significant separate markets; mobile, fixed-line consumer and business fixed. For this report, the mobile market is the most significant. It consists of 4 mobile network operators: KPN, VodafoneZiggo, T-Mobile and Tele2[7]. Each of these operators is also present in the fixed-line consumer broadband market. KPN owns a nationwide fixed-line copper and fibre network. VodafoneZiggo owns a near-nationwide cable (DOCSIS)-network. T-Mobile[8] and Tele2 offer consumer fixed network services on the network of KPN. In addition KPN, VodafoneZiggo and Tele2 have significant business fibre connections throughout the country. In the business fibre market there are also a number of other players, such as Eurofiber, Relined (which resells fibre infrastructure of ProRail, the Dutch Rail infrastructure company and Tennet the Dutch high-voltage electricity grid operator), BT, Colt and several regional players such as Trent.

[6] In theory small cell layers can also operate in other frequency bands. For the model based on discussions with several operators the 3.7 GHz band is chosen as 'common practice' approach. This was also presented and discussed in the workshop with the Dutch operators

[7] While this study was being carried out, T-mobile and Tele2 announced their proposed merger.

[8] T-Mobile exited the consumer fixed market in 2012 by selling its DSL network to Online.nl and re-entered the consumer fixed market in 2016 when it bought Vodafone's fixed business.

KPN and (a forerunner of) Vodafone were the first two GSM providers in the Netherlands, opening networks in 1994 and 1995 respectively. The forerunner of T-Mobile entered the market as an 1800 MHz only operator in 1998. The indoor and outdoor propagation characteristics of the 1800 MHz band was considerably lower than that of the 900 MHz band. As a result it needed a large number of sites to achieve the same level of coverage. T-Mobile still has the largest number of cell sites in the country. Tele2 entered the mobile market in 2012 when it received a spectrum license. It was already active as an MVNO, first on the network of KPN, later on the network of T-Mobile. It also operates as a fixed line operator on KPN's network and business network operator over its own and KPNs fibre network. Tele2 is building out the 4G network aiming to have countrywide coverage, often partly by sharing sites and antennas with T-Mobile, but with its own backhaul and active radio equipment. On 15 December 2017 Tele2 Group and Deutsche Telekom announced their intention to merge their Dutch subsidiaries Tele2 Netherlands and T-Mobile Netherlands into one company.

Table 2: Current spectrum allocation per Mobile Network Operator (MNO) in the Netherlands

Band	KPN	Tele2	T-Mobile	VodafoneZiggo
800 MHz	**2x 10MHz**	**2x 10MHz**		**2x 10MHz**
900MHz	**2x 10MHz**		**2x 15MHz**	**2x 10MHz**
1800MHz	**2x 20MHz**		**2x 30MHz**	**2x 20MHz**
2100MHz	**2x 19.8MHz**		**2x 20MHz**	**2x 19.6MHZ**
2600MHz	**2x 10MHz**	**2x 20MHz**	**2x 5MHz**	**2x 30MHz**
2600MHz (unpaired)	**1x 30MHz**	**1x 5MHz**	**1x 25MHz**	

KPN, T-Mobile, VodafoneZiggo have the largest part of the available spectrum, particularly in the bands below 2600 MHz, with Tele2 having only 20 MHz in these bands.

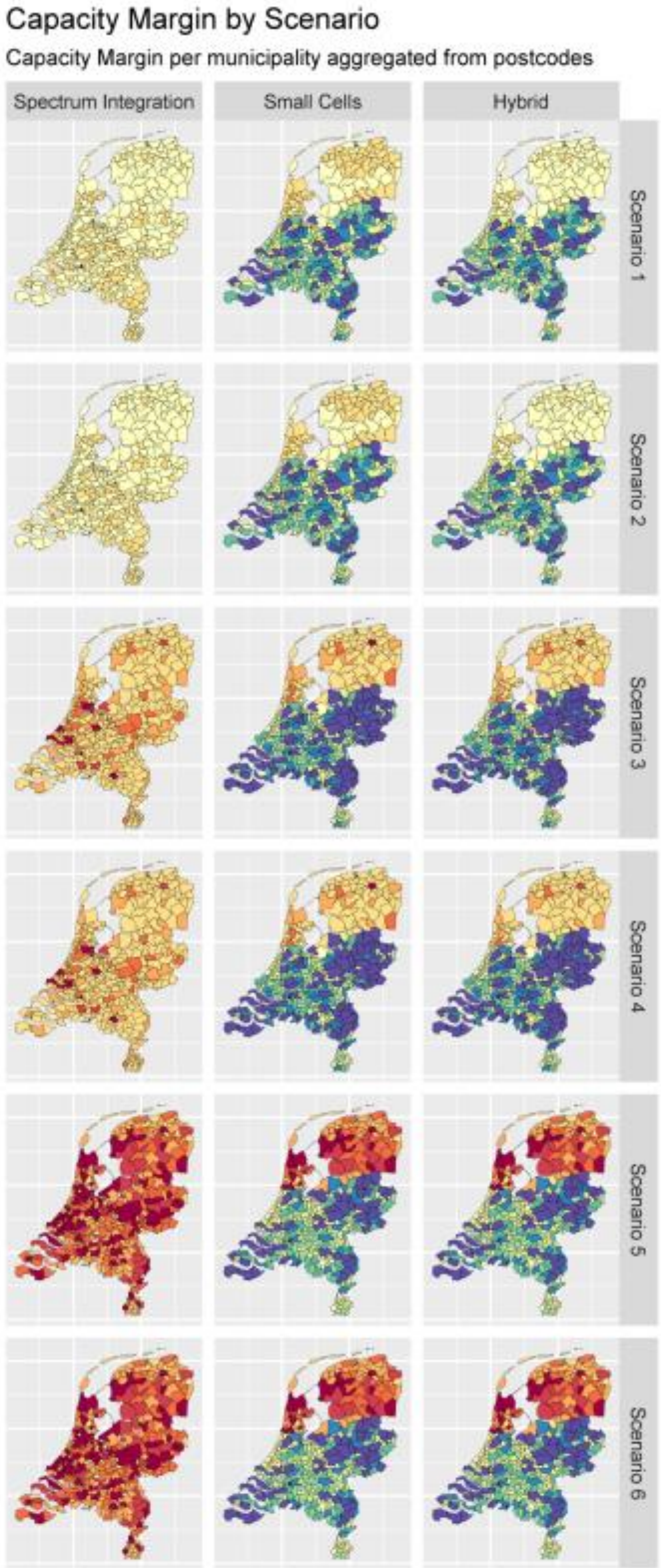
Results and Analysis

The general cost model for 5G developed by the University of Cambridge and the Universidad Politécnica de Madrid that was previously used to model potential rollout patterns in the UK proved usable in the Netherlands' situation and could be adapted to the geography, user density, antenna sites and frequency allocation in the Netherlands for a hypothetical operator. The cost model was used to calculate the investments for 5G rollout following the different strategies described in Table 1, for 6 different scenarios. The scenarios reflect the desired nation-wide coverage to provide a certain download speed (30 Mbps, 100 Mbps and 300 Mbps) per user in all the environments, from very urban to very rural, for two types of 'hypothetical operators': (1) a mobile-only operator, and (2) a 'fixed-mobile' operator that also owns a fixed access network to customers. However, it proved difficult to model the difference between a mobile-only operator and a fixed-mobile operator, as the access networks and their technical and economic advantage(s) vary between fixed-mobile operators. The model provides only limited support for calculating this variance and local differences are challenging to fully integrate into a general model. Table 3 gives an overview of the modelled scenarios.

Table 3: Scenario overview

Scenario legend	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Speed per user	30 Mbps	30 Mbps	100 Mbps	100 Mbps	300 Mbps	300 Mbps
Type of operator	Mobile-only	Mobile-fixed	Mobile-only	Mobile-fixed	Mobile-only	Mobile-fixed

The model calculates the rollout from year to year beginning with the existing situation with regard to antenna sites, used frequency bands, etc. considering also factors such as (average) maximum available investment costs per year. The results give insight in technological and economic implications, such as the level in which the rollout will undershoot or overshoot the capacity needed to support the desired speed for the number of users per km2 that are normally present in different types of areas. *Figure 1* shows clearly that for the 30 Mbps case 'spectrum integration' already provides enough capacity, except for some urban areas. For the 'small cells' and 'hybrid' case a considerable capacity margin can be achieved across the country.



Scenario legend	Speed per user	Type of operator
Scenario 1	30 Mbps	Mobile-only
Scenario 2	30 Mbps	Mobile-fixed
Scenario 3	100 Mbps	Mobile-only
Scenario 4	100 Mbps	Mobile-fixed
Scenario 5	300 Mbps	Mobile-only
Scenario 6	300 Mbps	Mobile-fixed

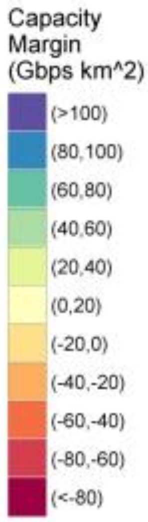


Figure 1: Breakdown of capacity margin by scenario and strategy

For the 100 Mbps and 300 Mbps cases it is more difficult to provide enough capacity by just integrating new spectrum into the existing macro networks ('spectrum integration'). However, for the 'small cells' and 'hybrid' cases a considerable capacity margin surplus can be achieved by using the 3.7 GHz-band for the deployment of small cells. So for higher bandwidths a strategy which includes smaller cells really is necessary to provide the results aimed for; these smaller cells contribute more to the capacity margin than spectrum integration. However, this comes at a cost.

The graphs in Figure 2 show the cumulative cost curves across strategies and scenarios. They provide very useful insights to assess the investment needed to reach any one level of population coverage. However, note that the cell capacity margin may differ greatly per geotype, scenario and strategy. When we look at the costs for providing this result we see that deploying smaller cells is costly, especially for providing coverage to more than 75% of the population. For example, we see that a hybrid scenario is not cheaper than a small cells only scenario, and provides almost no extra capacity margin.

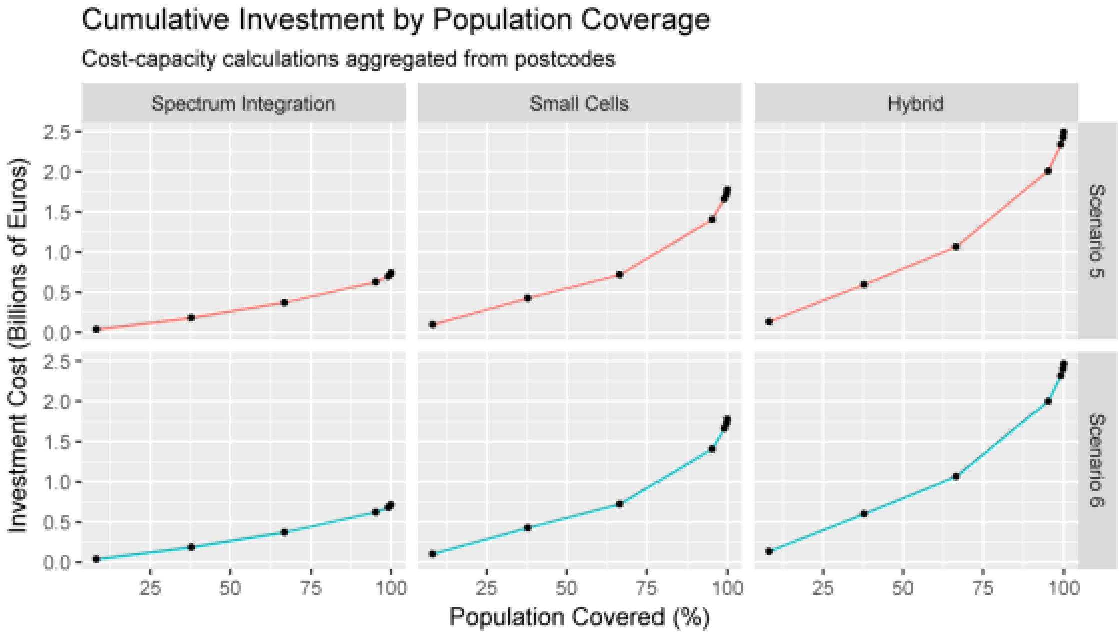


Figure 2: Cost curves by scenario and strategy for scenario 5 (300 Mbps, Mobile only operator) and scenario 6 (300 Mbps, Mobile-fixed operator)

Figure 1 and also the geographical breakdown of costs in Figure 3 show clearly the spectrum demarcation line, north of which the use of the 3.5 GHz frequency band (3.4 GHz – 3.8 GHz) is currently prohibited. This is accounted for within the model.

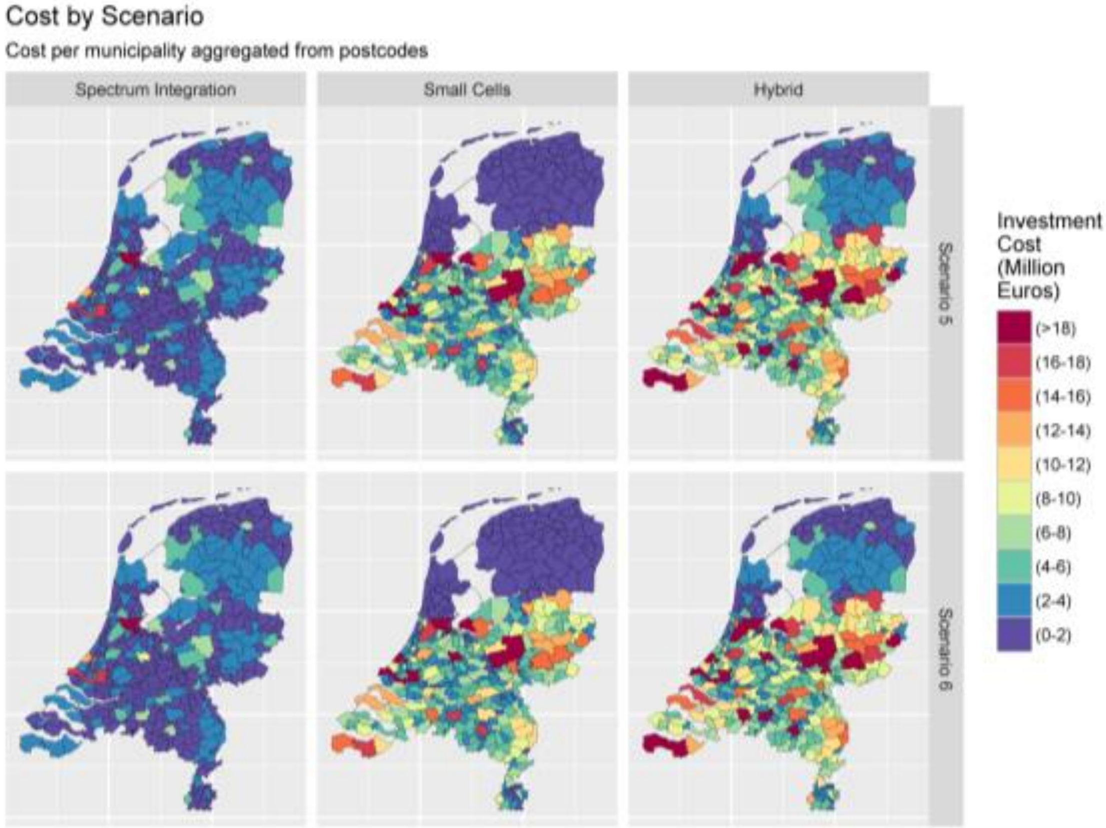


Figure 3: Geographical breakdown of cost by municipality for scenario 5 (300 Mbps, Mobile only operator) and scenario 6 (300 Mbps, Mobile-fixed operator)

Considerations regarding re-use of other networks

The re-use of other networks (utilities, public and sometimes private) has been discussed as a way of promoting the roll-out of fixed and mobile broadband. The European Union has adopted a directive to promote the roll-out of such networks (Directive 2014/61/EU). To quote the Directive: This Directive should apply not only to public communications network providers but to any owner or holder of rights to use, in the latter case without prejudice to any third party's property rights, extensive and ubiquitous physical infrastructures suitable to host electronic communications network elements, such as physical networks for the provision of electricity, gas, water and sewage and drainage systems, heating and transport services. The Netherlands is currently implementing this directive. The usefulness of this utility type infrastructure in the Netherlands for broadband and 5G depends however on two elements. First of all, the way infrastructure is available and second the characteristics of 5G. In the Netherlands, this type of infrastructure is sometimes available to fixed and mobile telecom companies. For example, there have been occasions where telecom operators were able to coordinate their digging with Rijkswaterstaat or buy access to existing ducts. Infrastructures of the Dutch rail company Pro-Rail and high-voltage electricity network Tennet are available through commercial company Relined. In addition, there have been opportunities for telecom companies to locate their antennas on fixed infrastructures, such as on portals across highways.

For 5G however, this type of infrastructure is likely to be of less use. The densification needed means that it is not so much the national or regional backbone, but the last few hundred metres, the local rings and extensions, that need additional investment. At this level there is no infrastructure that can easily be shared. (This unlike other EU countries where municipalities or utilities have concrete ducts to house electricity cables, water ducts and sewers, that can be re-used) If an operator needs to roll-out to a location, that means they either need access to existing ducts owned by themselves or by their competitors. If these ducts are not present, then they need to be dug. Municipalities do try to coordinate these works and can require that those intending to dig do so in coordination so that the same street isn't dug open multiple times a year. However, most infrastructure is already present and in the short term, it isn't expected that new infrastructure other than for telecom will be built.[9]

This however, doesn't mean owners of infrastructure can't help with densification of 5G networks. Particularly for small cell capabilities, the re-use of local fixed infrastructure such as streetlights and buildings can be beneficial. Already there are trials to incorporate antennas in streetlights. Other infrastructure could be bus stops, traffic lights, advertising locations etc., some of which are publicly owned. Just as with any new location, there will be costs. Bus stops, traffic lights, advertising locations may be chosen more because of their convenience in hiding away antenna's then that they represent a direct cost saving. Indeed, coordination costs might increase, compared to a normal antenna, however it might result in an easier permit application process.

Considerations regarding regulatory issues

Roll-out of 5G will positively contribute to the digital connectivity in the cities and the Netherlands and thus contribute to the Netherlands position as a digital front-runner. Regulation can promote or harm the roll-out of mobile networks. Finding a location to place an antenna and receiving the necessary permits for the antenna and the backhaul network from municipalities are a concern. Regulations regarding emitted radiation are less of an issue in the Netherlands.

There are several national laws that are relevant for rolling out a telecom network. The telecom law[10] contains several articles on construction of networks. Other relevant laws are those regarding, zoning, construction and the environment as they affect what can be built where and how. Even laws on cultural heritage can be of relevance if an antenna is placed on or near historic buildings or its placement affects the way a town or region is visible, the so-called "protected town or village conservation area" ("beschermd dorpsgezicht"). The two main national laws to consider when rolling out mobile network infrastructure are:

1. The **Dutch telecom law** describes two elements of constructing networks:

- Construction of cables: Chapters 5 states that owners of public grounds have to allow the construction of telecom networks on their grounds. (gedoogplicht).

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[9] In the future there might be an investment in new forms of energy networks, to replace gas networks and help with the energy transition, however that is likely outside of the 2025 timeframe of this report.
[10] Telecomwet Telecommunicatiewet

- Construction of antenna sites: Article 3.24 Telecommunications Law requires operators to share antenna sites, if feasible, when requested by another operator.

For the owners of networks, this allows them to roll-out to and reach their antenna sites and guarantees them a possibility to use existing antenna infrastructures. For the construction of cables, a permit is still necessary. For the construction of antennas the requirement for a permit is based on the Environmental Licensing Act and a further contract (Antenna Covenant) between the government and telecom operators.

2. The **Environmental Licensing Act (Wabo)** governs the construction of antenna sites higher than 5 metres. Those under 5 metres high can be built without a construction and planning license, except if built on or around historical sites or protected town or village conservation area. However, to enable an orderly roll-out and to alleviate concerns in society the Antenna Covenant further specifies how this is done.

Though there are national regulations and agreements regarding the roll-out of new antenna sites, there are still local adaptations, and municipalities have a right to make specific legislations with regard to leges, precario, digging depths etc. which increases costs and delays a massive 5G network rollout.

Laws that cover building, monuments, environment, underground infrastructure all can have an effect on the placement of antennas. There is currently a revision underway to revise the Environment and Planning Laws. The new law is designed to replace a patchwork of laws with one uniform framework of regulations. In its current design, the Act will replace 15 existing laws, including the Water Act, the Crisis & Recovery Act and the Spatial Planning Act. The provisions of eight other laws will be transferred to the Environment & Planning Act. The new bill has been approved by both Chambers of Parliament. The cabinet is now drawing up introductory legislation. The expectation is that the Act will take effect in 2021.

Two expected benefits of the new law that are relevant for the 5G densification are:

- *'One-stop-shop' for citizens and companies*
  If citizens or companies want to implement a project, they will be able to apply for a (digital) permit at a 'one-stop-shop'. The municipality or province will then make a decision. Are they both responsible for the decision? No matter, only one will make the decision. This simplifies things for the applicant and speeds up the permit application procedure.
- *Companies need to conduct fewer studies*
  To obtain a permit for a project concerning physical planning, building and construction, companies have to conduct studies (for example, a soil survey). With the Environment and Planning Act, research data will remain valid for longer. This makes it easier to re-use data. Moreover, some research obligations will be abolished and this means lower costs.

Such benefits would be welcomed by MNOs. However, there is some scepticism as to whether the law will actually be able to deliver on its promise of simplification; the law still leaves much to municipalities and it is this individual approach by municipalities that forms the greatest source of costs and complications.

Building owners can make it difficult to extend existing leases and to find new locations, which now appears to create a scarcity of sites for antennas and masts. Moreover, currently some municipalities are not very cooperative with regard to the development of more sites for antennae and masts or are imposing additional and restrictive conditions based on visual suitability or health. Finding the (large numbers of) sites required for the large-scale roll-out of 5G will be challenging, although the trend towards smaller equipment and smaller antennas at lower positions may ease this challenge somewhat.

Based on the research performed in this project and the outcomes of the model a number of conclusions can be drawn:

30Mbps is achievable through spectrum integration; higher speeds will require significant investment

The new frequency bands that will become available by 2020 and the current antenna-sites are enough to deliver 30 Mbps. For a goal of 100 Mbps, small cell rollout is necessary to provide the coverage and cell capacity needed. A goal of 300 Mbps will be only possible with a yearly investment budget far above that what is currently common. It would require an extensive combination of spectrum integration and cell densification.

The model shows that, for a hypothetical mobile operator with 30% market share, providing 30 Mbps in every location of the Netherlands to customers can be achieved by investing 0.75 to 1.5 billion Euros in the rollout of 5G and the accompanying integration of new frequency bands, depending on the used rollout strategy. For higher goals (100 Mbps and 300 Mbps) the model shows that in the northern part of the Netherlands it is difficult to achieve enough cell capacity in every location. This is mainly due to the fact that in the northern part of the country the 3.5 GHz frequency band (3.4 GHz – 3.8 GHz) cannot be used whilst the model uses these frequencies for both increasing capacity in the macro network as well as for the roll-out of small cells. In the remainder of the Netherlands where the model assumes that the 3.5 GHz frequency band (3.4 GHz – 3.8 GHz) is used, the capacity margins for the small cell and hybrid strategies are sufficient, even for the higher goals (100 Mbps and 300 Mbps). In the theoretical case that the 3.5 GHz frequency band (3.4 GHz – 3.8 GHz) will be usable in the whole of the Netherlands, roughly extrapolating the costs to the whole of the Netherlands for a hypothetical operator, a rollout offering 300 Mbps to customers would be possible for around 5 billion Euros per operator.

A fixed mobile operator has a limited advantage over a mobile-only operator in extending and densifying its mobile network

In theory, fixed mobile operators have a more extensive backbone and backhaul network that they can also utilise for their mobile backhaul network. In the Netherlands, however, mobile-only operators have accrued an extensive fibre network and therefore only a small fraction of the sites will require backhaul upgrades. or the installation of new fibre cables. In most locations in the Netherlands, there is a possibility to acquire business grade fibre access from ‘other licensed operators’ to connect new sites and/or small cells. Many of the existing antenna sites are shared locations with a presence of fibre networks. It is likely that commercial fibre networks will also extend their networks to new shared antenna locations. In more and more situations new small cells can also make use of existing business or consumer network access, especially when fibre access is already present. Based on the access regulation in place in the Netherlands (like most European Union Member States), an antenna site (e.g. a small-cell) can make use of the access network of a competing operator at a customers' premise by acquiring unbundled broadband service. Alternatively, a site can be provided to be connected 'over the top' on existing broadband services. In the future many factors may impact the relative advantage of a fixed-mobile operator compared to a mobile-only operator in the future. Some examples are:

- More cost efficient femto equipment ('small cells')
- New methods for network planning
- New methods to ease the use of access networks for 5G backhaul, and
- Discussions, interpretations or regulation trends with regard to net neutrality and the position of the demarcation point of an access network.

Main cost components of 5G rollout independent of scenario

The main cost components for the two most different strategies described in Table 1 are:

- **Spectrum integration**: Around 80% of the costs is macro RAN equipment, with macro civil works only being about 20% of the overall cost;
- **Small cells**: Around 84% of the costs are small cell civil works, with the actual small cells being only approximately 16% of the cost.

5G networks will need to be so dense that the economics of the rollout will likely not allow for four overlapping networks providing the same extent of coverage and capacity. Thus, it is very likely that at least the backhaul for small cells will be shared or outsourced to companies specialised in providing fibre or mmWave connections to serve as the backhaul for 5G small cells. Whether or not this will happen in practice or needs government intervention is uncertain.

Availability of the 3.5 GHz frequency band (3.4 GHz – 3.8 GHz) will be of extreme importance for the next generation of mobile networks

Due to restrictions by the government, the small cells that already are deployed in the Netherlands, in general, do not use the 3.5 GHz frequency band (3.4 GHz – 3.8 GHz). If this frequency band will not be available in the future, it will be more difficult to deploy additional small cells, because without this spectrum range the only way to increase existing capacity will be to densify the macrocell network. The cost model we use does not capture this scenario at the moment since this is a very rare case that telecommunications operator would prefer to avoid. Macrocell densification poses significant challenges since it is even harder to find new locations for macro cells because mobile networks in western European countries are already very dense. However, if due to spectrum restrictions, macrocellular densification is the only available strategy to meet the demand for the Dutch operators in many cases, even more effort in facilitating access to any locations that can serve as a macro cell site (public facilities, etc.) will be important. Nonetheless, even in that case, delivering 100 or 300 Mbps per user will be (extremely) challenging.

Governments can influence the costs of civil works, but not the costs of the Macro RAN

Macro RAN upgrade costs are significant, but the market for this equipment is a commercial and competitive market, hence governments may have limited ways to influence these costs. Small cell civil works cost is very high and because there is no standardisation in the conditions under which street furniture can be accessed, nor standardisation in possible additional costs of local municipalities, the costs vary greatly.

Availability of nationwide networks (utilities, public and private) has a low impact on 5G investments. Using regional and municipal networks are key, but there are issues

Local presence of existing and commercial fibre backhaul networks in the Netherlands is relatively high. Only in a limited set of cases nationwide networks have a presence in areas where other networks do not have a presence. The chance that mobile network operators would like to use other networks is relatively small. Locally there may be cases where local publicly owned fibre networks may be very interesting for mobile network operators. But economic, organisational and procedural challenges have to be overcome to successfully make use of these networks. In many cases, operators prefer to build and deploy their own fibre network routes, or use Managed Ethernet Services (MES) or Managed Dark Fiber Services (MDFS) offered by commercial operators.

Fragmented regional regulation could have a large impact on organisational costs and effort of operators

Regulation of the roll-out of networks is fragmented. The new ‘Omgevingswet’ is aimed to create a one-stop-shop, which is beneficial; however, the implementation will remain local. MNOs will still be faced with municipalities who will not allow antennas fixed to the fronts of buildings, differences in digging costs, different rules on repaving and multiple offices within a municipalities’ organisation being involved in issuing the permit. Most people want to have good data coverage and excellent connectivity, but at the same time for various reasons some people prefer not to live in close proximity to mobile antenna sites. This is a paradox, even so, because smaller cells may even be a solution for the reasons that people mention. Smaller network cells generally use lower electromagnetic field strengths than larger network cells and also for smaller cells antennas can be smaller and placed at lower heights. Municipalities are important in dealing with these trade-offs in the way they structure their local regulation on the placement of antennas.

1 Introduction

1.1 Background of the study

After the success of the introduction of LTE fourth generation (4G) mobile communication, the improvements in mobile broadband performance and further globalisation this has brought, the next and 5th generation (5G) mobile communication technology is on the horizon. The specifications of 5G technology have not yet been completed, but expectations are high for improvements in service performance, radio access and network architecture capabilities. A preliminary version for Non-Stand-Alone 5G has been finalised by 3GPP just before Christmas 2017.

The deployment of 5G networks will require additional investments in mobile communication infrastructure, that are expected to be caused by densification of radio network sites to reach smaller cell sizes and to be able to support ultra-reliable low latency, massive machine type communication and enhanced mobile broadband rates that 5G makes possible.

Of importance for the deployment of 5G will be that mobile network providers have sufficient spectrum resources available. While several spectrum ranges have been made available to network providers in the Netherlands (450 MHz, 800 MHz, 900 MHz, 1800 MHz, 2100 MHz and 2600 MHz) new allocations of spectrum are expected in the 700 MHz and potentially for the 3.5 GHz frequency band (3.4 GHz – 3.8 GHz) in the coming years.[11] Currently, there is limited knowledge and understanding of the financial impacts of the rollout of 5G and the expected densification of the radio network. Depending on the outcome of the ITU World Radio Conference 2019 (WRC-19) other frequency bands may be added.

1.2 Objective of the Study

The objective of the study is to identify and analyse the cost elements that are of relevance in (passive) infrastructure, active network elements and power facilities for the rollout of mobile networks making use of fifth generation (5G) mobile communication technology. In addition, the study aims to analyse to which extent existing infrastructure can be used for this rollout.

1.3 Policy background

The aim of this study is to provide insight into a number of issues. First of all, it should help to make an indication of the investments required to achieve certain access speeds for end users and to what extent this is influenced by making new frequencies for mobile communi-

[11] https://www.rijksoverheid.nl/actueel/nieuws/2017/09/20/voorbereiding-landelijke-veiling-mobiele-communicatienetten-gestart

cations available. Secondly, it should help to understand the differences in the investments required by different types of market players. In particular, those that own both a fixed and mobile network on the one hand, and those that only own a mobile network on the other hand. Thirdly the study should help to provide insights into the factors that determine investment costs and their weight. These insights should help policymakers to better assess the main factors that determine investment costs so that they can better prioritise the policy goals that need to be pursued. The study is explicitly not meant to get exact estimates of the total investments of market players and the results should not be interpreted as such.

1.4 Scope

The study focuses on estimating the order of magnitude of capital expenses for 5G network upgrades. The study assumes the current 4G network 'as is' and does not take into account investments or maintenance for 4G or other legacy networks, also the study does not include the impact of costs for spectrum licenses for existing or new spectrum and operational costs including network management, maintenance and repairs.

1.5 Key questions for the study

Key questions of the study were:

1. How will densification of antenna sites in mobile communication networks progress until 2025, and what will be the developments in backhaul networks and edge networks?

2. Which rules and regulations are applicable for the rollout of small mobile network cells particularly, and which restrictions may be expected? A description should be made of the process and steps forward to the deployment of the densified mobile communication network by using small cells or alternative technologies for coverage of the mobile network. It should be addressed specifically which phases in the process of the rollout are depending on law and regulation, and national and municipal authorities?

3. To what extent does the installed base of mobile communication need to be expanded? Several scenarios will need to be investigated including in dense urban areas, and by distinguishing between mobile network providers that are 'mobile only', and mobile network providers that are also deploying access networks for fixed subscribers. The study should address to what extent public fibre transmission networks are able to contribute to the densification of the mobile networks for the rollout of the 5G technology.

4. The study should describe the cost elements and the order of magnitude of investments required until 2025 for each of these cost elements (fibre and backhaul technology, active radio equipment, power facilities). This should lead to a range of the level of investments required, whereby specific attention should be paid to:

a) The investments of a fixed mobile network operator;
b) The investments of a mobile-only network provider;

c) Whether or not backhaul capacity owned by third parties (public organisations, private (non-telecom) companies, and fixed network providers can be used for 5G rollout and cell densification.

1.6 Methodology

The study makes use of a cost modelling method that was developed for the United Kingdom by researchers from the University of Cambridge, Cambridge and Universidad Politécnica de Madrid, Madrid. The researchers that have worked on this model were part of the Stratix team for the cost modelling study for the Netherlands. The cost model as defined for the United Kingdom has been further amended and customised in order to be able to analyse radio network rollout scenarios for the Netherlands.

During this report, it will be further explained that several assumptions in the cost model have been taken over from the cost modelling project for the United Kingdom, while other parameters have been customised for the Netherlands specific case.

A workshop has been organised with key stakeholders in the Dutch telecom industry. The key objective of the workshop was to verify cost parameters and assumptions underlying the model. Comments and remarks that were received during the workshop have been taken into account in the cost model and in the study report. Participants in the workshop included representatives from fixed and mobile access operators, public and private network owners and backhaul and business operators, and representatives from the Ministry of Economic Affairs and Climate. The full participant list can be found in Annex B. In addition to the workshop, a separate meeting was organised with KPN for the purpose of verification of cost parameters and model assumptions.

The scenarios that are described in section 5.2 and analysed in chapter 6 of the report have been agreed with the Ministry of Economic Affairs and Climate Policy.

1.7 Derived requirements for scenarios and modelling

Based on the research questions and the discussions with the ministry the following elements were modelled and analysed specifically as scenarios for this study:

1) A minimum service level of 30 Mbps with a geographic coverage of 100%;
2) A minimum service level of 100 Mbps with a geographic coverage of 100%;
3) A minimum service level of 300 Mbps with a geographic coverage of 100%.
4) Difference between a Mobile-only carrier and a Fixed-Mobile carrier (Fixed and Mobile access);
5) Available network capacity dependent on geographic distribution of customers;

Based on the calculated outcomes of the modelled scenarios and variants the following elements were also analysed, and estimated where possible:

6) Impact of availability of 3.5 GHz spectrum (200 MHz) for the entire geography of the Netherlands;
7) Impact of covering water areas such as Markermeer.

Additionally, in parallel, a qualitative analysis of the following elements was carried out. Not based on modelled scenarios and variants, but where possible modelling and analysis work inspired each other.

8) Analysis of the opportunity to make use of backbone facilities from government/municipal/transport organisations (varying from countrywide to local fibre network along railways, motorways etc.).
9) Qualitative analysis of the effects of additional costs due to building permits, environmental regulation, municipal regulation (based on the new 'omgevingswet').

1.8 Reading instruction and document structure

The report describes the study of the cost elements in the rollout of 5G networks in the Netherlands. Chapter 1 provides an introduction to the study and describes the background, the objectives, the Key questions for the study and the methodology.

Chapter 2 describes the new 5G technology in more detail and provides an explanation of basic functionality in 5G technology and Service Uses cases (eMBB, mMTC and URLLC). This chapter also describes 5G Research Activities, 5G Architecture and the choice of spectrum for 5G.

Chapter 3 gives a description of the General Cost Model, as it was defined and developed initially for the United Kingdom. It describes the modelling methodology and the UK context for the model, and the methodological application of the model to the Netherlands.

Chapter 4 is a description of the Telecom market of the Netherlands including Frequency allocation overview and of key market players.

Chapter 5 provides in further detail the customisation of the cost model to the Netherlands. It describes the key assumptions used for customising the model to the Netherlands as well as scenarios for the 5G rollout in the Netherlands.

Chapter 6 describes the results of the model simulation for the scenarios as describes in Chapter 5, results (baseline scenario, the impact of the availability of the 3.5GHz band, the impact of variations in spectrum license requirements, considerations regarding re-use of other networks, the difference between a Mobile carrier and a Convergent carrier). Chapter 7 elaborates on and analyses these results further. In section 7.6 the results of the regulatory analysis are described.

Chapter 8 provides conclusions. Chapter 9 provides recommendations for further study of the cost elements of the rollout of 5G technology for the Netherlands.

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2 What is 5G?

2.1 Introduction

5G is the fifth generation of mobile communication technology. It is the next step in mobile technology and the successor of Long Term Evolution (4G) technology. The 5G radio access and network architecture will have specifications beyond those for 4G, although the complete set of specifications have not been agreed upon to date. Late December 2017 3PGG, the relevant standardisation body, announced that NSA 5G NR (Non-Stand-Alone 5G New Radio) specifications were approved[12], however, it is expected that further updates and modifications to these specifications are necessary for 5G to come to full maturity. Expectations for 5G are that it will bring new developments and improvements compared to previous generations of mobile communications enabling higher data rates, and lower latency to larger amounts of devices per square kilometre. This is done by technologies such as the more effective use of high frequency (millimetre wave) bands, a new air interface Massive MIMO/beamforming, Device-to-Device communications, Network virtualisation (cloud-based network) and massive machine communication.

2.2 Roadmap

Full 5G deployment may still be years away. However, LTE Advanced and LTE Advanced Pro – evolutions of 4G – are stepping stones towards full 5G.

LTE Advanced is already available on a variety of phones, and frequency bands. LTE Advanced is also taking advantage of a technology called Carrier Aggregation. Advanced Carrier Aggregation allows the utilisation and combination of more than one (frequency) carrier in order to increase the overall transmission bandwidth. These carriers may be either contiguous carriers of the same frequency band, or they may be separated by other carriers or even be in different bands.

LTE Advanced Pro is the next evolution of LTE that might make gigabit mobile internet a reality, to be built on existing radio infrastructure, similar to how HSPA+ built on UMTS infrastructure.

It's also worth considering that experience from the past, has taught us to temper expectations and to be patient with an emerging technology to come to full maturity. LTE technology may be referred to as '4G' but isn't really 4G according to the agreed-upon specifications and standards from the International Telecommunication Union (the ITU) and 3GPP. Per those standards and specifications, a 4G network (among other things) would provide a 100 Mbps data rate when moving and a 1 Gbps data rate while stationary. Not something that the current LTE ('4G') networks can deliver. In the same way, UMTS (3G) never achieved to deliver

[12] http://www.3gpp.org/news-events/3gpp-news

the 2 Mbps that was promised but needed HSPA (3.5G) to reach reasonable data rates and acceptable latency. So historically it is unlikely that future networks that will be labelled 5G will meet all expectations that are now attributed to 5G.

Just as for previous generations of mobile communications technology, drivers for 5G are higher peak data rates, lower latency, more capacity, and better cost efficiency. In addition, the Internet of Things (IoT) introduces requirements on mobile networks that need to be addressed through 5G technology. Such as millions of terminals and devices communicating to each other and to the network (e.g. machine to machine (M2M) or vehicle-to-vehicle (V2V)). Such devices require low-power radio solutions, a long battery life, short response times, high reliability and security. Current Narrow Band -IoT market developments are already showing signs of how mobile networks will address these requirements.

2.3 5G Basics

One of the prominent new capabilities is the use of millimetre wave (mmWave) band transmission: Mobile communication in frequency bands between roughly 30 GHz and 300 GHz[13]. mmWave technology promises higher data capacity than currently available due to the larger frequency ranges in this part of the spectrum. Also, the antennas used to transmit and receive the signals can be made comparably smaller due to the shorter wavelengths. The challenge for mmWave will be the reduced propagation and increased interference of radio signals that come with these higher frequencies.

New capabilities that are expected of 5G technology are:

Millimetre-waves: Using higher frequency ranges will allow the deployment of larger carriers, which will lead to higher peak data rates and better system capacities.

New air interfaces: The OFDM-based LTE air interface will not be suitable for some use cases and therefore several new air interface candidates are under discussion.

Massive Multiple-Input Multiple-Output (MIMO beamforming active antennas): At higher frequencies (e.g. millimetre-waves) the significantly increased propagation path loss has to be compensated by higher antenna gains. Additionally, adaptive beamforming algorithms – even on a per-device basis – are required and can be implemented using active antenna technology.

Device-to-device (D2D) communications: Making it possible for devices to communicate directly with each other without direct involvement from the mobile network. This is already an existing use case for LTE in order to satisfy requirements from the public safety sector. Allowing D2D communications will also provide low latency for specific scenarios.

[13] This is a general definition of mmWave bands. In practice some bands between 20 GHz and 30 GHz are also used for this purpose.

Network virtualisation (cloud-based network): The aim is to deploy today's dedicated hardware functions as virtualised software functions on general-purpose (server) hardware in the core network. This is extended to the radio network by separating base stations into radio units and baseband units (connected via e.g. fibre) and by pooling baseband units to handle a high number of radio units.

Splitting control and user plane and/or decoupling downlink and uplink: The focus is on heterogeneous network deployments, making it possible to control all user devices on a macro layer, whereas user data is independently provided via a small cell.

Light MAC and optimised Radio Resource Management (RRM) strategies: Considering the high number of potentially very small cells, radio resource management needs to be optimised. Scheduling strategies would potentially require more lean protocol stacks, which could also be deployed in uncoordinated scenarios.

For 5G, the wireless-access link and wireless backhaul should not be considered as two separate entities with separate technical solutions. Rather, backhaul and access should be considered as an integrated wireless-access solution able to use the same basic technology and operate using a common spectrum pool. This will lead to more efficient overall spectrum utilisation as well as reduced operation and management effort[14].

Frequency Division Duplex (FDD) has been the dominating duplex arrangement since the beginning of the mobile communication era. In the 5G era, FDD will remain the main duplex scheme for lower frequency bands, also for historical reasons. However, for newer allocated higher frequency bands targeting very dense deployments, Time Division Duplex (TDD) will play a more important role. For the dynamic traffic variations expected in very dense deployments, the ability to dynamically assign transmission resources (time slots) to different transmission directions may allow for more efficient utilisation of the available spectrum. To reach its full potential, 5G should, therefore, allow for very flexible and dynamic assignment of TDD transmission resources.

2.4 Service Use Cases

For 5G, ITU-T suggests the following service use cases:

- enhanced Mobile Broadband (eMBB);
- Machine-type Communications (MTC);
- Ultra-Reliable and Low-Latency Communications (URLLC).

Each of these service use cases presents different functional requirements, as described in the paragraphs below.

[14] Access/Backhaul Integration, Ericsson White Paper, Uen 284 23-3204 Rev C | April 2016, Radio Access

2.4.1 Enhanced Mobile Broadband (eMBB),

Traffic demands in mobile communication networks are predicted to further increase dramatically. Mobile networks are therefore upgraded to keep up with users' ever-growing demand for higher data speeds and larger mobile data volumes. Examples may be gigabit connections to vehicles and trains, data-intensive applications such as video, video-on-demand, streaming, Virtual Reality (VR), Augmented Reality (AR), and Gaming. All these examples are driving the demand for more coverage and capacity. Some of the newer applications such as e.g. VR and AR are expected to consume far larger amounts of bandwidth than current applications. To support this traffic in an affordable way, 5G networks must deliver data at a much lower cost per bit compared to the networks of today. Furthermore, the increase in data consumption will result in an increased energy footprint. 5G must, therefore, consume significantly less power per delivered bit than current cellular networks to make enhanced mobile broadband a reality.

2.4.2 Massive Machine-type Communications (mMTC)

Massive MTC refers to services that typically span very large numbers of devices, such as e.g. sensors and actuators. Sensors are low-cost devices and consume very low amounts of energy in order to sustain a long battery life. Clearly, the amount of data generated by each sensor is typically very small, and will individually, or even in large groups, have limited impact on the overall traffic volume of a mobile communication network. Very low latency is not a critical requirement for MTC. While actuators are similarly limited in cost, they will likely have varying energy footprints ranging from very low to moderate energy consumption. However, the sheer number of connected devices seriously challenges the ability of the network to provision signalling and management of connections, without compromising security capabilities that the devices require[15].

Sometimes, the mobile network may be used to bridge connectivity to the device by means of capillary networks. Here, local connectivity is provided by means of a short-range radio access technology, for example, Wi-Fi, Bluetooth or 802.15.4/6LoWPAN. Wireless connectivity beyond the local area is then provided by the mobile network via a gateway node.

There is much to gain from a network being able to handle as many different applications as possible, including mobile broadband, media delivery and a wide range of MTC applications by means of the same basic wireless-access technology and within the same spectrum. This avoids spectrum fragmentation and allows operators to offer support for new MTC services for which the business potential is inherently uncertain, without having to deploy a separate network and reassign spectrum specifically for these applications.

2.4.3 Ultra-Reliable and Low-Latency Communications (URLLC).

Very low latency will be driven by the need to support new applications. Some envisioned 5G use cases, such as traffic safety and control of critical infrastructure and industry processes,

[15] Ericsson White Paper, Uen 284 23-3204 Rev C | April 2016, Radio Access

may require much lower latency compared with what is possible with current mobile-communication systems. On the other hand, low device cost and energy consumption are not as critical as for massive MTC applications. While the average volume of data transported to and from devices may not be large, wide instantaneous bandwidths are useful in being able to meet capacity and latency requirements.

To support such latency-critical applications, 5G should allow for an application end-to-end latency of 1 ms, although application-level framing requirements and codec limitations for media may lead to higher latencies in practice. Many services will distribute computational capacity and storage close to the air interface. This will create new capabilities for real-time communication and will allow ultra-high service reliability in a variety of scenarios, ranging from entertainment to industrial process control.

2.5 Research Activities

In several countries and regions, programs and initiatives have started for 5G development. The European 5G research program falls within the horizon 2020 framework. It gives an idea of the anticipated timeline (2020) for the deployment of the new technology. Further research projects are 5GNow (part of the 7th Framework Program FP7), METIS (part of FPF), and there is 5GPPP, the 5G Infrastructure Public-Private Partnership initiative between the European ICT industry and the European Commission.

In the United Kingdom, the 5G Innovation Centre is a 5G research effort that started in November 2013. In China, Taiwan, Korean, Japan and the USA, 5G research projects have also been launched.

2.6 5G Architecture

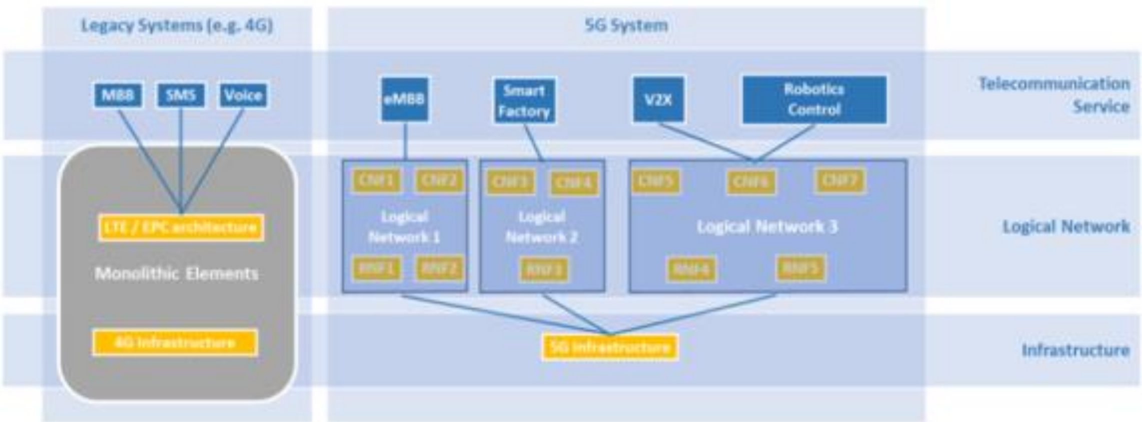

Figure 4: Overview of 5G architecture (source: 5G PPP Architecture Working Group, View on 5G Architecture (version 2.0) date 2017-07-18)

One of the fundamental changes in 5G compared to 2G, 3G and 4G is that the network architecture will no longer be a structure of monolithic elements (e.g. MME, HSS, PCRF, SGW, and PGW as in LTE/EPC architecture, and HLR, MSC-S, SMSC, SGSN, GGSN etc. as in UMTS and GSM architecture). Instead, the architecture is based on a network slicing concept that makes use of network virtualisation and 'softwarisation' of the different network elements.

In the View on 5G Architecture (version 2.0, dated 2017-07-18), a 'network slice' is defined as a composition of adequately configured network functions, network applications, and the underlying cloud infrastructure (physical, virtual or even emulated resources, RAN resources etc.), that are bundled together to meet the requirements of a specific use case, e.g., bandwidth, latency, processing, and resiliency, for a specific business purpose.

An infrastructure provider will assign the required resources for a network slice, that in turn realises the relevant service of a service provider's portfolio (e.g., the vehicular URLLC network slice, the factory of the future URLLC network slice, the health network mMTC network slice etc.). This way, a network slice comprises a subset of virtual network infrastructure resources and the logical mobile network instance with the associated functions using these resources.

The network slice is dedicated to a specific tenant (e.g. a service provider) that, in turn, uses it to provide a specific telecommunication service (e.g. eMBB). The decoupling between the virtualised and the physical infrastructure allows for efficient scaling-in/out/up/down of slices. This concept allows for the economic viability of adapting the network on demand to serve specific requirements.

Network slices will span the whole protocol stack from the underlying (virtualised) hardware resources up to network services and applications running on top of them. Although the infrastructure resources could be shared among several parallel network slices, every provider may use a specific control framework or/and a specific cloud management system, and, in addition, all the configuration effort and fine-tuning of the components may be left to users.

From a business point of view, a network slice includes a combination of all the relevant network resources, network functions, and service functions required to fulfil a specific business case or service, including OSS and BSS.

To support network slicing, the management plane of a network creates a group of network-based resources, connects with physical and virtual network and service functions as needed, and it initiates all the network and service functions assigned to the slice. For slice operations, the control plane takes over governing of all the network resources, network functions, and service functions assigned to the slice.

3 The General 5G Rollout Cost Model

3.1 Modelling methodology overview

In this chapter, we present the model for mobile wireless communication infrastructure that has been used in this work. It is a highly disaggregated model for the assessment of demand, capacity and costs of next-generation wireless infrastructure. The model allows to test (i) the impact of key demand drivers, including the number of users and desired capacity per user on the rollout costs, (ii) the current network capacity based on spectral efficiency, network density and available spectrum resources, and (iii) the performance of different infrastructure upgrade options available to network providers to meet the demand, including the use of additional spectrum resources.

A scenario-based approach is utilised allowing one to explore the performance of different hypothetical mobile wireless network operators, under varying roll-out scenarios. This scenario-based approach can help policy-makers to make better-informed decisions through ‘what if’ scenarios and build long-term strategies to maximise the social benefits of mobile wireless infrastructure.

The model can be adjusted to reflect the particular characteristics of any one country with sufficient granularity. Indeed, the model has been previously used in the UK context for an assessment of the national infrastructure to help advise the digital strategy (Oughton & Frias, 2016; Oughton & Frias, 2017). Additionally, parts of the modelling framework have been applied to model 4G LTE in Spain (Pérez Martínez, Frias, & González-Valderrama, 2014) and to develop a methodology to assess spectrum value (Frias, González-Valderrama, & Pérez Martínez, 2017). The model has been developed using a combination of R and Matlab[16].

As illustrated in Figure 2, the model consists of a demand module and a model for mobile networks, which in turn consist of a network dimensioning module and a cost module. Additionally, it implements different capacity-expansion strategies, as it is summarised next. To assess the costs and capacity of future 5G infrastructure, a set of possible operator strategies for deploying these new communication systems is used. The model we present assumes that 5G will progressively be rolled out reusing as much existing (“brownfield”) infrastructure as possible to minimise rollout costs.

[16] R and Matlab are software environments

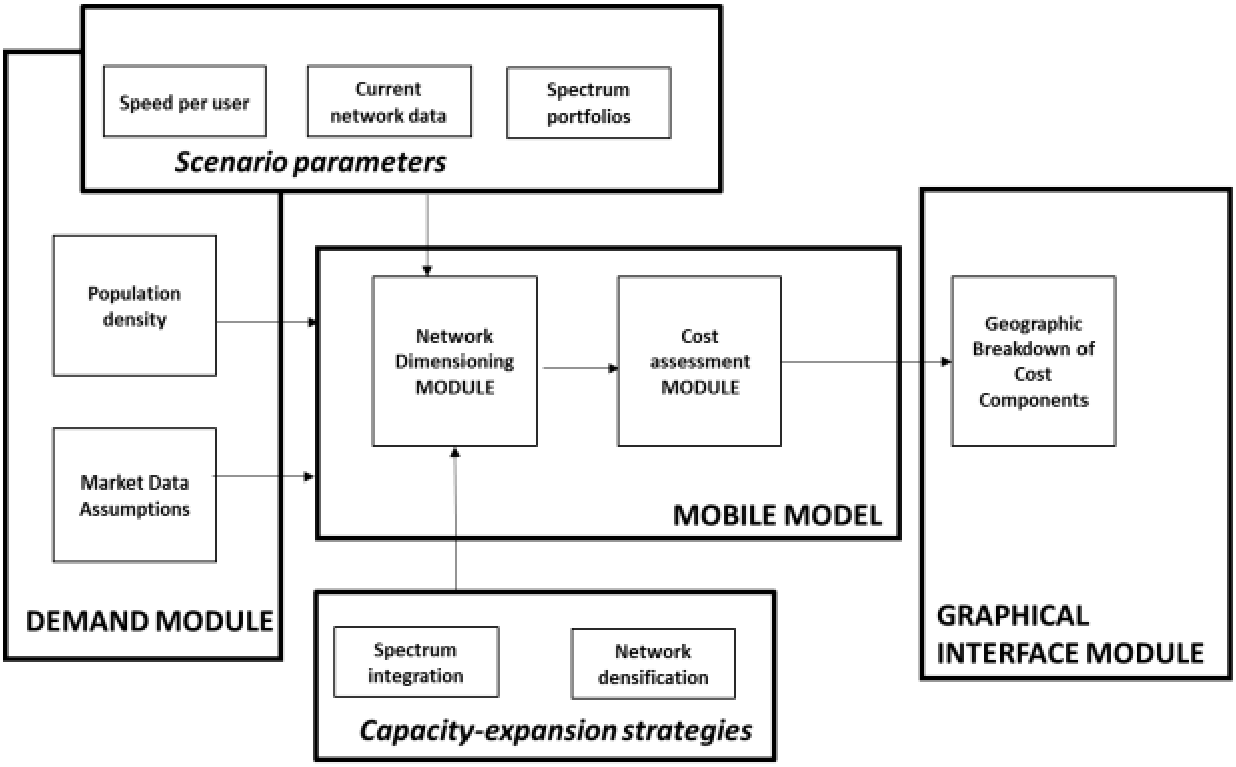

Figure 5: Methodological Sequence

In the first place, in the demand module, the model assesses whether existing network capacity meets demand at any one point in the country. If so, no expansion of capacity is carried out at that location. Otherwise, the capacity of existing 4G networks needs to be expanded. From an engineering perspective, the options available to an operator facing such a shortfall are: i) to integrate new spectrum bands on existing macro cellular base stations, ii) to densify the existing network, or iii) to utilise a hybrid strategy combining both options.

The model implements the second option (the network densification strategy) as an additional small cell layer that makes for a dense low-power network. This has become a very common strategy that operators use to densify the network, particularly in the cases of already very dense macrocellular networks, where it is even harder to find new locations for macrocells.

3.1.1 Operator strategies towards 5G infrastructure

As explained above, in the case of capacity shortfalls, operators have several possible strategies to expand their network capacity. These include the ability to integrate new spectrum bands on existing macrocellular base stations, deploy a small cell layer, or utilise a hybrid strategy combining both options. These strategies are outlined in Table 4.

Table 4: Overview of infrastructure strategies in the model. Note that the strategies that were used in the application of the model for the Dutch situation are described in chapter 4.1 and do not include frequency for mobile legacy networks.

Infrastructure Strategy	**Description**
Spectrum Integration Strategy	Integrate all available spectrum in the frequencies 700 MHz, 1500 MHz and 3.5 GHz (3.4-3.6 GHz) into the brownfield macrocellular network.
Small Cell Strategy	Deploy a greenfield small cell layer operating in TDD at 3.7 GHz.
Hybrid Strategy	Integrate all available spectrum in the frequencies 700 MHz, 1500 MHz and 3.5 GHz (3.4 GHz-3.6 GHz) into the brownfield macrocellular network and deploy a greenfield small cell layer operating in TDD at 3.7 GHz.

In the *spectrum integration strategy*, the model progressively adds new frequencies into the existing base stations until sufficient capacity is provided. It is assumed that lower frequencies will be preferred by the operator and therefore 700 MHz will be integrated first. However, no cost-optimisation is considered at this point, since spectrum costs are not taken into account. In reality, high spectrum prices for 700 MHz might shift the operator's strategy towards integrating high-frequency bands first, should the cost of the license be lower.

In the *small cell strategy*, the model deploys a greenfield layer of small cells operating in TDD at the 3.5 GHz range (3.4 GHz -3.8 GHz) to provide enough capacity to reach the speed per-user. These (and higher) ranges are ideal for small cells due to the greater bandwidth available. Like in the spectrum integration strategy, no spectrum costs are taken into account. Although no cost-optimisation is performed across strategies, testing the performance of a small-cell-only strategy allows assessing the extent to which operators may be motivated not to upgrade or integrate more spectrum in their existing macrocells.

The *hybrid strategy* follows a rational investment approach where operators would first deploy spectrum resources, and if this is unable to meet the scenario capacity objectives, a small cell infrastructure layer is delivered. No cost-optimisation has been implemented between the spectrum integration and the small cell strategies when they are combined. Rather, it is assumed that operators will always prefer to squeeze the potential of existing macrocells by integrating new spectrum in them before deploying a greenfield small cell layer.

Assumed frequency allocation for macrocells based on harmonisation and legacy networks

The rationale to select the frequencies stated above is the existing allocation of spectrum in the European Union, which is currently used by 3G and 4G networks mainly. Since the use and channelisation of spectrum bands are harmonised across the EU, the existing network capacity is assessed based on 4G infrastructure using the spectrum bands of 800 MHz, 900 MHz, 1800 MHz and 2600 MHz. Note that these spectrum bands are assumed to operate in Frequency Division Duplexing (FDD) mode, where the spectrum is equally divided between Downlink (DL) and Uplink (UL) communications. The same hypothesis is valid for 2100 MHz, historically used for 3G. Newly allocated spectrum, such as 1500 MHz and 3.4 – 3.8 GHz (3.5

GHz and 3.7 GHz bands) are expected to have different duplexing modes. In particular, the band at 1500 MHz, known as the L band has recently been opened by the European Commission[17] for wireless broadband under harmonised technical conditions of *downlink-only* (so-called SDL, Supplementary Down Link) (European Commission, 2015). With regard to 3.4 - 3.8 GHz band, the Commission established in 2014 (European Commission, 2014[18]) a preferable operating mode of Time Division Duplexing (TDD), which allows for unequal distribution of resources between DL and UL communications[19]. Finally, 700 MHz is assumed to operate in FDD.

Note that the current cost model does not take into account that for the spectrum integration strategy one could also use frequency bands that are now allocated to the small cells strategy, and vice versa. For example, in real life operators that acquire spectrum in the 3.6 GHz - 3.8 GHz range could use these frequencies in their macrocell networks instead of using these bands for small cells. However, this may be substantially less beneficial, since the propagation properties of these frequencies are poorer, which makes them more suitable for short-range small cells.

Assumed frequency allocation for new small cells based on harmonisation and legacy networks

In most countries of the world, in terms of spectrum, small cells are currently assumed to use the 3.5 GHz band (3.4 – 3.6 GHz and/or 3.6 – 3.8 GHz). The 3.5 GHz spectrum bands have emerged as one of the capacity band for LTE and next-generation networks worldwide[20]. Additionally, in the EU Member States, 5G small cells may be assumed to use primarily the upper part of the 3.5 GHz band, since the lower part is already being used for electronic communication technologies (mainly LTE) in some countries (ECO report 03, march 2018). Small cells provide additional capacity to the macrocellular networks at certain locations. They comprise an additional infrastructure layer that coexists with macrocells. This coexistence requires that macrocells and small cells use different spectrum to avoid interference. Macrocell infrastructure is already using currently-allocated frequencies at 800 MHz, 900 MHz, 1800 MHz, 2100 MHz and 2600 MHz bands. Therefore, since small cells shall be deployed at different frequencies, they will necessarily be deployed using newly allocated spectrum, which, means either 700 MHz, 1500 MHz or 3.5 GHz (3.4-3.8 GHz). However, as mentioned above, 1500 MHz is downlink-only and therefore cannot be used standalone, and at 700 MHz the bandwidth is very limited. For this reason, small cells are most likely to be deployed at 3.5 GHz, either, using the entire bandwidth (3.4 GHz-3.8 GHz) or part of it. From a regulatory perspective, the 3.5 GHz band is divided into 2 sub-bands, and both the

[17] http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1431416821549&uri=OJ:JOL_2015_119_R_0006 http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1431416821549&uri=OJ:JOL_2015_119_R_0006

[18] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2014.139.01.0018.01.ENG http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2014.139.01.0018.01.ENG

[19] FDD is allowed in 3.4-3.6 GHz for the purpose of: a) ensuring greater efficiency of spectrum use, such as when sharing with existing rights of use during a co-existence period or implementing market-based spectrum management; or b) protecting existing uses or avoiding interference; or c) coordination with non-EU countries.

[20] See also https://www.sciencedirect.com/science/article/pii/S2352864817302584

3.4-3.6 GHz and 3.6-3.8 GHz parts in the Netherlands are already being used for a number of regional licenses for a varying range of specific or innovative public and private services, varying from providing a Wireless Local Loop in rural areas[21] and container terminals in Rotterdam[22] to streaming video of remote camera's in Amsterdam[23]. Thus a new greenfield rollout for a new technology, such as 5G, is more likely to be done in the upper band (3.6 - 3.8 GHz), which, also when looking at the EU as a whole, is "cleaner". Thus, the model utilised for this work assumes only the upper part of the band will be used for the small cell rollout because the lower part will be used in the existing macrocell to provide additional capacity with a broader coverage.

From the reasoning above, we can envision the importance of the 3.5 GHz frequency band (3.4-3.8 GHz) for the rollout of 5G. 700 MHz and 1500 MHz will also be available for next-generation mobile technologies. However, due to either restriction (much less bandwidth at 700 MHz and downlink-only mode at 1500 MHz), they will not play such a key role as the 3.5 GHz frequency band (3.4-3.8 GHz) for enhanced Mobile Broadband (eMBB) services (i.e. for 100 Mbps or 300 Mbps per user), although they will be of significant importance for other services such as URLLC or mMTC.

The Netherlands is a particular case when it comes to the use of the 3.5 GHz. However, the equipment available to network operators is likely to be based on the worldwide state of the band, due to economies of scale. Therefore, since the 3.5 GHz frequency band (3.4-3.8 GHz) is expected to be progressively refarmed[24] for mobile across the EU, the model assumes the lower band will be included in multi-carrier macrocells and the upper band will be used for small cell rollout.

In the next two subsections, we describe the mobile model, comprising the network dimensioning module and the costs module. Further on, we briefly present the other parts of the model. These parts will be customised to capture specifics of the Netherlands, as we explain in chapter 5.

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[21] https://www.stratix.nl/media/media/documents/07.2%20rapport%20stratix.pdf

[22] https://www.rijksoverheid.nl/binaries/rijksoverheid/documenten/kamerstukken/2018/02/07/antwoorden-op-kamervragen-over-experimenten-met-5g/antwoorden-op-kamervragen-over-experimenten-met-5g.pdf

[23] https://www.tenderned.nl/papi/tenderned-rs-tns/publicaties/116517/documenten/2660208/content http://publicaties.dsp-groep.nl/getFile.cfm?file=11sfnoord_evaluatie_draadloos_cameratoezicht_amsterdam_noord.pdf&dir=rapport

[24] Refarming (or repurposing) spectrum is the concept used in the spectrum allocation domain to refer to the process of cleaning the use of some frequencies by a certain technology or use to allow other. The worldwide trend of refarming spectrum is driven by technological innovations of manufacturers innovations, and the subsequent standards updates. Historical and regional considerations and national legislation specifics lead to different applications per operator.

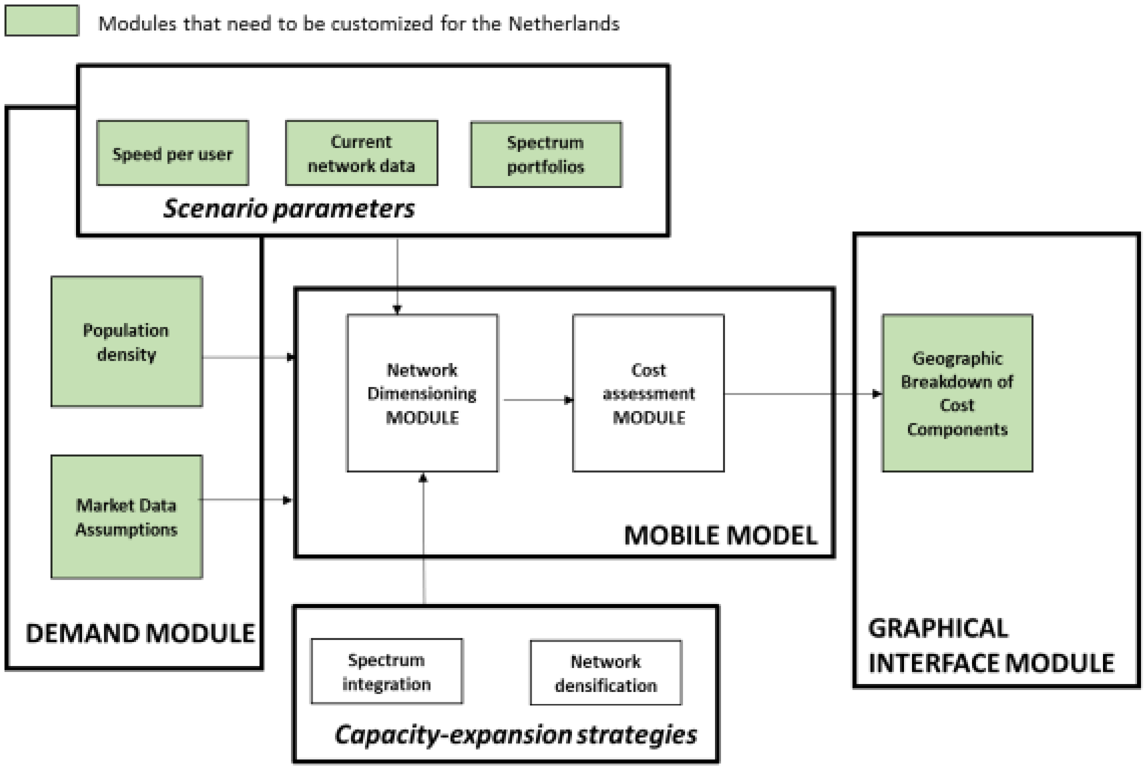

Figure 6: Methodological Sequence modules that need to be customised per country

To assess how well each strategy performs in meeting present demand, a *capacity margin* metric is utilised for area i at time t and is calculated by subtracting current $Demand_{it}$ from $Capacity_{it}$.

3.1.2 Network dimensioning module

The first version of the '5G' release was determined while this project was being undertaken and the standard is still evolving and maturing. Given this uncertainty, we approached this problem by extrapolating the known technical characteristics of 4G LTE and LTE Advanced. This section describes the how the number of required assets is calculated for both the macrocell and the small cell networks.

With regard to the macrocell network performance, the methodology followed is summarised in the diagram in Figure 7, which is further described next.

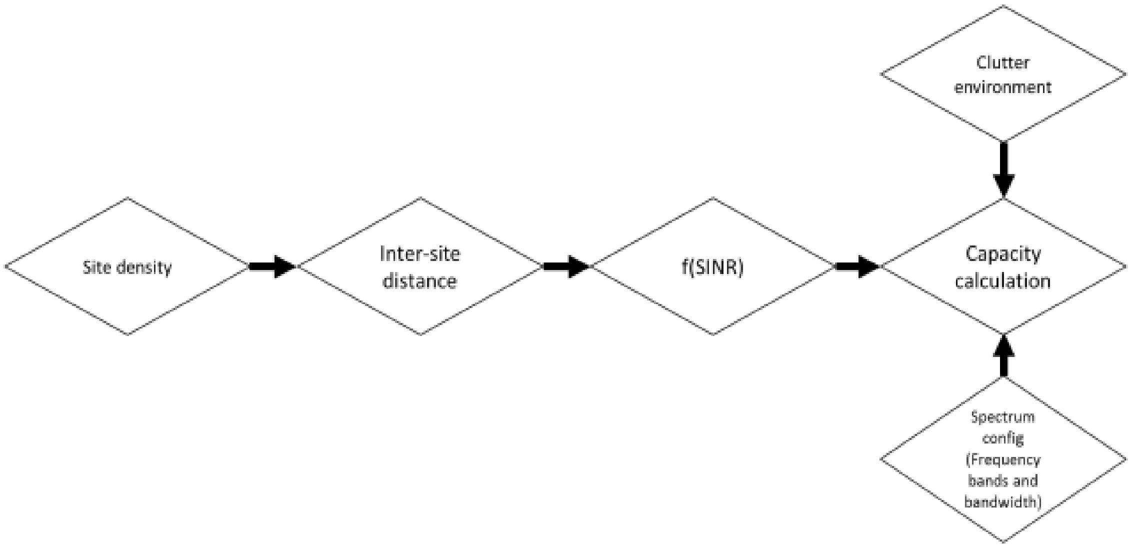

Figure 7: Flowchart for asset calculations for macrocell and small cell configurations

As illustrated, the macrocell capacity is estimated based on the existing inter-site distance (ISD), which is derived from the base station density, calculated as described in section 5.2 for the case of the Netherlands. Based on this base station density, the model uses system level simulations of a typical mobile network (Frias et al. 2017) to estimate both the current network capacity and the expanded capacity if new frequencies are integrated.

For every frequency considered, the probability distribution function (PDF) of the quality of the signal (measured as the Signal to Interference and Noise Ratio, SINR)[25] is estimated with over 90% confidence interval, based on propagation characteristics. Three clutter types are used, namely urban, suburban and rural, used for the homonym geotypes.

The PDF function of the SINR ($f(SINR)$) is then used to estimate the average spectral efficiency, as in equation (1), where the spectral efficiency at each SINR follows Mogensen (2007).

$$\eta_{ISD} = \int \eta\,(SINR) f(SINR)\, dSINR \qquad (1)$$

Based on the average spectral efficiency for the base station density (η_{ISD}), the average throughput (Mbps) is finally calculated, as noted in equation 3. For this, three-sector cells are assumed and the available bandwidth at each frequency band (BW^f) must be taken into account $Throughput_{ISD}{}^{cell} = 3 \sum_f \eta_{ISD}^f \, BW^f$ (2)

[25] The SINR is a measure of the signal quality and therefore determines network capacity, along with available bandwidth.

With regard to the small cells, the rollout strategy option involves deploying small cells at the 3.5 GHz range (3.4 to 3.8 GHz) using TDD mode. Here, to estimate the required number of small cells, high spectral efficiency is assumed (6 bps/Hz) along with 50 MHz available bandwidth, a maximum coverage of 200m and a 5:1 download-to-upload ratio. Parameter values are outlined in Table 5.

Table 5: Key network dimensioning parameters

Parameter	Value
Macrocell RAN architecture	Three-sector cells
Frequency re-use factor	1
Shadow fading log-normal distribution	$\sigma = \begin{cases} 4.2 + 1.3\ log_{10}(f(MHz))dB;\ urban \\ 3.5 + 1.3\ log_{10}(f(MHz))dB;\ other \end{cases}$
Building penetration loss log-normal distribution	(μ, σ) = (12 dB, 6.5 dB)
Propagation model	SEAMCAT (2010)
% indoor users	50% urban and suburban, 0% rural[26]
Bandwidth	Depending on frequency band and sharing

The network model utilised follows the 3GPP technical recommendations for defining transmitted power, antenna height and propagation (3GPP, 2010). Using the SEAMCAT (2010) 'Hata Extended' propagation model, log-normal distributions for signal loss due to (i) slow fading or shadow fading (due to clutter), and (ii) building penetration.

The SEAMCAT model is valid up to 3 GHz, although it is also used for 3.5 GHz modelling and it can be expected to give reasonably reliable results for these higher frequency bands also. Other than SEAMCAT there is no other feasible option to have one and the same model used across all spectrum bands that can guarantee the coherence in the modelling results.

Overbooking factor is assumed at 1:50[27]. The overbooking factor is in accordance with LTE Networks design and planning practice (Holma and Toskala, 2011).

The outputs of the network dimensioning module provide the number of required assets according to the strategy selected, which is further used to assess the costs components.

[26] Rural areas are assumed to be areas with population densities below 782 persons per km^2, as further explained in section 3.1.5. These areas only comprise 46% of the population in the Netherlands but 89% of the surface.

[27] Overbooking or oversubscription refers to the ratio of allocated and guaranteed capacity per user. Overbooking is a normal phenomenon in access networks because it is not necessary and not feasible to dimension a network in such a way that every end user can use the full capacity at the same time. See https://en.wikipedia.org/wiki/Overselling#Telecommunication_Industry

3.1.3 Cost module

After network dimensioning the different infrastructure expansion strategy options, the number of required elements per asset type is calculated for each scenario. The scenarios reflect the desired nation-wide coverage to provide a certain download speed per user in all the environments, from very urban to very rural. Cost data are then allocated to each asset type to obtain the required investment for each infrastructure strategy option. The costs used have been taken from a combination of (i) local costs for fibre cost per kilometre, and (ii) asset costs either from the Ofcom Call Termination Model (MCT) (2015) or the Horizon 2020 5G NORMA project[28]. In the case of the Ofcom MCT model, the costs have been broadly agreed by UK mobile operators which provides a degree of confidence in the costs applied as opposed to using arbitrary cost assumptions. In the case of NORMA, costs are subject to higher uncertainty since they're prospective estimates, but they have been agreed by the members of the consortium, among which there are telecommunication operators. As some costs are in British pounds, we have converted them into Euros based on an exchange rate of 1 Euro: 0.8955 GBP (Exchange rate as of 15th November 2017).

Table 6 illustrates the costs used by assets as applied during the 5G cost modelling study for the United Kingdom, with the cost equivalents in Euros.

[28] https://5g-ppp.eu/5g-norma/

Table 6: Deployment costs per infrastructure type (GBP and EUR)

Strategy	Cost type	UNIT	Capex		Source
			(GBP)	(EUR)	
Spectrum integration on the macrocelluar network	Deploying a 5G multi-carrier BS	BS	40,900	45,673	Ofcom (2015a)
	Additional carrier on current BS	carrier	15,000	16,750	Ofcom (2015a)
	Civil works	Cell site	18,000	20,101	5G NORMA (2016)
	Fibre backhaul	Km	20,000	22,334	Assumption
Network densification through small cells	Small cell equipment	Cell site	2,500	2,791	5G NORMA (2016)
	Small cell civil works	Cell site	13,300	14,852	5G NORMA (2016)
	Small cell backhaul		-		5G NORMA (2016)

The RAN costs that are represented in the breakdown of the results per cost components include a 5G multicarrier base station and as many additional carriers as spectrum bands for each macrocell. As explained in paragraph 3.1.3, the small cells' backhaul is considered to be an OPEX, rather than a CAPEX because in most cases operators either make use of already existing connections or outsourced. Under these assumptions, it would be rented from companies specialised in providing mmW connections to serve as the backhaul for 5G small cells, or make use of an existing end-user connection (for instance for an office or residential building with an antenna on its rooftop). This is in line with what the European Project (NORMA, 2016) assumed and thus the designers of the cost model took the same approach. The idea behind this is that in areas with very dense small cells networks, it is very likely that some infrastructure will be (partly) shared or outsourced to specialised service providers since four completely different overlapping networks will not be feasible. Thus, the backhaul of small cells is assumed to be an opex (as in NORMA, 2016) and is not taken into account in the investment calculations of this work.

3.1.4 Scenario parameters

The scenario parameters allow testing the model for different contexts. As illustrated in Figure 2: Cost curves by scenario and strategy for scenario 5 (300 Mbps, Mobile only operator) and scenario 6 (300 Mbps, Mobile-fixed operator)Figure 2 and Figure 3, these parameters comprise demand-related inputs and other inputs referred to the legacy infrastructure and market structure. First, regarding the demand, the model can test the key cost differences of the desired per-user data rate (i.e. 30 Mbps) as well as the relationship between coverage obligations and costs.

In terms of the market structure and the legacy infrastructure, the model can represent varying cases through the parametrisation of the number of operators in the market, their base station network, their market shares, their spectrum portfolios and their existing backhaul infrastructure. In this regard, mobile-only carriers are typically defined as mobile network operators who do not operate their own fixed network and would, therefore, have a less extensive backhaul network for their mobile base stations, the impact of which may vary per country.

Even if the economics of a specific operator can be captured by the model, due to the sensitivity associated with this type of analysis, we do not model specific network operators. Consequently, we use notional hypothetical operators as a way of addressing this issue, that are usually assumed to have 30% of the market and thus route 30% of the traffic generated.

As the digital ecosystem experiences very rapid change, long-term forecasting is extremely challenging. Consequently, although the model allows setting any time frame, the scenarios only focus on a time horizon of 2025.

3.1.5 Demand module

The demand module is fed with the surface area of each postcode (km2), population data and per-user speed. Population density bands are then defined using the boundaries outlined by Analysys Mason (2010) for the UK's Broadband Stakeholder Group. This includes geotype segmentations for seven settlement types which capture the key demand, capacity and cost characteristics for mobile wireless networks. These are Urban (>7,959 persons per km2), Suburban 1 (>3,119 persons per km2), Suburban 2 (>782 persons per km2), Rural 1 (>112 persons per km2), Rural 2 (>47 persons per km2), Rural 3 (>25 persons per km2) and Rural 4 (>0 persons per km2).

3.2 Application of the 5G rollout cost model to the UK

As mentioned at the beginning of this chapter, the mobile cost model described in the previous section has been used recently to analyse the situation of the UK in preparation for the roll-out of next-generation of mobile networks. The assessment is framed in the project ITRC-MISTRAL, a research consortium exploring ways to improve the performance of infrastructure systems.

In general, the UK's approach to infrastructure planning does not adopt a long-term strategic approach to infrastructure needs across transport, energy, telecommunications, water, and waste. Within the digital realm, the spectrum allocation process for 4G LTE was delayed by numerous legal challenges, which made the 4G rollout lag behind other countries. Originally planned for 2009, the spectrum auction did not take place until 2013. Yet, the UK does not want to end up in this position again and has therefore been pushing to become a leader in the deployment of 5G.

Consequently, George Osborne, as Chancellor of the Exchequer, tasked the National Infrastructure Commission in 2016 with advising 'the Government on what it needs to do to become a world leader in 5G infrastructure deployment, and to ensure that the UK can take early advantage of the potential applications of 5G services' (Osborne, 2016:1). The National Infrastructure Commission set out to produce a report based on an affiliated evidence base which included:

- A report by LS Telecom (2016) which focused on the 5G infrastructure requirements for the UK. This was undertaken by mapping current digital infrastructure assets in urban and rural geographic areas, the strategic road network and rail routes. This was accompanied by also focusing on associated opportunities, as well as barriers and challenges to deployment.

- A report by Frontier Economics (2016) which focused on the market incentives to invest in 5G, based on the current and future changes to the mobile ecosystem. The analysis addressed this topic by considering investment drivers in the network (with consideration of market structure), the impact of the regulatory framework, and finally the potential approaches to facilitate private sector investment in the sector.
- A report by Oughton & Frias (2016) which focused on the cost, coverage and rollout implications of 5G in Britain, and formed the original development of the modelling work applied here to the Netherlands. Within this report, the authors explored (i) the cumulative cost for serving the population with 50 Mbps ultrafast broadband, (ii) the total regional infrastructure cost for urban, suburban and rural areas, (iii) the spatial rollout of infrastructure based on annual capital expenditure constraints, and (iv) the estimated cost for rolling out infrastructure to underserved road and rail routes.
- A report by Real Wireless (2016) assessing the future use cases for mobile telecoms in the UK. The representative use cases are associated with connected vehicles, railways, healthcare, smart utilities, supply chains, and media and cloud everywhere, although they do point to over thirty potential uses.

Following this, the Department for Culture, Media and Sport in combination with HM Treasury, released the UK's 5G strategy in early 2017, entitled 'Next Generation Mobile Technologies: A 5G Strategy for the UK' (DCMS & HM Treasury, 2017). The strategy contains content on the economic case, regulation, governance, coverage and capacity, security, spectrum and technology.

5G infrastructure is also being considered in the UK's National Infrastructure Commission as it undertakes its very first comprehensive National Infrastructure Assessment, as part of the potential costs and benefits of mobile telecommunications (National Infrastructure Commission, 2017).

Mobile coverage for both voice and data can be a subject of much frustration which is often in the media. The British Infrastructure Group (2016), consisting of over 90 cross-party Members of Parliament, have supported calls for reform to the sector in a recent mobile coverage campaign, based on the elimination of areas of no coverage (known as 'not-spots'). In terms of existing provision, a recent analysis by the regulator Ofcom (2016a)[29], found that 4G coverage by all four operators now reaches 72% of premises indoors and only 4% of the premises are not covered by a 4G signal from any operator. However, only 40% of the geographic area is covered by all operators. Indeed, some feel the experience differs from the reported voice and data coverage statistics leading to disgruntled users, with this therefore, becoming a hot topic in the media. OpenSignal's (2017) State of LTE report shows that the UK ranks 43rd globally in terms of 4G availability and 39th in terms of speed (subject to the usual speed test caveats).

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[29] The data on the coverage of mobile networks in the Ofcom report were collected from the four UK mobile network operators, EE, O2, Three and Vodafone as 100m x 100m pixels for their coverage for 2G ,3G and 4G networks with signal thresholds for estimating outdoor, indoor and in-car coverage.

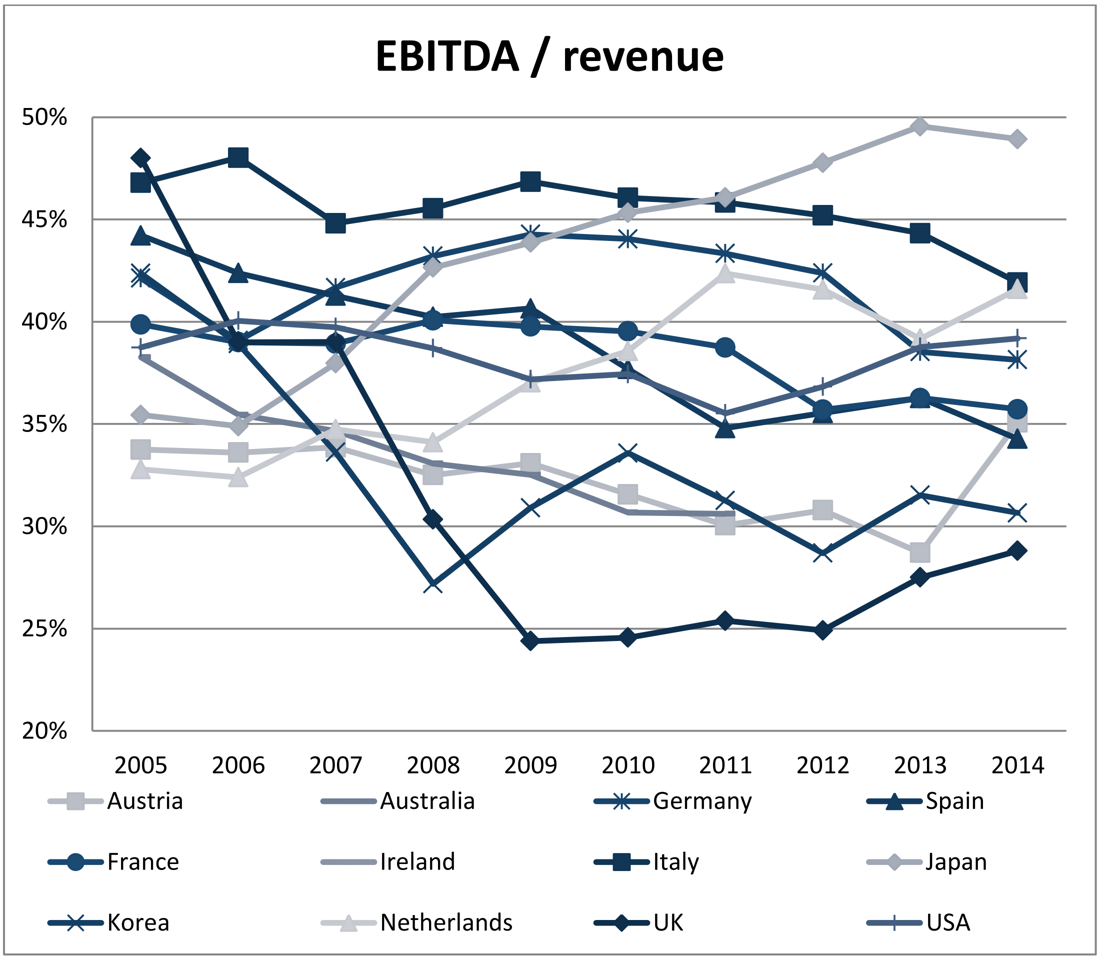


Figure 8: EBITDA / revenue of mobile operators in major countries 2005-2014 (New Street Research, cited in WIK-Consult, 2015)

Average monthly spends on mobile voice and data services have decreased significantly over the past decade. Falling Average Revenue Per User (ARPU) is also reflected in the general profitability of the UK mobile sector, which has declined since 2005. Two key metrics that represent 'profitability' include Earnings Before Interest, Tax, Depreciation and Amortisation (EBITDA), and Post-Tax Return On Capital Employed (ROCE). Firstly, Figure 8 shows between 2005-2014, the EBITDA for 12 countries, whereby the end of this period, the UK was lowest.

While countries such as Spain and Korea have also seen declining EBITDA/revenues, others have seen an increase, such as Japan and the Netherlands. Little change has taken place in the mobile markets of the USA, France and Austria with the EBITDA/revenues margin remaining around 35%.

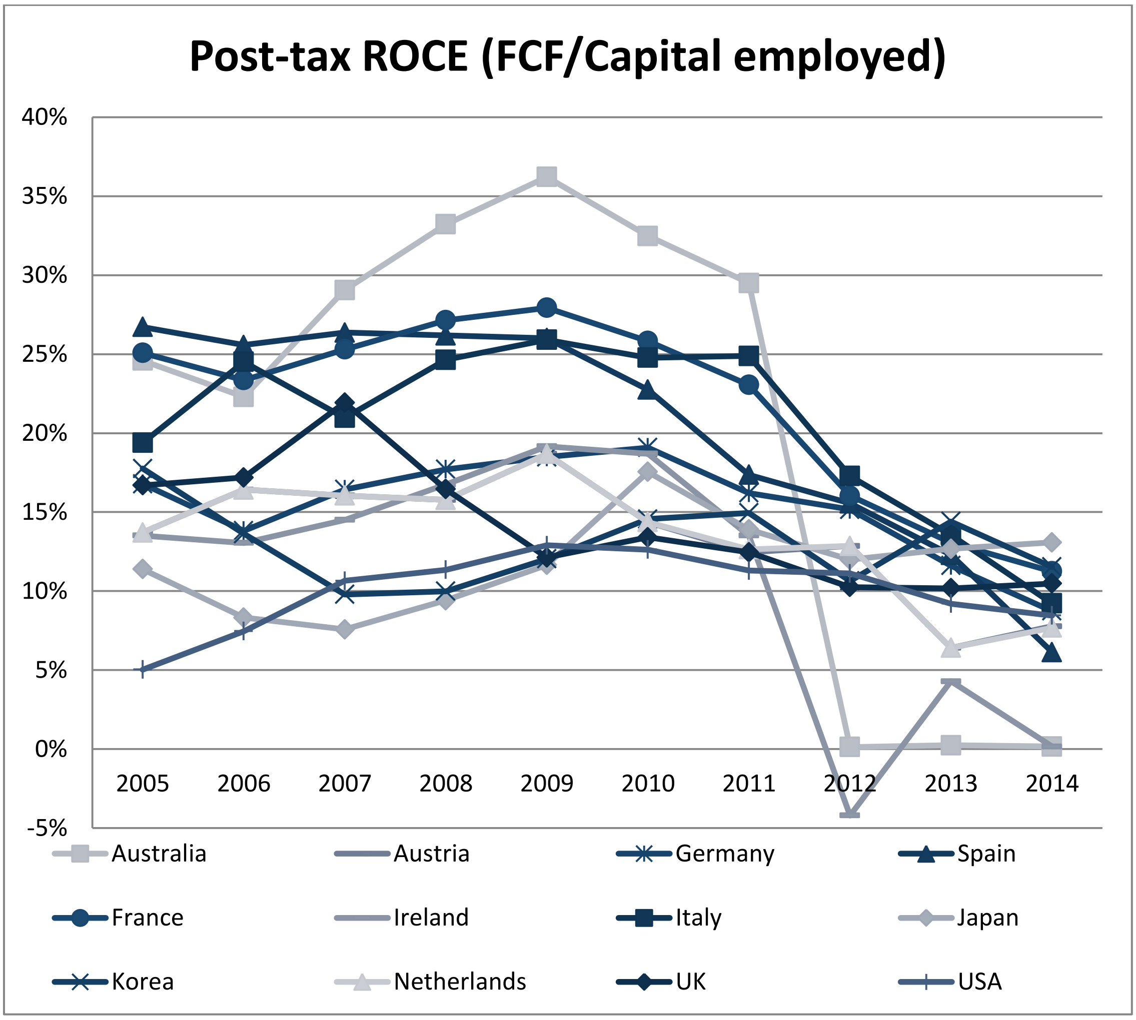


Figure 9: Post-tax ROCE of mobile operators in major countries 2005-2014 (New Street Research, cited in WIK-Consult, 2015)

Secondly, Figure 9 shows for the same period the Post-Tax ROCE. The UK mobile sector was in the middle of the distribution in 2015 at 10-11% return. In comparison with other countries, this shows that the UK mobile sector has potentially low investment attractiveness moving forward, which may detrimentally affect infrastructure investment. The Netherlands was in the middle of this distribution in 2014, just below 10% ROCE.

Within this context, the rollout of 5G networks seems more challenging in the countries in which telecommunications operators have been seeing declining revenues. Additionally, the concern is that not enough digital infrastructure is being deployed, which may lead to businesses and consumers being dissatisfied. In some cases, demand could exceed supply, which may have potential economic impacts as telecommunications underpin economic activities and bottlenecks lead to productivity issues. Both the National Infrastructure Assessment and the UK's 5G Strategy aim to eliminate or reduce connectivity issues, but there may have to be serious changes to the market incentives for investing in network infrastructure for this to be successful. In the UK, current investment has been approximately £2 billion[30] per year across the industry to upgrade and expand the cellular network to meet demand by both domestic and commercial users. This is approximately £30 per capita per year, based on a UK population of 65 million.

[30] Real Wireless. (2015). UK spectrum usage & Demand: First edition. Pulborough: Real wireless. Retrieved from https://www.techuk.org/insights/reports/item/6825-uk-spectrum-usage-demand-second-edition

4 The Dutch Telecom market

4.1 The Mobile market

The Dutch Telecom market can be described as consisting of three significant separate markets; mobile, fixed-line consumer and business fixed. For this report, the mobile market is the most significant. There are four mobile network operators active in the Netherlands, KPN, VodafoneZiggo, T-Mobile and Tele2. Each of these operators is also present in the fixed-line consumer broadband market. KPN owns a nation-wide fixed-line copper and fibre network. VodafoneZiggo owns a near-nationwide cable (DOCSIS)-network. T-Mobile and Tele2 offer consumer fixed network services on the network of KPN. T-Mobile exited the consumer fixed market in 2012 by selling its DSL network to Online.nl and re-entered the consumer fixed market in 2016 when it bought Vodafone's fixed business. In addition KPN, VodafoneZiggo and Tele2 have significant business fibre connections throughout the country. In the business fibre market there are also a number of other players, such as Eurofiber, Relined (which re-sells fibre infrastructure of ProRail, the Dutch Rail infrastructure company and Tennet the Dutch high-voltage electricity grid operator), BT, Colt and several regional players such as Trent.

KPN and (a forerunner of) Vodafone were the first GSM providers in the Netherlands, opening networks in 1994 and 1995 respectively. (The forerunners of) T-Mobile entered the market as an 1800 MHz only operator in 1998. As the indoor and outdoor propagation characteristics of the 1800 MHz is considerably lower than that of the 900 MHz, a large number of sites were needed to achieve the same level of coverage as network operators that were operating 900 MHz. T-Mobile still has the largest number of sites in the Netherlands. Tele2 entered the mobile market in 2012 when it received spectrum licenses. Tele2 was already active as an MVNO, first on the network of KPN, later on, the network of T-Mobile. It also operates as a fixed line operator on KPN's network and business network operator over its own and KPNs fibre network. Tele2 is building out the 4G network aiming to have countrywide coverage, partly by sharing sites and antennas with T-Mobile, but with its own backhaul and active radio equipment. Recently T-Mobile announced it intends to take over the Tele2 network and operation in the Netherlands.

In addition to the mobile network operators, there are many MVNOs (full MVNOs as well as Service Provider MVNOs) active in the Netherlands market that serve a considerable share of the market. KPN, but also T-Mobile and VodafoneZiggo are hosting these MVNOs.

Table 7: Number of active subscriptions in the Netherlands (source ACM)

	2016-Q1	2016-Q2	2016-Q3	2016-Q4	2017-Q1	2017-Q2
Data only	1.112	1.224	1.203	1.183	965	939
M2M	3.036	3.382	3.650	3.945	3.382	3.600
Postpaid MNO	11.827	12.175	12.367	12.483	12.516	12.974
Prepaid MNO	3.539	3.527	3.448	3.358	3.259	3.194
Post and prepaid MVNO	4.402	4.634	4.923	5.049	5.090	4.939
Total	**23.916**	**24.942**	**25.591**	**26.018**	**25.212**	**25.646**

The mobile market consists of 25,6 million subscriptions as per mid-2017 (latest figures ACM[31]) of which 14,4 million subscriptions are for a combination of telephony and data, which assumes these are used by persons. The number of subscriptions over time is still steadily growing. There was, however, a decline in the number of subscriptions in the first quarter of 2017. This may have been caused by efforts of ACM to optimise the utilisation of telephone numbers and to prevent exhaustion of numbering resources. The M2M market is relatively fast growing compared to traditional postpaid and prepaid subscriptions. The growth of the M2M market is expected to continue in the coming years.

Not only the number of subscriptions is growing, also the usage of mobile data is growing. Data usage grew 61% from the 4th quarter of 2015 to the 4th quarter of 2016 and stood at approximately 1GB/capita per month and grew 121% to the 2nd quarter of 2017. This is still considerably lower than the average use per capita in some other EU countries, where Finland particularly stands out with an average use of above 10GB/month.[32] Finland has had ‘unlimited’ mobile subscriptions for a few years. The figures for 3G and 4G data seem to reflect the introduction of ‘unlimited bundle’ mobile subscriptions in the Netherlands since the beginning of 2017.

Table 8: Usage of mobile networks in the Netherlands (source ACM)

(*1000)	2016-Q1	2016-Q2	2016-Q3	2016-Q4	2017-Q1	2017-Q2
SMS	787.275	852.319	852.007	797.503	752.442	994.271
Minuten	7.318.554	7.966.695	7.512.497	8.162.142	8.143.541	7.778.641
Data 3G MB	11.556.019	12.997.108	14.466.784	14.626.261	14.705.630	16.984.572
Data 4G MB	23.400.097	30.695.127	36.220.843	41.530.532	46.563.175	60.129.523

The retail market shares of mobile operators have been quite stable in recent years. KPN has 30-35% of the market, Vodafone 20-25%, T-Mobile has 15-20% and Tele2 has up to 5%, MVNO’s, excluding the captive brands of mobile network operators, have 20-25% market share.

4.2 Frequency use/ licenses

Spectrum for mobile communication in the Netherlands is allocated in the frequency bands in line with the European Union. Bands that are currently in use for public mobile communication are 800 MHz, 900 MHz, 1800 MHz, 2100 MHz, and 2600 MHz bands. The licenses for use of the 800 MHz, 900 MHz, 1800 MHz, and the unpaired spectrum in the 2600 MHz (and 2100 MHz) frequency bands were auctioned in 2012. The licences were issued at the start of 2013

[31]. https://www.acm.nl/sites/default/files/documents/2018-01/telecommonitor-rapportage-eerste-halfjaar-2017.pdf

[32] This is to some extent attributable to the high use of data-only subscriptions, which are also used to get broadband in locations where there is no fixed line broadband.

and run until 2030 (except for the 2100 MHz FDD licenses that originally ran until 2016, now extended until the end of 2020). In 2019 an auction is planned for the 700 MHz, 1500 MHz, and 2100 MHz bands[33].

Table 9: Current spectrum allocation per Mobile Network Operator (MNO) in the Netherlands

Band	KPN	Tele2	T-Mobile	VodafoneZiggo
800 MHz	2x 10MHz	2x 10MHz		2x 10MHz
900MHz	2x 10MHz		2x 15MHz	2x 10MHz
1800MHz	2x 20MHz		2x 30MHz	2x 20MHz
2100MHz	2x 20MHz		2x 20MHz	2x 20MHZ
2600MHz	2x 10MHz	2x 20MHz	2x 5MHz	2x 30MHz
2600MHz (unpaired)	1x 30MHz	1x 5MHz	1x 25MHz	

33 https://www.rijksoverheid.nl/onderwerpen/telecommunicatie/nieuws/2017/09/20/voorbereiding-landelijke-veiling-mobiele-communicatienetten-gestart

A general overview of spectrum allocation is depicted in Table 9 (see also Annex C for more details). Operators are changing the way they explore the spectrum. Spectrum initially allocated for 2G/3G technology is explored ('re-farming') also for 4G technology. This takes place in the 1800 MHz bands, but also in 900 MHz and 2100 MHz bands. In December 2017 Vodafone announced that it would terminate its 3G network in 2020. It has publicly stated that its 2G network will be active until 2025. T-Mobile has stated in the past that it intended to shut down its 2G network by 2020. KPN hasn't announced what its plans with its 2G/3G networks are.

In addition to using more and more spectrum for 4G, operators are also experimenting with Massive MIMO to further expand the capacity of the existing spectrum.[34]

4.3 Fixed broadband in the Netherlands

The broadband market in the Netherlands to a large extent is a duopoly between KPN and VodafoneZiggo. KPN has a nationwide DSL-network and in addition, it has an FTTH network that reaches a significant part of the country. VodafoneZiggo reaches over 90% of households with its DOCSIS network. In addition, there are some areas (Zeeland, Westland and around Almelo, around Gouda) where Delta has a coax cable network, Caiway-CIF has an FTTH network and REKAM has a coax network partially overbuilt to fibre that together reach near 600K homes. Also, some smaller regional FTTH networks spanning multiple municipalities are operational in Friesland (Kabel Noord) and Brabant (Mabin), and also a limited amount of small municipality sized FTTH networks have been implemented. In total over 35% of the Dutch households can get an FTTH subscription[35]

The FTTH and cable networks are mostly limited to the area within town borders and do not have coverage in the countryside or on business parks. The DSL network reaches almost every location in the country, however, the speeds attainable outside the main built-up areas are dependent on distance and can be lower than 1 Mbit/s[36].

Most businesses and the larger business parks are covered by forms of fibre to the office (FTTO). The Dutch regulator ACM has evaluated this market and found it to be competitive. The regulator concluded KPN's market share in this market was stable at 40%-45% and there were a number of alternative networks to choose from, which implies that for a significant part of the market operators have a choice in which fibre networks they use. To some extent, FTTO is the most interesting for mobile networks as unbundled access to fibre is the preferred backhaul technology. Strictly speaking connectivity to mobile sites isn't considered part of the FTTO-market and isn't regulated.[37] Suppliers to the FTTO-market are however also active in the mobile backhaul market and therefore although mobile backhaul isn't part

34 http://4gmasten.nl/nieuws/t-mobile/519-t-mobile-nederland-activeert-eerste-antenne-met-5g-technologie-in-amsterdam
35 Source: Stratix database
36 See for the available access speeds per location: https://www.breedbandatlas.nl/
37 https://www.acm.nl/sites/default/files/old_publication/publicaties/16207_besluit-marktanalyse-ftto.pdf

of the FTTO-market, the suppliers of FTTO can be considered part of the mobile backhaul market.

One of the main questions is whether the supply of residential broadband is relevant to the future 5G backhaul market. This is a hard question to answer. In general, it is the case that in the Netherlands mobile access networks and broadband access networks have little to no relation on the technical side. There may be some promotional pricing if a fixed/mobile bundle is used, but in the networks there is no technical interaction between the two. There were a few picocell solutions for consumers and small businesses, but these appear not to be available anymore (Vodafone ceased the sales of its picocell solution Signaalplus for 3G in 2016.) Internationally there are also few examples of such solutions, though Iliad/Free in France did integrate picocell in its broadband DSL and fibre modems. It, however, appears to be quite unique in this respect.

Coverage using indoor devices to also reach outdoor devices appears to be challenging using the higher 5G frequencies (3 GHz and higher), particularly in well-insulated Dutch homes. This combined with the costs of a 2G/3G/4G or 5G solution in modems and set-top boxes appears to be one of the reasons why there is little integration between the two networks.

One of the research questions was whether the integration between fixed and mobile networks will be more pronounced in the future. This is hard to answer. To some extent, it is likely that in the future there are some advantages in the integration of fixed and mobile networks, as small cells will require fibre networks to be extended closer to the users. Therefore, the availability of fibre in the last miles will also be an enabler for small cells supporting 5G. As fixed networks are evolving and being upgraded they also bring fibre closer to end users. This can have a positive side-effect on the economic feasibility for 5G. However, so far they have not achieved this for 4G networks. Capacity constraints appear to exist particularly in high density urban and suburban areas. Here high-frequency solutions appear to be an option. What is less clear however is how the backhaul for this technology will be organised. There are however many practical considerations. It isn’t just about fibre, but also about electricity, the correct location, access to equipment in case of failure. Indeed, in many locations where densification is needed to achieve the desired speed, there is a good chance that business fibre of multiple suppliers is already present. The two reasons for this are that there are likely many businesses at these locations and that in the past mobile networks have rolled out densification solutions to these locations already, and those solutions can also be used for 5G.

Backhaul over an existing business fibre connections should be no problem. Technically a consumer FTTH connection is no different to a business fibre, there is only a difference in the service level that is offered. VDSL and DOCSIS may not be ideal, but their street cabinets could be of use. Whether or not it is actually usable and used is a different matter. Street cabinets for VDSL and DOCSIS may, for example, be in the wrong location, not have adequate space or have a backhaul limited in fibre count. It is only when the costs of densification are significant that we expect operators to choose consumer broadband networks as the basis of their mobile networks.

4.4 The geography of the Netherlands

Compared with the UK, the Netherlands has a smaller geographical area and a higher population density. The UK has substantial areas designated as either rural or remote, with very low population density, making wide area coverage challenging. Also, the Netherlands has some large water areas like Waddenzee, IJsselmeer and Markermeer.

The model used in this research already provided several different geotypes that could be reused for the Netherlands. The model used takes into account both geographical and demographical coverage. The rollout is calculated using a combination of geographical and demographical parameters. The geographical coverage is used as a baseline and the demographical coverage uses address density parameters.

In paragraph 5.6 the translation of the Dutch geography in geotypes for the model is further described.

5 Customisation of the cost model to the Netherlands

5.1 Introduction

This chapter defines assumptions for the Netherlands 5G cost model, taking the United Kingdom 5G cost model as the reference. The section also describes to what extent the parameters used in the model for the UK may be suitable for the case of the Netherlands, or would need to be customised or modified. In general, the modelling sequence described in Figure 10 is applied, similar to the UK model. The blocks coloured in green are those that require changes to reflect the Dutch situation. In the next section we describe what changes were made to each one of them. Any other changes to parameters and scenarios are also discussed.

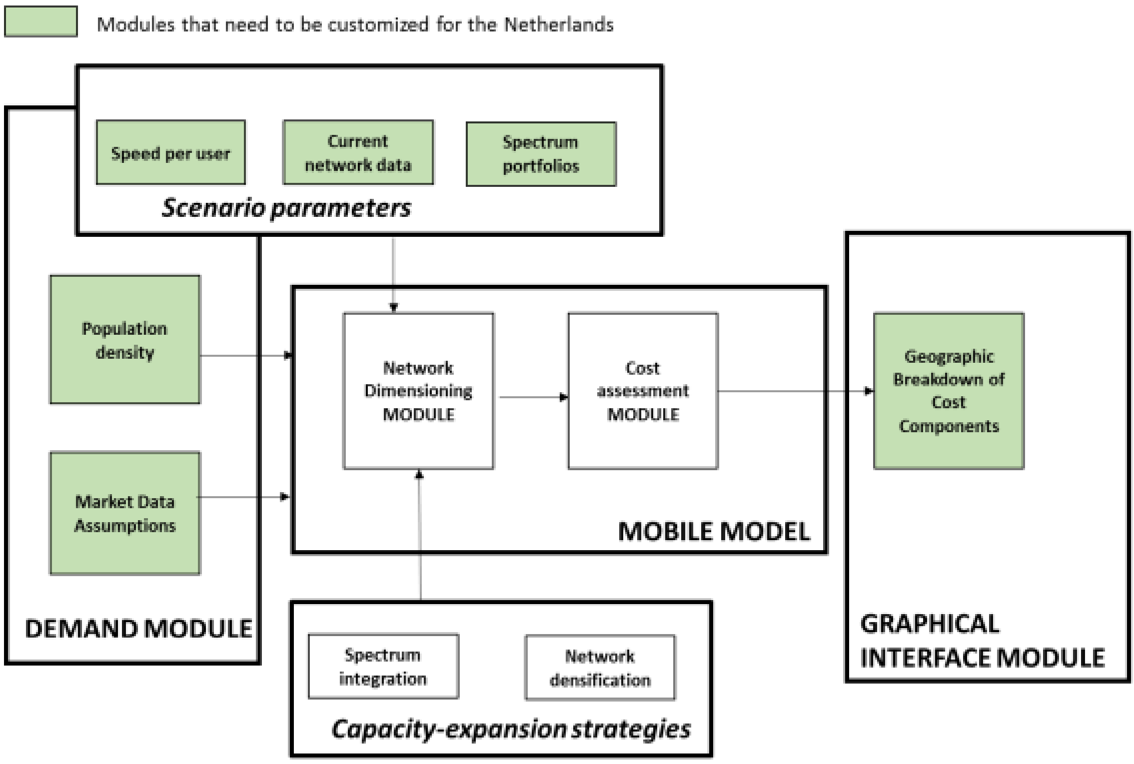


Figure 10: General modelling sequence and customisation for the Netherlands

The model's approach is to calculate the situation for a hypothetical operator with a 'typical' market share of 30%, rather than for the total of all operators. Alternative approaches, however, are less practical, or are likely to take more effort to provide similar or worse results, as discussed next:

- An alternative approach would be to calculate the costs for one or more specific operators. This would however lead to arbitrary and highly debatable choices and mean that the model would have to be run four times for every scenario. Also, the discussions with operators on several necessary input variables would have been even more difficult due to economic strategic sensitivities.

- An alternative approach would be to calculate only the total cost (using one hypothetical operator). This however does not take into account competition, and the fact that one operator may not have access to all possible frequency bands, cell sites and backhaul networks.

A number of input variables for the hypothetical operator, such as investment per year, number of sites, number of users, etc. are based on estimates, assumptions and 'educated guesses' resulting from a combination of market averages, outcomes of discussions with operators, experts in the workshop and expertise from the project members.

5.2 Scenarios for the situation in the Netherlands

Based on the original model and scenarios described in chapter 3, and taking into account the key assumptions for the Netherlands, which will be further described in section 5.4., the following scenarios have been modelled for the situation in the Netherlands:

Table 10: Basic scenario parameters

Scenario	S1	S2	S3	S4	S5	S6
Type of provider	*Mobile-only carrier*	*Mobile-fixed: Mobile carrier with fixed access network*	*Mobile-only carrier*	*Mobile-fixed: Mobile carrier with fixed access network*	*Mobile-only carrier*	*Mobile-fixed: Mobile carrier with fixed access network*
Per-user data rate	30 Mbps	30 Mbps	100 Mbps	100 Mbps	300 Mbps	300 Mbps
Time horizon	2025	2025	2025	2025	2025	2025
Annual capital expenditure	140 M€	140 M€	140 M€	140 M€	140 M€	140 M€
RAN sharing[38]	None	None	None	None	None	None

[38] In some countries RAN sharing between operators occurs, for instance in very rural areas. See for instance: http://www.bipt.be/public/files/en/680/3666_en_02_tech_infra_sharing_eng_final.pdf, https://www.telegeography.com/products/commsupdate/articles/2017/01/16/vodafone-o2-renegotiating-uk-network-sharing-pact-report-says/, https://www.gsma.com/publicpolicy/wp-content/uploads/2012/09/Mobile-Infrastructure-sharing.pdf.

Additionally with help of the model, in chapter 7 the impact of the availability of the 3.5 GHz frequency band (3.4 – 3.8 GHz) will be considered, as well as the impact of spectrum license requirements and the impact of availability of access to other (fibre) networks owned by utilities, public or private organisations.

The different scenarios set different goals for the available per-user rate, which is assumed to be constant once the investment has been made in a certain location. However, the time horizon is taken into account through the pace of the investments. It is assumed that a limited annual capital (140 M€) can be devoted to investments in mobile networks' infrastructure. Therefore, postcode sectors are covered as time goes by and there is more capital devoted to the new infrastructure. Postcode sectors in urban areas are assumed to be covered first, while most rural postcode sectors are assumed to be covered last, if at all. Whether all locations (all postcode sectors) are covered depends on the capital expenditures devoted to mobile networks and the time horizon (i.e. 140 M€/year, during 5 years.). It is worth to note that with this approach, the more expensive the urban areas are, the more likely it becomes that the rural areas are not covered within the time horizon set, given the same limited annual capital.

5.3 Geographic and network data for the Netherlands

5.3.1 Antenna sites and network cells

To identify the existing assets which provide a significant contribution to data capacity rates the current antenna asset register of the Dutch Radiocommunications Agency (Agentschap Telecom) for July 2017 was obtained and the coordinates of all the LTE cells (16,310) which operate at 800MHz and/or 1800MHz frequencies [1], were extracted. Legacy 2G and 3G assets are not specifically taken into account as they do not significantly contribute to data capacity. The capacity of the LTE cells forms the baseline for the capacity calculations of the model. The database does not explicitly give information which antennas are part of the same antenna site. So, to be able to consider costs per antenna site, clusters of antennas in close proximity to each other have to be considered part of the same antenna site (based on clustering cells within 80m into a single site). 'Site' determination, as opposed to a 'cell location' is dealt with as follows: Cells that are within 80 Meters distance from each other are assumed to be located at the same site. For the UK this distance was assumed to be 25 metres. This assumption is based on the outcomes of a study concerning the demand for antenna locations (See Annex A of Stratix 4G LTE Report (2015)). Overlapping buffers were then dissolved to get an approximation for the total number of cell sites, which was estimated at 8404. A point in polygon analysis[39] was then undertaken to count the number of sites in 4066 postcodes. This process is illustrated in Figure 11. The geographical distribution of sites obtained is illustrated in Figure 12.

[39] An analysis that determines which set of points (locations) fall within which sets of polygons (areas)

Sites need to be divided over different operators. This was done by looking at the market share each operator has. The assumption is that current market shares are a reasonable reflection of the division of sites[40]. For reasons explained in 5.1 in this study one hypothetical 'average' operator is considered. Therefore some generalisations and assumptions were made, which were presented and discussed in the workshop with operators that we organised in November 2017. For the cost model applied to the situation in the Netherlands, it is assumed that this hypothetical operator has access to 50% of all the existing sites. The underlying assumption is that operators have access to both sites shared with other operators and sites that belong to the hypothetical operator solely.

As the model has been developed to have a very high level of spatial resolution, the model outputs can be presented geographically. In this case, 4033 postcodes were used as the lower level statistical units for the Netherlands. While it is useful to calculate the demand, capacity and cost calculations at this level, reporting results at this level of spatial resolution can be challenging, both computationally and visually. Hence, we aggregate the lower level statistics into 725 postal code regions that present common characteristics. This still provides a high degree of spatial insight into potential upgrade costs, while providing better scalability.

[40] This is a simplification and generalisation for the hypothetical operator used in the model, based on the average market situation and input from experts and operators. However note that in reality the relation between market share and number of cell sites is not simple: T-Mobile for instance is not the largest operator but has the largest number of cell sites.

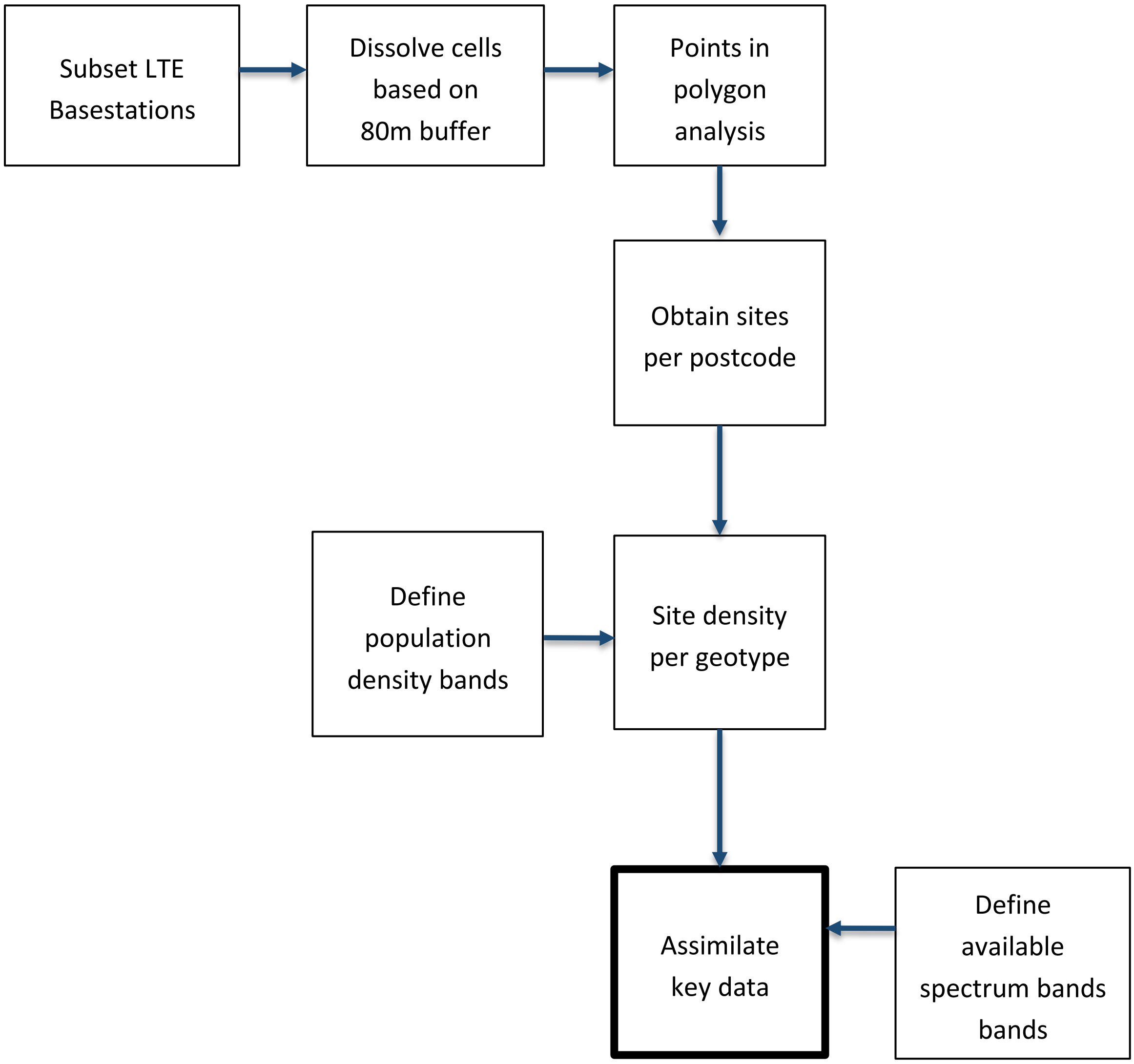


Figure 11: Using current network data (base stations, geographic information) as model input

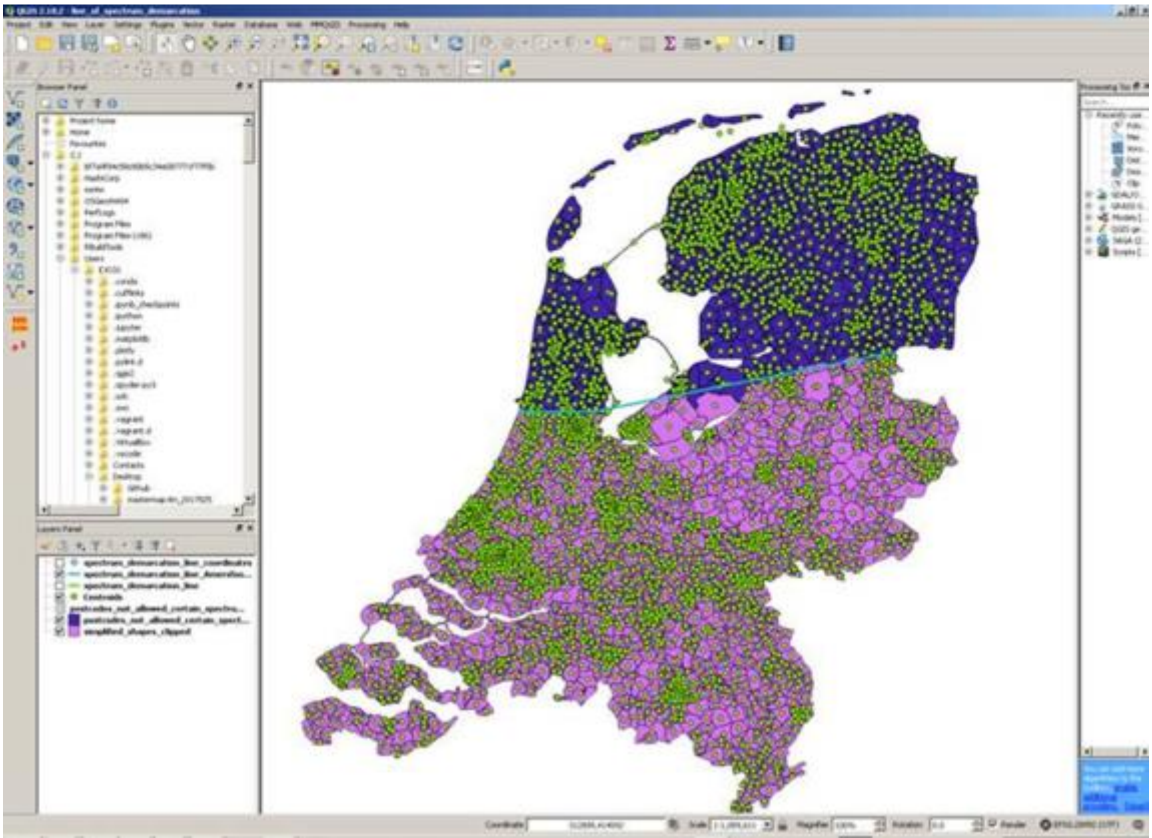


Figure 12: A screen dump of the modelling tool used with Geospatial processing of existing network data: cell sites and cell coverage areas.

5.3.2 Backhaul upgrades

In the UK model, we assume that a fixed-mobile carrier would have access to a fixed network for reduced cost, reducing backhaul expenditure. In this regard, we assume that a mobile-fixed operator will not need to roll out any fibre backhaul, while a mobile-only provider will need to upgrade its backhaul given its more limited fixed infrastructure. However, in the Netherlands, mobile-only operators have also accrued an extensive fibre network, there is availability of access to fibre in the FttO-market (see paragraph 4.3) and therefore, we assume that only a small fraction of the sites will require backhaul upgrades, depending on the area. Table 11 shows the percentage of existing sites that are assumed to require backhaul upgrades to fibre for each geotype. The assumptions are (rough) estimations based on discussions with operators during the workshop and in interviews.

Table 11: Assumptions for % of existing sites that need backhaul upgrades

Geotype	% sites needing backhaul upgrades
Urban	-
Suburban 1	-
Suburban 2	-
Rural 1	10%
Rural 2	20%
Rural 3	30%
Rural 4	30%

5.4 Key Assumptions for the model for the Netherlands

Several assumptions were made for the following parameters:

- General assumptions
- Level of investment
- Spectrum
- Throughput required
- Cost of network assets
- User parameters
- Other points specific to the Dutch situation (e.g. how to deal with water areas, border areas and spectrum restrictions specific to the Netherlands)

In the following subparagraphs, these assumptions are further described and discussed.

5.4.1 General Assumptions

The time window is 2020-2025 and we assume an operator with 30% market share, representing 30% of the total traffic demand in any area.

5.4.2 Level of investment

The market share also reflects the level of investment the hypothetical operator can be assumed to make in any one year. This is used as an input parameter in the cost model to be able to assess potential evolutions of the network over time under different strategies and scenarios. We utilise the average industry-wide investment in the Netherlands per year, over the period 2012-2016. Over this period 4.4 billion euros were invested, although this does include one Dutch operator making above average investments as a new entrant (Tele2), and hence we reduce this figure by an estimated 20%, as this should better reflect the investments made by a 'hypothetical operator', which we assume to be a "brownfield" operator[41]. Given how investment figures also include non-network related investment (e.g. IT systems) we reduce this by another estimated 20% to account for these types of expenditures. The remaining figure of 563.2 million euros per year is divided among the four operators to achieve an approximate 140 million euros of annual investment per operator.

5.4.3 Spectrum Assumptions

As has been mentioned in section 3.1, there is a high degree of harmonisation in the allocation of spectrum bands for (mobile) IMT[42] services across the European Union Member States. The spectrum bands that are considered in the model are 700 MHz, 800 MHz, 900 MHz, 1500 MHz, 1800 MHz, 2100 MHz, 2600 MHz, and 3.5 GHz. Based on the current spectrum allocation for the Netherlands provided in section 4.2, a hypothetical operator that represents the Dutch case has been defined for the application of the model.

The assumption is that in the 3.5 GHz (3.4-3.8 GHz) spectrum range, 400 MHz is available for wireless broadband applications, in accordance with the current National Frequency Plan for the Netherlands and the restrictions that follow from the current assignment: in the model this was translated to not use the 3.5 GHz (3.4-3.8 GHz) spectrum range in the northern part of the Netherlands, and use the range in the southern part of the Netherlands[43]. At the lower part of the band (3.4 - 3.6 GHz), we assume 40 MHz for the hypothetical operator with a downlink-to-uplink ratio 5:1. For the upper part (3.6 – 3.8 GHz) the hypothetical operator is assumed to have access to 100 MHz that it would use for network densification strategies, as described above in section 3.

Overall, the hypothetical operator is assumed to have a portfolio of spectrum as depicted in Figure 13. For the hypothetical operator, it is assumed that only 2100 MHz and a small fraction of the 900 MHz band will continue to operate legacy technologies (2G and 3G). 800 MHz, 1800 MHz, 2600 MHz and a fraction of the 900 MHz band are assumed to be used for LTE and LTE-A systems in order to meet end-user demand in each scenario.

[41] Based on ACM Telecommonitor data 2012-2017 and data from operator annual reports
[42] International Mobile Telecommunications, notation used by the International Telecommunicatino Union ITU, the organisation that internationally coordinates spectrum band assignments
[43] In reality there are also in the south additional restrictions with regard of the use of the 3.5GHz (3.4-3.8 GHz) spectrum bands.

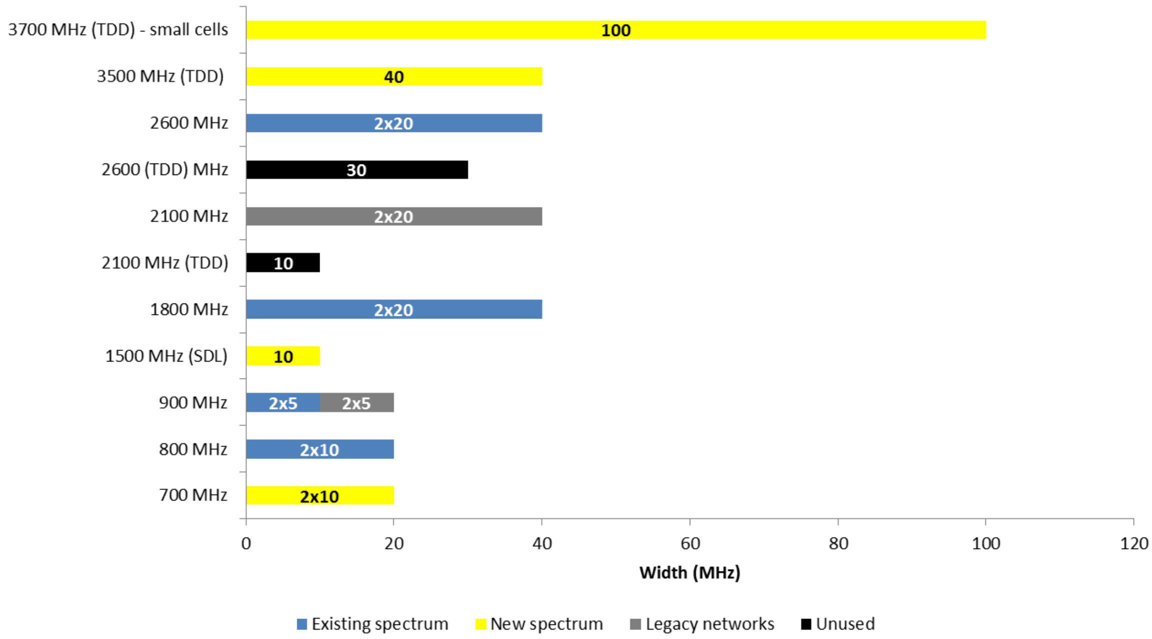


Figure 13: Spectrum available to the hypothetical operator (Existing spectrum refers to 4G and other legacy spectrum bands, New spectrum is spectrum that will be used for 5G)

Note that spectrum allocation for the hypothetical operator is somewhat arbitrary and assumes roughly ¼ of the total available spectrum that will become available in the upcoming years. For instance, 10 MHz in the 1500 SDL[44] MHz band is theoretically possible (there is 40 MHz available in total), but actual spectrum auction regulations and operator strategies may well lead to a situation where blocks of 20 MHz are acquired, or the total 40 MHz goes to one operator.

5.4.4 Speed target scenarios and Throughput Assumptions

Three target scenarios are calculated, for providing 30 Mbps, 100Mbps and 300 Mbps for every customer on every location in the Netherlands of the hypothetical operator. The throughput assumptions in these scenarios use the definitions that are described in 3.1.2.

5.4.5 Model Cost Parameter Assumptions

In the model, a number of cost parameters are of concern. As a starting point for the Netherlands, the same cost parameters as for the UK are used (see section 3.1.3).

For sites with 4G LTE, the UK-assumed cost parameter value ‘Deploying additional multicarrier BS’ will be re-used for the Netherlands. The suppliers of network equipment operate in a

[44] Supplementary DownLink

global market. There is no reason at this stage to assume that 5G equipment in the United Kingdom will be differently priced than in the Netherlands, even more as some of the mobile operators operate in both markets and may have global procurement.

As it is the case for sites with 4G LTE, the cost parameter values for sites with no LTE (Deploying a multi-carriers BS, Site lease, Civil Works) will be re-used for the Netherlands, as suppliers of relevant network equipment operate in a global market, and installation and civil works are expected to be fairly similar between the United Kingdom and the Netherlands.

In the Netherlands, geographic 4G coverage is virtually 100% and therefore, all sites have been assumed to be LTE-capable. However, new multicarrier base stations will be needed for 5G technologies, and they are assumed to be deployed at all sites which would lead to virtually 100% geographic coverage of 5G as well. Availability of small cell backhaul solutions in the Netherlands is comparable or better than in the UK. Therefore, as described in 3.1.3 also for the Netherlands' situation 5G Small cells backhaul is assumed to be an OPEX (as in NORMA, 2016) and it is therefore not taken into account in the investment calculations of this work.

5.4.6 User parameters

Mobile density[45] for the Netherlands is assumed at 1.53 (number of mobile subscriptions per population) based on CBS (total population) and ACM data (number of mobile subscriptions).

Table 12: Mobile subscriptions in the Netherlands

NL	2015	2016
subscriptions	23.590.000	26.018.000
total population	16.900.726	16.979.120
mobile density	1,40	1,53

(source CBP, ACM)

For Urban and Suburban geotypes the outdoor-indoor usage is assumed at 50%-50%. For Rural geotypes the outdoor-indoor usage is assumed at 100%-0%. These assumptions are estimates that were used in the UK study and were discussed with operators in the workshop.

The connection probability for the Netherlands is maintained at > 90%.

[45] Mobile density is ITU-T terminology, comparable with the marketing term 'penetration'.

Why the model uses traffic speed and not traffic volume

It should be noted that the study takes the availability of a certain data speed for the population (according to the geotypes) as a parameter and then calculates the cost for the rollout of the network, given the availability of spectrum.

A different approach would be to estimate the volume of traffic per average user and turn this into required network capacity given how traffic is distributed over time.

There is obviously a relation between data volume and data speed. The particular characteristics of the services being offered and used would be required in order to fully understand the relation between the volumes consumed and data speeds required: a background service (email, monitoring etc.) that is continuously active requires a relatively low data speed, other than more 'bursty' services or e.g. high-definition video that demands instantaneously high data speed, and also the time period when services are requested are of relevance. The distribution of volume units (e.g. data packet) for a large population would then determine the data speed that the network should minimally be able to deliver. This is however complicated if not all services would require the peak data speed.

The study focusses on data speed and not on volume as the license requirements differ and historically change, but the operator strategy that is driven by the license requirements generally is defined to deliver certain minimum data speeds to customers but does not take data volume per user required. In addition, the speed is usually a more restrictive requirement than the data volume, as it is described next. For a single user that would experience 100 Mbps data speed during the busy hour at an overbooking of 1:50, only during the busy hour, the data volume for this particular user would be approximately 26.3 GB per month[46], which is well above current and future estimates of network use.

As a comparison, in 2016, 185 billion MB was used in the Netherlands by a total of 13,834,000 bundled subscriptions and 1,183,000 data only subscriptions (Telecom Monitor 2016-Q4, ACM). This would be an average volume of 1 GB per month per user. This may be in sharp contrast to a (busy hour value) of 26.3 GB in 2025. However, it should be noted that the 2016 volume was 63% higher than 2015 volume and more than 500% higher than in 2013. Yet, according to the calculations, the speed of access is a more restrictive parameter than data volume in terms of network dimensioning.

5.4.7 Further customisation of the model for the Netherlands

Additionally, for the customisation of the model for the Netherlands, the following elements need attention.

1) The need to take into account large watery areas in the Netherlands ('Binnenwateren' including Markermeer and potentially IJsselmeer) that have no population but cannot be left without mobile coverage. This issue is discussed in paragraph 7.2 'Buitenwateren'

[46] Assuming only operation one full busy hour per day, 1/50 overbooking, 30 days in a month (100 mbps*3600*30/50/8/1024).

(Waddenzee, Noordzee, Oosterschelde, Westerschelde, Dollard, Eems) are not in scope of the study.

2) Border Areas with Belgium and Germany (in border areas power levels need to be reduced). This issue has not been taken into account in the model, as the impact, in this case, is low.
3) Forbidden Area for 3.5 GHz band (3.4 – 3.8 GHz). In the north of the Netherlands (north of line Amsterdam- Zwolle) it is not allowed to use the respective band (to avoid interference with satellite communication station in Burum), while south of this line power restrictions apply. The model uses a pragmatic approach with the 3.5 GHz frequency band not used in the north and fully used in the south. This issue is further discussed in section 7.1.
4) Availability of fibre as an option for backhaul (due to the difference in Microwave exploitation between Netherlands and United Kingdom). Here the assumption is made that a part of the existing sites will need a backhaul upgrade (see section 5.3.2). All new backhaul deployed is fibre in all geotypes.

5.5 Strategies

The strategies adapted to the situation in the Netherlands are described in Table 13 below[47].

Table 13: Modelled infrastructure strategies for the Netherlands

Infrastructure Strategy	Description	Frequency bands
Spectrum Integration Strategy	Integrate all available spectrum in the upcoming frequencies of 700, 1500 MHz and 3.5 GHz into the brownfield macrocellular network	2x10 @700MHz 10 @ 1500 MHz 40 @ 3.5 GHz
Small Cell Strategy	Deploy a greenfield small cell layer operating in TDD at 3.7 GHz	100 MHz @ 3.7 GHz
Hybrid Strategy	Integrate all other spectrum in the upcoming frequencies of 700, 1500 MHz and 3.5 GHz into the brownfield macrocellular network (700 MHz, 1500 MHz, 3.5 GHz). Deploy a greenfield small cell layer operating in TDD at 3.7 GHz	2x10 @700MHz 10 @ 1500MHz 40 @ 3.5GHz 100 MHz @ 3.7GHz

5.6 Geotypes

The Geotypes as defined for the 5G cost model and introduced in section 3.1.5 are adapted to the situation in the Netherlands using the CBS geographic population density data. The

[47] Note that the current cost model does not take into account that for the spectrum integration strategy one could also use frequency bands that are now allocated for the small cells strategy, and vice versa.

result can be seen in Table 14. We focus on the landmass, predicated on the principle that this is the area where an operator could plausibly deploy technology upgrades, either by upgrading brownfield sites or deploying greenfield small cells. Figure 14 illustrates the geotype breakdown by postcode for the Netherlands. The geotypes segmentation is defined for

(a) the case that all spectrum bands are available:, and areas where in the model all frequency bands described in Table 12 are available, roughly south of the line Amsterdam-Zwolle ('all bands') and

(b) the case where a limited set of spectrum bands are available: areas where in the model 3.5 GHz band is not allowed, roughly north of the line Amsterdam-Zwolle ('Limited bands')

Table 14: Geotype Segmentation for the Netherlands

Geotype	Minimal population density (p/km2)	Available spectrum bands	Population	Total sites	Area (km2) (land mass)	Site density (per km2)	Site density hypothetical operator (km2)
Urban	7,959	All	1,289,085	422	109.1	3.87	1.93
Suburban 1	3,119	All	4,295,390	1545	897.3	1.72	0.86
Suburban 2	782	All	3,946,195	1783	2570	0.69	0.35
Rural 1	112	All	3,680,935	2249	12410.8	0.18	0.09
Rural 2	47	All	364,285	463	4668.6	0.1	0.05
Rural 3	25	All	42,085	178	1154.4	0.15	0.08
Rural 4	0	All	8,925	220	914.1	0.24	0.12
Urban	7,959	Limited	73,975	23	7.2	3.19	1.6
Suburban 1	3,119	Limited	689,470	181	148.4	1.22	0.61
Suburban 2	782	Limited	887,425	347	602.9	0.58	0.29
Rural 1	112	Limited	1,109,115	555	4085.2	0.14	0.07
Rural 2	47	Limited	293,185	258	3849.3	0.07	0.03
Rural 3	25	Limited	77,170	116	2135.5	0.05	0.03
Rural 4	0	Limited	19,770	64	1265.2	0.05	0.03

The descriptions of the values in Table 14 are as follows:

Table 15: Description of Geotype values

Geotype	**Area classification based on grouping postcodes with similar cost characteristics**
Population	Total population number
Total sites	Number of sites (based on grouping cells within 80 me-tre of each other
Area (km2) (land mass)	Surface area of postcode in km^2
Site density (per km2)	The site density for the geotype using all sites in km^2
Site density hypothetical operator (km2)	Is the site density available to the hypothetical operator with 30% market share, assuming an operator has ac-cess to 50% of all of existing sites

Postcodes are allocated to these categories based on population density, and finally, the site density is calculated for (i) all sites per km2, and (ii) sites per km2 based on a 50% share. Finally, as some spectrum bands are prevented from being used in a certain geographic area, we categorise the postcode centroids that lay above the Dutch spectrum line of demarcation which are unable to use the 3.5 GHz frequency bands (3.4-3.8 GHz)[48]. The results of this process have been outlined in Table 14 and illustrate the geotype segmentation for the Netherlands.

The clipped landmass of the Netherlands covers a total of 34,809 km^2, which consequently excludes IJsselmeer and Markermeer which have a combined surface area according to the Dutch National Statistics Bureau of 1,831 km^2. We did not undertake demand-capacity modelling for users in the IJsselmeer and Markermeer areas, as they would ultimately require only wide-area coverage from sites on the borders of the lakes (hence, no new small cell deployments or densification of macro cells can be modelled in such areas). Correctly modelling this would require a significantly different methodology. Importantly, however, given that there are very few users on the water, generally their demand can be covered with the upgrades of the existing sites. The cost of new spectrum integration upgrades to existing brownfield macro cellular sites along the water's edge is included already in the model, which would provide significant enhancement of existing capacity and coverage to this area. See also section 7.2.

[48] https://www.agentschaptelecom.nl/onderwerpen/zakelijk-gebruik/lokale-breedbandnetwerken/lokale-breedbandnetwerken-de-35-ghz-band-0

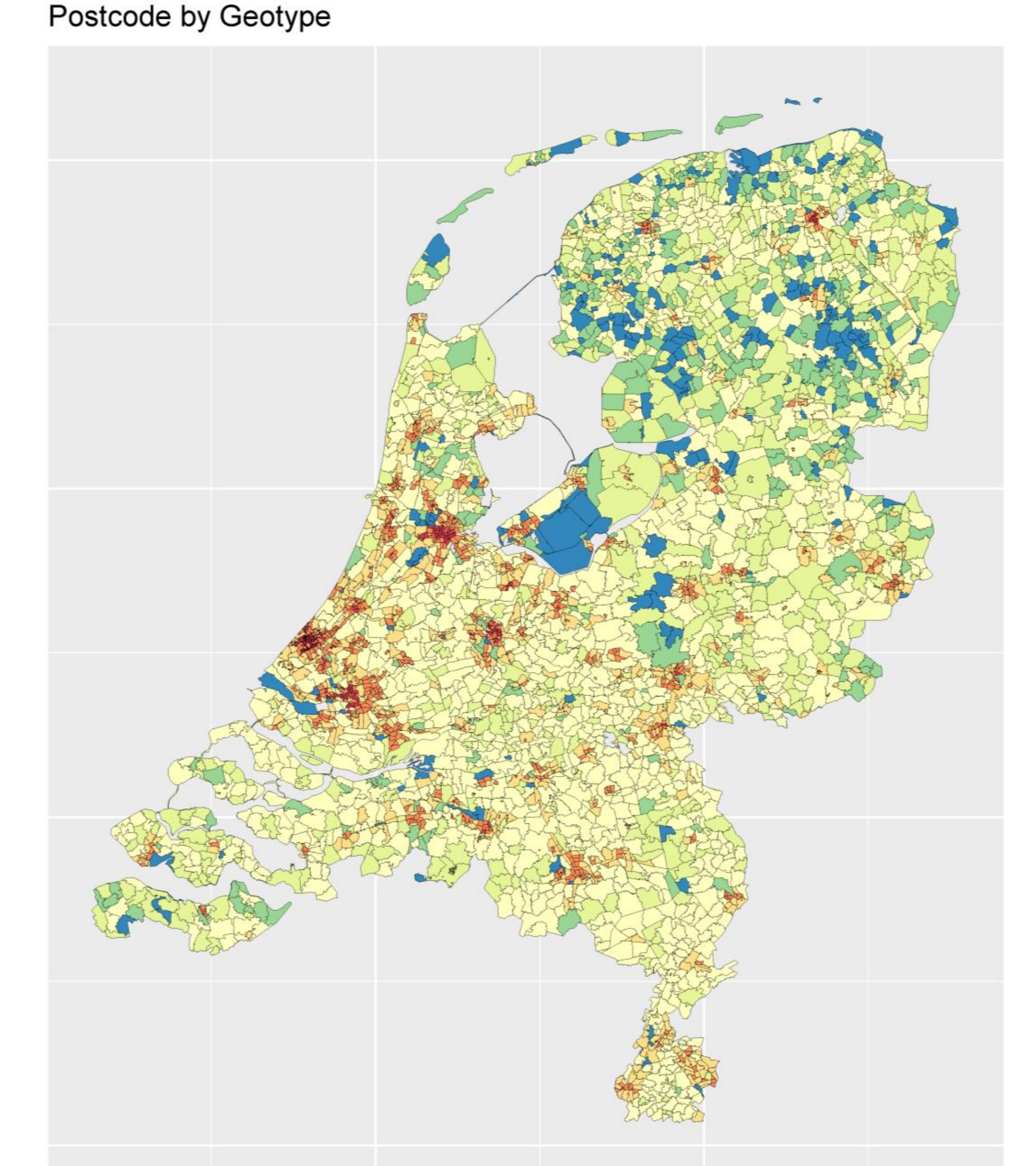
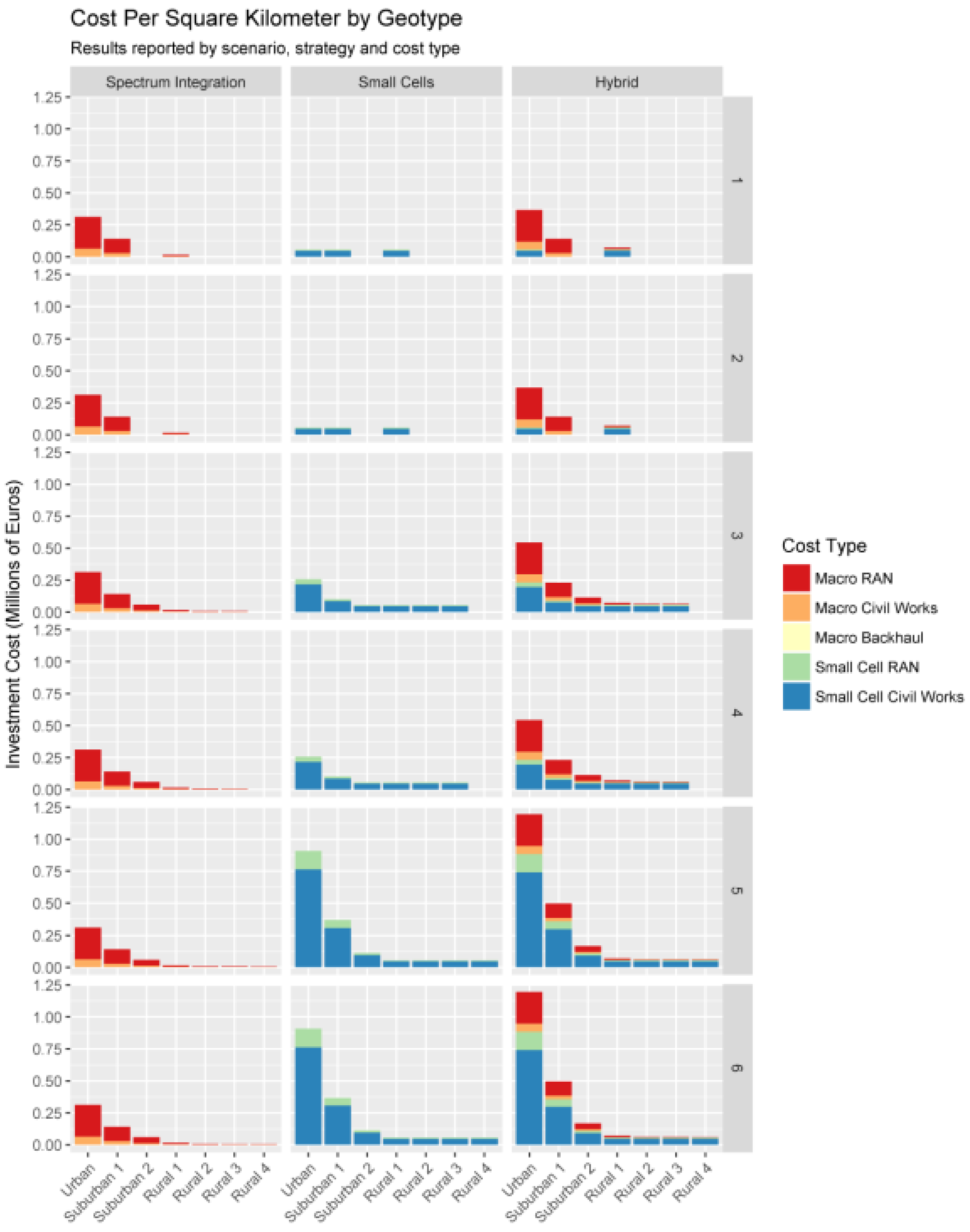


Figure 14: Postcodes illustrated by geotype

6 Results

This section details the results based on per square kilometre cost, total area cost, capacity margin (see 3.1.1) by area, cumulative cost, geographical cost breakdown, assets' costs breakdown, and potential rollout patterns up to 2025.



Scenario legend	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Speed per user	30 Mbps	30 Mbps	100 Mbps	100 Mbps	300 Mbps	300 Mbps
Type of operator	Mobile-only	Mobile-fixed	Mobile-only	Mobile-fixed	Mobile-only	Mobile-fixed

Figure 15 (on previous page, with legend on this page): Cost breakdown per square kilometre by geotype for a hypothetical operator

6.1 General results and observations

Overall, the costs increase as the required technical specification of the infrastructure system is raised. Hence, as Figure 15 illustrates, greater investment is needed per km^2 moving from 30 Mbps per user (scenarios 1 and 2), which is not so far from current capacity in some locations, to much more ambitious thresholds such as 100 Mbps (scenarios 3 and 4) and 300 Mbps per user (scenarios 5 and 6). Indeed, existing capacity is enough to provide 30 Mbps in less densely populated geotypes, particularly in Suburban 2, Rural 2, Rural 3 and Rural 4. In the areas classified as Rural 1, some investments would be needed because the demand would slightly exceed current supply.

Cost components depend on geotype

Figure 16 illustrates the per km^2 cost by geotype, broken down by cost component. We can see that per km^2 costs are significantly higher in urban areas than in other geotypes. This is due to high capacity-constrained networks in these areas, which require extreme network densification to meet high user demand, particularly in scenarios 5 and 6. The cost structure across the different geotype segments resembles an exponential decay, with suburban areas being considerably cheaper than high population density areas. Rural area costs are very low in terms of required investments per square kilometre. In the case of scenario 1 and 2, this is because there is no capacity margin deficit for those cases, meaning no new infrastructure needs to be deployed to meet the desired 30 Mbps per user capacity. The current capacity in part of the areas on 4G is often, although not always, sufficient to support the 30 Mbps goal[49].

Cost components depend on goal and strategy

The use of small cells, and network densification in general becomes more important as the required speed per user increases. As spectrum resources are insufficient to meet demand, more small cells are required. For example, in the hybrid deployment strategy in scenario 1 and 2 (30 Mbps), macrocell related costs are approximately 75% of required investment in

[49] According to OpenSignal 4G is available 89% of the time in the Netherlands and will then reach 42.12Mbps on average. (see https://opensignal.com/reports/2018/02/state-of-lte) That does not mean that this is available everywhere, nor that it is available all the time. The OpenSignal data is empirical and averaged and based on their own methodology. Their results are constrained by users handsets, location (indoor/outdoor) and movement. This report uses a localized theoretical model that aims to achieve the speed everywhere. So there will be discrepancies based on local radio conditions and network load at the location.

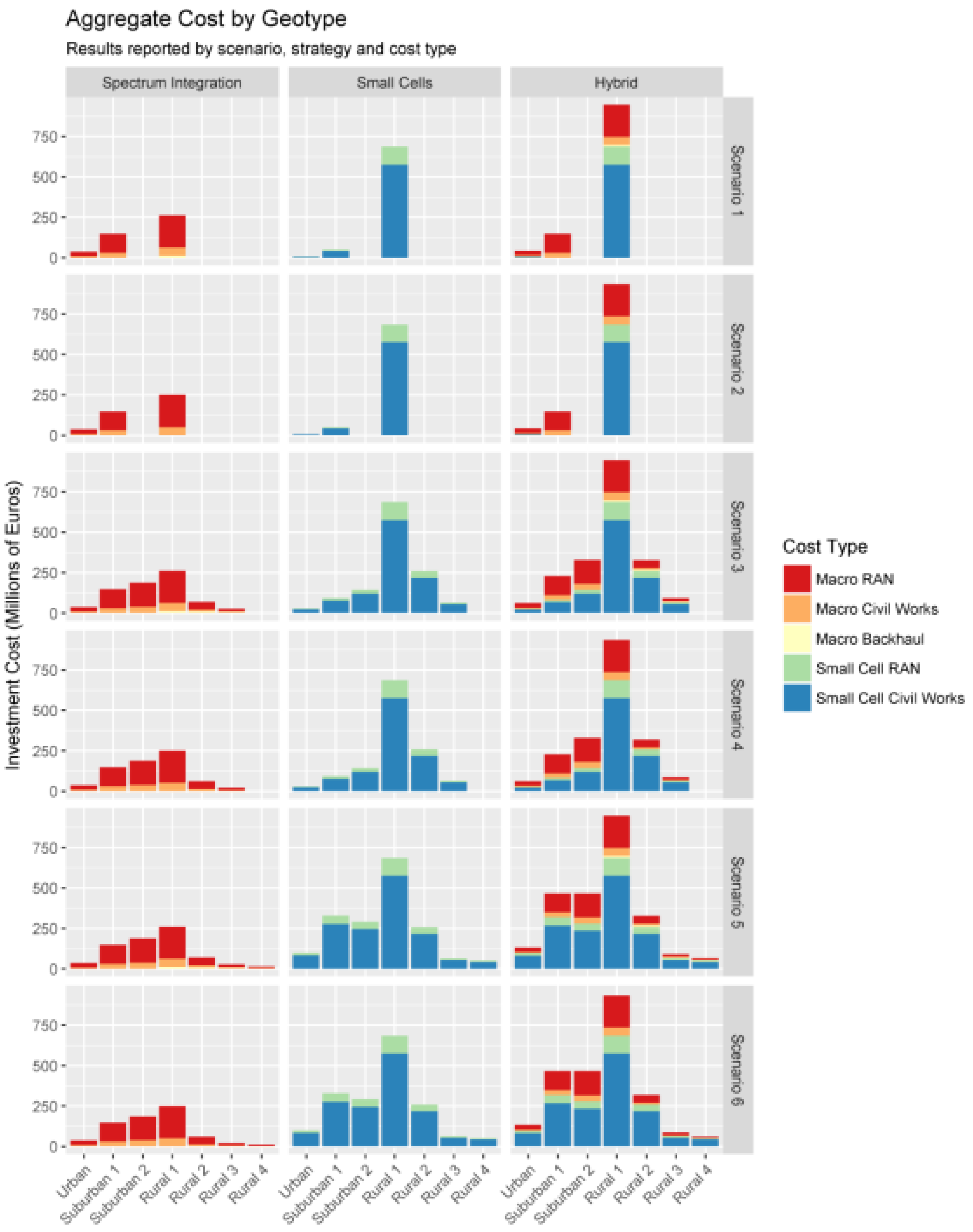
urban areas. However, in scenario 5 and 6 (300 Mbps) macrocell related costs are a much smaller proportion overall at approximately 25%, with the cost per square kilometre being dominated by small cells, particularly by the civil works of small cells' sites (~62%). Similarly, in most rural areas (Rural 4), the existing capacity meets the demand requirements in scenarios 1 and 2, while small cells' sites civil work comprise 77% of the costs for scenarios 5 and 6 when the traffic demand per user is increased to 300 Mbps.

In terms of the breakdown of equipment costs, there are some differences between the two expansion strategies tested. In the macrocellular case, the active Radio Access Network (RAN) equipment was on average 80% of the cost, with civil works being only 20% . In comparison, the small cell strategy had an average proportion of 84% of the costs being spent on civil works and only 16% on RAN equipment. Here no backhaul costs are mentioned as they are considered OPEX as is explained in chapter 3.1.3. Hence, the costs for construction of the passive components comprise most of the required investment. This cost distribution has important ramifications for policy-makers that will be discussed in the next chapter.

Few cost advantages for mobile-fixed operator compared to mobile-only operator

Regarding the comparative economics of a mobile-only and a mobile-fixed operator, the results obtained suggest that there is little difference. This is because minimal upgrades are required to existing macrocellular backhaul links, except for the rural geotypes where the cost ranged from 1-25% for the mobile-only operator. In a less densely populated country, with a less dense fibre network, this might have had more impact. Therefore, the backhaul capex costs remain similar across the user speeds scenarios (namely, scenario 1 vs 2 – 30 Mbps, scenario 3 vs 4 – 100 Mbps, scenario 5 vs 6 – 300 Mbps). However, the percentage contribution of the backhaul capex cost differs, with it being highest in the scenarios 1 & 2 (1-25% across different geotypes), and lowest in scenarios 5 & 6 (1-3% across different geotypes).

Figure 16 shows total costs per geotype. These aggregate costs represent the required investment across the total area affiliated with each geotype segment. As few postcodes have a low enough population density to fall in the least dense segments, such as Rural 2, Rural 3 and Rural 4, total required investment is very low in these geotypes. Depending on the scenario, the largest investment was generally required in Suburban 1, particularly as the desired throughput is increased to 100 or 300 Mbps. Approximately 30% of the population fell into the Suburban 1, Suburban 2 and Rural 1 bands, leaving the remaining population spread across the other segments. This is reflected in the aggregate cost structure, with the distribution skewed towards these density bands. Moreover, Rural 1 accounts for 47% (see Table 14), which makes the aggregate costs per geotype outstand. In terms of cost component, we can see in Figure 16 that the RAN costs are the significant expenditure item across the spectrum integration and hybrid strategies. Civil works are a significant proportion of the overall cost for the small cells and hybrid strategy. As in the cost per squared kilometre graph, macrocell backhaul cost is negligible.



Scenario legend	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Speed per user	30 Mbps	30 Mbps	100 Mbps	100 Mbps	300 Mbps	300 Mbps
Type of operator	Mobile-only	Mobile-fixed	Mobile-only	Mobile-fixed	Mobile-only	Mobile-fixed

Figure 16: Aggregate cost breakdown by geotype

The high aggregate costs of geotype rural 1 in scenario 1 and 2 are noticeable, particularly in the case of the small-cells only strategy. In addition to the fact that this geotype accounts for 47% of the area, this is because the existing network capacity along with the integration of all potential spectrum (described elsewhere in section 5 regarding the assumptions of the hypothetical operator) are not able to meet demand, leading to a small capacity deficit. This is shown in Figure 17 below. Nonetheless, as there is a capacity deficit, the algorithm in the model decides to continue with the network densification strategy adding a small cell layer and hence the rollout costs increase substantially, due to the small coverage radii of the small cells, which makes that the rollout of small cells entails a big fixed cost. On the upside, this comes with the benefit of having a large capacity margin[50] as illustrated in Figure 17 (hybrid strategy, scenario 1 and 2). This can also be seen in Figure 16 as we move to higher user speeds (scenarios 3 - 6), in which case the costs for Rural 1 remain constant. In short, there is a small capacity deficit in scenarios 1 and 2 for Rural 1, which requires a large investment in small cells, but then creates a large over-capacity.

As described in the previous paragraph, it useful to understand the geographic distribution of the demand, the capacity and the affiliated cost. Below, in Figure 17, the capacity margin is assessed for each scenario and strategy, which indicates whether current capacity meets present demand or not. Based on this analysis, spectrum integration alone is generally unable to meet demand in all cases. But while there is only a minor capacity deficit in Scenarios 1 and 2 (-5 Gbps km^2)[51], in more ambitious scenarios the deficit is much larger. For example, in other scenarios in urban areas such as Amsterdam, The Hague, Rotterdam, Utrecht and Groningen, the capacity deficit will be larger than 20 Gbps per km^2. The use of small cells operating at 3700 MHz below the spectrum demarcation line 'Amsterdam-Zwolle' enables demand to be easily met, with a large surplus of capacity remaining in not so densely populated areas. On the other hand, the spectrum demarcation line 'Amsterdam-Zwolle' means that northern areas generally end up with a higher capacity margin deficit. This is due to the fact that the 3400-3800 MHz-band cannot be used to increase capacity on the macrocell level, or for small cells. In this analysis, we do not test further densification of the macrocellular network, although this may be an important area for further research as it allows one to test the cost implications of this strategy, which is usually not considered in areas with an already dense legacy macrocell network due to problems in the practical implementation[52].

To summarise, there is overall no capacity deficit when small cells are deployed, as it can be noticed in Figure 17 (column at the centre and the right). For the cases where no small cells are deployed, which are the spectrum integration strategy or any case in the postcode sectors above the demarcation line Amsterdam-Zwolle, significant capacity deficits arise. These

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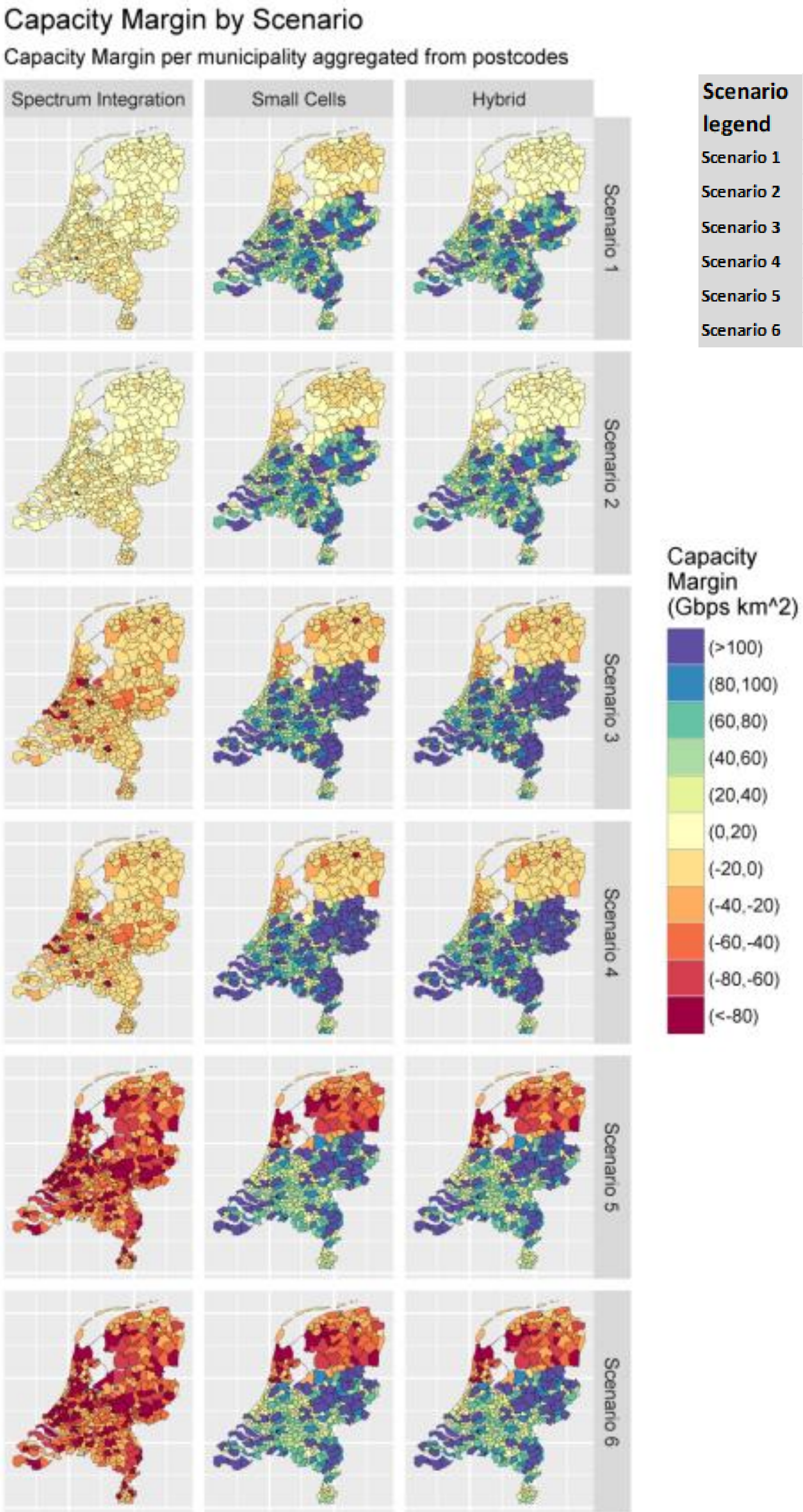
[50] The capacity margin is a metric for the relation between available cell capacity and the expected use by the users in that cell, considering user density in that cell and average use. See 3.1.1 for definition.

[51] This may look a high number, but as there are generally many users per square kilometer, especially in the urban areas, this is actually not very high.

[52] However, many operators (BT/EE) have announced their 5G deployment is going to be based on massive MIMO, so macrocellular sites are likely to still play a key role. But for densification of macro cells it is even harder to find locations for new macrosites then it is for small cells (hight, coverage requirements).

results suggest the importance of the 3.5 GHz frequency band (3.4 – 3.8 GHz) for high-capacity networks, as it is discussed next in chapter 7. Where the 3.5 GHz band cannot be used for small cells operators will be (and are) forced make choices with regard to spectrum band allocation and refarming of cells that diverge from what is internationally considered common practice.



Scenario legend	Speed per user	Type of operator
Scenario 1	30 Mbps	Mobile-only
Scenario 2	30 Mbps	Mobile-fixed
Scenario 3	100 Mbps	Mobile-only
Scenario 4	100 Mbps	Mobile-fixed
Scenario 5	300 Mbps	Mobile-only
Scenario 6	300 Mbps	Mobile-fixed

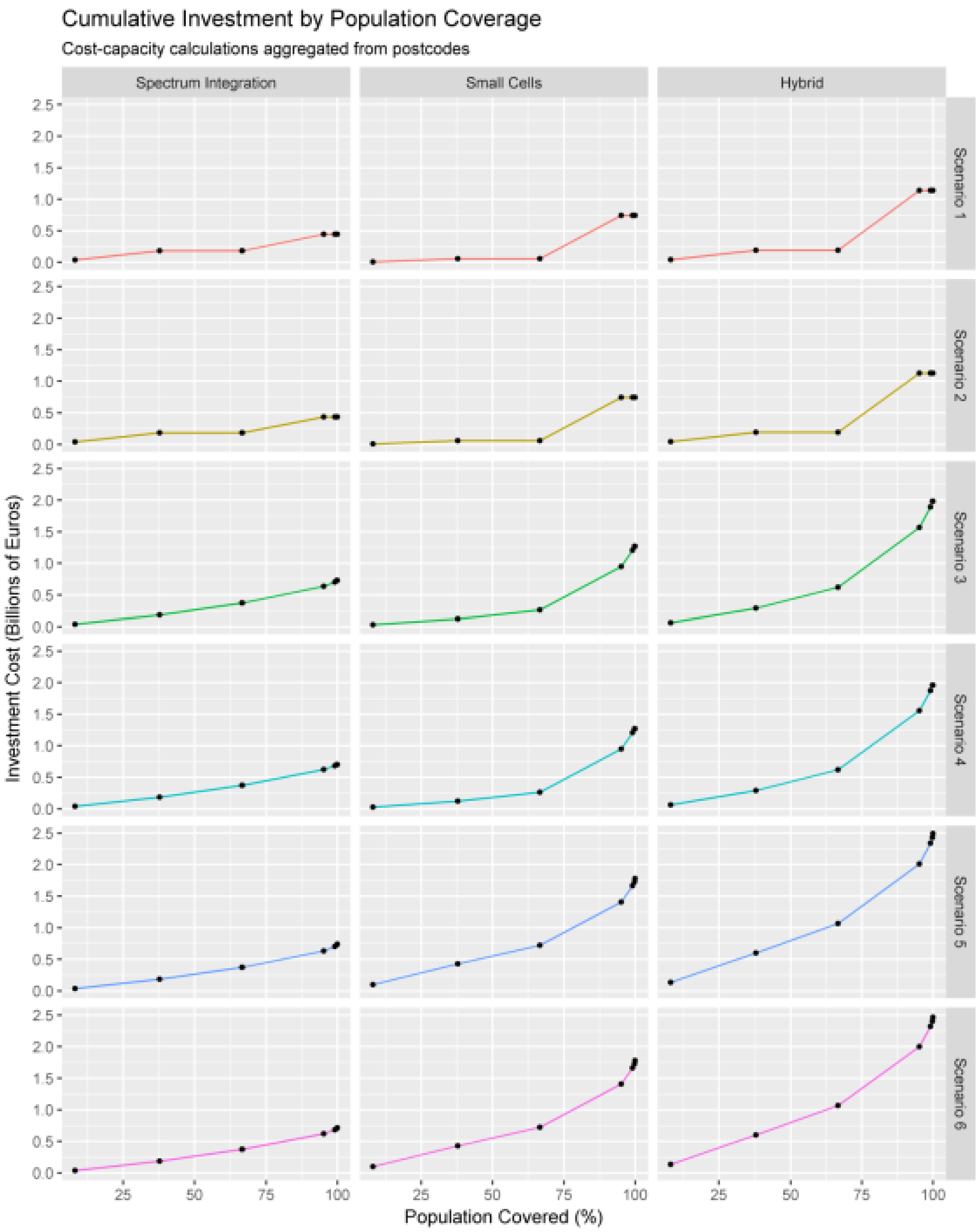
Figure 17: Breakdown of capacity margin by scenario and strategy

6.2 Coverage, capacity and rollout

In Figure 17 we clearly see that for the 30 Mbps case the 'spectrum integration' strategy is able to provide enough capacity, except for some urban areas. For the 'small cells' and 'hybrid' case a considerable capacity margin appears.

For the cases of 100 Mbps and 300 Mbps, it is more difficult to provide enough capacity only by integrating more spectrum ('spectrum integration' strategy). However for the 'small cells' and 'hybrid' cases a considerable capacity margin can be achieved when the 3.5 GHz band can be used. In the model, small cells only use 3.5 GHz frequencies. In theory, other frequency bands might also be used, but this requires extensive network replanning[53] and still requires costs for additional cells. Nonetheless, to provide higher capacity, a strategy deploying smaller cells is generally necessary to provide the results aimed for. However, this comes at a cost. Figure 18 illustrates cumulative cost curves for the two scenario's and strategies, indicating the required investment necessary for reaching different population coverage levels. As it is illustrated, while the costs of the spectrum integration strategy increase linearly along with the population covered, the small cells rollout costs increase exponentially when the threshold of 75% population is surpassed, particularly for high-speed scenarios (3-6). It is also worth to note that when it comes to broad coverage and high-capacity (100 Mbps and 300 Mbps), a hybrid strategy does not provide any benefit: the costs are not smaller compared to the other two strategies and there almost no extra capacity margin**.**

[53] This may not be the case for unused frequencies at macrocells, which, if used, would not cause interference, for example the TDD spectrum at 2600 MHz.



Scenario legend	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Speed per user	30 Mbps	30 Mbps	100 Mbps	100 Mbps	300 Mbps	300 Mbps
Type of operator	Mobile-only	Mobile-fixed	Mobile-only	Mobile-fixed	Mobile-only	Mobile-fixed

Figure 18: Cost curves by scenario and strategy

Figure 19 shows the geographical breakdown of the investments that would take place in the study period. At this point it is worth to recall that the rollout pattern is assumed to be from most to least densely populated areas, as it would logically occur in reality if no specific geographical coverage obligations are set. Therefore, given limited annual capital expenditures, an interdependence between urban and rural areas arise. Whether rural areas would receive any investment under the study period would strongly depend on how much it costs to cover urban areas in the first place. This is noticeable in Figure 19.

For example, in the spectrum integration strategy, rural municipalities in the north would get some investments because i) urban areas are less expensive to cover than in the other strategies and ii) it is possible to expand the infrastructure in the northern municipalities through integrating 700 MHz and 1500 MHz into existing macro cells. However, this may not be required for scenarios 1 and 2, since the existing network can already provide per-user speed capacities of around the target level of 30 Mbps.

In the small cell strategy, urban areas are more expensive to cover and therefore they appear coloured in red: they get higher investments and they are the first in the line for the rollout sequence. In this case, the areas in the north do not get any investments. This is because in the small-cell-only strategy, no investments can be done in these areas, as there 3.5 GHz spectrum use is prohibited.

Finally, for the hybrid strategy the most-densely populated postcode sectors reach investments up to 18 million Euros, while most rural areas in the north may not receive investment in new infrastructure that enhances network capacity. In contrast to the case of the small-cell-only strategy, the areas in the north do receive new infrastructure due to the integration of 700 MHz and 1500 MHz.

When there is no investment in any one postcode sector it could be due to i) all the budget available within the study period has been used up, ii) there is no need to invest (there is a capacity margin) or iii) there are restrictions to the deployments, such as those regarding the use of 3.5 GHz spectrum. To have a better insight about the reasons for each case, Figure 19 needs to be read along with Figure 20, Figure 21 and Figure 22, where the temporal dimension is shown and with Figure 16, which shows the capacity margin of the network at any one location.

Clearly, in most of the areas above the line Amsterdam – Zwolle the reason for the absence of investments in the cases of 100 Mbps and 300 Mbps is the restriction to use 3.5 GHz frequency band (3.4 – 3.8 GHz).

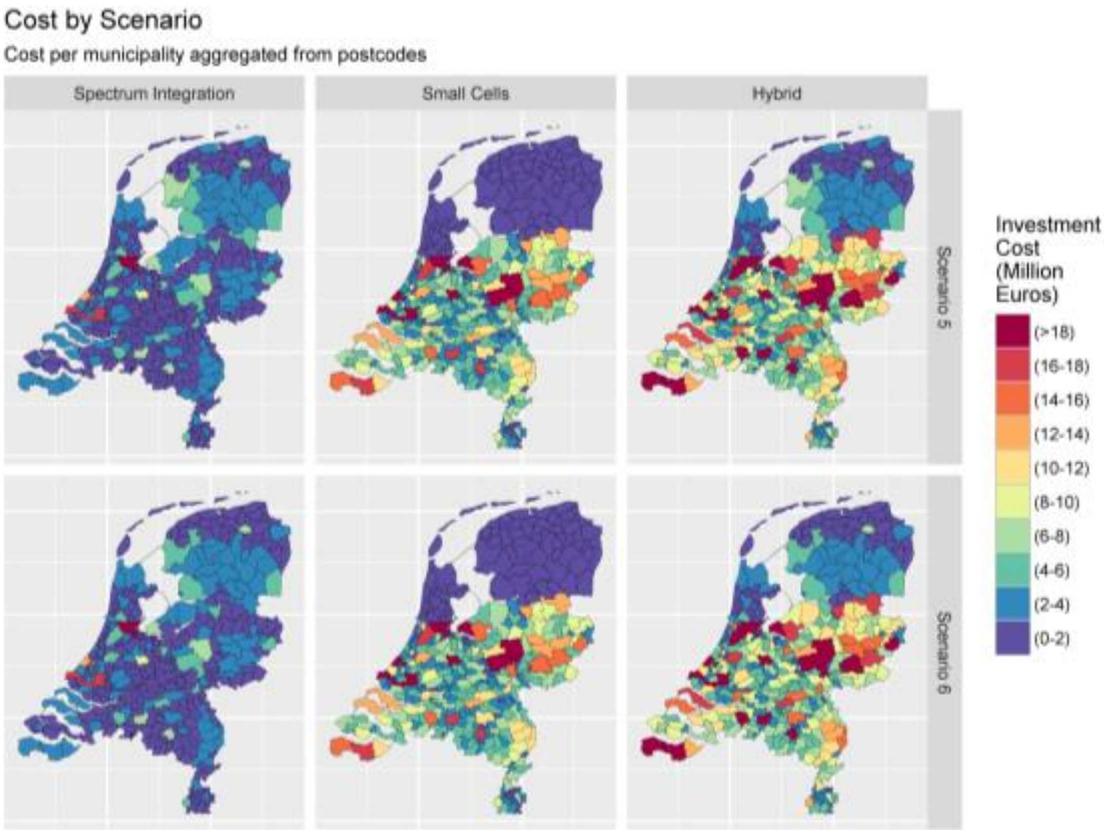


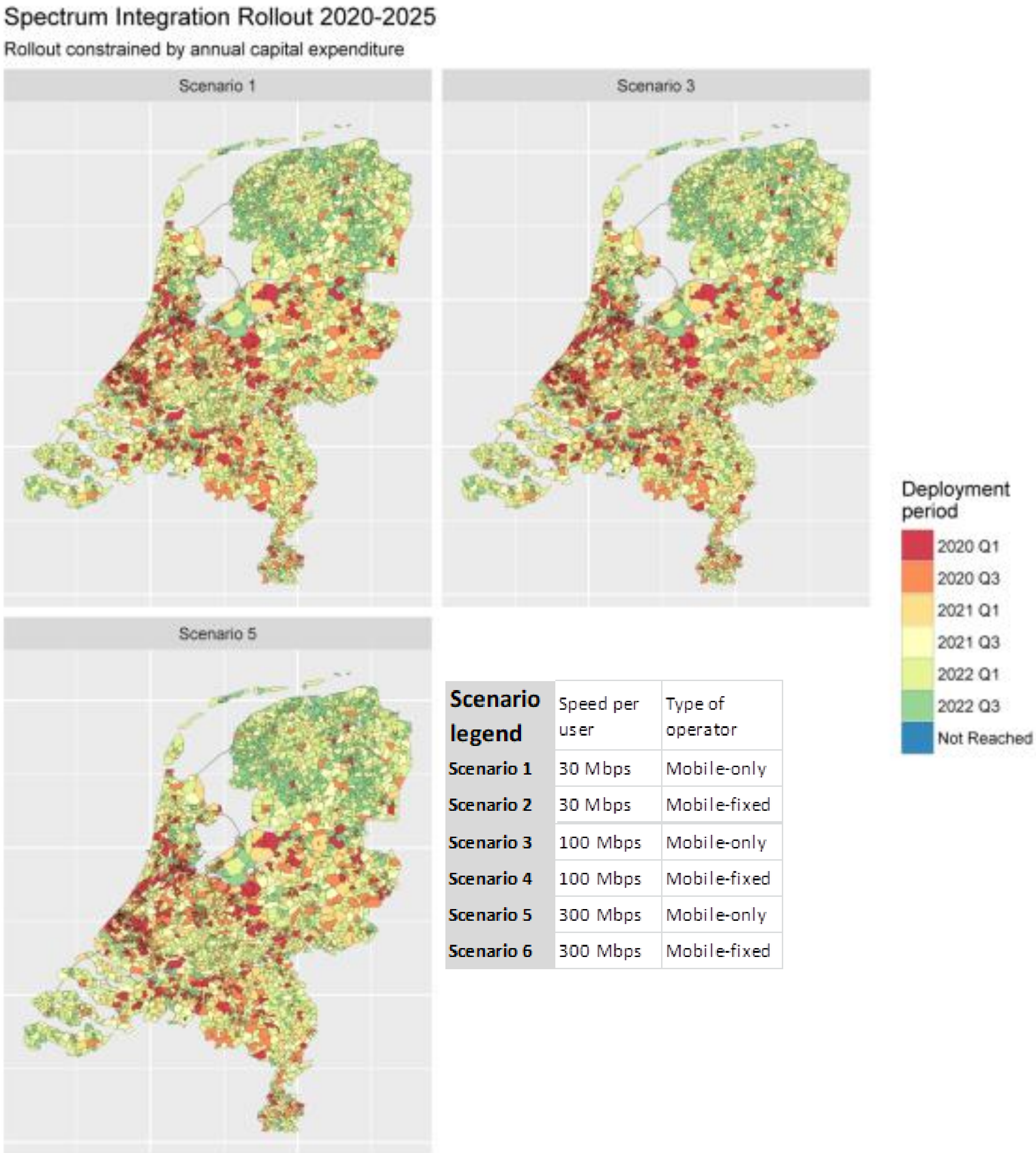
Figure 19: Geographical breakdown of investments by municipality (only for scenario 5 (300 Mbps, Mobile only) and 6 (300 Mbps, mobile/fixed). For the full set see Annex B)

The three figures below show when investments will possibly be made in any one area to attain the data rates defined for each scenario.

Figure 20 shows this for the spectrum integration strategy, where all postcode sectors are reached at some point within the study period. Here full deployment of all the frequencies that are used in this strategy (700 MHz, 1500 MHz, and 3.5 GHz-band only where allowed) can be reached in virtually all regions by 2022. This is because integrating spectrum is a relatively inexpensive strategy, as it is illustrated in Figure 15.

Figure 21 shows when the rollout will reach each postcode sector if a small-cell-only strategy is adopted. Because use of the spectrum band used for small cells in the model – part of the 3.5 GHz-band – full deployment cannot be reached, contributing to a capacity deficit. This does not mean that these areas cannot ever be served with 30, 100, or 300 Mbps by the mobile networks. Mobile network operators could, for instance, densify their macro network or roll out small cells on other frequencies than the 3.5 GHz. Furthermore, the Ministry of EZK is trying to open up the 3.5 GHz-band for use, which will help to close the capacity deficit.

Figure 22 shows when the rollout will probably take place in the hybrid rollout strategy. For the 30 Mbps scenarios, this strategy would allow the required data rates to be attained well before 2025, with sufficient extra capacity remaining in places. For the higher speed scenarios (100 Mbps, 300 Mbps) the model shows deployment speeds to be slower, especially in the northern part of the Netherlands.



Scenario legend	Speed per user	Type of operator
Scenario 1	30 Mbps	Mobile-only
Scenario 2	30 Mbps	Mobile-fixed
Scenario 3	100 Mbps	Mobile-only
Scenario 4	100 Mbps	Mobile-fixed
Scenario 5	300 Mbps	Mobile-only
Scenario 6	300 Mbps	Mobile-fixed

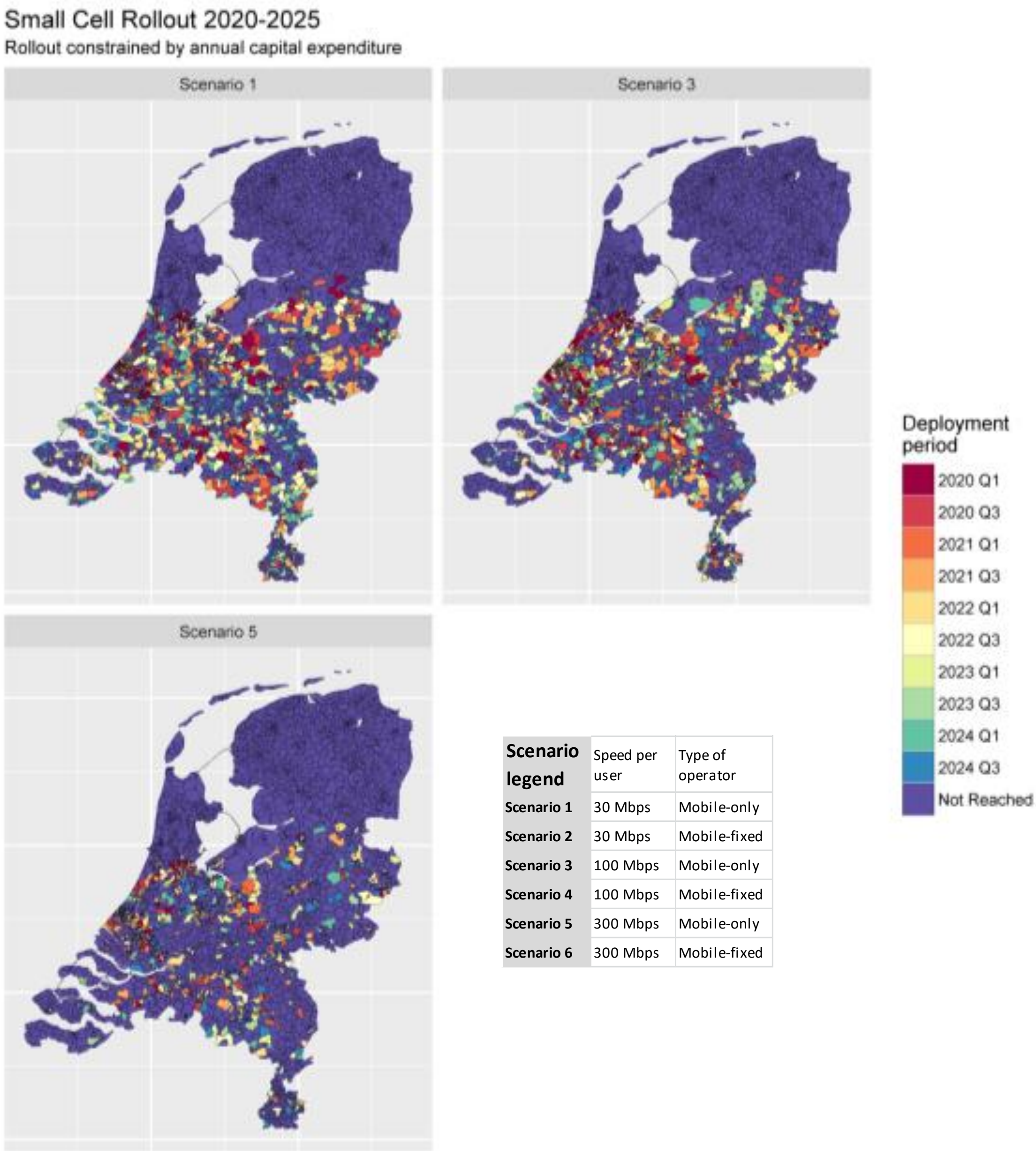
Figure 20: Simulated rollout based on constrained capital expenditure for the spectrum integration strategy showing the deployment period per region. The deployment period is determined according to the annual capex available and assuming that locations will be covered from urban to rural. For the full set see Annex B.

In contrast, for a small cells-only rollout, many postcodes are not reached, as shown in Figure 21. In the north it is due to the fact that no small cells can be deployed since the 3.5 GHz frequency band (3. – 3.8 GHz) cannot be used. For the rest of the country, in the scenarios 1 and 2 (30 Mbps), the reason for the absence of investments is the sufficient capacity of the existing network. Therefore, it can be noted that these postcode sectors are indeed reached when the target speed is increased to 100 Mbps (scenarios 3-4). If the speed per user is further increased, to 300 Mbps per user, the network needs to be further densified, which increases the cost per squared kilometre three-fold (see column at the centre in Figure 15) and also the costs per user increase significantly (see Table 16). That means more capital expenditures need to be allocated to urban areas, which are served first and use the available budget by 2025 up, leaving less-densely populated areas unserved. The costs per user also show that for some rural areas for some goals a significant jump in costs occurs: in that case for those particular geotypes there are probably too many users for a simpler and cheaper situation to provide enough bandwidth, but too few users for the more complicated and more expensive situation to efficiently use the upgrade in capacity.

The same phenomenon can be observed for the hybrid strategy in Figure 22.

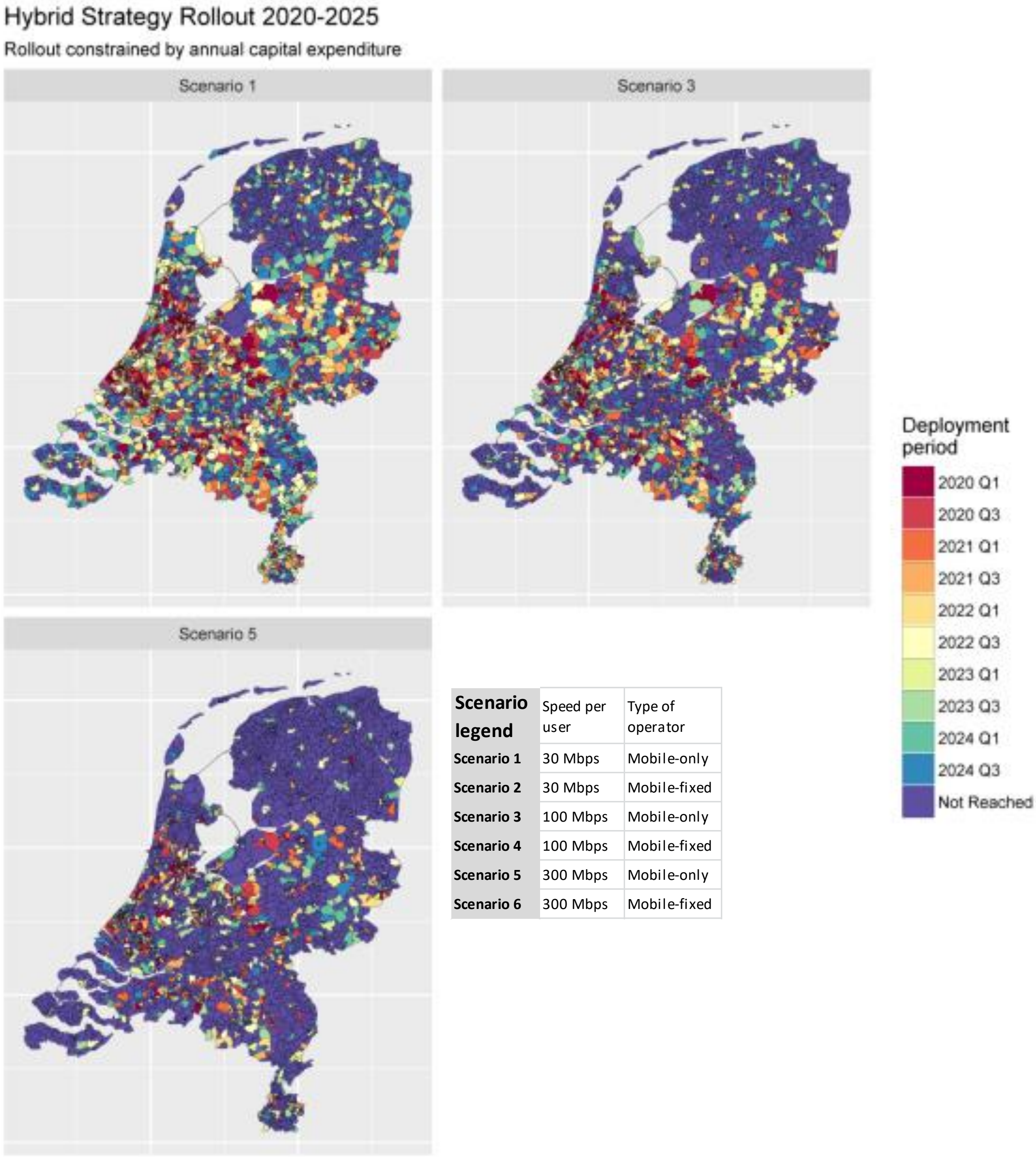
Table 16: Breakdown of costs per user for hybrid strategy only (see Annex B for a more detailed cost breakdown)

Scenario	Geotype	Total investment cost per user (Euro) to reach 30Mbps	Total investment cost per user (Euro) to reach 100Mbps	Total investment cost per user (Euro) to reach 300Mbps
mobile only	Urban	€ 37,00	€ 54,78	€ 120,34
mobile only	Suburban 1	€ 37,66	€ 61,65	€ 132,48
mobile only	Suburban 2	€ -	€ 100,65	€ 147,66
mobile only	Rural 1	€ 362,18	€ 362,18	€ 362,18
mobile only	Rural 2	€ -	€ 1.795,85	€ 1.795,85
mobile only	Rural 3	€ -	€ 7.446,95	€ 7.446,95
mobile only	Rural 4	€ -	€ -	€ 51.163,54
fixed-mobile	Urban	€ 37,00	€ 54,78	€ 120,34
fixed-mobile	Suburban 1	€ 37,66	€ 61,65	€ 132,48
fixed-mobile	Suburban 2	€ -	€ 100,65	€ 147,66
fixed-mobile	Rural 1	€ 358,71	€ 358,71	€ 358,71
fixed-mobile	Rural 2	€ -	€ 1.768,44	€ 1.768,44
fixed-mobile	Rural 3	€ -	€ 7.244,73	€ 7.244,73
fixed-mobile	Rural 4	€ -	€ -	€ 49.825,09



Scenario legend	Speed per user	Type of operator
Scenario 1	30 Mbps	Mobile-only
Scenario 2	30 Mbps	Mobile-fixed
Scenario 3	100 Mbps	Mobile-only
Scenario 4	100 Mbps	Mobile-fixed
Scenario 5	300 Mbps	Mobile-only
Scenario 6	300 Mbps	Mobile-fixed

Figure 21: Simulated rollout based on constrained capital expenditure for the Small cell rollout strategy showing the deployment period per region. For the full set see Annex B



Scenario legend	Speed per user	Type of operator
Scenario 1	30 Mbps	Mobile-only
Scenario 2	30 Mbps	Mobile-fixed
Scenario 3	100 Mbps	Mobile-only
Scenario 4	100 Mbps	Mobile-fixed
Scenario 5	300 Mbps	Mobile-only
Scenario 6	300 Mbps	Mobile-fixed

Figure 22: Simulated rollout based on constrained capital expenditure for the hybrid rollout strategy showing the deployment period per region. For the full set see Annex B.

6.3 Observations on the model

The 5G rollout cost model described in chapter 3 proved usable for the case of the Netherlands, with the changes and additions discussed in the previous chapter. However, there are some caveats to the assumptions made and to how some specificities were captured. Particularly, it proved difficult to specifically model the difference between a mobile-only operator and a fixed mobile converged operator, as these differences are subtle and advantages and disadvantages also differ per mobile-only and mobile-fixed operator. This is due, for instance, to technical differences between cable and copper access networks, the footprint of networks and current antenna sites, backhaul networks and strategies of operators. The current model does not capture substantial differences in the backhaul and there is a lack of information about the real backhaul of either type of operator. Also there are many uncertainties with regard to potential relevant developments from a technological, economic and regulatory perspective that were not taken into account in the model. For instance, very recently new technologies have been announced that facilitate the use of DOCSIS cable access networks for 5G backhaul[54]. It is unclear whether these technologies will mature between now and 2025. Also the prices of femto (small cell) equipment that can be placed at homes of fixed (or mobile) customers, net neutrality laws and laws with regard to whether an access modem is part of the network or part of the user equipment[55] may have an impact on a potential advantage of a fixed-mobile operator.

[54] http://www.lightreading.com/cable/docsis/cisco-cable-nets-can-backhaul-small-cells/d/d-id/737372
[55] https://www.rijksoverheid.nl/documenten/publicaties/2017/12/13/toelichting-consultatie-beleidsregel-netwerkaansluitpunt

7 Analysis

In this chapter, the implications and ramifications of the results for policy-making are further discussed and analysed, and some general observations are made.

7.1 Impact of the availability of the 3.5GHz band

To further analyse the impact of the availability of the 3.5 GHz bands, the differences in capacity margins and costs per square kilometres for the two cases were calculated for all scenarios and strategies. The results are shown in Figure 23 and Figure 24. It is worth to note that the highest capacity deficits differences are obtained for the strategies involving small cells (small-cells only and hybrid), since small cells are expected to be deployed in this frequency band.

It is shown that for these cases (particularly for 100 Mbps and 300 Mbps), and especially in more urban environments, positive capacity margins can only be reached when using a combination of small cells which for the purpose of this model requires the availability of the 3.5 GHz band. However, this strategy comes at significant extra costs (see figure 24). These costs mainly arise from having to invest heavily in the rollout of small cells in urban areas and the areas that fall under the geotype suburban 1. Additionally, when no investments can be made (figure 24, row 3) the largest capacity deficit is obtained.

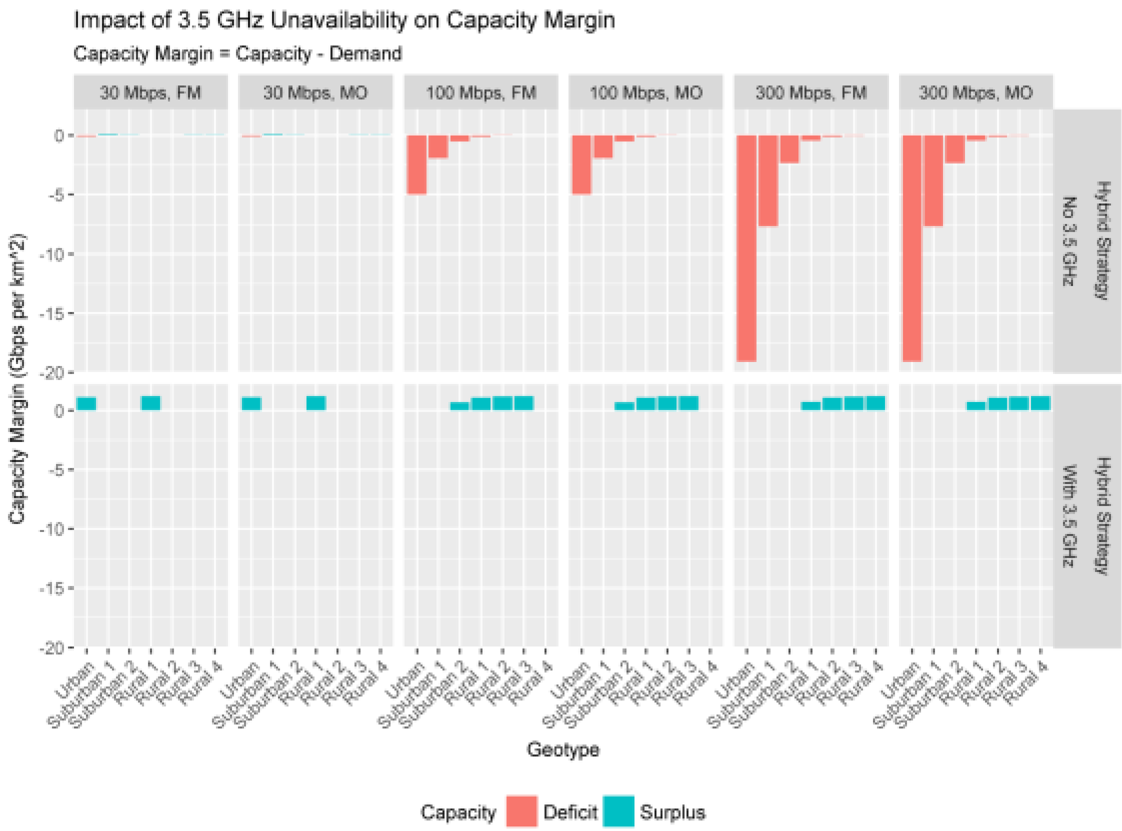


Figure 23: Impact of unavailability of 3.5GHz bands on cell capacity margins for the hybrid strategy only. For the full set see Annex B.

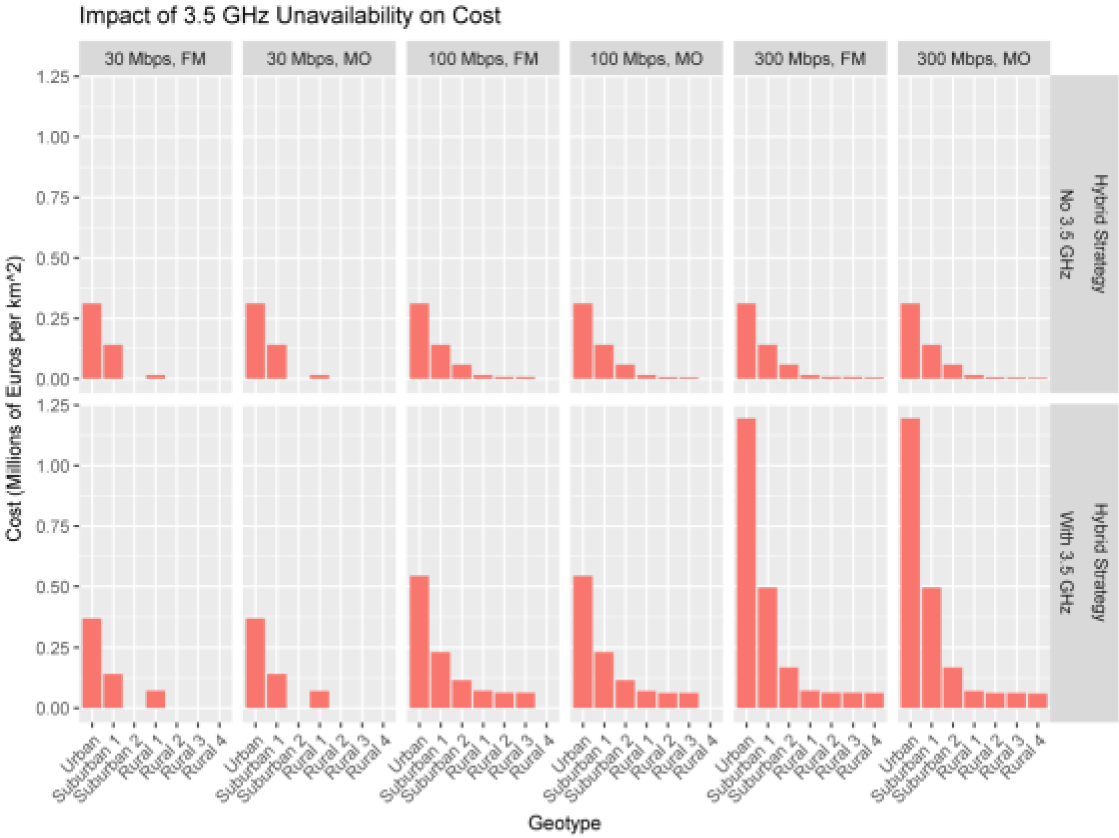


Figure 24: Impact of unavailability of 3.5GHz bands on (upgrade) costs per square kilometre for the hybrid strategy only. For the full set see Annex B.

7.2 Considerations regarding variations in license requirements

Existing spectrum license requirements differ from one another, including tentative new requirements that may be introduced through the auction of the 700 MHz band. An important new requirement under deliberation is related to the level of geographical coverage that will have to be achieved outdoors[56]. The cost and availability of spectrum licenses are elements in a mobile network operator's strategy. End users do not distinguish between different spectrum bands when they use their end-user equipment on mobile networks. It is in this respect unclear what can be regarded as the total resulting requirements for data coverage of an operator in general. The model used and the scenarios and strategies calculated did not take into account all possible variations in existing and future spectrum requirements and, indeed, did also not take into account the license fees for spectrum use. However such variations and the resulting effective obligations for operators may have considerable effects on an operator strategy and on the costs.

[56] New spectrum licenses are aimed to be a technology neutral, but it is likely that the related spectrum bands will primarily be used for 5G based technology.

7.3 Considerations regarding water areas

Based on the model results, the impact of imposing coverage requirements for water areas such as Markermeer and IJsselmeer was briefly analysed.

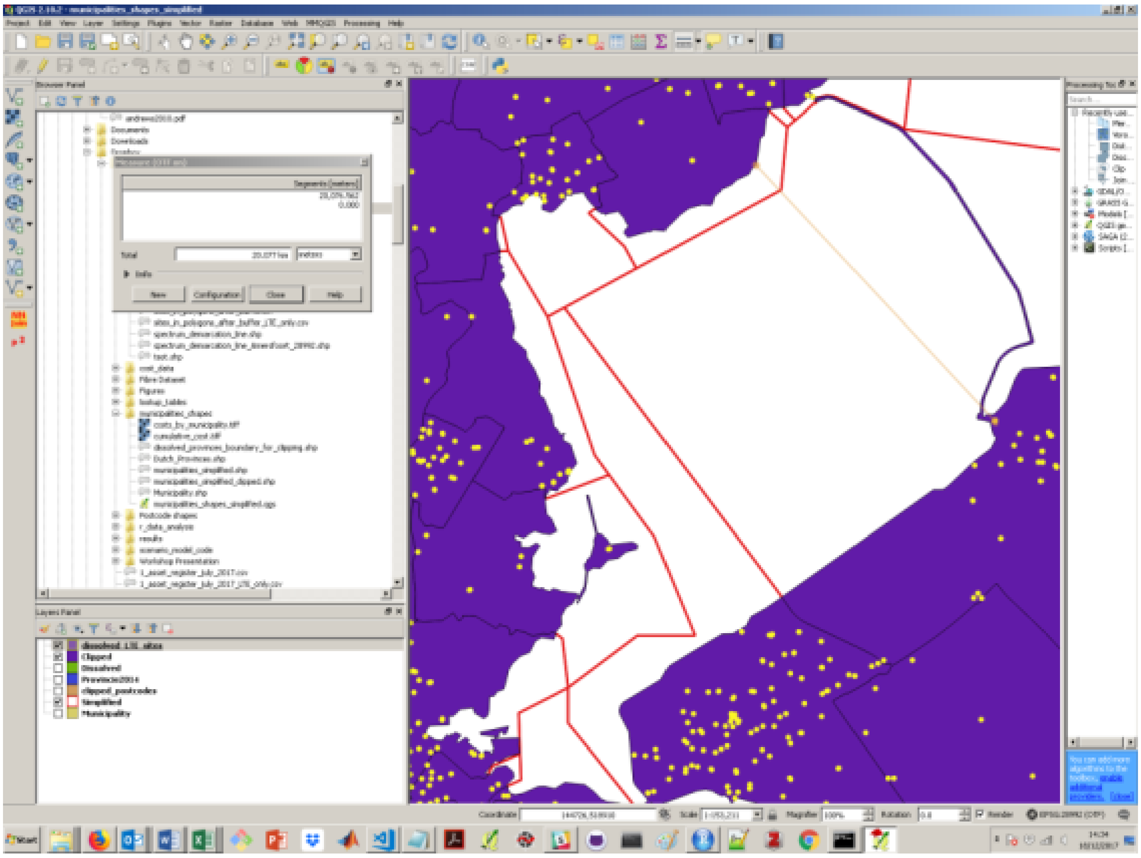


Figure 25: The largest distance between modelled sites in the Markermeer area is in the order of 20 km

A large water area can be regarded as a very rural area geotype (geotype ‘rural 4’) where the number of users is expected to be very low, and the capacity requirement is therefore also low, but there is still an expectation of coverage from end-users. A base station at a water's edge would provide ~150 Mbps to a user located at 10 km distance (or ~100 Mbps if the 3.5 GHz-band is not available)[57]. As the maximum distance between sites in the Markermeer and IJsselmeer area is around 20 kilometres, coverage of these water areas can be achieved with no or minimal extra costs, depending on the scenario.[58]

Future, enhanced versions of the cost model may be able to test variations in license requirement or different coverage obligation levels tied to the allocation of some portions of the band, but this is still under development.

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[57] This is calculated with the same network dimensioning methodology described in chapter 3. The rates are calculated considering the frequencies and bandwidth configuration of the hypothetical operator (Figure 12)

[58] Depending on factors such as site capacity, in some cases extra antennas/sectors may be needed.

7.4 Considerations regarding regulatory issues

This section deals with the current regulatory bottlenecks of network construction and densification in the Netherlands, and the bottlenecks with the roll-out of 5G in the medium-term. The bottlenecks appear primarily with regards to two activities: 1. Digging of fibre to antenna sites and 2. Erecting antennas or affixing them to buildings. National laws govern the general framework and local regulations give specific guidelines.

7.4.1 Current regulations that affect 5G rollout

This section provides an overview of the most relevant current regulations that govern the rollout of new fixed and/or mobile networks.

National laws

There are several national laws that are relevant for rolling out a telecom network. The telecom law[59] contains several articles on construction of networks. Other relevant laws are those regarding, zoning, construction and the environment as they affect what can be built where and how. Even laws on Heritage can be of relevance if an antenna is placed on or near historic buildings or its placement affects the way a town or region is visible, the so-called "protected town or village conservation area" ("beschermd dorpsgezicht"). The two main national laws to consider when rolling out 5G are:

3. The **Dutch telecom law** describes two elements of constructing networks:

- Construction of cables: Chapters 5 states that owners of public grounds have to allow the construction of telecom networks on their grounds. (gedoogplicht). This also extends to owners of private grounds in so far as this is necessary to build interlocal networks and to connect private homes. Whereas the owner of the grounds has to allow the construction for free, the owner of the cables has to relocate the cables for free following a reasonable request.
- Construction of antenna sites: Article 3.24 Telecommunications Law requires operators to share antenna sites, if feasible, when requested by another operator.

For the owners of networks, this allows them to roll-out to and reach their antenna sites and guarantees them a possibility to use existing antenna infrastructures. For the construction of cables, a permit is still necessary. For the construction of antenna's the requirement for a permit is based on the Environmental Licensing Act and a further contract (Antenna Covenant) between the government and telecom operators.

4. The **Environmental Licensing Act (Wabo)** governs the construction of antenna sites higher than 5 metres. Those under 5 metres high can be built without a construction and planning license, except if built on or around historical sites or protected town or village conservation area. However, to enable an orderly rollout and to alleviate concerns in society the Antenna Covenant further specifies how this is done.

[59] Telecomwet

Antenna Covenant

The Antenna Covenant is a binding contract from 2002 and 2010 between the central government, the association of municipalities and MNOs.[60] It governs the careful placement of license-free antennas. It particularly binds the operators as individual municipalities are not a party to it. It specifies that operators inform municipalities and each other of all new to be placed antennas in a municipality. Operators can then coordinate their placement of antennas in a placement plan (Plaatsingsplan). If other operators do not respond to an operator indicating it wants to place antennas, this implies that for the period of the plan (1 year generally) they do not intend to place new antennas. This allows operators and municipalities to jointly find the best location and not burden the municipal organisation or the citizens too much.

One of the principals of the covenant is that antennas are only placed on buildings people live in if this is absolutely necessary and cannot be avoided. If the antenna is to be placed on a building people live in, the residents need to be asked for permission through a vote. If permission isn't given then the antenna cannot be built.

Other national regulations

There are a number of other national laws that can be of relevance when building networks or erecting and affixing antennas:

- Law on the exchange of data concerning underground networks (WION) to be replaced by the Law on the exchange of data concerning networks above and under the ground (WIBON)
- Soil protection act (Wet bodembescherming)
- Heritage act of 2016 that governs monuments and also "protected town or village conservation area"
- Law on Underground Register (Wet Basisregistratie Ondergrond)

These national laws often require local authorities to implement specific ordnances for their province, water board or municipality.

Local regulations

The relevant local authorities in the Netherlands with regards to the construction of 5G networks are generally the municipal authorities[61]. In some cases when dykes and waterways are involved, the water board (waterschap)[62] is also relevant. Provinces are involved when

[60] Started in 2002, extended to new operators in 2010 and valid until 2019, when it will likely be extended.

[61] For example the city of 's Hertogenbosch has its guidelines on cables here https://www.s-hertogen-bosch.nl/fileadmin/Website/Ondernemer/Vergunningen/Kabels_leidingen/Handboek_Kabels_en_Leidingen.pdf and its antenna policy here http://decentrale.regelgeving.overheid.nl/cvdr/XHTMLoutput/Actueel/'s-Hertogenbosch/423153.html

[62] See for such a policy https://www.waterschaprivierenland.nl/producten/vergunningen/kabels-en-leidingen-aanbrengen-en-onderhouden.html

digging or placing antennas near provincial roads and waterways, though municipalities often coordinate this when it concerns telecom networks.[63]

Each municipality, water board and province will have regulations on who can dig how, when and where. They also have regulations on where antennas can be placed. In addition they have statutes and guidelines on what kind of levies they charge for giving permits and regulations with regards to for example digging and re-paving. The central government sometimes aids municipalities by creating guidelines for local policies. Because municipalities face the same laws and requests, they often work together on establishing common guidelines and standards for these local regulations. These guidelines and standards serve as templates for local regulations. Examples are the antenna policy of the Dutch Antenna bureau for municipalities and the guidelines of the municipal platform for cables and ducts (GPKL)[64].

Steps to be taken by network operators in case of network densification

In the table below a general overview is given of steps that operators have to take when densifying their networks and implementing extra (small) cells at new locations (to be read from top to bottom, where the further left indicates an increase in works and complexity).

[63] See for example the rules in the Province of Utrecht https://www.provincie-utrecht.nl/@244527/aanleggen-van-kabels-in-provinciale-vaar-weg-verzoek/ or Friesland https://zoek.officielebekendmakingen.nl/prb-2014-9.html
[64] https://www.gpkl.nl/

Table 17: General overview of steps towards network densification

General Step-by-step overview of placing small cells and other forms of network densification					
Reason	Coverage and capacity complaints of users, connection requests, expected growth and network planning.				
Network Planning	Integration and optimisation of previously mapped locations/areas, knowledge of land/building owners, and residents, and other preconditions and restrictions.				
Fixed Infra-structure	Expansion of current fixed infrastructure	Backhaul extension with short digging distance: Obligated to report			Dig / Install / Connection Restoration by contractor
	Digging ex-pansion	In the case of *"graafrust"*, research of alternatives with the municipality, calculation costs and effec-tiveness.	Coordination with any other activities.	With per-mission to dig, carry out any required soil testing.	
Antennae	Replacing existing antenna installation				Replacement
	Add antennas to existing devices				Add and con-nect
	New antennas	Annual com-mon placement plan with search areas	Consultation/ participation with residents and inhabit-ants in some municipalities	Contracting locations	Placement and opening up of antennae (with corresponding procedures)
Masts	New mast	Apply for build-ing permit	Participation procedure	Contracting	Construction and opening up
In case of rejection	Repetition of previous steps of the above process				

7.4.2 Current bottlenecks

Variations in local regulations cause delays

Dutch rules and regulations have enabled the roll-out of the current networks, which are ranked as some of the best in the world. Most of the 388 municipalities are willing to work with operators in realising new networks and connections, though there are some municipalities that are considered more difficult than others. This section focuses more on the difficulties that operators experience in the Netherlands; however such problems aren't universal.

The Dutch market for sites of masts and antennae is to some extent fragmented due to different local procedures and costs, which increases costs and delays a massive densification of mobile networks. The national government can consider taking measures to prevent fragmentation of the market, by harmonising rules and costs; however, it touches the balance between setting a national framework, local autonomy and local specific considerations. Bottom-up harmonisation by branch/interest associations can be useful, but it is a slow process. Particularly densification in older inner cities, near monuments and protected town or village conservation area. In such cases, the local policies govern where and how antennas can be placed.

Too many stakeholders with different interests

Rolling out a commercial mobile network is complicated business, there are many stakeholders are involved in both rolling out and the regulation of it, to name a few: Municipality, province, water board, network operators, installation companies (like VW telecom), dark fiber network companies (Eurofiber), antenna companies (companies that only own sites, and rent them to mobile operators), building owners (where small antenna-sites and small cells are built) and citizens.

Each of these stakeholders, and even within some of these stakeholders (like politics versus civil servant within a municipality) have different interests and priorities. The clash of these interests can form a bottleneck, especially in the coordination of the rolling out activities like digging the streets and building facilities for connectivity.

Not much space left for antenna-sites

Finding a location to place an antenna and receiving the necessary permits for antenna and the network to connect it, are a concern. For operators, it is often difficult to extend existing leases and to find new locations, which now seems to create a scarcity of sites for antennas and masts. Moreover, each municipality has different rules on where antennas can be built. For example, some require them to be placed on the outskirts of a town or village and will object to placement on a building within the town. Technically this might violate the antenna covenant as there is no basis for this either on the grounds of the power radiated by the antenna installation, or the fact that it's an antenna. However, municipalities may consider the effect on those living nearby the antenna, the living environment, aesthetics of the environment and living space, and city planning.[65]

It is therefore unclear how the (large numbers of) sites required for the densification associated with the rollout of 5G will be found.

Coordination between different municipal departments

Many municipalities in the Netherlands have a Smart City policy such as the Municipality of Amsterdam. However, municipalities find it difficult to coordinate the operational implementation. This is partly due to the complexity of the municipal organisations, which is optimised for functional tasks, such as one organisation for public transport and another for street lighting and yet another for ICT. A mobile operator may have to coordinate with the departments of civil works, transport, culture and environment within one municipalities' organisation, that each has its own way of working, but have to coordinate their activities to allow innovative placement of antenna's. These departments may have different priorities than giving networks access to bus stops, street lights and historic buildings. Various smart city pilots with new possibilities, such as integrating base stations in street lighting, confirm these kinds of bottlenecks.

In general, municipalities at political, administrative and executive level seem to be relatively unfamiliar with new technologies and opportunities for users. As a result, the location of broadband infrastructure in the various policy areas is lacking, resulting in sub-optimisation at the municipal level. Because of this relative unfamiliarity, any problems of the rollout are more difficult to bring to the governing political part of the municipality.

7.4.3 The role of municipalities in backhaul issues

Municipalities have a very strong role in determining the conditions under which new fibre and new antennas can be rolled out. Each municipality is to some extent free in the way it approaches this as long as it sticks to the general framework as given by the relevant laws and regulations. There are guidelines available for both digging and placing antenna's, such as an example antenna policy of the Dutch Antenna bureau for municipalities[66] or the guidelines of the municipal platform for cables and ducts (GPKL) of the Dutch association of municipalities: VNG. From a policy perspective, this may be a correct way of working: local rules, to fit local circumstances. For companies that want to work on a national scale, however, this means that there are 380 independent frameworks to deal with.

Some general concerns for either cables or antennas are:

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[65] See for example the antenna policy of the city of Haaksbergen. It concludes with "Uit bovenstaande blijkt dat vergunningsplichtige antennemasten bij voorkeur niet in de woonomgeving worden geplaatst. Binnen een afstand van 200 m tot scholen worden geen vergunningsplichtige antenne-installaties geplaatst. De plaatsing van antenne-installaties in de woonomgeving wordt slechts overwogen als is aangetoond dat plaatsing buiten de woonomgeving op (zwaarwegende) technische bezwaren stuit." https://www.haaksbergen.nl/Docs/Verordeningen/1.33_Nota_antennebeleid_29_januari_2014.pdf

[66] Voorbeeldnota Gemeentelijk Antennebeleid, Antennebureau, https://www.antennebureau.nl/sites/default/files/voorbeeldnota_gemeentelijk_antennebeleid_2016.pdf and the site of VNG GPKL at https://vng.nl/onderwerpenindex/ruimte-en-wonen/kabels-en-leidingen

- *Different rules in different municipalities:* As already stated, municipalities are obliged to tolerate cabling by the Telecom law. This law seems sufficient to provide space for rolling out fibre networks that are needed for 5G small cells, however, there are several local handbooks to accommodate digging that defer among municipalities. The difference in local rules can lead to slowing down the rolling out process.

- Municipalities also ask for "*graafrust*"; a period of three years after the last work, in which the same route over which a cable duct was dug cannot be reopened, other than for a calamity. This can slow down the rapid and massive deployment of small cells which may be used for the rollout of 5G.

- *Permit costs and procedures:* Permit costs and procedures are different in each municipality. It may even be necessary to apply for a permit to dig the network and one to then place the antenna, requiring two permits for what is from the point of view of an MNO a single project. In some municipalities, a permit is set for a fixed fee. In others, it's dependent upon the size of the project, the length of digging etc.

- *Re-paving:* Some towns allow the construction company that digs the fibre to repair the roads/sidewalks that were opened up. Others require that a company appointed by the city does the work. The argument for the latter is that those companies are certain to provide the required quality, whereas the construction company contracted by the telecom operator is generally considered faster and cheaper but less reliable from a municipalities' point of view. In addition, each municipality charges different costs related to repaving. Annex A gives more detailed examples.

- *Requesting soil research, even when the data is already available:* some towns require soil sample analysis for contamination each time that digging takes place whilst others base themselves on previous analyses or other sources of information that the city already has. For example, the city of Amsterdam requires soil analysis, despite the inner city having been determined to have contaminated soil as a result of 17th and 18th-century activities. Operators could save several thousand euro per dig by not having to conduct soil sample analysis for areas where the results are known.

- *High ground prices:* In some Dutch cities, the square meter prices of the ground antennas are to be placed on, are seen by some operators as (too) high, which could be seen as a bottleneck.

7.4.4 Near-future developments

Densification could rekindle latent issues

In the near future (2019-2020) new spectrum blocks will be auctioned in the Netherlands, which will accelerate the rolling out of 5G networks. For local authorities, rolling out and densification of networks could open up latent societal discussions. Municipalities will have to reconsider the various interests of users, the economic importance of high-quality mobile networks, protection of cityscape and other public interests.

The expected massiveness associated with the 5G rollout and the combination of having to roll out infrastructure both above and underground is, however, more complex and pervasive than for previous generations of mobile technologies. For example: achieving cost reduction through coordination of public and digital connectivity activities or giving networks access to access to street furniture/buildings may also create new bottlenecks for municipalities. One thing that may help densification is the notion of smart cities. Several cities have said they want to be smart cities. This implies physical and data infrastructures that span a city. Integrating small cells and/or 5G in the smart city vision might lead to a cross-departmental approach to support the rollout of the required infrastructure.

New Environment and Planning laws "Omgevingswet"

Environment and Planning Laws that cover buildings, monuments, the environment, and underground infrastructure(s) can all have an effect on the placement of antennas.

There is currently a revision underway to the various existing Environment and Planning Laws. A new law is designed to replace a patchwork of laws with one uniform framework of regulations. The Environment & Planning Act will replace 15 existing laws, including the Water Act, the Crisis & Recovery Act and the Spatial Planning Act. The provisions of eight other laws will be transferred to the Environment & Planning Act. The new bill has been approved by both Chambers of Parliament. The cabinet is currently in the work of drawing up the required introductory regulations. The expectation is that the new Act will take effect in 2021.

Two expected benefits of the new law that are relevant for the densification of mobile networks are:

- *'One-stop-shop' for citizens and companies*
  If citizens or companies want to implement a project, they will be able to apply for a (digital) permit at a 'one-stop-shop'. Either the municipality or province will make a decision. In case both are responsible, only one of them will make the decision. This simplifies things for the applicant and speeds up the permit application procedure.
- *Companies need to conduct fewer studies*
  To obtain a permit for a spatial project, companies have to conduct studies (for example, a soil survey). With the Environment and Planning Act, research data will remain valid for longer. This makes it easier to re-use data. Moreover, some research obligations will be abolished and this means lower costs.

Such benefits would be welcomed by MNOs. However, there is some scepticism as to whether the law will actually be able to deliver on its promise of simplification. The law still leaves much to municipalities and it is the individual approach of municipalities that is the greatest sources of costs and complications.

Latent social resistance can become active

In recent years, an incremental, small-scale expansion of the mobile networks has taken place, as a result of which the social resistance is greatly reduced. This could give the impression that there is no longer any social resistance to antennas.

Due to a possible large-scale rollout of 5G, social resistance to masts and antennas could become active again. There are still lobby organisations regarding this subject, moreover, there are experts or group of consultants who offer services to residents when masts or antennas are built in their environment[67].

A more extensive analysis of regulation issues can be found in Annex A.

7.5 Considerations regarding re-use of other networks

7.5.1 EU framework on the re-use of existing networks

The re-use of publicly owned networks has been discussed as a way of promoting the roll-out of fixed and mobile broadband. The European Union has adopted a directive to promote the roll-out of such networks (Directive 2014/61/EU). It states:

It can be significantly more efficient for electronic communications network operators, in particular new entrants, to re-use existing physical infrastructures, including those of other utilities, in order to roll out electronic communications networks, in particular in areas where no suitable electronic communications network is available or where it may not be economically feasible to build up a new physical infrastructure. Moreover, synergies across sectors may significantly reduce the need for civil works due to the deployment of electronic communications networks and therefore also the social and environmental costs linked to them, such as pollution, nuisances and traffic congestion. Therefore this Directive should apply not only to public communications network providers but to any owner or holder of rights to use, in the latter case without prejudice to any third party's property rights, extensive and ubiquitous physical infrastructures suitable to host electronic communications network elements, such as physical networks for the provision of electricity, gas, water and sewage and drainage systems, heating and transport services.

The Netherlands is currently implementing this directive.

The usefulness of existing infrastructure in the Netherlands for broadband and 5G depends on two elements. Firstly, the way infrastructure is available. Secondly, the characteristics of 5G. With regards to the first, the Netherlands is quite unique in the way it has rolled out most of its public infrastructure, be it electricity, gas, water, telecom or sewage. Historically it chose direct-buried cables and pipes. Directly burying these is possible in the Netherlands, because the soil consists of sand, clay and other loose soil types. The soil composition in the Netherlands differs from the various forms of rock common in other countries In other countries those that build utility type networks often choose to build a concrete or other type of duct for their electricity cable, water pipe or telecom infrastructure. It protects the cables and pipes and allows future expansion without significant digging. This leaves a bit of space that can be used to put fibre ducts in. That existing infrastructure is of great value if it can

[67] For example Dr. Leendert Vriens en Dr. Jan van Gils http://www.emstraling.nl/ and https://www.bureaustralingmeten.nl/

be used for 5G as it allows rollouts without significant investment.[68] Direct burial in the Netherlands means that there is no additional space to run fibre ducts. This public infrastructure is therefore of little use for telecom operators.

Re-use of utility poles also allows the cheap roll-out of fibre networks as no digging is necessary (though they suffer from higher operational costs with more breaks). Poles were used for electricity in rural areas in the Netherlands in the past, however by 2000 the last of the wooden poles that carried this infrastructure were replaced by underground networks.

Incumbent telecom and utility operators across the EU (and the world) often objected to the use of "their" ducts and poles by others, making it harder to roll-out new infrastructure. Some incumbent operators had preferential access to such existing networks, unlike new entrant telecom operators. It is for this reason the EU drafted a directive requiring the sharing of infrastructure. (Whether the ownership of the poles or ducts lays with municipalities or other local governments or with the incumbent public or private utility provider is of less concern to the Directive. What is relevant whether the infrastructure can be re-used).

7.5.2 The re-use of public and private infrastructure.

Telecom networks can be seen to consists of three basic layers:

1. National backbone
2. Regional rings (aka regional backbone, aka regional backhaul)
3. Local rings/extensions[69] (aka local backbone, aka local backhaul)

Antenna sites are connected through local rings/extensions to regional rings and the further national backbones. Operators prefer to connect their sites with fibre as it has a large capacity and low operational cost. They will first aim to use their own network, then either dig to the site, lay fibre through the duct of a third party or purchase dark fibre depending on what is most economic. If this isn't possible they may purchase managed fibre from a third party, but this is less preferred because it means that the operator has less control over its network and operational costs are often higher. Only when a fibre solution isn't economic will operators consider using wireless point to point connections to connect an antenna site. Microwave solutions to reach an antenna site generally have less capacity and require more operational support (and cost). An advantage to microwaves may be that it's quicker to set-up than the time required for laying fibre.

Telecom networks (both commercial and publicly owned) roll out fibre networks by laying down ducts. Innovations in duct-in-duct technology have allowed them to increase the capacity and lifetime of these ducts. They also tend to lay more ducts than needed, in order to

[68] An example is the sewer system of the city of Paris. The tunnels are large enough to walk upright in and it is therefore used for FTTO and FTTH networks. Paris also has a network of ducts below the pavement that was developed for electricity and is also re-used for fibre networks.

[69] Though rings are preferred for resilience, sometimes an extension of a network can't be built economically through a ring and a point to point connection will be made instead.

be prepared for the future. As a result, there are still empty ducts available for deployment of new fibre cables. Operators will first use this infrastructure to extend their local networks.

With the roll out of 5G a question has become to what extent this requires an increase in underground infrastructure and whether the re-use of public networks (meaning those owned by governments or utilities) can be beneficial. The major telecom networks already have their own nationwide backbones that sometimes make use of available publicly owned infrastructure. The capacity on these national backbones is significant and can be easily expanded by moving to faster speeds and higher numbers of lit fibres and/or the use of multiple colours of light. It is therefore not likely operators will need additional capacity on backbone routes in the near future.

In the Netherlands, existing infrastructure is sometimes available to fixed and mobile telecom companies. For example, there have been occasions where telecom operators were able to coordinate their digging with Rijkswaterstaat (manages all the main roads and waterways) or to buy access to existing ducts which are publicly owned. Infrastructures of the Dutch rail company Pro-Rail and high-voltage electricity network Tennet are available through their commercial joint-venture Relined. In addition, there have been opportunities for telecom companies to make use of fixed infrastructures to locate their antennas on, such as on portals across highways.

For achieving the data rates in the different 5G scenarios, available publicly owned infrastructure is likely to be of less use to expand local rings and extensions. The densification needed means that it is not so much the backbone, but the last few hundred meters that are relevant. Because most existing infrastructure in the Netherlands is directly buried it's of no use for telecom operators. If they need to roll-out to a location, that means they need access to existing ducts owned by themselves or their competitors. If these ducts are not present, then they need to be laid down. Municipalities do try to coordinate these works and can require that those intending to dig do so in coordination so that the same street isn't dug open every other week. However, most infrastructure is already present and in the short term, it isn't expected that new infrastructure other than for telecom will be built.[70]

It is sometimes suggested that the network infrastructure present for municipal functions, such as offices or street and traffic lights could be re-used. However, the experience of Stratix is that street and traffic lights generally don't use a municipality owned fibre optic telecom network of some sort. There are many solutions on the market, for example using mobile networks, proprietary protocols over electricity networks, copper networks etc. However, these solutions do not have sufficient bandwidth for a serious contribution to a 5G network. All in all, there isn't a universal network that can be re-used for connecting small cells used when densifying a mobile network. The same goes for networks owned by municipal authorities. In many cases, such networks are leased from commercial operators. Often these networks cover only a few city buildings. There are some exceptions, such as for example the TRENT/NDIX networks in the east of the Netherlands or the city ring of Rotterdam,

[70] In the future there might be an investment in new forms of energy networks, to replace gas networks and help with the energy transition, however that is likely outside of the 2025 timeframe of this report.

and also in some regions in the Netherlands such as Flevoland and North and South Holland fibre networks were built for remote control and monitoring of bridges, locks and water pumping stations. However, in many cases, this infrastructure is already in use by mobile operators and other (secondary) users. We, therefore, do not expect significant additional benefits from re-use of other than the already used network infrastructure for densifying networks in the course of rolling out 5G networks.

This, however, doesn't mean owners of existing infrastructure and public authorities can't help with densification of 5G networks. Particularly for small cell capabilities, the re-use of fixed (non-network) infrastructure such as street furniture and buildings can be beneficial. Already there are trials to incorporate antennas into streetlight-poles. In its initiatives on smart digging (Slim Graafwerk) the Ministry of Economic Affairs and Climate has also promoted that municipalities lay ducts when opening the ground for other (public) works, such as road reconstructions or when replacing sewer pipes.

Other infrastructure could be bus stops, traffic lights, advertising locations etc, some of which are publicly owned. Access to this infrastructure could be beneficial. However, just as with any new location, there will be costs. Bus stops, traffic lights, advertising locations may be chosen more because of their convenience in hiding away antennas than that they represent a direct cost saving. Indeed, coordination costs might increase, compared to a normal antenna, however it might result in an easier permit application process.

7.6 Considerations regarding power facilities

The Netherlands has a relatively dense electricity distribution network. In the model, connecting new sites to the power grid is taken into account in the general investment assumptions for new antenna sites. However, for very rural sites these costs may be substantial.

Power consumption and related costs is another issue. The power consumption of a single macrocell base station can be assumed to be 3.7 kW/base station[71]. This is not taken into account in the model as this only models investment costs. Electricity prices, but also the use of alternative energy sources such as solar panels, and the use of local storage may influence these costs.

71 https://www.researchgate.net/publication/228774201_Power_Consumption_in_Telecommunication_Networks_Overview_and_Reduction_Strategies

8 Conclusions

This report describes the results of a research project commissioned by the Dutch Ministry of Economic Affairs and Climate Policy. The project aims to estimate the cost components of the rollout of 5G networks in the Netherlands under certain scenarios and assumptions. In particular, this research analyses the necessary investments in new passive and active infrastructure and its power supply.

Key questions of the study were:

1. How will densification of antenna sites in mobile communication networks progress until 2025, and what will be the developments in backhaul networks and edge networks?

2. Which rules and regulations are applicable for the rollout of small mobile network cells particularly, and which restrictions may be expected? A description should be made of the process and steps forward to the deployment of the densified mobile communication network by using small cells or alternative technologies for coverage of the mobile network. It should be addressed specifically which phases in the process of rollout are depending on law and regulation, and national and municipal authorities?

3. To what extent does the installed base of mobile communication need to be expanded? Several scenarios will need to be investigated including in dense urban areas, and by distinguishing between mobile network providers that are 'mobile only', and mobile network providers that are also deploying access networks for fixed subscribers. The study should address to what extent public fibre transmission networks are able to contribute to the densification of the mobile networks for the rollout of the 5G technology.

4. The study should describe the cost elements and the order of magnitude of investments required until 2025 for each of these cost elements (fibre and backhaul technology, active radio equipment, power facilities). This should lead to a range of the level of investments required, whereby specific attention should be paid to:

a) The investments of a fixed mobile converged network operator;

b) The investments of a mobile-only network provider;

c) Whether or not backhaul capacity owned by third parties (public organisations, private (non-telecom) companies, and fixed network providers can be used for 5G rollout and cell densification.

The study was performed using a calculation model for a hypothetical mobile operator that has already been successfully used to estimate the rollout costs for 5G in the UK. This model has been adapted to the situation in the Netherlands and is used to assess the rollout costs of a hypothetical operator with 30% market share providing on average 30 Mbps, 100 Mbps and 300 Mbps per-user at every location in the Netherlands.

To this aim, three different capacity-expansion strategies have been considered:

i) spectrum integration, adding more spectrum (2x10 MHz at 700 MHz, 10 MHz at 1500 MHz, and 40 MHz in the frequency range 3.4-3.6 GHz) on the existing macrocellular networks,
ii) the rollout of additional small cells (100 MHz in the frequency range 3.6-3.8 GHz), or
iii) a hybrid scenario combining both of the aforementioned strategies.

This final chapter briefly describes the main conclusions of this project.

The general model proved very useful to model 5G rollout in the Netherlands, but every country has its specifics.

The work developed has been built on a general model, first developed for the UK and later adapted to the Dutch situation by using the postcode areas of the Netherlands. The model utilised the antenna database from the Dutch Radiocommunications Agency 'Agentschap Telecom', which was up to date and very useful. The results provide valuable insights about the impact of different possible strategies on the coverage and capacity of the rollout given a certain investment budget. However, in the current model the yearly investment budget also limits the total investment costs to realistic proportions so the total costs of more ambitious goals have to be estimated using extrapolations. Also some pragmatic choices were needed with regard to modelling the use of the 3.5 GHz bands in the Netherlands, and which cost elements are considered CAPEX and which OPEX. Although the choices are based as much as possible on facts, standard practices, scientific literature, expert opinions and discussions with several operators, some choices may remain debatable, especially when considering a specific operator.

The model's approach using a hypothetical operator is a workable approach but with some disadvantages and inaccuracies. Alternative approaches however are less practical, or would likely not provide more accurate estimates.

- An alternative approach would be to only calculate the total cost (using one hypothetical operator). This approach however does not take into account competition, or the fact that one operator may not have access to all possible frequency bands, cell sites and backhaul networks.
- An alternative approach would be to calculate the costs for one or more specific operators. This approach would necessitate making arbitrary and highly debatable choices and require calibrating and running the model four times for every scenario. Also the discussions on several necessary input variables would have been even more difficult due to economic strategic sensitivities barring operators from providing the information necessary to truly model reality.

A number of input variables for the hypothetical operator, such as investment per year, number of sites, number of users, etc. are based on estimates, assumptions and 'educated guesses' resulting from a combination of market averages, outcomes of discussions with operators and experts in the workshop and expertise from the project members.

30Mbps is achievable through spectrum integration; higher speeds will require significant investment

The performance of any mobile network is dependent upon the spectrum bandwidth it has available and the site density. If an operator has access to more spectrum, it could theoretically reach the same service level with fewer sites and vice versa. Depending on the targeted service level (measured in Mbps per customer), MNOs need to adopt different rollout strategies. Along with the allocation of spectrum, they are also constrained by their investment resources.

The results suggest that for an average speed of 30 Mbps per user everywhere and at all times, just integrating new spectrum within the upcoming frequency bands (700, 1500 MHz and 3.5 GHz) into the existing macrocellular network can provide satisfactory results.

Integrating the aforementioned spectrum into an existing macro network is enough to deliver 30 Mbps everywhere by 2025 if the current yearly rate of investment (assumed to be 140 million Euros) is sustained. The model shows that providing 30 Mbps everywhere would cost 750 million Euros if done through the spectrum integration strategy (see Figure 18, taking into account the capacity margins in Figure 17). Although there are some regions with small capacity deficits, this would be the preferred option for the hypothetical operator under study. The hybrid strategy – integrating new spectrum and rolling out a small cell network using 100 MHz in the frequency range 3.6-3.8 GHz) would provide higher capacity margins, which would be valuable in the long-term. However, this would be at double the cost (1.5 billion Euros).[72]

In both cases of 100 and 300 Mbps of average data rate per user everywhere and at all times, the model shows that in the northern part of the Netherlands this is difficult to achieve with any of the three capacity-expansion strategies tested. This is mainly due to the fact that in the northern part of the country the 3.5 GHz frequency band (3.4-3.8 GHz) cannot be used. In the hypothetical case that the 3.5 GHz frequency bands would be available in the entire country, a rough extrapolation of the costs of Figure 18, considering the capacity deficits in the northern parts in Figure 17 and the impact on cell capacity margins shown in Figure 23, shows that the hypothetical operator used in the model would need to invest 5 billion Euros if he wants to achieve the 300 Mbps goal. This estimate takes into account that the costs (estimated around 2.5 billion Euros) that were calculated in the model should roughly be doubled to provide the necessary capacity in the whole country (instead of only the southern part).

The impact of the existing backhaul

Relative to, for example, the United Kingdom, the effect of additional investment in backhaul networks is limited, as in most locations in the Netherlands access to fibre networks is possible with a minimum of civil works. All mobile operators already have extensive national and regional fibre networks to reach core, aggregation and antenna sites. Wireless backhaul is

[72] These figures exclude the costs associated with acquiring the spectrum.

used sparingly. New sites are often located close to existing fibre networks. Based on the input assumptions used, the cost model also shows a limited impact.

A fixed mobile converged operator has a limited advantage over a mobile-only operator in extending and densifying its mobile network

In theory fixed-mobile operators have a more extensive backbone and backhaul network that they can also utilise for their mobile backhaul network. In the Netherlands, however, mobile-only operators have accrued an extensive fibre network and therefore only a small fraction of the sites will require backhaul upgrades. In most locations in the Netherlands there is a possibility to acquire business grade fibre access from 'other licensed operators' to connect new sites and/or small cells. Many of the existing antenna sites are shared locations with a presence of fibre networks. It is likely that commercial fibre networks will also extend their networks to new shared antenna locations. In more and more situations new small cells can also make use of existing business or consumer network access, especially when fibre access is already present. Based on the access regulation in place in the Netherlands like most European Union Member States, an antenna site (e.g. a small-cell) can make use of the access network of a competing operator at a customers' premise by acquiring unbundled broadband service. Alternatively, a site can be provided to be connected 'over the top' on existing broadband services. In the future, several factors may impact the relative advantage of a fixed-mobile operator compared to a mobile-only operator in the future. Some examples are:

- More cost efficient femto equipment ('small cells')
- New methods for network planning
- New methods to ease the use of access networks for 5G backhaul, and
- Discussions, interpretations or regulation trends with regard to net neutrality and the position of the demarcation point of an access network.

Main cost components of 5G rollout (independent of scenario)

As described earlier, roughly two strategies can be distinguished for a mobile operator: use existing sites and integrate and extend spectrum, or introduce smaller cells. Also a combination of these strategies is possible. The choice of which strategy will be chosen by an operator is outside the scope of this research and may depend on historical considerations and business strategies regarding current and future obligations of spectrum licenses, antenna sites, backhaul options etcetera. The main cost components that can be distinguished for the two basic strategies are:

- **Spectrum integration**: Around 80% of the costs is macro RAN equipment, with macro civil works only being about 20% of the overall cost
- **Small cells**: Around 84% of the costs is small cell civil works, with the actual small cells being only approximately 16% of the cost.

Future mobile networks will need to be so dense that the economics of the rollout will, in our view, not allow for four competing and overlapping networks. Thus, it is very likely that at least the backhaul of the small cells will be shared or indeed outsourced to other companies, specialised in providing fibre or mmWave connections to serve as the backhaul for 5G small cells.

Availability of 3.5 GHz spectrum will be of extreme importance for the next generation of mobile networks.

If 3.5 GHz is not available, in the used cost model small cells will not be deployed as they use 3.5 GHz bands, and the other blocks are needed to upgrade the capacity of the macro network. In case the 3.5 GHz is not available the only way to increase existing capacity will be to densify the macrocell network, or deploy a variant with a radio planning using frequency bands for new small cells that are now in the model allocated to macrocells. The model does not capture this scenario at the moment since this is a very rare case that telecommunications operator would prefer to avoid. Macrocell densification poses a significant challenge, since it is even harder to find new locations for macro cells because mobile networks in western European countries are already very dense.

However, if due to spectrum restrictions, macrocellular densification is the only available strategy to meet the demand for the Dutch operators in many cases getting access to locations that can serve as a macro cell site (public facilities, etc.) will become an important issue. Nonetheless, even in that case the demand is very unlikely to be met in the case of 100 and 300 Mbps per user.

Additionally, enhanced mobile broadband (100, 300 Mbps) is one of the promising services of 5G. Also, low-latency and high-reliable services will also find a place in 5G. Densifying the macrocell network is not a future-proof strategy. Not having 3,5 GHz available will limit the mobile operators in the short term to try and offer these services with all the other available bands.

Governments can influence the costs of civil works, but not the costs of the Macro RAN

Macro RAN upgrade costs significant, but the market for this equipment is a commercial and competitive market, hence national, regional and local governments may have limited ways to influence these costs.

Small cell civil works cost is very high and because there is no standardisation in the conditions under which street furniture can be accessed, nor standardisation in possible additional costs of local municipalities, the costs vary greatly.

Availability of nationwide existing networks (utilities, public and private) has a low impact on 5G investments. Using regional and municipal networks is key, but there are issues

Local presence of existing and commercial fibre backhaul networks in the Netherlands is relatively high. Only in a limited set of cases do existing networks (utilities, public and private) have a presence in areas where other networks do not have a presence. The probability that mobile network operators can effectively use these networks is relatively small. Locally there may be cases where local publicly owned fibre networks may be very interesting for mobile network operators. But economic, organisational and procedural challenges have to be overcome to successfully make use of these networks. In many cases operators prefer to build and deploy their own fibre network routes, or use Managed Ethernet Services (MES) or Managed Dark Fibre Services (MDFS) from commercial operators.

Fragmented regional regulation could have a large impact on organisational costs and effort of operators

Regulations for the roll-out of networks is fragmented. In almost every variant and step of a network upgrade license applications with local governments play an important factor: construction of new fibre routes but also when planning a new cell site. It isn't that the laws and general principles are different across the country. However, the implementation has been left to local governments. This has as a benefit that their implementation is tailored to the local situation. At the same time it also means that every municipality is unique and uses their own regulations. The new 'Omgevingswet' is aimed to create a one-stop-shop, which is beneficial. However the implementation is still local. MNOs will still face municipalities that will not allow antennas to be fixed to the fronts of buildings, differences in digging costs and different rules on repaving and multiple parts of a municipalities' organisation involved in issuing the permit.

Most people want to have good data coverage and excellent connectivity, but at the same time for various reasons prefer to not live too close from a mobile antenna site. This is a paradox in the sense that smaller cells may be a solution for some of the reasons that people mention for resisting the placement of antennas. Smaller network cells generally use lower radiated power than larger network cells, and for smaller cells antennas can be smaller and placed at lower heights than macrocell antennas. Municipalities will play an important role in dealing with these trade-offs in the way they structure their local regulation on the placement of antennas.

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Annex A Knelpunten lokale netwerkverdichting (2017-2025)

A.1 Introductie

Omdat het gebruik van de vaste en mobiele netwerken in Nederland blijft toenemen en applicaties data intensiever worden, is in het eerste deel aan de hand van een aantal scenario's berekend wat de investeringshoogtes zouden kunnen zijn.

In dit deel van het rapport wordt ingegaan op de *tweede vraag van het onderzoek "Welke regelgeving en procedures gelden voor de uitrol van onder meer small cells? Zijn hier belemmeringen te verwachten? Beschrijf de stappen in het proces om te komen tot plaatsing van small cells of andere vormen van netwerkverdichting*.

Hieronder worden de knelpunten voor lokale netwerkverdichting behandeld, waarbij begonnen wordt met de huidige situatie. Daarna wordt ingegaan toekomstige ontwikkelingen en daarmee samenhangende knelpunten.

A.2 Huidige Situatie

A.2.1 Nederland met hoge ambities in de digitale koplopers groep

Nederland kent in 2017 een hoge breedband en 4G dekking. De dekkingsgraad is 97%, met nog enkele white spots op het platteland. Met deze dekkingsgraad behoort Nederland tot de koplopers groep van digitale connectiviteit wereldwijd. Het Ministerie van Economische Zaken en Klimaat wil deze positie van Nederland in de koplopers groep met goede connectiviteit bestendigen of zelfs uitbouwen.

De hoge dekkingsgraad in Nederland is onder meer tot stand gekomen door een goede samenwerking tussen gemeenten, operators en diverse stakeholders. Momenteel vindt op kleinere schaal verdichting plaats met z.g. *small cells* om dekking te verbeteren voor plekken waar onvoldoende capaciteit is, of waar 'shadowing' door gebouwen optreedt.

Maar om nieuwe, toonaangevende diensten aan gebruikers te kunnen aanbieden op basis van 5G, zoals autonoom rijdende voertuigen, wordt een uitrol verwacht, die van een andere ordegrootte is, dan incrementele verbeteringen om de huidige dekking en capaciteit te verbeteren. Een uitrol voor 5G infrastructuur voor 5G diensten vergt waarschijnlijk een substantiële investering van operators. De vraag naar nieuwe 5G diensten is nog in ontwikkeling en van 5G diensten zijn slechts de contouren zichtbaar.

In de context van een plaats in de koplopers groep door een 5G infrastructuur zijn een aantal factoren van belang, die in dit deel van het onderzoek naar knelpunten naar voren komen. Belangrijke elementen aan de uitvoeringskant zijn homogeniteit en duidelijkheid van regels in de lokale omgeving, kosten van uitrol, snelheid en voorspelbaarheid van uitvoering. Aan de vraagkant is een omgeving waarin vraagontwikkeling bevorderd wordt van belang. Meerdere gemeenten hebben Smart City plannen en operationele pilots, zoals de gemeenten Amsterdam, Den Haag/Scheveningen en Eindhoven. Deze activiteiten sluiten aan op de landelijke doelstellingen.

Deze verschillende elementen komen hieronder aan de orde met nadruk op de belemmeringen. Maar eerst zal een inleidend overzicht gegeven worden van het huidige wetgevende en algemene kader. Hierbij wordt aandacht gegeven aan aspecten, die betrekking hebben op zowel mobiele als vast infrastructuur omdat voor 5G antenne sites met glasvezel ontsloten worden.

A.2.2 Wettelijke en algemeen kader voor vaste en mobiele infrastructuur

De Telecommunicatie Wet (TW) geeft de basis voor de aanleg van mobiele en vaste telecommunicatie infrastructuur. De TW wordt op landelijk niveau geflankeerd door wet- en regelgeving op, ondermeer op het gebied van volksgezondheid (straling) en ruimtelijke ordening. Dit wettelijke kader leidt tot diverse stappen om tot netwerkverdichting te komen, die hieronder opgenomen zijn in tabel 18.

Voor de ruimtelijke ordening is sinds 2010 de **Wet Algemene Bepalingen Omgevingsrecht (WABO)** van kracht, waarin wet- en regelgeving en diverse vergunningstelsels met betrekking tot de omgeving zijn ondergebracht in één set van indieningsvereisten en één vergunningstelsel. Veel telecomantennes zijn in principe vergunningsvrij, omdat ze niet hoger dan 5 meter zijn en op/aan een gebouw bevestigd zijn.

Table 18: Stappenoverzicht plaatsing small cells

Stappenoverzicht tot plaatsing van small cells en andere vormen van netwerkverdichting **Algemeen overzicht**					
Aanleiding	Netwerk klachten, aansluitaanvragen, te verwachten groei en netwerkplanning				
Netwerk-planning	Integratie en optimalisatie van eerder in kaart gebrachte locaties/gebieden, kennis van grond/gebouw eigenaren en bewoners/inwoners, en andere randvoorwaarden en beperkingen				
Vaste infra-structuur	Uitbouw vanuit huidige vaste infra-structuur	Uitkoppeling met korte graafafstand: meldingsplicht			Graven/aanleg/ aansluiting Herstel door aan-nemer
	Uitbreiding met graven	In geval van graafrust, onder-zoeken van alter-natieven met gemeente, bere-kening kosten en effectiviteit	Afstemming met eventuele andere werkzaamheden	Bij verkregen toestemming tot graven, eventueel ver-eist bodemon-derzoek uitvoe-ren	
Antennes	Vervanging bestaande antenne installatie				Vervanging
	Bijplaatsen antennes in bestaande inrichtingen				Bijplaatsing en aansluiten
	Nieuwe antennes	1x jaar gemeen-schappelijk plaat-singsplan met zoek gebieden	Overleg /inspraak met bewoners en in sommige ge-meenten inwo-ners	Contracteren van locaties	Plaatsing en ont-sluiting antennes (met bijbehorende procedures)
Masten	Nieuwe mast	Aanvragen bouwvergunning	Inspraak proce-dure	Contractering	Bouw en Ontsluiting
Bij afwijzing	Herhaling van eerdere stappen van bovenstaand proces				

Op gemeentelijk niveau vindt dan de lokale invulling en maatschappelijke afweging plaats van deze verschillende beleidsterreinen.

Het **landelijke Antenneconvenant**[73] is een operationele afspraak tussen de mobiele operators, de VNG, de Ministeries van Economische Zaken (nu EZK) en VROM (nu I&W). In dit convenant zijn voorwaarden vastgelegd voor de plaatsing van lage, vergunningsvrije antenne-installaties (lager dan 5 meter) waarmee zorgvuldige plaatsing van antenne-installaties wordt beoogd[74]. Lage antennes, moeten wel voldoen aan algemene landelijke voorwaarden, zoals type goedkeuring.

Gemeenten zelf zijn formeel geen partij bij dit convenant, maar hebben wel via het plaatsingsplan invloed. Plaatsing van lage antennes dient 1x per jaar aan de gemeente voorgelegd te worden in een plaatsingsplan van de gemeenschappelijke operators, gevolgd door instemming van de gebouw eigenaar en/of inspraak bewoners, indien er sprake van bewoning is. Verder heeft de gemeente de mogelijkheid om in beperkte mate aanvullende eisen te stellen, bijvoorbeeld op het gebied van visuele inpasbaarheid en instemming.

Op gemeentelijk niveau moet voor masten en vergunningsplichtige antennes een bouwvergunning aangevraagd worden en voor het plaatsen van antennes zijn verschillende regelingen van toepassing. Ook voor antenne-installaties met een opgenomen vermogen van meer dan 4 kilowatt moet ongeacht de hoogte, een vergunning worden aangevraagd voor de milieu component

Voor masten en antennes heeft het **Agentschap Telecom een voorbeeld beleid**[75] geformuleerd, welke door veel gemeenten als basis voor hun antennebeleid gebruikt wordt

Andere nationale regelgeving

Er zijn een aantal andere wetten welke relevant zijn wanneer netwerken aangelegd worden of antennes opgericht of bevestigd worden:

- De Wet informatie-uitwisseling ondergrondse netten en netwerken en zijn opvolger de Wet informatie-uitwisseling boven en ondergrondse netten en netwerken
- De Wet bodembescherming
- De Erfgoedwet welke monumenten en beschermde dorps en stadsgezichten betreft
- De Wet Basisregistratieondergrond

Deze nationale wetten vergen veelal een lokale implementatie waar provincies, waterschappen en gemeenten zorg voor dragen.

[73] https://www.antennebureau.nl/onderwerpen/plaatsing-antennes/antenneconvenant

[74] Bij overige, omgevingsvergunningsplichtige, antennes is de gemeente verantwoordelijk voor de ruimtelijke ordening en bouwkundige procedures conform de Wabo en het Bouwbesluit.

[75] https://www.antennebureau.nl/onderwerpen/plaatsing-antennes/voorbeeldnota-gemeentelijk-antennebeleid

A.2.3 Huidige knelpunten bij de aanleg van mobiele infrastructuur

Lastige lokale afwegingen omdat veel stakeholder met verschillende belangen betrokken zijn bij de aanleg

Op lokaal niveau wordt duidelijk dat breedband communicatie plaats vindt in een maatschappelijke context, die grenzen stelt aan de opstelpunten van masten en antennes i.v.m. volksgezondheid (straling) en visuele inpasbaarheid. Daardoor is een breed pallet van stakeholders bij breedband communicatie betrokken, wat ook publieke opinie en leveranciers van opstelpunten omvat, waarbij de stakeholders verschillende belangen en doelstellingen hebben.

De gemeenten hebben hierbij een belangrijke rol in de afweging van de verschillende belangen van burgers als inwoners, de private en zakelijke gebruikers, de aanbieders van breedbanddiensten en het beleid van de landelijke overheid.

Figure 26: verschil in ambities en doelstellingen tussen stakeholders

Druk op plaatsen voor masten, antennes en small cells

Hoewel het merendeel van gemeenten soepel blijkt te zijn ten aanzien van bouwvergunningen voor masten, bestaan er in Nederland echter aanzienlijke verschillen tussen gemeenten. Er zijn gemeenten die masten categorisch afwijzen, zoals Haaksbergen, en ook gemeenten, die langdurig tegenwerken, zoals Bergen, waar één procedure al tien jaar loopt. Daarnaast zijn er gemeenten, die wel meewerken, maar aanvullend eisen stellen, zoals de Gemeente Haarlemmermeer, die antennes niet te dicht bij scholen plaatst (“minimaal 50 meter van scholen”) om tegemoet te komen aan maatschappelijke onrust, die uit een soort voorzorg om een minimum afstand tot scholen vraagt.

Meer in het algemeen ontbreken in veel bestemmingsplannen de gebieden voor zendmasten. Sommige gemeenten, zoals Hoogeveen en Zeewolde, hebben wel plekken voor zendmasten opgenomen, maar deze zgn. “designated areas”, zijn een beperking op het bestemmingsplan. Een andere categorie beperking bestaat in bijvoorbeeld Bronkhorst, waar een afstandseis tot woonhuizen geldt. Dit soort beperkingen komen vaak tot stand door burgers en organisaties, die in een gemeenteraad invloed hebben op het antennebeleid, zoals dit bijvoorbeeld ook in Súd Westfryslân het geval is.

Knelpunten zijn ook aan het ontstaan voor het vinden en contracteren van opstelpunten voor antennes. Er zijn ook gemeenten zoals Amsterdam, die strikte welstandsbeperkingen hebben in wijken met monumenten[76]. Hierdoor is een afname van de mogelijke opstelpunten voor lage antennes ontstaan, en daardoor een toenemend gebruik van masten. Daarnaast zijn er woningbouw verenigingen, die categoraal antennes afwijzen, waardoor, zoals in Zwolle, hele flatwijken afvallen voor het plaatsen van antennes. Bij huidige private landlords blijkt, bij verlenging van de leases, een afnemende interesse voor continuering van de overeenkomst te zijn, omdat het meer kost (in tijd) dan dat het oplevert. Potentiele nieuwe landlords hebben vaak (te) hoge financiële verwachtingen.

Op lokaal niveau worden soms aanvullende plaatselijke eisen gesteld m.b.t de landschappelijk inpassing. Op provinciaal niveau zijn er ook beperkingen bijvoorbeeld vanuit de Ecologische Hoofd Structuur, die zendmasten zo goed als uitsluiten.

Doordat antenne-opstelpunten lastiger te vinden zijn, neemt de vraag naar masten toe. Door de aanvullende en beperkende voorwaarden voor de plaats van masten gaan deze meer en meer naar technisch ongunstiger plekken, wat kosten verhogend werkt.

Latente maatschappelijke weerstand kan actief worden

In de afgelopen jaren heeft een incrementele, kleinschalige uitbreiding van de mobiele netten plaats gevonden, waardoor de maatschappelijke weerstand sterk verminderd is. Hierdoor zou de indruk kunnen ontstaan dat er geen maatschappelijke weerstand tegen antennes meer te verwachten is.

Organisaties, zoals Stop UMTS, kunnen inspelen op de latente stralingsweerstand bij bewoners en inwoners, vanwege de grootschalige 5g uitrol. Er zijn ook diverse werkgroepen met consultants, die diensten aanbieden aan inwoners [77].

Bovendien zijn er gemeenten, zoals Breda, die operators verplichten niet alleen de bewoners (van gebouwen) maar ook inwoners in het algemeen te informeren, waardoor burgers betrokken worden voor het vinden van de juiste locatie. Latente weerstand kan zo gemakkelijk naar buiten komen, evenals door politisering van issues in de gemeente raad al dan niet bij de gemeenteraadsverkiezingen.

In tegenstelling tot de UMTS uitrol in 2013–2014, zijn er nu niet alleen personen, die tegen masten en antennes zijn, maar ook andere groepen mensen, die mobiele dekking eisen, maar, die aanvullende voorwaarde eisen, zoals een afstand van twee kilometer van de stad/dorp.

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[76] https://www.amsterdam.nl/beleidskadermonumenten/daken/voorzieningen-daken/

[77] Zie bijv. Dr. Leendert Vriens en Dr. Jan van Gils http://www.emstraling.nl/ en https://www.bureaustralingmeten.nl/

Voor gemeenten blijft het een lastige opgave om een goede balans te vinden tussen luisteren naar de burger en invulling geven aan het antennebeleid, zodat de operators de mogelijkheden hebben om zendmasten en antennes te plaatsen om mobiele communicatie diensten aan te bieden.

A.2.4 Hindernissen voor backhaul en glasvezel

Variërende lokale regels voor aanleg en verdere praktische afwijkingen

De Telecom Wet geeft aan dat graven gedoogd moet worden. De VNG heeft een landelijk handboek graven[78] ontwikkeld, maar dit wordt echter niet altijd gevolgd. In de praktijk hebben veel gemeenten een eigen handboek "kabels en leidingen" laten ontwikkelen, zoals bijv. de Gemeente Vlaardingen. [79] Lokale handboeken hebben uiteenlopende en toenemende volumes. Zo zijn in de lokale uitvoering de nodige variaties ontstaan tussen de 388 gemeenten. Deze verschillen werken kosten verhogend.

Daarnaast vragen de gemeenten soms ook om graafrust, in bijv. nieuw bestrate centrumgebieden. Dit is wettelijk niet afdwingbaar, maar operators respecteren verzoeken meestal voor de goede verstandhouding en zijn dan geneigd om samen naar oplossingen te zoeken.

Naast de gemeenten zijn er nog diverse andere lokale organisaties, zoals provinciën, waterschappen, rijkswegen en organisaties van natuurgebieden, die ook eigen regels hebben.

(Te) hoge en niet-kostengeoriënteerde gemeentelijke kosten

Leges

Er zijn verschillen tussen gemeenten in leges[80]. Voor een te graven tracé van 250 meter hanteert de Gemeente Rotterdam een tarief van bijna € 2.100, terwijl de Gemeente Amsterdam een standaard tarief van € 385 hanteert. De Gemeente Nijmegen brengt €1.100 in rekening voor leges en de Gemeente Hardinxveld Giessendam slechts € 200. Deze verschillen in leges komen voor doordat leges soms een vast bedrag is, en in andere gevallen bepaald wordt aan de hand van het aantal te graven meters.

Door een verschil van mening over de hoogte van de leges van de gemeente Amersfoort zijn partijen juridische procedures aangegaan, die tot aan Europees Hof van Justitie gegaan zijn[81].

Hoge herbestratingskosten

Als de gedoogplichtige grondeigenaar besluit om zelf te herbestraten, dan vallen de werkzaamheden die onder lokale afspraken vallen meestal hoger uit, dan die van de operators, omdat deze landelijke volumekortingen bedongen hebben. Operators hebben in het algemeen 25-30 % lagere kosten, dan een gemeente. Ook vallen de kosten, die door gedoog-

[78] https://vng.nl/onderwerpenindex/ruimte-en-wonen/kabels-en-leidingen/brieven/aanbieding-modelverordening-werkzaamheden-kabels-en-leidingen
[79] https://zoek.officielebekendmakingen.nl/gmb-2017-132427.html
[80] https://www.agconnect.nl/blog/verglazing-zakelijk-nederland-gaat-snel Eurofiber
[81] https://uitspraken.rechtspraak.nl/inziendocument?id=ECLI:NL:HR:2015:1467

plichtigen in rekening gebracht worden soms hoger uit, doordat breder herbestraat wordt dan strikt noodzakelijk, waarbij afgeweken wordt van de methodiek, die de VNG voorstelt.

Bodemonderzoek
In toenemende mate wordt bodemonderzoek als standaard voorwaarde gesteld, wat niet altijd noodzakelijk is, omdat er al eerder of zelfs recent gegraven is. Bodemonderzoek betekent een vertraging van minimaal 4 weken en kosten van ca. €3.500. Een alternatief kan een gesprek met de gedoogplichtige zijn, wat op zijn minst vertragend werkt.

Grondprijzen
Sommige gemeenten lijken (te) hoge prijzen voor gebruik van gemeentelijke grond in rekening te brengen, maar dit is lastig inzichtelijk te maken omdat grondprijzen locatie afhankelijk zijn.

A.3 Toekomstige ontwikkelingen en knelpunten

A.3.1 Uitdagingen voor gemeenten bij de uitrol van 5G

Voor gemeentelijke besluitvorming zal de introductie van 5G voor een deel herhaling zijn van eerdere maatschappelijke discussies. Voorlichting, inspraak, emotie, het creëren van maatschappelijke draagvlak, coördinatie met inwoners/stakeholders en operators zullen opnieuw aan de orde komen. Hierbij zullen gemeenten opnieuw afwegingen moeten maken tussen het economisch en gebruiksbelang, de lokale politieke verhoudingen en maatschappelijke stellingname t.o.v. antennes en straling.

In de komende jaren (2019-2020) komt met veilingen nieuw spectrum beschikbaar en zal 5G technologie ook geïntroduceerd worden. 5G zal met name in de steden door een meervoudige verdichting van het netwerk met small cells gebeuren, waarbij vast en mobiel zich naar elkaar toe ontwikkelen, omdat de backhaul van small cells veelal met glas gedaan zal worden. Daardoor vergt 5G een mix van grootschalige bovengronds en ondergronds werk.

Door deze verwachte grootschaliger uitrol van een andere “ordegrootte” en door de toenemende complexe mix van bovengronds en ondergronds werk zal de facilitering van de 5G uitrol anders zijn, dan eerdere uitrollen.

A.3.2. Omgevingswet

Milieu en ruimtelijke ordening wetten die betrekking hebben op gebouwen, monumenten, het milieu en ondergrondse infrastructuur (en) kunnen allemaal een effect hebben op de plaatsing van antennes. Er is momenteel een herziening gaande om de milieu- en planningswetten te herzien. Een nieuwe wet is bedoeld om een lappendeken van wetten te vervangen door één uniform regelgevingskader, namelijk de omgevingswet. De nieuwe omgevingswet is veel omvattender dan de huidige Wet Algemene Bepalingen Omgevingswet (WABO). De nieuwe omgevingswet vervangt 26 bestaande wetten, waaronder de Waterwet, de Crisis en herstelwet en de Wet ruimtelijke ordening. Het nieuwe wetsvoorstel is door beide kamers goedgekeurd. Het kabinet is momenteel bezig met het werk of het opstellen van de vereiste inleidende voorschriften en vier AMvB’s. De verwachting is dat de nieuwe wet in 2021 in werking treedt.

Twee verwachte voordelen van de nieuwe wet die relevant zijn voor de verdichting van mobiele netwerken zijn:

'One-stop-shop' voor burgers en bedrijven

Een bedrijf die een project wilt uitvoeren, kan een (digitale) vergunning aanvragen bij een 'one-stop-shop'. De gemeente of provincie neemt een beslissing. In het geval beide verantwoordelijk zijn voor de beslissing, neemt een van hen de beslissing. Dit vereenvoudigt dingen voor de aanvrager.

Bedrijven moeten minder onderzoeken uitvoeren

Om een vergunning voor een ruimtelijk project te krijgen, moeten bedrijven studies uitvoeren (bijvoorbeeld een bodemonderzoek). Met Omgevingswet blijven onderzoeksgegevens langer geldig. Dit maakt het gemakkelijker om gegevens opnieuw te gebruiken. Bovendien zullen sommige onderzoeksverplichtingen worden afgeschaft en dit betekent lagere kosten.

Dergelijke voordelen zouden door MNO's worden verwelkomd. Er bestaat echter enige scepsis over het feit dat de wet de belofte van vereenvoudiging daadwerkelijk zou kunnen waarmaken. De wet laat nog steeds veel over aan gemeenten en het is de reeds beschreven, gefragmenteerde benadering van gemeenten die de grootste bron van kosten en complicaties is.

A.3.3 Facilitering van gemeenten bij knelpunten van 5G diensten

Informatie uitwisseling voor coördinatie

De mate van uitrol van infrastructuur voor 5G diensten hangt van verschillende factoren af, waaronder de kosten van aanleg. Coördinatie van werkzaamheden tussen gemeenten en operators kan tot verlaging van de aanlegkosten leiden.

Het wetsvoorstel Wet informatie-uitwisseling bovengrondse en ondergrondse netten en netwerken (Wibon) is door de 2^{e} kamer aangenomen.[82] De doelstelling is om door afstemming tussen werkzaamheden van verschillende stakeholders tot kosten besparingen en andere synergiën te komen.

Maar coördinatie tussen gemeenten en operators zou moeilijk kunnen zijn, door verschillen in planningstermijn. In het algemeen hebben gemeenten een wat langere planningshorizon dan de operators, die veelal op kortere termijn werken. Een snelle uitrol verplichting bij een volgende veiling kan ook een knelpunt zijn voor het realiseren van de beoogde synergiën.

Mogelijkheden tot hergebruik van bestaande netwerken lijken beperkt

In gemeenten zijn verschillende soorten netwerken aanwezig, die in principe kunnen bijdragen aan kostenbeperking van de uitrol van 5G netwerken.

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[82] https://www.eerstekamer.nl/wetsvoorstel/34739_wet_informatie_uitwisseling

Er bestaan netwerken voor lantaarnpalen, bewakingscamera's, verkeersregelsystemen (stoplichten, routeinformatie, pollers, parkeergaragebezetting, brug- en sluisbediening), gebruikersinformatiesystemen voor openbaar vervoer, besturing van tram & metro, elektronische advertentieborden (digital signing) en smart grid netwerken voor energie en water. Een veelheid van technieken wordt voor deze netwerken gebruikt, zo worden in sommige gemeentes de stoplichten en het straatverlichtingsnetwerk aangestuurd via het elektriciteitsnet. Ook wordt gebruik gemaakt van publieke mobiele netwerken voor aansturing.

Een deel van deze netwerken zijn in bovenstedelijke, verzelfstandigde organisaties ondergebracht, zoals de distributie netwerken voor energie (DSO) en water, of uitbesteed, zoals het openbaar vervoer, of in taak gerichte gemeentelijke afdelingen ondergebracht, zoals verkeersregelsystemen, waardoor kosten besparende of ander soortige synergiën organisatorisch lastig te bereiken zijn. Een ander deel is commercieel ingekocht bij openbare telecommunicatienetwerken. De gemeenten hebben zelfs maar zeer beperkt netwerken in handen.

Daarnaast zijn uitvoerende organisaties gericht op het goed functioneren van het specifieke netwerk wat beheerd wordt en zijn afhoudend om mobiele operators te faciliteren vanwege technische complicaties, die zouden kunnen optreden. Een voorbeeld hiervan is storing op bewakingscamera's, die op zou kunnen treden door nabijheid van mobiele communicatie antennes.

Door deze factoren is hergebruik van bestaande infrastructuur in Nederland beperkt. Bovendien zijn kabel voor dit soort systemen niet in ducts gelegd, maar direct in de grond.

Gemeentelijk pilots geven verder inzicht in knelpunten

In verschillende steden in Nederland wordt al enige tijd aan pilots gewerkt, die gericht zijn op een volgende generatie connectiviteitsdiensten.

In Eindhoven loopt het Triangulum project[83], in Den Haag Living Lab Scheveningen[84] en in Rotterdam worden lantaarnpalen gebruikt voor small cells. Deze projecten geven inzichten in toekomstige knelpunten. De opzet in Eindhoven[85] vindt in een greenfield situatie plaats, terwijl de knelpunten meer in een brownfield omgeving verwacht worden. Ervaringen in Living Lab Scheveningen geven aan dat de uiteenlopende looptijden van contracten voor verschillende diensten belemmerend werkt. In de pilots in Rotterdam komt de afwezigheid van stroom overdag in lantaarnpalen als een uitdaging naar voren.

Deze initiatieven geven inzicht in de obstakels om de stap van pilot naar grootschalige uitrol te bevorderen.

Taak gedreven ("silo") Gemeentelijke organisatie en Smart City beleid

Veel gemeenten in Nederland hebben een Smart City beleid zoals de Gemeente Amsterdam. Maar veel Smart City gemeenten hebben echter een beperkte vertaling naar de operationele

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[83] http://www.eindhoven247.nl/nl/nieuws/archief/smart-city-eindhoven-lanceert-city-beacons
[84] https://futureproofthehague.com/projects/living-lab-scheveningen
[85] http://triangulum-project.eu/

uitvoering. Dit komt deels door de complexiteit van de gemeentelijke organisaties (B&W, directie, taak gerichte operationele afdelingen etc.) en de wijze waarop een aantal taken in uitvoerende organisaties ondergebracht zijn, die op zekere afstand werken, zoals de organisaties voor verkeersregelsystemen, openbaar vervoer, etc. Hierdoor heeft elk domein een eigen dynamiek en prioriteiten. Bovendien lijken sommige gemeenten ook meer de nadruk te leggen op inkomsten, wat bijvoorbeeld blijkt uit grond- en huurprijzen, die boven het niveau van de kaderstelling schijnen te liggen. Wanneer de waarde van smart city initiatieven duidelijk wordt voor de gehele gemeentelijke organisatie, kan ook verwacht worden dat de bereidheid om mee te werken aan de uitrol van 5G netwerken ook toeneemt.

Meer in het algemeen lijken gemeenten op politiek, bestuurlijk en uitvoerend niveau nog relatief onbekend te zijn met nieuwe technologieën en de kansen voor gebruikers. Hierdoor ontbreekt de plaats van breedband infrastructuur in de diverse beleidsterreinen, waardoor op gemeentelijk niveau sub-optimalisaties ontstaan. Door deze relatieve onbekendheid zijn eventuele problemen van de uitrol lastiger onder de bestuurlijke aandacht te brengen.

A.4 Conclusies

Dit deel van het onderzoeksrapport gaat over de hedendaagse knelpunten van netwerk aanleg en verdichting, en de knelpunten op middellange termijn bij de uitrol van 5G. Uitrol van 5G zal een positieve bijdrage geven aan de digitale connectiviteit in de steden en Nederland en daarmee bijdragen aan de positie van Nederland in de digitale koplopers groep. De Nederlandse markt voor opstelpunten van masten en antennes kent nu een fragmentatie door verschillende lokale procedures en kosten, wat kosten verhogend en vertragend werkt bij een massale 5G netwerk uitrol.

De landelijke overheid kan maatregelen te nemen om deze versplintering van de markt tegen te gaan, door harmonisatie van regels en kosten, maar raakt hier de balans tussen het zetten van een landelijke kader en de lokale autonomie en afweging. Bottom-up harmonisatie door branche-/belangenverenigingen kan zinvol zijn, maar is een wat langzaam proces, voordat het resultaten geeft. Landelijke richtlijnen zijn in het verleden als te ingrijpend ervaren. Zo zijn eerdere richtlijnen, van bijv. van het VNG, door gemeenten naast zich neergelegd.

Voor operators is het nu vaak lastig om bestaande leases te verlengen en nieuwe locaties te vinden, waardoor nu een schaarste aan opstelpunten voor antennes en masten lijkt te ontstaan. Bovendien werken sommige gemeenten momenteel niet mee aan opstelpunten voor antennes en masten, of stellen aanvullende en beperkende voorwaarden vanuit het perspectief van visuele inpasbaarheid of bezorgdheid over gezondheid, die de inwoners uiten.

Vanuit de kwalitatieve vraagstelling - lokale knelpunten – worden de problemen van het heden door de operators naar de toekomst geëxtrapoleerd. Of dit een kwantitatief inzicht geeft kan ter discussie gesteld worden. Maar het ligt voor de hand dat de massaliteit van de vraag van 5G uitrolpunten tot een praktisch tekort zal leiden. Onduidelijk is dan ook hoe de (grote aantallen) opstelpunten voor 5G gevonden zullen gaan worden.

Verder kan een massale 5G uitrol de latente maatschappelijke weerstand tegen mobiele communicatie en straling oproepen en tot verdere discussies en vertragingen leiden.

Stratix

Doorlooptijden voor controversiële lokale beslissingen zouden nog langer kunnen worden door lokale politieke verhoudingen, waardoor vertragingen kunnen ontstaan en besluitvorming wordt uitgesteld. De omgevingswet geeft gemeenten verdere vrijheden, waarvan het onduidelijk is hoe deze gebruikt zullen worden. Het uitstel van de invoering van de nieuwe omgevingswet tot 2021 schuift deze onzekerheid naar achteren, waardoor het een rol kan spelen bij de aanstaande frequentie veiling. Onzekerheid heeft in het algemeen een negatieve invloed op investeringen.

Voor het ontsluiten van de 5G antennes lijkt de wettelijke gedoogplicht voor het leggen van kabels lijkt in eerste instantie voldoende ruimte te geven voor een verdere vermazing van glasvezel netwerken ten behoeve van het ontsluiten van 5G small cells. In de praktijk vragen gemeenten echter ook om graafrust, iets wat een snelle en massale ontsluiting van 5G small cells met glas, door nieuw te graven tracés, kan vertragen.

Gemeenten

Voor de gemeenten betekent netwerk verdichting en een grootschalige 5G uitrol voor een deel herhaling van eerdere processen. Netwerk verdichting en uitrol van 5G kan opnieuw om voorlichting, inspraak en het creëren van maatschappelijke draagvlak vragen. Gemeentes zullen opnieuw afwegingen moeten maken tussen de diverse belangen, van gebruikers, economisch belang, bescherming van stadsgezicht en andere publieke belangen. Voor een deel is dit herhaling, maar de massaliteit van 5G uitrol is nieuw.

Gemeentes zijn zich ook bewust van het belang van een toonaangevende communicatie infrastructuur, zoals dat in Smart City visies van sommige gemeenten uiteengezet is. De grotere operationele invulling hiervan moet nog van de grond komen en gemeenten kunnen hierbij een faciliterende rol hebben. Maar de gemeentelijke organisatie structuur in geoptimaliseerde functionele taken lijkt dit soort facilitering te beperken. Diverse pilots met nieuwe mogelijkheden bevestigen dit soort knelpunten.

Het ontwikkelen van een gemeenschappelijke visie en een daar op afgestemde implementatie lijkt beperkt te zijn door de relatieve onbekendheid met de ontwikkelingen en mogelijkheden in communicatie technologie. In het slechtste geval kunnen beslissers voor een optimalisatie op één gebied kiezen, bijv. financiën of enkel naar de burgers luisteren, maar dit kan in tot een suboptimaal geheel leiden.

Wat een financieel knelpunt kan zijn voor operators, is dat er slechts een beperkte kosten vermindering gerealiseerd kan worden, door bijv. coördinatie van publieke en digitale connectiviteitswerkzaamheden of het gebruiken van reeds bestaande netwerken.

Collectief kader

De complexere 5G netwerken bieden commerciële, financiële, organisatorische en logistieke uitdagingen voor alle stakeholders. Het vinden van oplossingen is van belang om een toonaangevende rol in de koplopers groep van digitale connectiviteit te hebben. Nederland kan een toonaangevende rol hebben door ruimte te creëren voor commerciële toepassingen en breed maatschappelijk gebruik. De Smart City pilots zijn slechts een bescheiden stap naar de volgende fase van digitale connectiviteit.

Een brede samenwerking tussen gebruikers, burgers, bedrijven, operators, lokale en landelijke overheden biedt kansen voor het gemeenschappelijk aangaan van de uitdagingen van Smart City visie, planning én uitvoering.

Annex B Results figures

This annex contains the overview figures of the model results. To improve readability, in the main report some figures show only a subset of all calculated scenarios.

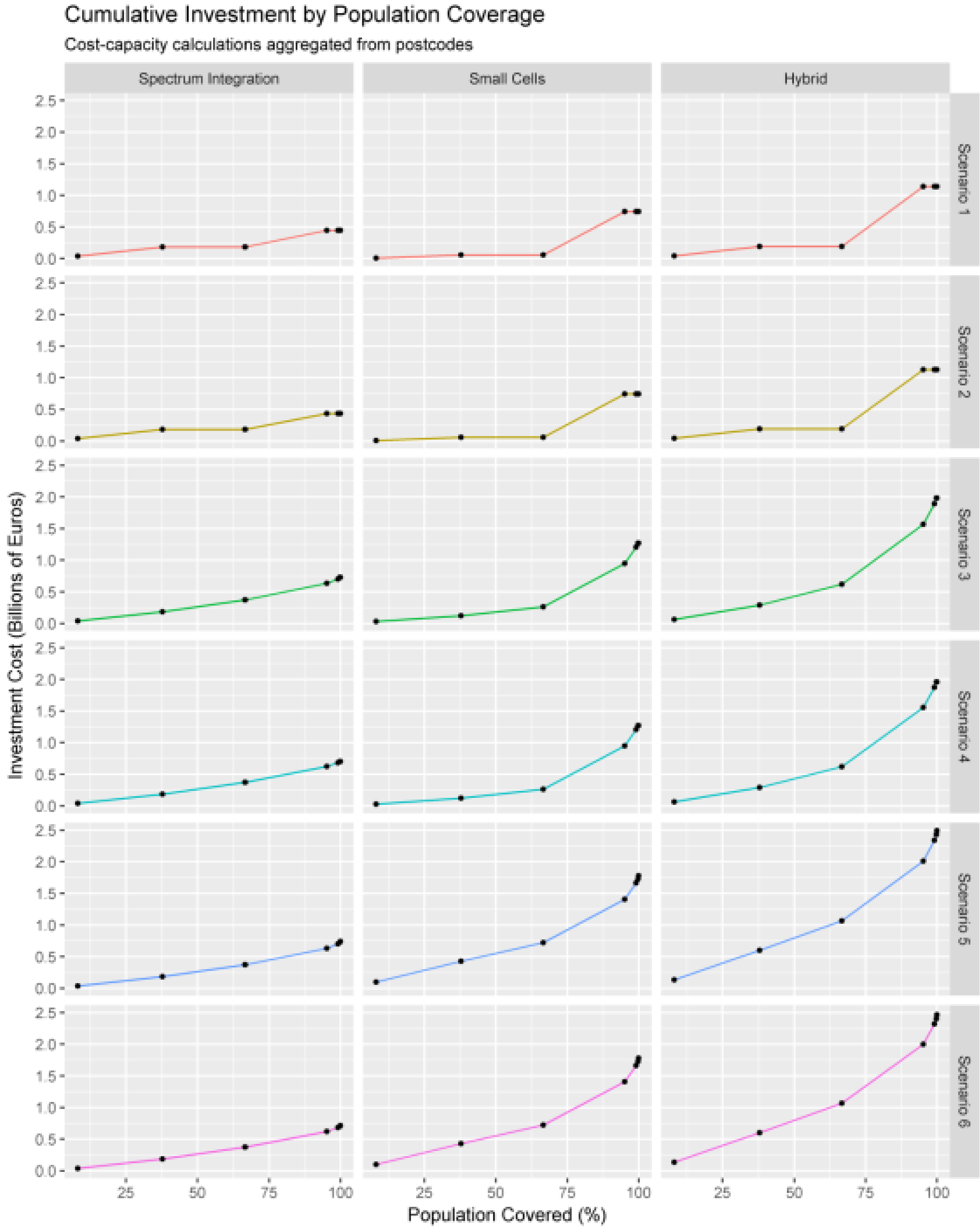
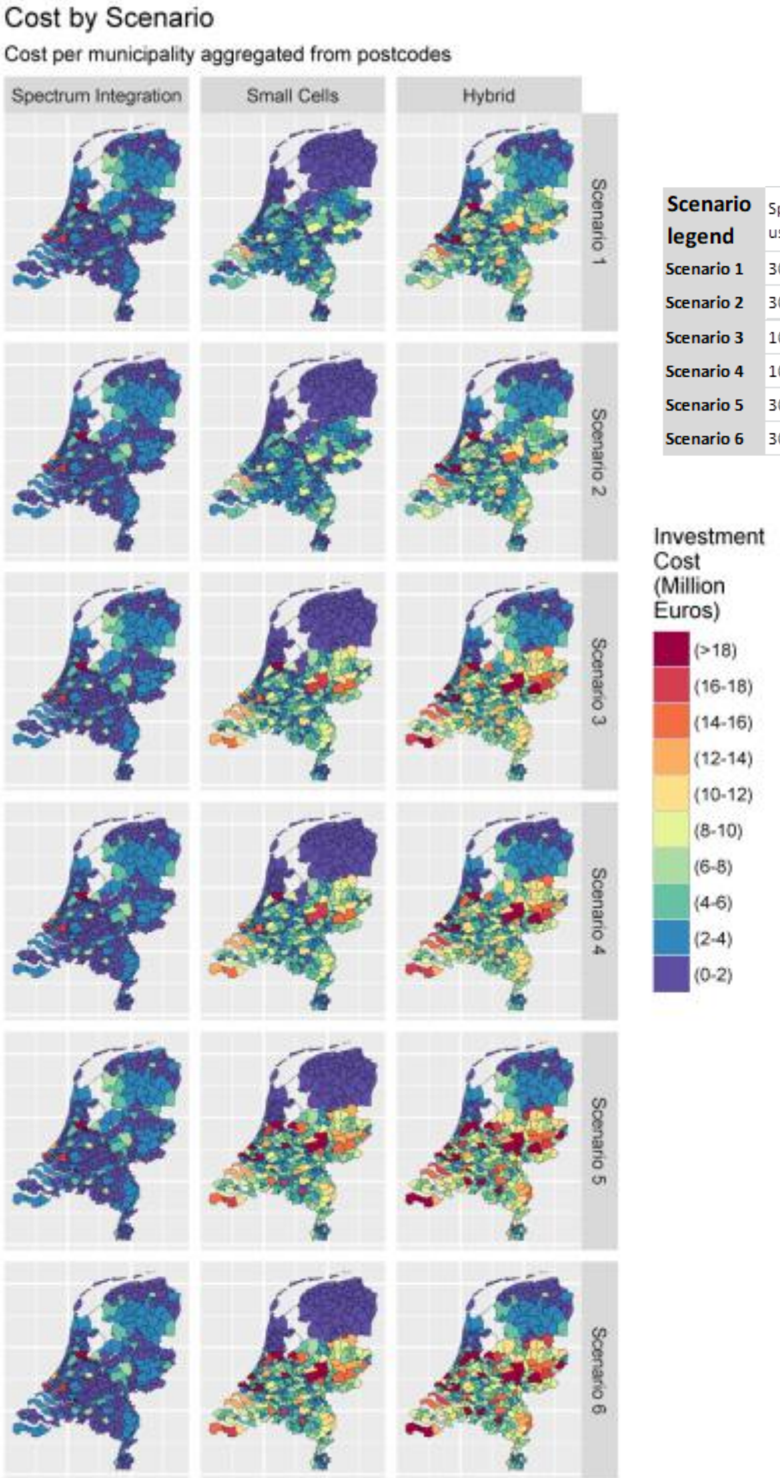


Figure 27: Cost curves by scenario and strategy

Table 19: Scenario legend for figures

Scenario legend	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Speed per user	30 Mbps	30 Mbps	100 Mbps	100 Mbps	300 Mbps	300 Mbps
Type of operator	Mobile-only	Mobile-fixed	Mobile-only	Mobile-fixed	Mobile-only	Mobile-fixed



Scenario legend	Speed per user	Type of operator
Scenario 1	30 Mbps	Mobile-only
Scenario 2	30 Mbps	Mobile-fixed
Scenario 3	100 Mbps	Mobile-only
Scenario 4	100 Mbps	Mobile-fixed
Scenario 5	300 Mbps	Mobile-only
Scenario 6	300 Mbps	Mobile-fixed

Figure 28: Geographical breakdown of cost by municipality

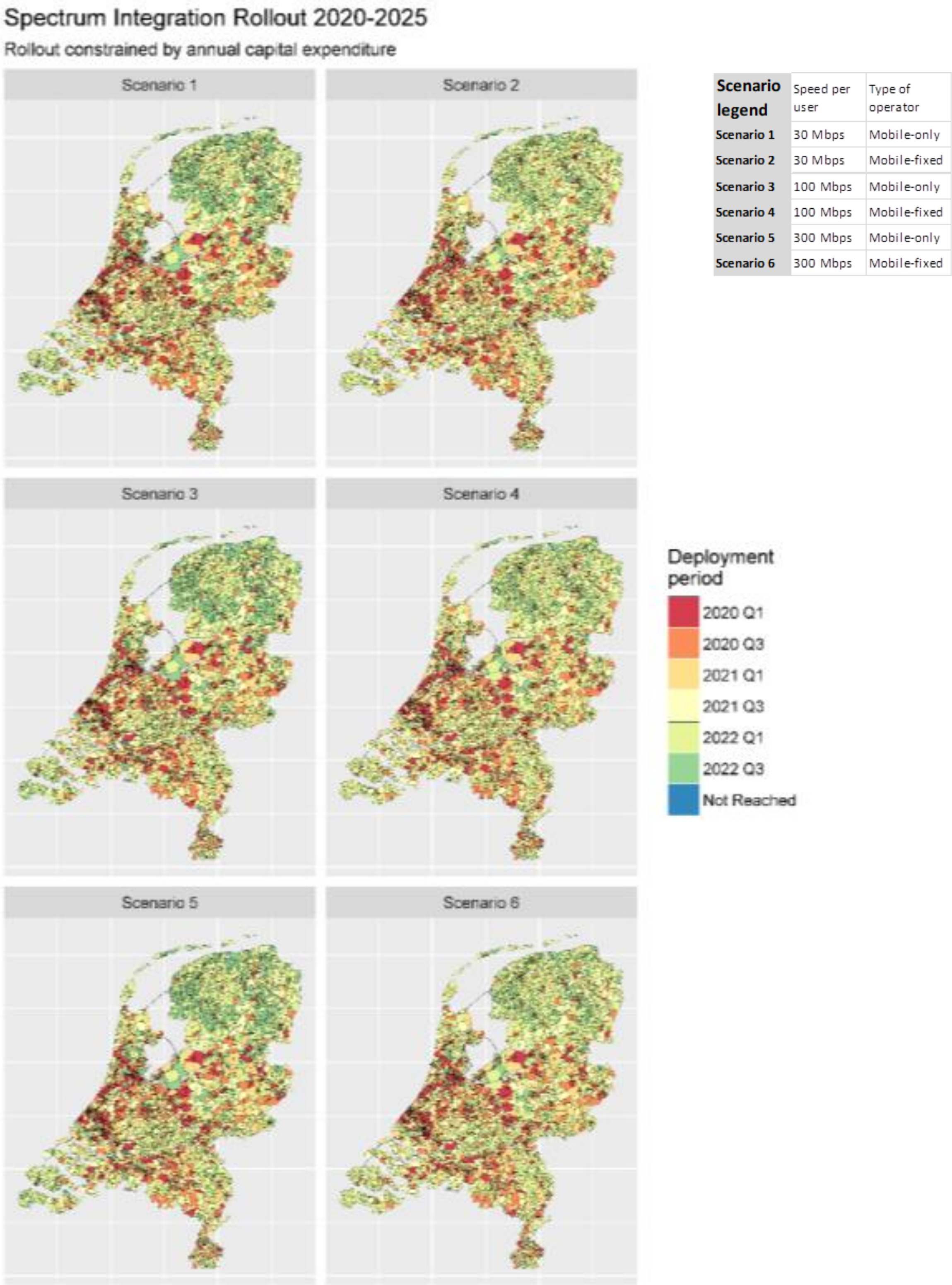
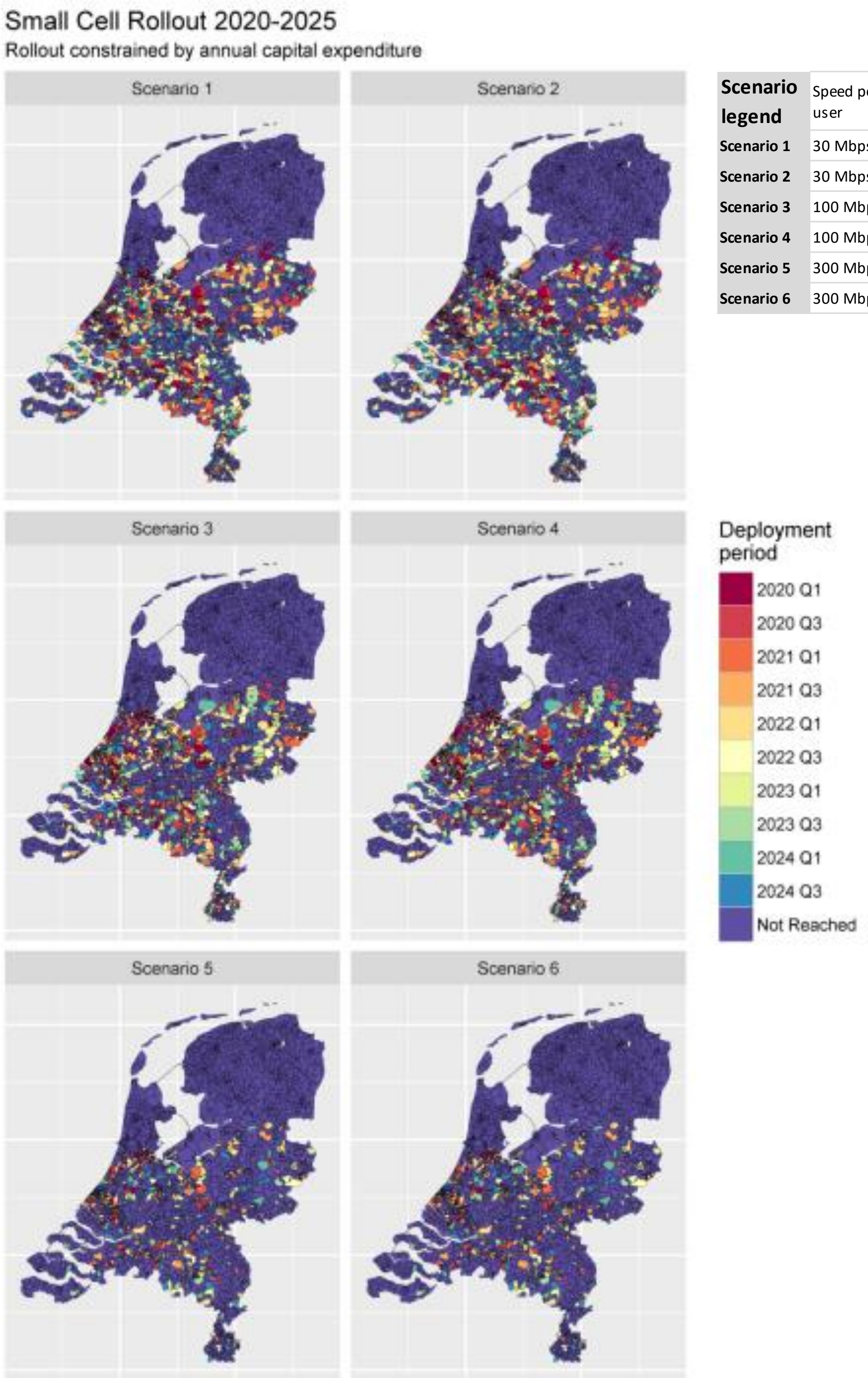
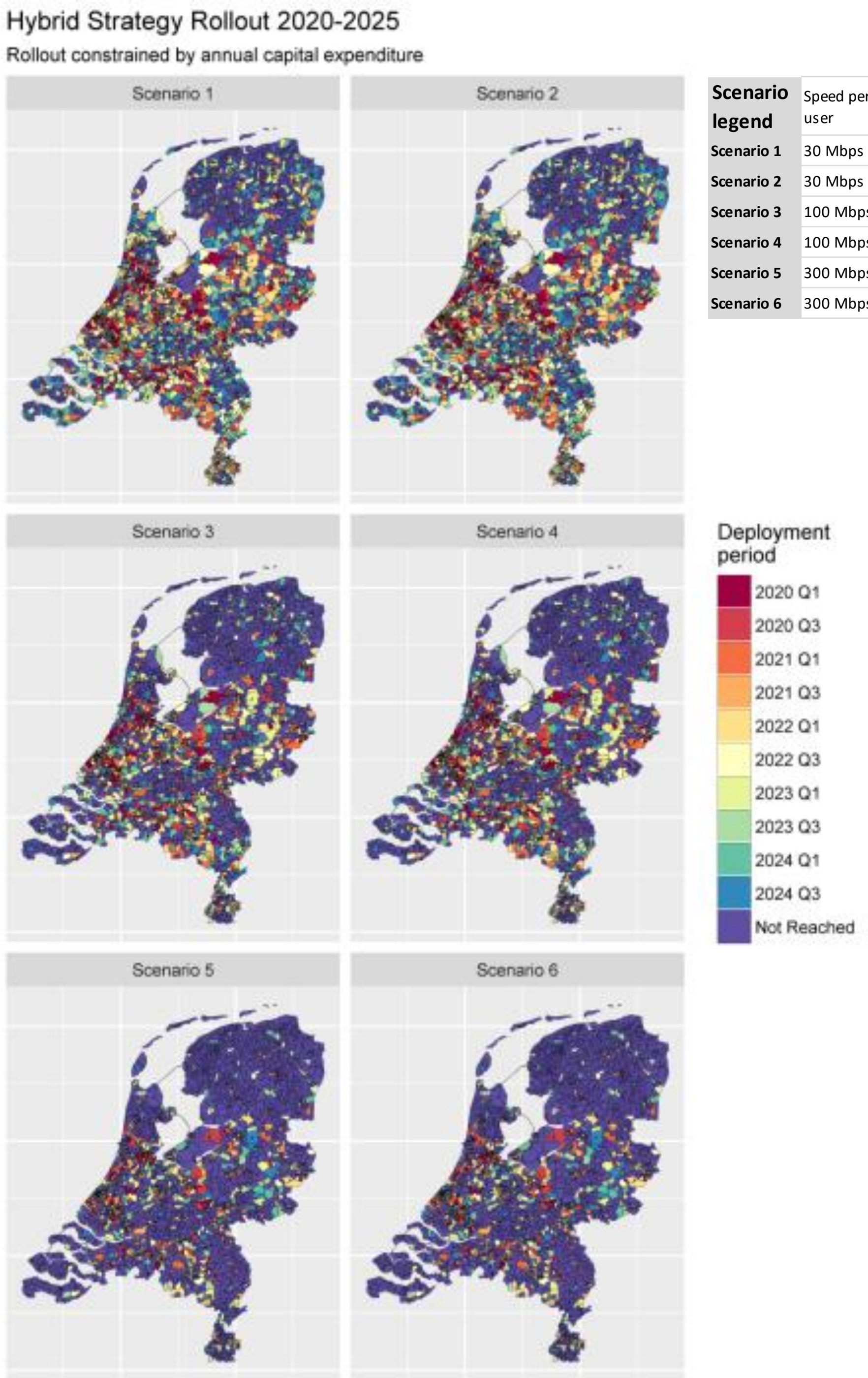


Figure 29: Simulated rollout based on constrained capital expenditure for the spectrum integration strategy showing the deployment period per region. The deployment period is determined according to the annual capex available and assuming that locations will be covered from urban to rural.



Scenario legend	Speed per user	Type of operator
Scenario 1	30 Mbps	Mobile-only
Scenario 2	30 Mbps	Mobile-fixed
Scenario 3	100 Mbps	Mobile-only
Scenario 4	100 Mbps	Mobile-fixed
Scenario 5	300 Mbps	Mobile-only
Scenario 6	300 Mbps	Mobile-fixed

Figure 30: Simulated rollout based on constrained capital expenditure for the Small cell rollout strategy showing the deployment period per region.



Scenario legend	Speed per user	Type of operator
Scenario 1	30 Mbps	Mobile-only
Scenario 2	30 Mbps	Mobile-fixed
Scenario 3	100 Mbps	Mobile-only
Scenario 4	100 Mbps	Mobile-fixed
Scenario 5	300 Mbps	Mobile-only
Scenario 6	300 Mbps	Mobile-fixed

Figure 31: Simulated rollout based on constrained capital expenditure for the hybrid rollout strategy showing the deployment period per region.

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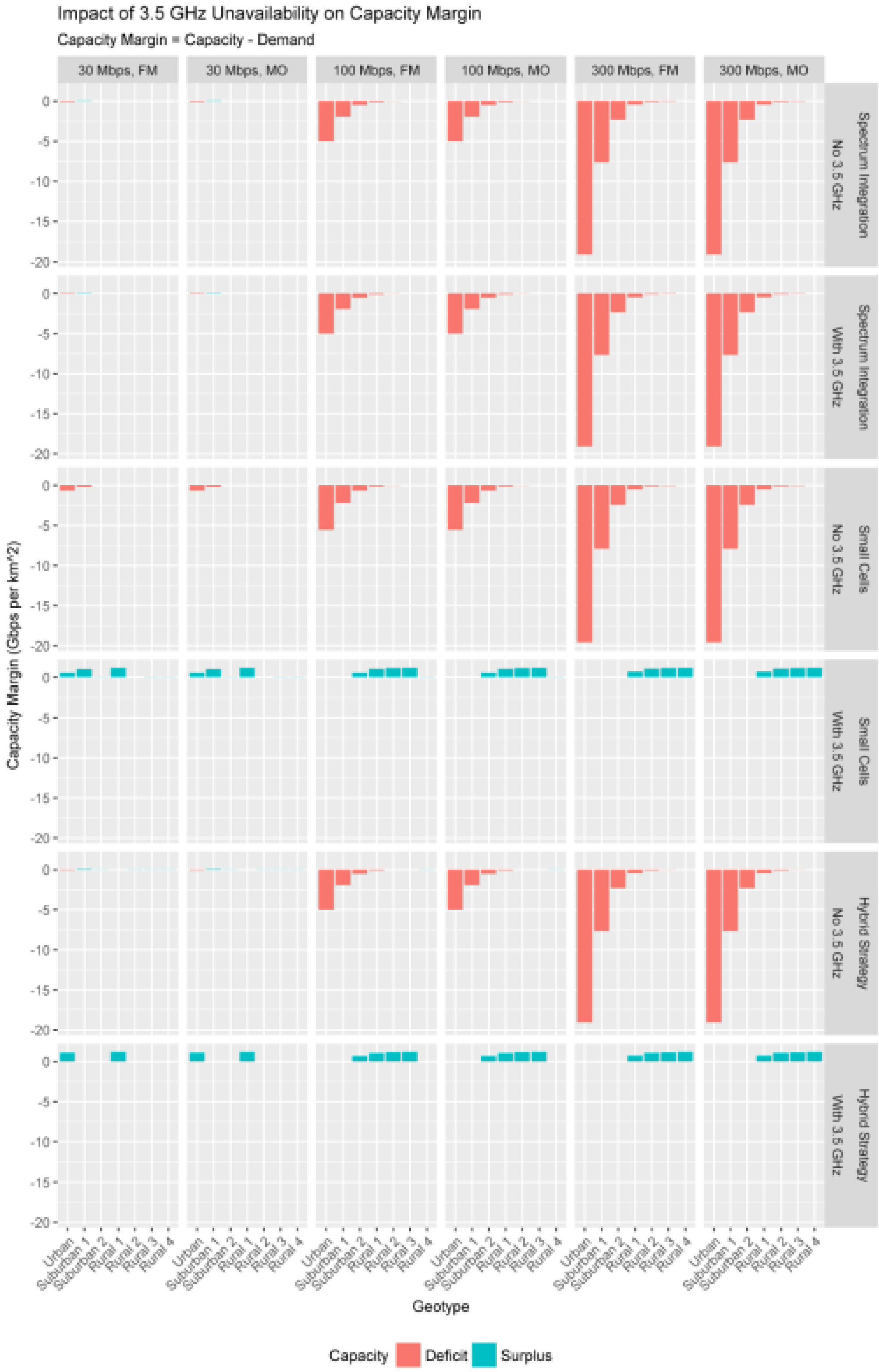

Figure 32: Impact of 3.5 GHz availability on capacity margin, for all strategies

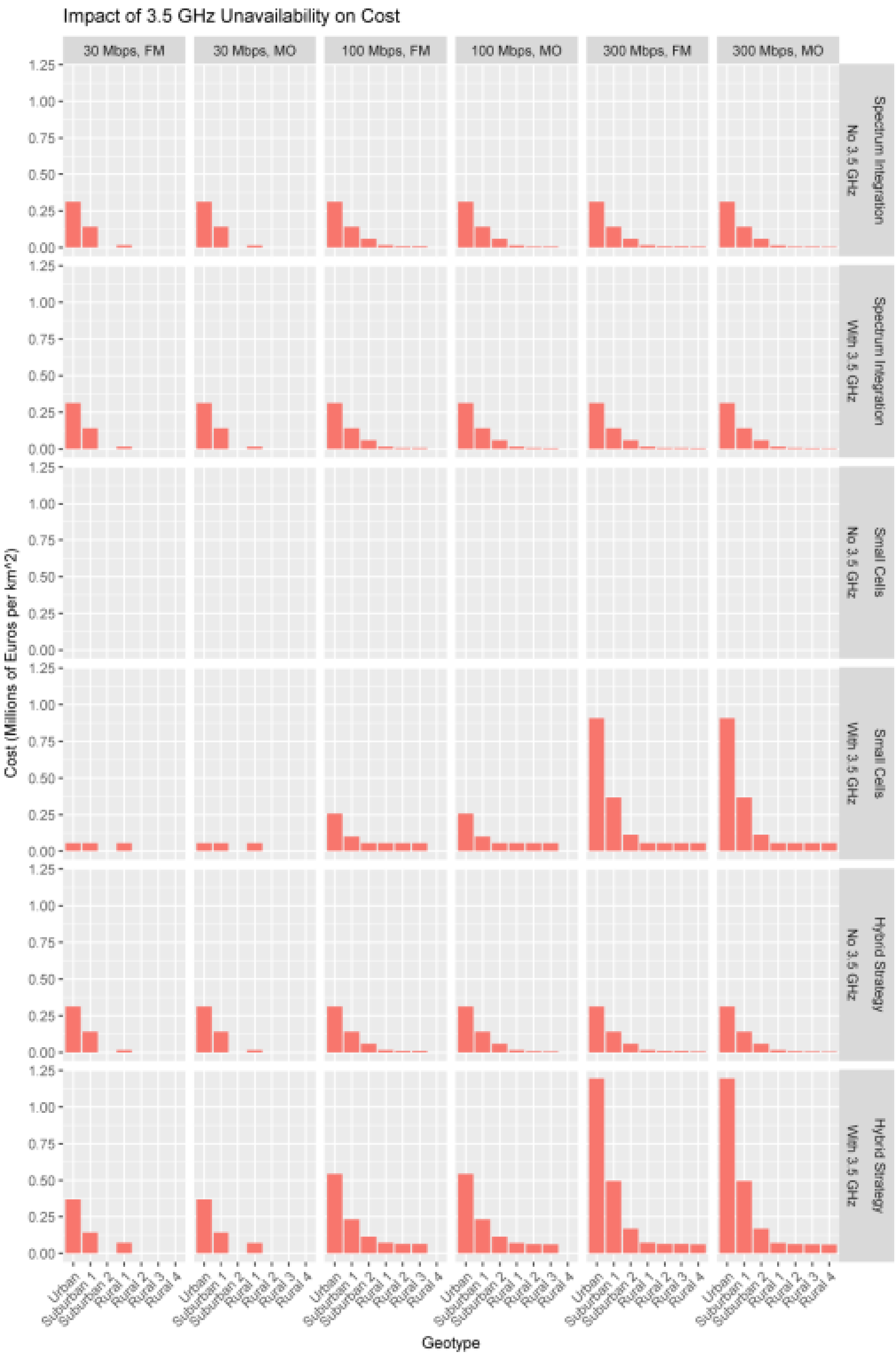

Figure 33: impact of 3.5 GHz unavailability on costs, for all strategies. Note the row "Small cells, no 3.5 GHz" is empty. This is because when 3.5 Ghz is not available, the model deploys no cells in the 'small cells' strategy, and therefore no costs are made.

Table 20: Breakdown of costs per km2 and per user

Scenario	Geotype	Strategy	Cost per user
1: 30 Mbps, Mobile-only	Urban	Spectrum integration	€ 31,44
		Small cells	€ 5,56
		Hybrid	€ 37,00
	Suburban 1	Spectrum integration	€ 37,66
		Small cells	€ 14,76
		Hybrid	€ 37,66
	Suburban 2	Spectrum integration	€ -
		Small cells	€ -
		Hybrid	€ -
	Rural 1	Spectrum integration	€ 80,59
		Small cells	€ 281,59
		Hybrid	€ 362,18
	Rural 2	Spectrum integration	€ -
		Small cells	€ -
		Hybrid	€ -
	Rural 3	Spectrum integration	€ -
		Small cells	€ -
		Hybrid	€ -
	Rural 4	Spectrum integration	€ -
		Small cells	€ -
		Hybrid	€ -
2: 30 Mbps, Mobile-fixed	Urban	Spectrum integration	€ 31,44
		Small cells	€ 5,56
		Hybrid	€ 37,00
	Suburban 1	Spectrum integration	€ 37,66
		Small cells	€ 14,76
		Hybrid	€ 37,66
	Suburban 2	Spectrum integration	€ -
		Small cells	€ -
		Hybrid	€ -
	Rural 1	Spectrum integration	€ 77,12
		Small cells	€ 281,59
		Hybrid	€ 358,71
	Rural 2	Spectrum integration	€ -
		Small cells	€ -
		Hybrid	€ -
	Rural 3	Spectrum integration	€ -
		Small cells	€ -
		Hybrid	€ -
	Rural 4	Spectrum integration	€ -
		Small cells	€ -
		Hybrid	€ -

Scenario	Geotype	Strategy	Cost per user
3: 100 Mbps, Mobile-only	Urban	Spectrum integration	€ 31,44
		Small cells	€ 25,89
		Hybrid	€ 54,78
	Suburban 1	Spectrum integration	€ 37,66
		Small cells	€ 27,10
		Hybrid	€ 61,65
	Suburban 2	Spectrum integration	€ 51,95
		Small cells	€ 48,70
		Hybrid	€ 100,65
	Rural 1	Spectrum integration	€ 80,59
		Small cells	€ 281,59
		Hybrid	€ 362,18
	Rural 2	Spectrum integration	€ 230,49
		Small cells	€ 1.565,36
		Hybrid	€ 1.795,85
	Rural 3	Spectrum integration	€ 951,29
		Small cells	€ 6.495,66
		Hybrid	€ 7.446,95
	Rural 4	Spectrum integration	€ -
		Small cells	€ -
		Hybrid	€ -
4: 100 Mbps, Mobile-fixed	Urban	Spectrum integration	€ 31,44
		Small cells	€ 25,89
		Hybrid	€ 54,78
	Suburban 1	Spectrum integration	€ 37,66
		Small cells	€ 27,10
		Hybrid	€ 61,65
	Suburban 2	Spectrum integration	€ 51,95
		Small cells	€ 48,70
		Hybrid	€ 100,65
	Rural 1	Spectrum integration	€ 77,12
		Small cells	€ 281,59
		Hybrid	€ 358,71
	Rural 2	Spectrum integration	€ 203,08
		Small cells	€ 1.565,36
		Hybrid	€ 1.768,44
	Rural 3	Spectrum integration	€ 749,07
		Small cells	€ 6.495,66
		Hybrid	€ 7.244,73
	Rural 4	Spectrum integration	€ -
		Small cells	€ -
		Hybrid	€ -

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Scenario	Geotype	Strategy	Cost per user
5: 300 Mbps, Mobile-only	Urban	Spectrum integration	€ 31,44
		Small cells	€ 91,45
		Hybrid	€ 120,34
	Suburban 1	Spectrum integration	€ 37,66
		Small cells	€ 97,93
		Hybrid	€ 132,48
	Suburban 2	Spectrum integration	€ 51,95
		Small cells	€ 100,00
		Hybrid	€ 147,66
	Rural 1	Spectrum integration	€ 80,59
		Small cells	€ 281,59
		Hybrid	€ 362,18
	Rural 2	Spectrum integration	€ 230,49
		Small cells	€ 1.565,36
		Hybrid	€ 1.795,85
	Rural 3	Spectrum integration	€ 951,29
		Small cells	€ 6.495,66
		Hybrid	€ 7.446,95
	Rural 4	Spectrum integration	€ 5.304,74
		Small cells	€ 45.858,80
		Hybrid	€ 51.163,54
6: 300 Mbps, Mobile-fixed	Urban	Spectrum integration	€ 31,44
		Small cells	€ 91,45
		Hybrid	€ 120,34
	Suburban 1	Spectrum integration	€ 37,66
		Small cells	€ 97,93
		Hybrid	€ 132,48
	Suburban 2	Spectrum integration	€ 51,95
		Small cells	€ 100,00
		Hybrid	€ 147,66
	Rural 1	Spectrum integration	€ 77,12
		Small cells	€ 281,59
		Hybrid	€ 358,71
	Rural 2	Spectrum integration	€ 203,08
		Small cells	€ 1.565,36
		Hybrid	€ 1.768,44
	Rural 3	Spectrum integration	€ 749,07
		Small cells	€ 6.495,66
		Hybrid	€ 7.244,73
	Rural 4	Spectrum integration	€ 3.966,28
		Small cells	€ 45.858,80
		Hybrid	€ 49.825,09

Annex C Mobile spectrum allocation overviews

Table 21: Overview of frequency bands per network operator (source Agentschap Telecom)

800 MHz

Provider	Bandwidth	Downlink Frequency	Uplink Frequency
KPN	2 x 10 MHz	811 - 821 MHz	852 - 862 MHz
Tele2	2 x 10 MHz	791 - 801 MHz	832 - 842 MHz
Vodafone	2 x 10 MHz	801 - 811 MHz	842 - 852 MHz

900 MHz

Provider	Bandwidth	Downlink Frequency	Uplink Frequency
KPN	2 x 10 MHz	935 - 945 MHz	890 - 900 MHz
T-Mobile	2 x 15 MHz	945 - 960 MHz	900 - 915 MHz
Vodafone	2 x 10 MHz	925 - 935 MHz	880 - 890 MHz

1800 MHz

Provider	Bandwidth	Downlink Frequency	Uplink Frequency
KPN	2 x 20 MHz	1805 - 1825 MHz	1710 - 1730 MHz
T-Mobile	2 x 30 MHz	1845 - 1875 MHz	1750 - 1780 MHz
Vodafone	2 x 20 MHz	1825 - 1845 MHz	1730 - 1750 MHz

2100 MHz

Provider	Bandwidth	Downlink Frequency	Uplink Frequency
KPN	2 x 20 MHz	2125-2140 and 2150-2155 MHz	1935-1950 and 1960-1965 MHz
T-Mobile	2 x 20 MHz	2140-2150 and 2160-2170 MHz	1950-1960 and 1970-1980 MHz
Vodafone	2 x 20 MHz	2110-2125 and 2155-2160 MHz	1920-1935 and 1965-1970 MHz

The 2100 GHz TDD frequency licenses expired at the end of 2016.

2600 MHz[86]

Provider	Bandwidth	Downlink Frequency	Uplink Frequency
KPN	2 x 10 MHz	2655 - 2665 MHz	2535 - 2545 MHz
T-Mobile	2 x 5 MHz	2650 - 2655 MHz	2530 - 2535 MHz
Tele2	2 x 20 MHz	2665 - 2685 MHz	2545 - 2565 MHz
Vodafone	2 x 10 MHz	2620 - 2630 MHz	2500 - 2510 MHz
Ziggo (ZUM)	2 x 20 MHz	2630 - 2650 MHz	2510 - 2530 MHz

2600 MHz (TDD)

Provider	Bandwidth	Frequency
KPN	1 x 30 MHz	2590 - 2620 MHz
T-Mobile	1 x 25 MHz	2565 - 2590 MHz
Tele2	1 x 5 MHz	2685 - 2690 MHz

[86] Note that Ziggo, ZUM and Vodafone now are part of one merged company.

Annex D Participants Workshop 5G future wireless network

The table below gives an overview of organisations participating in the workshop on Monday November 13th in Den Haag

Naam	*Organisatie*
Bart Heinink	Tele2
Ed Boerema	Alticom / Cellnex
Edward Oughton	Cambridge University
Ellen Koopmans	Colt
Fred Herrebout	T-Mobile
Han van Bussel	T-Mobile
Hind Abdulaziz	Stratix
Jaap Hulshoff	VolkerWessels Telecom
Kees Mulder	Ascolo / Stratix
Maarten van Waveren	Ministerie van EZK
Martin Vos	Eurofiber
Peter Jan Kamst	VolkerWessels Telecom
Raymond Bouwman	Rabion Consultancy BV / Stratix
Rosalie Weijers	Relined / Novec
Rudolf van der Berg	Stratix
Ruud Koeyvoets	VodafoneZiggo
Sietse van der Gaast	Stratix
Walter Kroeze	VodafoneZiggo
Zoraida Frias	UPM

Annex E Gesprekspartners regelgevingsanalyse (vertrouwelijk)

Gemeentes: Amsterdam, Rotterdam, Den Haag

Bedrijven: BMCC Consultancy, Caiway, Colt, Eurofiber, KPN, Novec, T-Mobile, Volker Wessel Telecom

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