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Technical feasibility study on coexistence of private IMT networks and satellite ground stations in the 3800-4200 MHz band and interference study on radar altimeters in the 4200-4400 MHz band

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Samenvatting

Achtergrond

Het ministerie van Economische Zaken en Klimaat (EZK) is bezig met het herinrichten van de frequentieband 3400-3800 MHz, zodat vanaf 1 september 2022 het middelste deel van deze band (300 MHz van 3450-3750 MHz) in gebruik kan worden genomen voor landelijke mobiele 5G netwerken.

De bestaande vergunningen voor lokale netwerken in de 3400-3800 MHz band zullen zoveel mogelijk worden ondergebracht in de 2x50 MHz aan de onder- en bovenzijde van de band (3400-3450 MHz en 3750-3800 MHz). Deze 2x50 MHz zal beschikbaar blijven voor lokaal/bedrijfsspecifiek gebruik. Het kabinet heeft daarnaast de wens om meer frequentieruimte beschikbaar te maken voor lokale besloten netwerken voor bedrijfsspecifieke toepassingen. De verwachting is namelijk dat veel meer bedrijven dan nu mobiele communicatie zullen gaan integreren in hun productieprocessen en daarvoor deels een eigen besloten netwerk zullen willen inzetten.

Een mogelijkheid voor aanvullende frequentieruimte is de aangrenzende 3800-4200 MHz band, aangezien 5G-technologie ook bruikbaar is in deze band. In deze band is er bestaand gebruik door satellietgrondstations van commerciële aanbieders en van het ministerie van Defensie. Daarnaast beschikt Defensie over een satellietinterceptiefaciliteit in Burum. Satellietgrondstations maken momenteel gebruik van de C-band (3400-4200 MHz) voor ontvangst van radiocommunicatie vanaf een satelliet (satelliet-aarde). Vanaf 1 september 2022 is dit gebruik door satellietgrondstations in Nederland niet meer beschermd in het onderste deel van de C-band, maar blijft ontvangst wel beschermd in het bovenste deel van de C-band, van 3800 tot 4200 MHz. Dit gebruik wil EZK niet verstoren. Verder dient rekening te worden gehouden met bestaand gebruik in de aanpalende frequentieband 4200-4400 MHz.

Onderzoeksvragen

De hoofdvraag van het onderzoek is binnen welke kaders, naast het bestaande gebruik, in de toekomst regionaal en lokaal frequentiegebruik mogelijk gemaakt kan worden in de 3800 – 4200 MHz band. De onderliggende deelvragen zijn:

- 1) Onder welke (technische) voorwaarden kunnen de frequenties in het bereik 3800-4200 MHz beschikbaar worden gesteld voor lokaal/bedrijfsspecifiek gebruik (private mobiele netwerken) onder de voorwaarde dat het huidige gebruik van commerciële satellietgrondstations in Nederland en daarnaast het gebruik door Defensie (satellietcommunicatie en SIGINT) gewaarborgd blijft?
- 2) Wat zijn de verwachtingen voor de toekomstige (wijze van) benutting van de 3800-4200 MHz band door satellietgrondstations en wat betekent dat voor de beschikbaarheid van de frequentieband voor (toekomstige) satellietgrondstations en het gebruik door lokale/regionale netwerken?

- 3) Welke (technische) voorwaarden moeten er worden gesteld aan het gebruik van de frequenties in de frequentieband 3800-4200 MHz voor lokaal/bedrijfsspecifiek gebruik (private mobiele netwerken) om te waarborgen dat er geen interferentie optreedt op het gebruik van radarhoogtemeters en radionavigatie in het frequentiegebruik boven de 4200 MHz?

Aanpak

TNO heeft het huidige en toekomstige gebruik in de band 3800-4200 MHz in kaart gebracht door middel van een vragenlijst en interviews met de huidige vergunninghouders voor vaste satellietgrondstations: Speedcast (Biddinghuizen), Signalthorn (Amsterdam/Amstelveen), Inmarsat (Batum), Castor Networks (Batum) en Defensie (Zoutkamp).

Op basis van de informatie is een co-existentieanalyse uitgevoerd om antwoord te geven op bovenstaande deelvragen 1 en 2. Het beleid ten aanzien van eventueel toe te laten typen lokale netwerken tot deze band is nog in een verkennende fase. In deze studie kijken we naar lokale gesloten netwerken (binnen en buiten), opgebouwd uit één of enkele basisstations op basis van IMT-technologie, met een EIRP tussen 25 en 43 dBm / 5 MHz en een bandbreedte tussen 10 en 100 MHz.

Om antwoord te geven op deelvraag 3 is een verkennende studie uitgevoerd naar mogelijke interferentie van een IMT basisstation op radar hoogtemeters.

Huidige gebruik 3800-4200 MHz band

In het Nationale Frequentie Plan (NFP 2014, laatste update 20-10-2020) is de 3800-4200 MHz band gereserveerd voor i) vaste verbindingen en voor ii) vaste satellietverbindingen (ruimte naar aarde).

Voor vaste verbindingen is vergunningverlening door Agentschap Telecom (AT) noodzakelijk. Er zijn momenteel echter geen actieve vergunningen voor gebruik door vaste verbindingen in deze band.

Vaste satellietgrondstations maken voor verbindingen van aarde naar ruimte gebruik van zendvergunningen in de band 5850-6425 MHz. Voor vaste satellietverbindingen is vergunningverlening in de 3800-4200 MHz band niet van toepassing, aangezien het ontvangst van radiocommunicatie vanaf geostationaire satellieten betreft (van ruimte naar aarde). De huidige zendvergunningen zoals verleend door Agentschap Telecom voor vaste satellietgrondstations zijn gebruikt om vast te stellen wat het huidige frequentiegebruik is voor verbindingen van satelliet naar grondstation in de 3800-4200 MHz band.

Huidig en toekomstig gebruik door satellietgrondstations

De huidige vergunninghouders zijn Speedcast (Biddinghuizen), Signalthorn (Amsterdam / Amstelveen) , Inmarsat (Batum), Castor Networks (Batum) en het Ministerie van Defensie (Zoutkamp).

Huidige locaties satellietgrondstations

De satellietgrondstations bevinden zich op vier locaties in Nederland: Batum, Zoutkamp, Biddinghuizen en Amsterdam/Amstelveen. De satellietgrondstations worden beheerd door vier commerciële bedrijven en door Defensie. In Batum is ook

een satellietinterceptiefaciliteit van Defensie gevestigd. Momenteel zijn 15 vergunningen voor satellietgrondstations uitgegeven met einddata tot december 2025. Bij Agentschap Telecom zijn er geen lopende aanvragen voor vergunningen op andere locaties.

Frequenties en bandbreedte van satellietgrondstations

De frequenties in de 3800-4200 MHz-band worden gebruikt voor het ontvangen van radiotransmissie van satellieten (ruimte naar aarde). Vergunningen voor satellietgrondterminal zijn verleend om te zenden (aarde-satelliet) in de band 5850-6425 MHz en zijn gekoppeld aan ontvangst in de band 3800-4200 MHz.

De satellietgrondstations zijn geschikt voor ontvangst in de gehele 3800-4200 MHz-band en maken hier ook gebruik van. De bandbreedte per satellietgrondstation varieert van minder dan 5 MHz tot 120-160 MHz. De totale (deels overlappende) bandbreedte die wordt gebruikt in de 3800-4200 MHz ligt tussen 350 en 400 MHz (januari 2021, zie hoofdstuk 2 voor de details per satellietgrondstation).

Toekomstig gebruik door satellietgrondstations

De bestaande vergunningen (15) kennen een einddatum tussen september 2021 en december 2025. Alle huidige gebruikers verwachten hun bestaande vergunningen te verlengen na deze einddatum. Twee vergunninghouders verwachten hun beperkte frequentiegebruik (<5 MHz) niet uit te breiden. Twee vergunninghouders willen de volledige 3800-4200 MHz-band kunnen gebruiken voor toekomstige zakelijke klanten en organisaties. Bovendien is flexibiliteit in gebruik van alle zichtbare geostationaire satellieten - nu en in de toekomst - gewenst bij een deel van de vergunninghouders. Voor enkele vergunninghouders waaronder Speedcast in Biddinghuizen is sprake van (zeer) dynamisch spectrumgebruik, wat ook in de toekomst zo zal blijven. .

Voor Defensie zal, afhankelijk van toekomstige missiegebieden en de omvang van de te ondersteunen missies, de werkelijk benodigde satellietcapaciteit variëren. Afhankelijk van de missiegebieden, de vereiste satellietcapaciteit versus de beschikbare satellietcapaciteit en de bijbehorende kosten, is flexibiliteit noodzakelijk om ook in de toekomst meerdere satellieten te gebruiken.

Co-existentie analyse IMT-netwerken en satellietgrondstations

Op basis van de verkregen informatie over het huidige en toekomstige spectrumgebruik van satellietgrondstations en de technische parameters van antenneschotels, is een co-existentie analyse uitgevoerd voor de introductie van lokale private IMT-netwerken op basis van 5G-technologie.

Hierbij zijn de mogelijkheden van co-existentie op basis van *co-channel* gebruik (beide in dezelfde frequentie sub-band) en *adjacent channel* (gebruik in aangrenzende sub-banden) geanalyseerd.

Technische voorwaarden co-existentie

Ieder IMT-basisstation dat in een sub-band binnen de 3800-4200 MHz-band werkt, moet tegelijkertijd voldoen aan de co-existentiecriteria van alle satellietgrondstations in Nederland. Dit betekent dat het IMT-basisstation niet kan worden ingezet:

- Binnen de uitsluitingszones van de satellietgrondterminals die in dezelfde subband werken (co-channel gebruik), noch

- Binnen de uitsluitingszones van de satellietgrondterminals die niet in dezelfde sub-banden werken (adjacent channel gebruik).

Bij co-channel gebruik is het mogelijk om de volledige frequentieband van 3800-4200 MHz te gebruiken voor IMT-netwerken. Het gebied waarin de IMT-netwerken kunnen worden ingezet, wordt in dit geval echter sterk beperkt door de uitsluitingszones die zeer groot zijn en zich kunnen uitstrekken tot delen van België en Duitsland. Deze zones kunnen echter wel aanzienlijk worden verkleind door mitigerende maatregelen te nemen (zoals lagere zendvermogens voor IMT-basisstations en/of minder strikte interferentiecriteriën voor satellietgrondstations).

Bij *adjacent channel* gebruik kunnen IMT-netwerken worden ingezet in het grootste deel van Nederland, omdat in dit geval de uitsluitingszones veel kleiner zijn dan bij co-channel gebruik. Het aantal subband(en) met voldoende bandbreedte voor breedbandtoepassingen (van 50 tot 100 MHz) die gedurende een voldoende lange periode beschikbaar zijn voor IMT, is dan echter (zeer) beperkt of niet aanwezig.

Inmarsat en Signalthorn gebruiken slechts een klein deel van de 3800-4200 MHz-band wat in de nabije toekomst nauwelijks zal veranderen. Defensie gebruikt ook een relatief klein deel van de 3800-4200 MHz-band, maar dit kan veranderen afhankelijk van de missies die ondersteund moeten worden.

Adjacent channel gebruik is voor deze gevallen mogelijk met gebruikmaking van bv. een *Shared Access model* dat rekening houdt met het meer dynamische gebruik van de 3800-4200 MHz-band door Defensie.

Het frequentiegebruik door Speedcast en Castor Networks beperkt echter het gedeelde gebruik door IMT van de 3800-4200 MHz-band, aangezien ze een groot deel (zo niet het meeste) van deze band momenteel al gebruiken. Adjacent channel gebruik biedt in deze gevallen weinig mogelijkheden en co-channel gebruik is waarschijnlijk de enige optie. Om bij co-channel gebruik een redelijk groot inzetgebied voor IMT te verkrijgen is, zoals hierboven aangegeven, een substantiële mitigatie-inspanning nodig om de uitsluitingszones van de satellietgrondterminals van Speedcast en Castor Networks te verminderen.

Voor toekomstige lokale IMT-netwerken is het in het algemeen moeilijk te bepalen of een substantiële mitigatie-inspanning in alle situaties gemakkelijk kan worden gerealiseerd en of de impact van de hiervoor vereiste mitigerende maatregelen op de toepassing / dienst (in termen van bijvoorbeeld dekking) al dan niet aanvaardbaar is. Om vergunningen te kunnen verlenen voor toekomstige lokale IMT-netwerken zal dit nader moeten worden onderzocht.

In het Verenigd Koninkrijk (VK) wordt momenteel al gebruik gemaakt van co-existent in de 3800-4200 MHz band op basis van co-channel gebruik. Hierbij bieden men de gevestigde gebruikers van satellietgrondterminals bescherming op basis van dezelfde principes als gebruikt in dit rapport. In vergelijking met Nederland zijn de mogelijkheden om de frequentieband te delen in bepaalde regio's van het VK beter doordat i) de satellietterminals zich hoofdzakelijk in het zuiden van het VK bevinden, ii) het VK een grotere omvang heeft en iii) het meer golvende terrein in het VK dat meer afscherming biedt in vergelijking met het 'vlakke' terrein in Nederland.

Interferentie radiohoogtemeters in de 4200-4400 MHz-band

De band 4200 - 4400 MHz wordt vrijwel uitsluitend gebruikt voor radar (radio) hoogtemeters. Hoogtemeters worden in de landingsfase door luchtvaartuigen gebruikt om de afstand tot de grond te bepalen. Het gebruik van deze band door grondapparatuur is uitgesloten, behalve voor transponders ten behoeve van hoogtemeters in de lucht (indien nodig).

De interferentie van een enkel IMT-basisstation in de 3800-4200 MHz band op radarhoogtemeters in de 4200-4400 MHz-band is bestudeerd. De ITU M.2059 aanbeveling is gebruikt als belangrijkste referentiebron. Hierin zijn technische parameters opgenomen van een set van 10 referentiehoogtemeters en deze zijn gebruikt om de veilige afstand op grondniveau te berekenen ten opzichte van een IMT-basisstation met een EIRP van 43 dBm / 5 MHz. Hogere vermogensniveaus, zoals toegestaan door de IMT-norm, zullen resulteren in hogere interferentierisico's.

De conclusies van de studie van de hoogtemeterinterferentie zijn:

1. De veilige afstanden voor de 10 referentiehoogtemeters in een vliegtuig op 150 m (minimale vlieghoogte) variëren tussen 0 en 500 m.
2. Op luchthavens en tot 3 km voor start- en landingsbanen waar de hoogte van vliegtuigen lager is dan 150 m, is een veilige afstand tussen 80 en 590 m berekend.
3. Als het uitgangsvermogen van het basisstation beperkt is tot 28,7 dBm, is het luchtruim storingsvrij voor alle referentiehoogtemeters op een hoogte van 150 m en hoger.
4. De aanbeveling ITU M.2059 lijkt te conservatief: berekeningen conform deze richtlijn voorspellen ook storing door interferentie vanuit lagere frequentiebanden onder de 3800 MHz, terwijl dit in de praktijk niet blijkt (zie bijlage A, sectie 6). Dit kan betekenen dat veilige afstanden in de praktijk lager uitvallen dan de hier berekende waarden. Het wordt aanbevolen om deel te nemen aan een voorgestelde CEPT ECC PT1-studie en te pleiten voor het bestuderen van interferentie vanuit IMT-netwerken in zowel 3400-3800 MHz als 3800-4200 MHz en om de gevoeligheid van realistische hoogtemeters te bestuderen.

Summary

Background

The Ministry of Economic Affairs and Climate Policy has recently re-allocated the 3400-3800 MHz frequency band so that from September 1, 2022 the middle part of this band (3450-3750 MHz) can be used by public mobile 5G networks. The existing licenses for local, company-specific networks in this band will be accommodated as much as possible in the 2x50 MHz at the bottom and top of the band (i.e. 3400-3450 MHz and 3750-3800 MHz). This 2x50 MHz is intended to support local IMT (including 5G) networks. After September 1, 2022 satellite ground stations in the band 3600-3800 MHz are no longer protected and they have to move to the 3800-4200 MHz band.

The Ministry also wishes to make additional frequency spectrum available for private IMT networks for company-specific applications. The expectation is that – with 5G technology - many more companies will integrate mobile communication solutions into their production processes and want to use their ‘own’ spectrum for this, to be fully independent of mobile network operators. One possibility for additional frequency space is the adjacent 3800-4200 MHz band. Countries such as the United Kingdom and Belgium have already decided to make this frequency band available for company-specific applications. This band is currently used for fixed satellite earth stations (space-to-earth) and this existing use should be protected.

Scope of coexistence study

The main research question of this study is under which (technical) conditions - in addition to existing use - regional and local frequency use (coexistence) for private IMT networks in the 3800 - 4200 MHz band can be made possible in the future, i.e.

- 1) Under what (technical) conditions can the frequencies in the range 3800-4200 MHz be made available for local company-specific use (private IMT networks based on IMT technology) on the condition that the current use of commercial satellite earth stations in the Netherlands and the use by the Ministry of Defense (satellite communication and satellite interception) is guaranteed?
- 2) What are the expectations for the future utilization of the 3800-4200 MHz band by satellite earth stations and what does this mean for the availability of the frequency band for (future) satellite earth stations and for use by local private IMT networks?
- 3) What (technical) conditions must be imposed on the use of the frequencies in the frequency band 3800-4200 MHz to ensure that no interference occurs on the use of radar altimeters and radio navigation in the frequency use above 4200 MHz?

The policy with regard to possible types of local IMT networks to be admitted into the 3800-4200 MHz band is still in an exploratory phase. In this study, we consider compact broadband networks (indoor and outdoor), built up from a few base

stations based on IMT technology, with an EIRP ranging between 25 and 43 dBm / 5 MHz and channel bandwidth between 10 and 100 MHz.

Current and future by satellite ground stations

TNO has mapped the current use by fixed satellite earth stations in the 3800-4200 MHz of the current holders of licenses - as registered by Agentschap Telecom in January 2021 - for fixed satellite earth stations: Speedcast (Biddinghuizen), Signalforn (Amsterdam / Amstelveen), Inmarsat (Batum), Castor Networks (Batum), Ministry of Defense (Zoutkamp).

In the National Frequency Plan, the 3800-4200 MHz band is also assigned for licenses for Fixed Service (FS - A radiocommunication service between specified fixed points), but as of today there are no license holders for Fixed Service.

Current locations satellite ground stations

Currently, satellite ground stations for C-band operations are located around 4 locations in the Netherlands: Batum, Zoutkamp, Biddinghuizen en Amsterdam. The facilities are operated by 4 commercial companies and by MOD-NL. In Batum, also a satcom interception facility of the MOD-NL is located. 15 licenses for satellite ground stations are used today. No license requests for other locations were received by Agentschap Telecom.

Frequencies and bandwidths used by satellite ground stations

The frequencies in the 3800-4200 MHz band are used for receiving radio transmission from satellites (space to earth). The use of satellite ground terminals is related to licenses to transmit (earth-satellite) in the corresponding band 5850-6425 MHz. The receiving frequencies used by Inmarsat (Batum, TT&C) are fixed (around 3950 MHz), the frequencies used in Amsterdam/ Amstelveen are semi-static (3800-3850 MHz, around 3835). The bandwidth used at these facilities is also limited (< 5 MHz, per satellite ground station).

However, the frequencies and bandwidths at the other facilities in Batum, Biddinghuizen and Zoutkamp are not static, as these companies hire capacity from satellite providers. The satellite providers 'reshuffle' their transmit frequencies on satellite transponders on a regular basis (weekly) to accommodate the actual requested bandwidths of customers worldwide. Frequencies are used in the entire 3800-4200 MHz band. The bandwidth per satellite ground station varies between <5 MHz to 120-160 MHz. The total (partly overlapping) bandwidth used in the 3800-4200 MHz is between 350-400 MHz (January 2021).

Future use by satellite ground stations

The existing licenses (15) have end dates varying between September 2021 and December 2025. All current users expect to extend their existing licenses after these end dates.

Two license holders in Batum and Amsterdam/Amstelveen with limited frequency use (<5 MHz) do not expect to extend their use. Two other license holders in Batum and Biddinghuizen expect to use the full 3800-4200 MHz band for future customers - depending on actual contracts. In addition, all geostationary satellites which can be seen shall be useable in the future when needed. For some license holders,

including Speedcast in Biddinghuizen, there is (very) dynamic spectrum use, which will continue to be the case in the future.

For the Ministry of Defense, depending on the mission areas and the size of the missions to be supported, the actual required satellite capacity may vary. When more satellite capacity is required, the frequency band(s) in which the requested satellite capacity will be allocated is determined by the satellite operator. To ensure the allocated satellite capacity can be used, the frequency range of 4000-4200 MHz on the NSS-12 satellite and the frequency range of 3800-4100 MHz on the SES-4 satellite should be available for the next 5-7 years.

Depending on the mission areas, the satellite capacity requirement versus available satellite capacity, and the associated cost, the MoD may select a variety of satellites in the future.

Coexistence study IMT networks and satellite ground stations

Based on this information on current and future spectrum usage of satellite ground stations and satellites and the technical parameters of antenna dishes, an impact analysis of coexistence was carried out for the introduction of local private IMT networks based on 5G technology. Coexistence based on co-channel and adjacent channel is analysed.

Technical conditions for co-channel and adjacent channel coexistence

Co-channel operation will allow the full frequency band of 3800-4200 MHz to be used by IMT networks. The area in which the IMT networks can be deployed will however be limited by the exclusion zones of the satellite ground terminals. These exclusion zones cover a large part, if not all, of the Netherlands, but can be significantly reduced by implementing mitigation measures.

Adjacent channel operation allows IMT networks to be deployed in the largest area within the Netherlands. However, sub-band(s) with sufficient bandwidth to accommodate broadband applications (from 50 to 100 MHz) which are available for a sufficient period of time to be useful for IMT may be hard to find.

Each IMT base station operating in a sub-band within the 3800-4200 MHz band has to meet the coexistence criteria of all satellite ground stations simultaneously. This means that the IMT base station cannot be deployed:

- Inside any of the exclusion zones of the satellite ground terminals which operate in the same sub-band (co-channel operation), nor
- inside any of the exclusion zones of the satellite ground terminals which operate in adjacent sub-bands (adjacent channel operation).

Inmarsat and Signalthorn use only a small portion of the 3800-4200 MHz band which will hardly change in time. MOD-NL is also using a relatively small portion of the 3800-4200 MHz band, but this may change, depending on the missions which have to be supported. Adjacent channel operation of IMT could therefore be possible using e.g. a Shared Access model which takes into account the more dynamic use of the 3400-4200 MHz band by MOD-NL.

The frequency use by Speedcast and Castor Networks will however be limiting the shared use by IMT of the 3800-4200 MHz band, since they use a large portion (if

not most) of the 3800-4200 MHz band. Co-channel operation might therefore be the only option for IMT. In this case, to obtain a reasonable large deployment area for IMT, a substantial mitigation effort is needed to reduce the exclusion zones of the satellite ground terminals of Speedcast and Castor Networks.

From an IMT point of view, it is difficult to determine in general whether a substantial mitigation effort can be easily achieved in each case and whether or not the impact of the required mitigation measures on the application/service (in terms of e.g. coverage) are acceptable. This will have to be further investigated in order to be able to grant licenses for future local IMT networks.

Shared Access in the UK provides incumbent users (satellite ground terminals) protection based on same principles as used in this report, albeit with some mitigation measures already included (7 dB lower EIRP, 8 dB lower spurious level and a slightly loosened short-term criterion). Compared to the Netherlands, sharing opportunities are better, due to the larger size of the UK, the satellite ground terminals being mostly located in the South of the UK and the more undulated terrain in the UK providing more shielding compared to the 'flat' terrain in the Netherlands.

Interference study on radar altimeters in the 4200-4400 MHz band

The band 4200 – 4400 MHz is used almost exclusively for radio (or radar) altimeters. More specific, its use is designated for and limited to airborne altimeters. Ground equipment is excluded, except transponders for airborne altimeters (should they be necessary). The interference of a single IMT base station on radar altimeters in the 4200-4400 MHz band was studied. The ITU M.2059 recommendation is used as main source of reference, since it includes all relevant technical parameters for interference study of 10 reference altimeters (6 analogue, 4 digital). These technical parameters of actual altimeters in aircrafts are not available from suppliers. The interference results of this study are calculated with 43 dBm/ 5 MHz EIRP for a single IMT base station. Higher power levels as allowed by the IMT standard, will result in higher interference risks.

The conclusions of the altimeter interference study are:

1. The safe distances of these 10 reference altimeters for an aircraft at 150 m (minimum flight altitude) vary between 0 and 500 m.
2. At airports and up to 3 km in front of runways where the altitude of aircrafts is below 150 m, a safe distance between 80 and 590 m is retrieved.
3. If the base station output power is limited to 28.7 dBm, the airspace is interference free for all reference altimeters at altitudes of 150 m and above.
4. However, the ITU M.2059 appears to be too conservative: following its guidelines, calculations show that also interference from lower frequency bands will pose an interference risk to the reference altimeters. However, to date, no interference reports from these lower bands below 3800 MHz seem to exist (see appendix A, section 6 for details). This may imply that safe distances in practice are lower than the values calculated here. It is recommended to participate to a proposed CEPT ECC PT1 study and advocate to study adjacent channel co-existence of IMT networks in both 3.400-3.800 MHz and 3.800-4.200 MHz and to study sensitivity of realistic altimeters.

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1 Introduction

1.1 Background

The Ministry of Economic Affairs and Climate is currently redesigning the 3400-3800 MHz frequency band so that from 1 September 2022 the middle part of this band (3450-3750 MHz) can be used for national mobile communication via 5G technology. The existing local licenses in the 3400-3800 MHz band will be accommodated as much as possible in the 2x50 MHz at the bottom and top of the band (i.e. 3400-3450 MHz and 3750-3800 MHz). This 2x50 MHz is intended to support local networks. The cabinet also wishes to make more frequency spectrum available for private networks for company-specific applications. The expectation is that many more companies will integrate mobile communication solutions into their production processes and want to use their own spectrum for this, to be fully independent of mobile network operators.

One possibility for additional frequency space is the adjacent 3800-4200 MHz band. Countries such as the United Kingdom and Belgium have already decided to make this frequency band available for company-specific applications. This band is currently used for fixed satellite earth stations (space-to-earth) and this existing use should be protected. Furthermore, possible interference on the existing use in the adjacent frequency band 4200-4400 MHz must be considered.

The Ministry of Defence and the Ministry of Economic Affairs and Climate want to jointly investigate within which frameworks, in addition to existing use, regional and local frequency use can be made possible in the 3800 - 4200 MHz band in the future.

The policy with regard to possible types of local networks to be admitted to this band is still in an exploratory phase, but for the purposes of this research, one may consider compact broadband networks (indoor and outdoor), built up from a few base stations based on IMT technology, with an EIRP ranging between 25 and 43 dBm / 5 MHz. The term International Mobile Telecommunications (IMT) is the generic term used by the ITU community to designate broadband mobile systems. IMT-Advanced specifies 4G/LTE networks, while IMT-2020 is related to 5G networks. In this report the generic term IMT is used, as frequency allocations for local private networks will be technology neutral.

1.2 Conduct of investigation

The main research question of this study is under which (technical) conditions - in addition to existing use - regional and local frequency use (coexistence) for private IMT networks in the 3800 - 4200 MHz band can be made possible in the future.

The underlying sub-questions are:

- 1) Under what (technical) conditions can the frequencies in the range 3800-4200 MHz be made available for local / company-specific use (private IMT networks based on IMT technology) on the condition that the current use of commercial satellite earth stations in the Netherlands and the use by the

Ministry of Defense (satellite communication and satellite interception) is guaranteed?

- 2) What (technical) conditions must be imposed on the use of the frequencies in the frequency band 3800-4200 MHz to ensure that no interference occurs on the use of radar altimeters and radio navigation in the frequency use above 4200 MHz?
- 3) What are the expectations for the future utilization of the 3800-4200 MHz band by satellite earth stations and what does this mean for the availability of the frequency band for (future) satellite earth stations and for use by local private IMT networks?

1.3 Approach

TNO has mapped the current use by fixed satellite earth stations in the 3800-4200 MHz by means of a questionnaire and interviews with the current holders of licenses (as registered by Agentschap Telecom in January 2021) for fixed satellite earth stations: Speedcast (Biddinghuizen), Signalthorn (Amsterdam / Amstelveen), Inmarsat (Batum), Castor Networks (Batum), Ministry of Defense (Zoutkamp).

The 3800-4200 MHz band is also assigned for Fixed Service (FS - A radiocommunication service between specified fixed points), but currently no licenses are assigned.

Based on this information on current and future spectrum usage of satellite ground stations and satellites and the technical parameters of antenna dishes, an impact analysis of coexistence was carried out for the introduction of local private IMT networks based on 5G technology. Coexistence based on co-channel and adjacent channel is analysed.

1.4 Structure of this report

In chapter 2 the current situation of fixed satellite ground stations in the Netherlands is described, together with plans for future use in the next 5-10 years.

The results of the analysis of the coexistence study of satellite earth stations and local IMT networks are described in chapter 3.

The study on interference of local IMT networks on altimeters in the 4200-4400 MHz bands is reported in chapter 4.

2 Satellite ground terminals in the Netherlands

2.1 Introduction

In this chapter an overview is given of the current locations of satellite ground terminals, their characteristics (to determine antenna diagram and satellite receiver noise level) and the frequencies used in the 3800-4200 MHz band, now and expected in the (near) future (as obtained by interviews and information provided by the involved parties).

Satellite ground terminals in the Netherlands are operated today in (see Figure 2.1):

- Lauwersmeer (Zoutkamp) by MOD-NL
- Burum by Inmarsat, Castor Networks and JSCU (Interception Facility)
- Biddinghuizen by Speedcast
- Amsterdam/Amstelveen by Signalhorn



Figure 2.1: Locations of satellite ground terminals.

2.2 Burum, MOD-NL (JSCU)

The Interception Facility (JSCU) in Burum is suited for interceptions in the 3800-4200 MHz band. Might the Ministry of Economic Affairs and Climate Policy consider issuing local licenses in the 3800-4200 MHz band, this would require further coordination with the Ministry of Defence, which is outside the scope of this public report.

2.3 Lauwersmeer (Zoutkamp), MOD-NL

In the Netherlands, the MOD operates two C-band satcom ground terminals at the anchor station in Lauwersmeer. They are used for connections with the anchor station in Curaçao and with tactical satcom terminals in mission areas. Preparation activities by the MOD for the tactical terminals (configuration and testing) to be used in mission areas takes place in Apeldoorn. In addition, the tactical terminals may be used anywhere in the Netherlands for training and exercises.

2.3.1 Location Anchor Station (AS)

The Anchor Station is located at:

Latitude: 53.361°N

Longitude: 6.266°E



Figure 2.2: Anchor Station in Lauwersmeer (Zoutkamp) indicated by white border (top, left).



Figure 2.3: Anchor Station satellite ground terminals (zoomed in).



Figure 2.4: Anchor Station satellite ground terminals (close view).

2.3.2 *Technical specifications*¹

Two C-band terminals are used in Lauwersmeer (denoted C1 and C2).:

Terminal C1

Antenna diameter D:	11.1 m
Efficiency η :	0.73
System noise temperature T_s :	70 K (at 15° elevation)
Antenna height ² (h):	6.5 m

¹ The antenna diameter and efficiency define the antenna diagram, while the system noise temperature determines the satellite receiver noise level. Both are needed to calculate the exclusion zones.

² Antenna height = center of dish above ground level

Terminal C2

Antenna diameter D:	9 m
Efficiency η :	0.70
System noise temperature T_s :	70 K (at 15° elevation)
Antenna height (h):	5.5 m

Detailed specifications of these terminals can be found in the classified (Stg Confidential) report:

TNO 2020 R10143, *“Coexistence of radar systems and satellite terminals operated by the Netherlands MoD with 5G mobile communication networks in the 3.5 GHz band”*

The specifications are as provided by MOD-NL during this study.

2.3.3 Current spectrum use

About 30~40 MHz is currently used on two geostationary satellites:

- SES-4 (located at 22°W) and
- NSS-12 (located at 57°E).

2.3.4 Future spectrum use

Depending on the mission areas and the size of the missions to be supported, the actual required satellite capacity may vary. When more satellite capacity is required, the frequency sub-band(s) in which the requested satellite capacity will be allocated is determined by the satellite operator. To ensure the allocated satellite capacity can be used, the frequency range of 4000-4200 MHz on the NSS-12 satellite and the frequency range of 3800-4100 MHz on the SES-4 satellite should be available for the next 5-7 years.

Depending on the mission areas, the satellite capacity requirement versus available satellite capacity, and the associated cost, different satellites may be selected in the future. This requires the possibility to use any geostationary satellite which is visible at elevation angles of 10° or more.

2.4 Burum, Inmarsat

In C-band, Inmarsat operates Telemetry, Tracking and Command (TT&C) links above 3800 MHz and feeder links (serving mobile terminals in L-band) below 3800 MHz. The feeder links cannot be moved to another frequency band (>3800 MHz) and a possible solution can be to rebuild this facility at another location outside the Netherlands. This may also affect the TT&C links, i.e. the operation of the TT&C links may remain in Burum or may be moved (together with the feeder links) to another location outside the Netherlands.

2.4.1 Location Satellite Access Station

The Satellite Access Station is located at:

Latitude: 53.284°N / Longitude: 6.216°E



Figure 2.5: Satellite Access Station, terrain (yellow border) is shared with Castor Networks (Castor Networks terminals marked by orange circles).

2.4.2 Technical specifications

The main technical parameters of the satellite dishes used to receive the satellite signals (TT&C) from Alphasat and Inmarsat I-4 are:

Antenna diameter D:	13.10 m
Efficiency η :	0.72
System noise temperature T_s :	79 K
Antenna height (h):	10 m

These two terminals are the same as the ones in the previous study:
TNO 2019 R11753, "Coexistence of 5G mobile networks with Burum Satellite Access Station operating in C-band"

The specifications are as provided by Inmarsat during this study.

2.4.3 Current spectrum use

Inmarsat is using frequencies in the 3800-4200 MHz band for Telemetry, Tracking and Command (TT&C) of two geostationary satellites:

- Alphasat (located at 25°E) and
- Inmarsat I-4 (located at 63.9°E).

These TT&C links operate at **fixed** frequencies which cannot be relocated. The TT&C links are all located within a bandwidth of 6 MHz.

2.4.4 Future spectrum use

As stated before, operation of the TT&C links may remain in Burum or moved (together with the feeder links) to another nation. In any case, the relatively small amount of spectrum in use for TT&C links will not change. The spectrum use is therefore static.

2.5 Burum, Castor Networks

2.5.1 Location Teleport

The Teleport is located at:

Latitude: 53.286°N / Longitude: 6.215°E

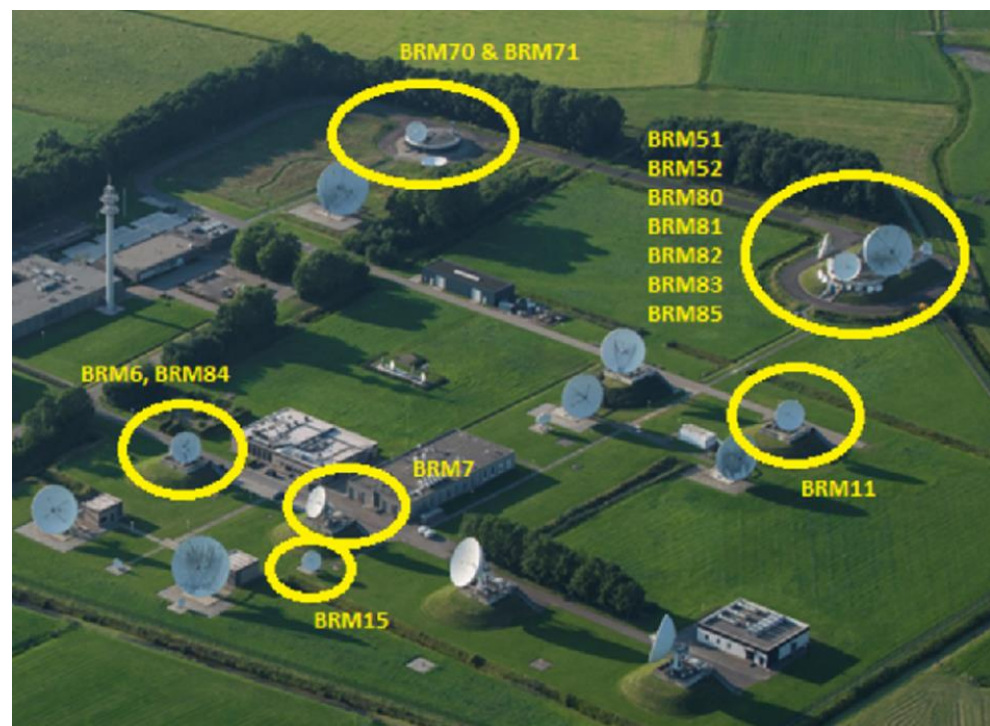


Figure 2.6: Castor Networks satellite ground terminals marked by yellow circles³.

2.5.2 Technical specifications

Three C-band terminals are used (denoted BRM-51, BRM-52 and BRM-70). Two of these are active, BRM-52 operating over Arabsat-5C and BRM-70 operating over

³

<https://www.kivi.nl/uploads/media/5a21abf743a8a/Satelliet%20communicatie%20KIVI%20site.pdf>

AMOS-17. The third terminal, BRM-51, is acting as a backup. Specifications are obtained from an Excel sheet provided by Castor Networks.

Terminal BRM-51 (backup)

Antenna diameter D:	9.2 m
Efficiency η :	0.72
System noise temperature T_s :	74 K
Antenna height (h):	10 m

Terminal BRM-52 (active)

Antenna diameter D:	16.4 m
Efficiency η :	0.72
System noise temperature T_s :	83 K
Antenna height (h):	13.5 m

Terminal BRM-70 (active)

Antenna diameter D:	7.3 m
Efficiency η :	0.72
System noise temperature T_s :	67 K
Antenna height (h):	8.5 m

2.5.3 *Current spectrum use*

The following sub-bands in the 3800-4200 MHz band on the various satellites are used:

- Arabsat-5C (located at 20°E):
3905.75 – 3941.75 MHz (36 MHz bandwidth)
- AMOS-17 (located at 17°E):
20 MHz bandwidth within 3800-3900 MHz in the near future, for current customers still using 3600-3620 MHz that have to be relocated to free the 3400-3800 MHz band for 5G before September 2022.
300 MHz bandwidth, for a project in the acquisition phase (currently Proof of Concept), requiring support for 0.5 Gbps in November 2021 with growth to 1 Gbps⁴.

2.5.4 *Future spectrum use*

Castor Networks expects to use the full 3800-4200 MHz band for future customers.

⁴ Allocation of (sub)band(s) are/will be determined by satellite operator.

2.6 Biddinghuizen, Speedcast

Speedcast consists of the companies Globecom Europe BV and Carrier to Carrier Telecom BV which are still mentioned in the various licenses.

2.6.1 Location Teleport

The Teleport is located at:

Latitude: 52.463°N

Longitude: 5.710°E



Figure 2.7: Speedcast Teleport in Biddinghuizen indicated by yellow border (top, right).



Figure 2.8: Speedcast satellite ground terminals.



Figure 2.9: Speedcast satellite ground terminals (close view).

2.6.2

Technical specifications

Seven terminals are used in C-band. Specifications are obtained from specification sheets provided by Speedcast.

Terminal type 1 (three out of seven terminals)

Antenna diameter D : 13 m

Efficiency η : 0.74

System noise temperature T_s : 84 K (at 20° elevation)

Antenna height (h) :	7 m
Terminal type 2 (one terminal)	
Antenna diameter D:	9.3 m
Efficiency η :	0.69
System noise temperature T_s :	83 K (at 20° elevation)
Antenna height (h):	5.2 m
Terminal type 3 (one terminal)	
Antenna diameter D:	9 m
Efficiency η :	0.74
System noise temperature T_s :	81 K (at 20° elevation)
Antenna height (h):	5 m
Terminal type 4 (two terminals)	
Antenna diameter D:	3.8 m
Efficiency η :	0.66
System noise temperature T_s :	73 K (at 20° elevation)
Antenna height (h):	2.4 m

2.6.3 *Current spectrum use*

The following sub-bands in the 3800-4200 MHz band on the various satellites are used:

- Arabsat-5C (located at 20°E):
4076.0-4094.0 MHz (18 MHz bandwidth)
4092.5-4097.5 MHz (5 MHz bandwidth)
- F-SAT-N-E (located at 3.1°E):
4025.0-4075.0 MHz (50 MHz bandwidth)
4117.5-4132.5 MHz (15 MHz bandwidth)
- YAMAL-601 (located at 49°E):
125 MHz bandwidth, in multiple sub-bands within 3805-4200 MHz
- SES-4 (located at 22°W):
3999.5-4070.5 MHz (71 MHz bandwidth)
- F-SAT-C-E (located at 10°E):
3888.5-3893.5 MHz (5 MHz bandwidth)
- AMOS-17 (located at 17°E)
12 blocks of 19.2 MHz (230.4 MHz bandwidth) located within 3801-4125 MHz
(license in progress)

The terminals (mentioned in the section above) operating over these satellites are not statically assigned. This may change in time, depending on the need. In addition, the spectrum use is highly dynamic as explained below.

Speedcast has a satellite network of more than 95+ satellites and 35+ Speedcast and Partner teleports, combined to form the largest global network in the world. Speedcast has over 3,200 customers in 140 countries, serving over 10,000 maritime vessels and over 8,000 active terrestrial sites. The Teleport at Biddinghuizen is only one of the 35+ teleports in the global network of Speedcast.

Speedcast supports many customers which have to be supported on the move, like for instance ships. When these ships move out of the coverage area of a satellite, a 'hand-over' to another satellite has to be performed. This could also include a 'hand-over' to another teleport, since each teleport only operates over limited number of satellites (much less than the 95+ in the global Speedcast network). Similar, there are also customers which have to be supported at times and locations when/where needed, like for disaster recovery, red cross, international peace keeping missions, aero nautical flight tests, etc. This makes the spectrum use by the Speedcast Teleport at Biddinghuizen highly dynamic and changes occur almost on a weekly basis. In addition, many of these changes have to be implemented within a day after notification and sometimes even within an hour.

2.6.4 *Future spectrum use*

Speedcast expects to use the full 3800-4200 MHz band for future customers. In addition, all geostationary satellites which can be seen at an elevation angle of 5° or more should be useable in the future when needed. The spectrum use will remain highly dynamic as noted above.

2.7 Amsterdam/Amstelveen, Signalhorn

Two VSAT terminals (end user equipment) of an international VSAT network (operated by Signalhorn) are located in Amsterdam and Amstelveen. The exact locations and the exact frequencies used are known (and used in calculations) but are requested not to be disclosed.

2.7.1 *Location VSAT terminals*

The two VSAT terminals are located in the area shown below.



Figure 2.10: Signalhorn VSAT terminals are located within the yellow ellipse.

2.7.2 Technical specifications

The VSAT terminals are located on the top of buildings. The specifications are obtained from specification sheets provided by Signalhorn.

VSAT-1

Antenna diameter D :	2.4 m
Efficiency η :	0.65
System noise temperature T_s :	65 K (at 20° elevation)
Antenna height (h):	83 m

VSAT-2

Antenna diameter D:	2.4 m
Efficiency η :	0.65
System noise temperature T_s :	65 K (at 20° elevation)
Antenna height (h):	23 m

2.7.3 *Current spectrum use*

The VSAT terminals operate over the:

- Yamal-601 (located at 49°E using a total of 1.52 MHz bandwidth in the frequency band 3800-3850 MHz).

2.7.4 *Future spectrum use*

The Yamal-601 will be used until 2030 with a possible extension beyond 2030. The VSAT terminals will keep using the same frequency band, unless the satellite operator decides otherwise. The spectrum use will therefore be almost static.

2.8 **Summary****2.8.1** *Current locations*

Satellite ground stations, deploying multiple satellite ground terminals and offering access to terrestrial networks like internet, are (co)located around 3 locations in the Netherlands: Burum, Zoutkamp, and Biddinghuizen. These facilities are operated by 3 commercial companies and by MOD-NL. In addition, two VSAT terminals (end user equipment) which are part of an international VSAT network are located in Amsterdam and Amstelveen and operated by Signahorn. In Burum there is also a satcom interception facility of the MOD-NL. At the moment, 15 licenses for satellite ground stations/terminals are used. No new license requests for other locations were received by Agentschap Telecom.

2.8.2 *Frequencies and bandwidths*

The frequency sub-bands in use by Inmarsat (Burum, for TT&C) are fixed (static) and cannot be changed (which is a satellite limitation). The frequency sub-bands used by the VSAT's in Amsterdam/ Amstelveen which are part of an international satellite network (operated by Signahorn) are semi-static (3800-3850 MHz), meaning that these will only change if required by the satellite operator to accommodate changes in customers and their requirements. The bandwidth used by these facilities is limited (< 5 MHz each).

The sub-bands in use at the other facilities are more dynamic, since they are also supporting users with varying requirements for capacity and/or locations. Examples are mobile users like ships (which may move out of coverage on one satellite requiring a 'hand-over' to another satellite/teleport) and users which have to be supported where and when needed, like for instance the missions of MOD-NL. Changes are reported by Speedcast to occur almost on a weekly basis, while many of these changes have to be implemented within a day after notification and sometimes even within an hour.

The table below shows the center frequencies used and the bandwidth per ground station, related to the license of Agentschap Telecom. It should be noted that some of these frequencies (and bandwidths) vary over time.

	Location	Organisation, ground station name	Satellite	Bandwidth (MHz) – total
1	Amsterdam	Signalhorn, VSAT-1	49E	<5
2	Amstelveen	Signalhorn, VSAT-2	49E	<5
3	Biddinghuizen	Speedcast, BID-02	20E	20-40
4	Biddinghuizen	Speedcast, BID-03	49E	120-160
5	Biddinghuizen	Speedcast, BID-07	3.1E	40-80
6	Biddinghuizen	Speedcast, BID-12	22W	40-80
7	Biddinghuizen	Speedcast, BID-14	10E	5-20
8	Burum	Inmarsat, BRM-18A	64E	<5
9	Burum	Inmarsat, BRM-19A	25E	<5
10	Burum	Castor Networks, BRM-52	20E	5-20
11	Burum	Castor Networks, BRM-70	17E	20-40
12	Zoutkamp	MOD, SGS LWMR C9	22W	20-40
13	Zoutkamp	MOD, SGS LWMR C11	57E	20-40

The total (partly overlapping) bandwidth used in the 3800-4200 MHz is between 350-400 MHz (January 2021).

2.8.3 Future use

The existing licenses (15) have end dates varying between September 2021 and December 2025. All current users expect to extend their existing licenses after their end date, in the period 2025-2030.

Two license holders expect to extend their limited frequency use (<5 MHz). Two license holders expect to use the full 3800-4200 MHz band for future customers (depending on actual contracts). In addition, all geostationary satellites which can be seen at an elevation angle of 5° or more should be useable in the future when needed. The spectrum use will remain highly dynamic as noted above.

For the Ministry of Defence, depending on the mission areas and the size of the missions to be supported, the actual required satellite capacity may vary. When more satellite capacity is required, the frequency sub-band(s) in which the requested satellite capacity will be allocated is determined by the satellite operator. To ensure the allocated satellite capacity can be used, the frequency range of 4000-4200 MHz on the NSS-12 satellite and the frequency range of 3800-4100 MHz on the SES-4 satellite should be available to be used for the next 5-7 years.

Depending on the mission areas, the satellite capacity requirement versus available satellite capacity, and the associated cost, different satellites may be selected in the future. This requires the possibility to use any geostationary satellite which is visible at elevation angles of 10° or more.

3 Coexistence of IMT networks and satellite ground stations

3.1 Introduction

It should be noted that C-band satellite ground terminals are only receiving satellite signals in the 3800-4200 MHz band. Transmission occurs in a higher frequency band (around 6 GHz). Consequently, IMT base station transmissions in the 3800-4200 MHz band may cause interference at the (receiving) satellite ground terminals, but not the other way around. Whether or not IMT and satellite communications can coexist in the 3800-4200 MHz band, based on interference criteria, is therefore solely dependent on whether or not the interference experienced by satellite ground terminals due to IMT emissions is acceptable.

3.2 Satellite ground station characteristics

The existing C-band satellite ground terminals in the Netherlands are designed to receive satellite signals in the 3625-4200 MHz band (standard C-band) or 3400-4200 MHz (including the Super Extended C-band).

The 3400-3800 MHz band is however intended to be used for 5G mobile networks and in the draft decision to amend the National Frequency Plan (NFP) the use of frequencies in the 3400-3800 MHz band by satellite ground terminals will no longer be protected after 1 September 2022. Satellite services making use of frequencies below 3800 MHz are either (in progress of) being moved to the 3800-4200 MHz band or, when this is not possible, relocated to other nations.

Since C-band satellite ground terminals are designed to also receive signals below 3800 MHz, they may experience blocking due to signals radiated by 5G mobile networks once these are deployed. To mitigate this, satellite ground terminals are expected to be equipped with waveguide filters before the Low Noise Amplifier (LNA) limiting their receiving range to 3800-4200 MHz (see Appendix B, section 7). This is also assumed in this study, such that interference experienced from future 5G mobile networks operating below 3800 MHz (3400-3800 MHz) can be neglected.

The characteristics of the satellite ground terminals are given in chapter 2.

3.3 Reference IMT base station characteristics

An IMT network is considered to provide local coverage for a closed user group.

The assumptions for the reference IMT base station are:

- A maximum EIRP density of 43 dBm/5MHz.
- An antenna height of 10 m.
- A tilt angle of zero degrees.

In case mitigation measures are considered, an EIRP of 25 dBm/5MHz is taken as the lower EIRP density limit of the IMT base station.

When considering adjacent channel interference (and blocking) it is assumed that the EIRP density within the satellite frequency sub-band is limited by the spurious emission limit (output of transmitter) defined in 3GPP standards of -30 dBm/MHz [7, 8 and 9]. With an assumed antenna gain of 17 dBi and a feeder loss of 3 dB this results in an EIRP density of -16 dBm/MHz.

Assuming the bandwidth used by each IMT base station is less than 100 MHz, the spurious emission limit has to be achieved 10 MHz outside the operating transmission bandwidth of the IMT base station. In practice this might be less. This 10 MHz (or less in practice) is assumed to be included in the bandwidth allocated to an IMT base station, see Figure 3.1.

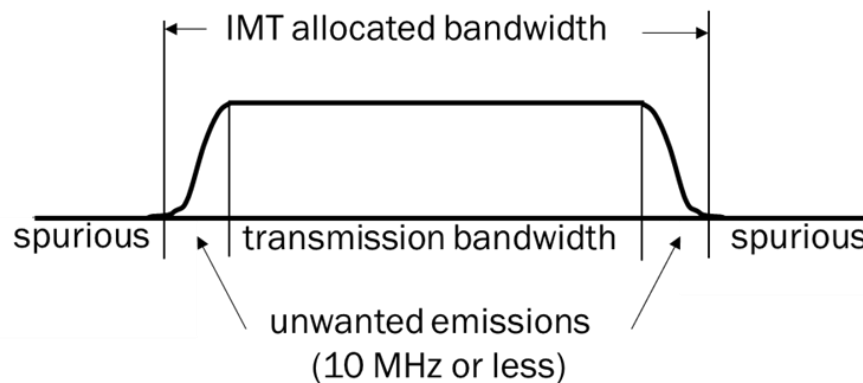


Figure 3.1: IMT allocated bandwidth.

3.4 IMT deployment

The specific requirements of local IMT networks, like coverage, bandwidth, etc., can vary widely depending on the service and service area to be supported. Also, an estimate of the number and size of the IMT networks to be accommodated in the 3800-42000 MHz band is not yet known. This prevents the coexistence study to be based on a realistic deployment scenario of IMT networks.

Therefore, it has been agreed with the Ministry of Economic Affairs and Climate Policy to consider the deployment of the **single** reference IMT base station (defined above) as the baseline for this coexistence study.

The defined reference IMT base station and its characteristics do not imply to be sufficient nor the minimum needed to support every intended service and service area of IMT-networks. Higher as well as lower EIRP densities, antenna heights etc. may be required by the various IMT networks depending on the services and service areas to be provided as well as the environment in which they operate (indoor/outdoor, etc).

3.5 Co-channel and adjacent channel operation

Although satellite ground stations operate in the 3800-4200 MHz band, they may actually only use parts, or sub-bands, of the 3800-4200 MHz band. Based on this, two situations are distinguished (see Figure 3.2):

1. If both the satellite ground terminal and IMT base stations operate in the same sub-band, this will be denoted by **co-channel operation** and the interference caused by IMT emissions in this sub-band is called **co-channel interference**. In this case, the interference level is determined by the IMT emissions in its transmission bandwidth, as shown in Figure 3.2.
2. If the satellite ground terminal and the IMT base stations operate in adjacent (not overlapping) sub-bands, this is denoted by **adjacent channel operation** and the interference caused by IMT emissions is called **adjacent channel interference**. In this case, the interference consists of spurious emissions of the IMT base stations within the sub-band(s) in use by the satellite ground terminal.

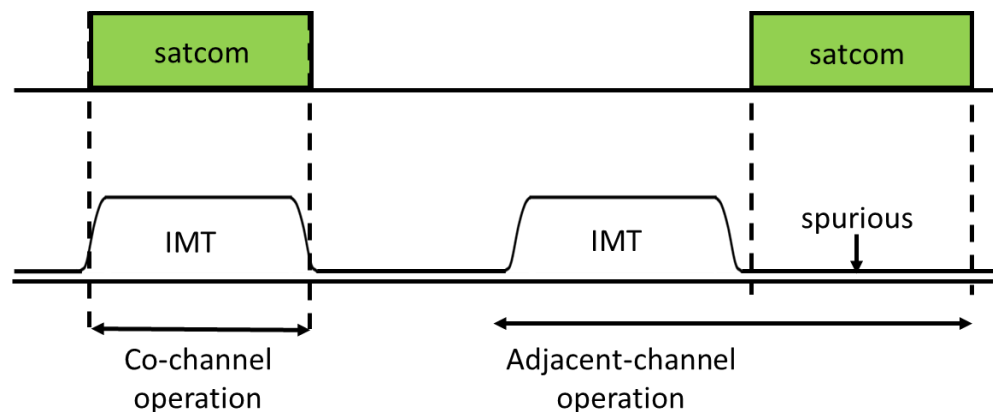


Figure 3.2: Spectrum use: Co-channel (left) and adjacent channel (right) operation.

3.6 Coexistence criteria

The coexistence criteria used are those recommended by the ITU. For each criterion, reference to the appropriate ITU documents is included. It should be noted that owners of satellite ground terminals might be willing to accept less stringent criteria. This has however to be negotiated, which is outside the scope of this study. The effect of less stringent criteria is however considered as a possible mitigation measure in this study.

3.6.1 Short-term criterion

The total IMT interference level shall not exceed the maximum permissible interference level for more than 0.005% of the time. The maximum permissible interference being defined as in [5] and [4, Table 8b], with a:

- Fade/link margin (M_s) of 2 dB,
- Link noise contribution by the satellite transponder including uplink noise (N_L) of 1 dB, and
- Thermal noise equivalence factor for interfering emissions (W) of 0 dB.

This maximum permissible interference level is equivalent to an increase of the satellite receiver noise level by 73.6% (or -1.329 dB).

This criterion is used to ensure that the reduction in availability of the satellite links due to interference is limited to 0.005% of the time.

Only the interference within the sub-bands used by a satellite ground terminal has to be considered for this criterion. In case of co-channel operation this is the interference due to IMT emissions in its transmission bandwidth and in adjacent channel operation the interference due to IMT spurious emissions.

3.6.2 Long-term criterion

The total IMT interference level shall not exceed 10% of the satellite receiver noise level for more than 20% of the time [5].

This criterion is used to ensure that the minimum desired quality of the received satellite signals is met for most of the time. This long-term criterion is applicable to IMT base stations and satellite ground stations operating in the same sub-band (co-channel operation).

In case of adjacent channel operation, the total IMT interference level (i.e. the total spurious in the adjacent channels in use by the satellite ground terminal) shall not exceed 1% of the satellite receiver noise level for more than 20% of the time [6, section 5.1].

3.6.3 Blocking criterion

The total aggregated received signal power originating from IMT base stations may drive the satellite receiver's first stage (LNA) outside its dynamic range, where it exhibits non-linear behaviour resulting into intermodulation products and gain compression. This situation is called blocking. ***Blocking will result in most, if not all, links supported by the terminal to become unavailable.***

To prevent blocking, the total aggregated signal power received by the LNA shall not exceed a given input threshold level. This input threshold level is determined by the technical specifications of the LNA [6]. For the considered satellite ground terminals, the threshold level for blocking is between -61 dBm and -53 dBm⁵.

The satellite ground terminals are assumed to be equipped with wave guide filters, limiting their receiving range to 3800-4200 MHz (see par 3.2), such that only the total aggregated signal power from IMT base stations within this frequency range has to be considered (see Appendix B).

3.7 Exclusion zones

The aim is to determine the areas around the satellite ground stations where IMT cannot be deployed since the coexistence criteria described above in section 3.5 are not met. The areas are denoted exclusion zones.

⁵ Based on information about the satellite ground terminals provided by the involved parties.

Calculations have been performed for each satellite ground terminal and a single reference IMT base station, based on the above-mentioned criteria, considering two situations:

- Co-channel operation,
both the IMT reference base station and satellite ground terminal operating in the same sub-band.
- Adjacent channel operation,
both the IMT reference base station and satellite ground terminal operating in different (non-overlapping) sub-bands.

It should be noted that for coexistence the criteria have to be met for ***all satellite ground terminals simultaneously***. This means that an IMT base station operating in a given (IMT) sub-band:

- Cannot be deployed in any of the exclusion zones for co-channel operation of satellite ground terminals using the same (IMT) sub-band, ***and***
- Cannot be deployed in any of the exclusion zones for adjacent channel operation of satellite ground terminals not using this (IMT) sub-band.

Also note that these situations are assumed to be possible and do not yet take into account any other requirement from:

- Satellite services providers, like the flexibility to use any geostationary satellite, being able to accommodate other (new) users, ability to support relocation of satellite carriers when required by satellite operators, or
- IMT networks, like availability of sufficient bandwidth for a certain period of time.

The exclusion zones have been calculated for co-channel and adjacent channel operation separately, since different criteria apply. For both cases the results are presented and discussed in the following order:

- The exclusion zones applicable to a single reference IMT base station (as defined in section 3.3).
- The impact of the deployment of multiple reference IMT base stations on the exclusion zones (which will increase compared with the exclusion zones for a single reference IMT base station).
- Possible mitigation measures to reduce the interference experienced by satellite ground terminals (expressed in dB by the mitigation effort), resulting in smaller exclusion zones.

The exclusion zones presented are always associated with a specific combination of:

- ***Reference IMT base station characteristics (specified in section 3.3),***
- ***Number of reference IMT base stations,***
- ***Mitigation effort and***
- ***Mode of operation (co-channel or adjacent channel).***

For this specified combination, the exclusion zone will exactly be what its name indicates: no reference IMT base station can be employed within the exclusion zone without violating the coexistence criteria as recommended by

the ITU.

Any change in the reference IMT base stations characteristics, their number, the amount of mitigation effort or mode of operation will have impact on the exclusion zones. The main objective is to show how these exclusion zones can be affected by changing on or more of these parameters.

3.8 Model

The various components of the model used to determine the exclusion zones are modelled according to the following ITU documents:

- IMT antenna diagram: ITU- R F.1336 [18]
- Satellite terminal antenna diagram: Radio Regulations 2020, Appendix 7 (Rev.WRC-19), Annex 3, section 3 [4]
- Propagation: ITU-R P.452 [10]

The IMT antenna is assumed to operate at a tilt angle of zero degrees and is always assumed to be pointed in the direction of the satellite ground terminal.

Concerning propagation, the influence of terrain elevations is taken into account.

To determine the exclusion zone, the total area containing the Netherlands is divided in squares of 1 km by 1 km. A reference IMT base station is then moved through all squares and in each square it is determined whether or not the criteria are met. If they are not met, the square is part of the exclusion zone.

Clutter, like buildings and vegetation, are not taken into account but considered as a possible mitigation measure, since clutter losses can vary widely (see e.g. Table 3.1) within an area of 1 km by 1 km.

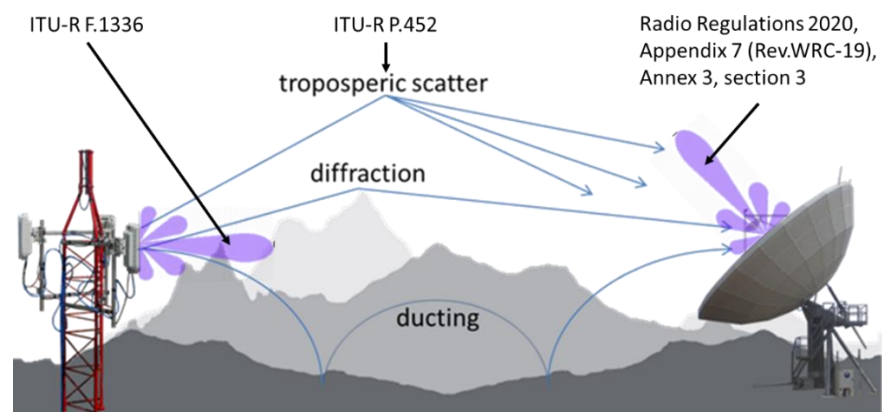


Figure 3.3: Spectrum use: Co-channel (left) and Adjacent channel (right) operation.

3.9 Exclusion zones for co-channel operation

3.9.1 Single reference IMT base station

A **single** reference IMT base station, operating in a sub-band also in use by a satellite ground terminal (co-channel operation), will cause the short-term criterion to be exceeded, which is dominating as shown in Figure 3.4.

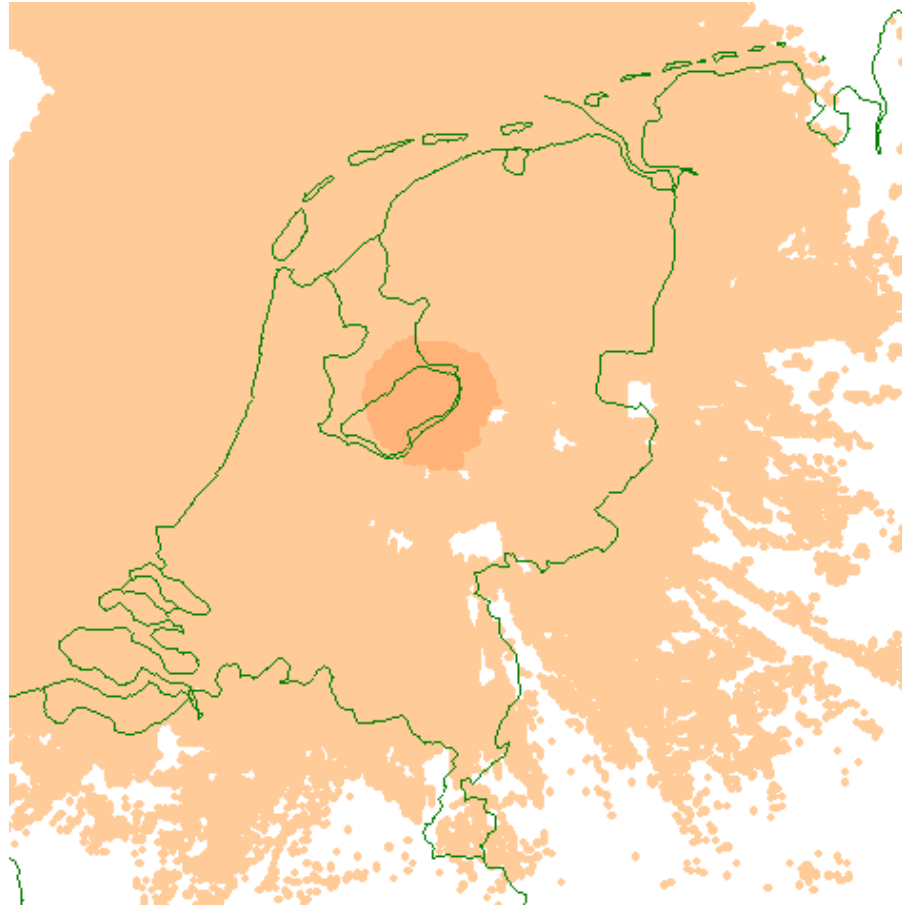


Figure 3.4: Exclusion zones for short-term criterion (light orange) and long-term criterion (dark orange) for satellite terminal Type 1 operating over YAMAL-601 at Biddinghuizen.

The figure below shows that the exclusion zone for the short-term criterion will only become approximately the same as the exclusion zone for the long-term criterion when the percentage of time for the short-term is raised from 0.005% to 4%. In this case the availability of the satellite links would become 96% of the time, which is considered to be unacceptably low as compared to the availability offered to customers (usually around 99.9%) and therefore deny current satellite services to be provided.

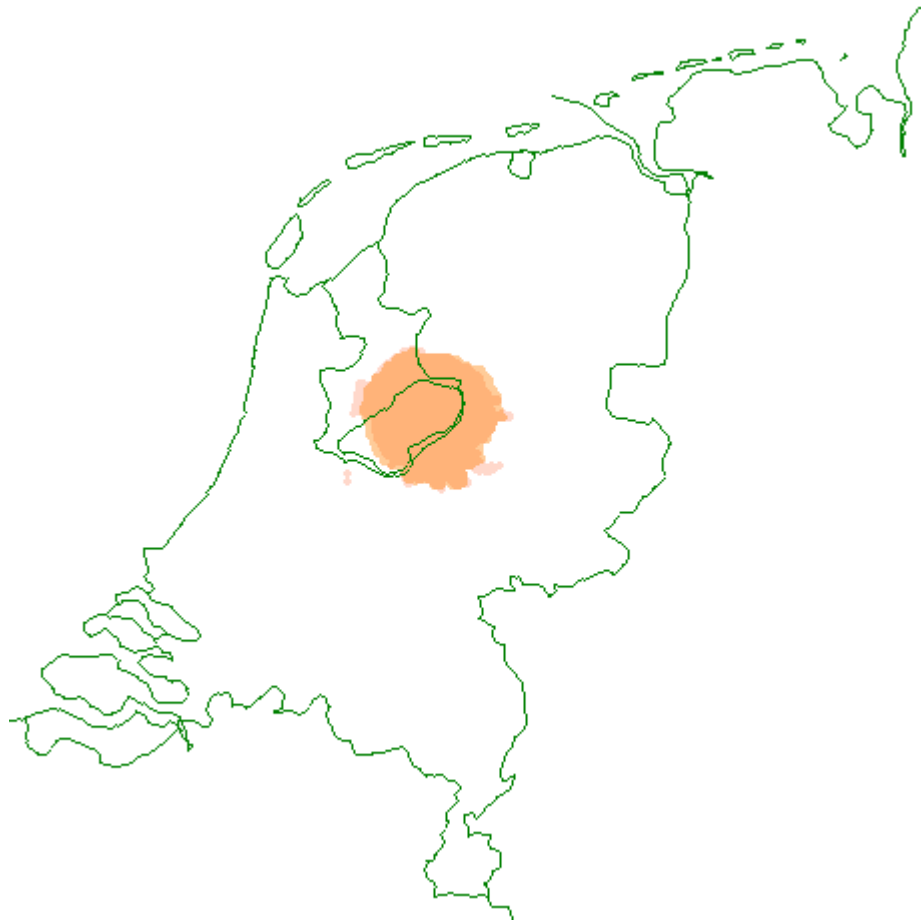


Figure 3.5: Exclusion zones for short-term criterion (light orange) and long-term criterion with time percentage of 4% instead of 0.005% (dark orange) for satellite terminal Type 1 operating over YAMAL-601 at Biddinghuizen.

Noting that the short-term criterion is dominating (and cannot be neglected), only the exclusion zones for the short-term criterion are considered in more detail. The figures below show the combined exclusion zones (in orange) of the satellite ground terminals of MOD-NL, Inmarsat, Castor Networks, Speedcast and Signalthorn respectively. The exclusion zones of each satellite ground terminal at a given location are shown as overlays in Figure 3.6 up to Figure 3.10, with a dark orange colour indicating overlapping exclusion zones while lighter orange indicate exclusion zones with no overlap.

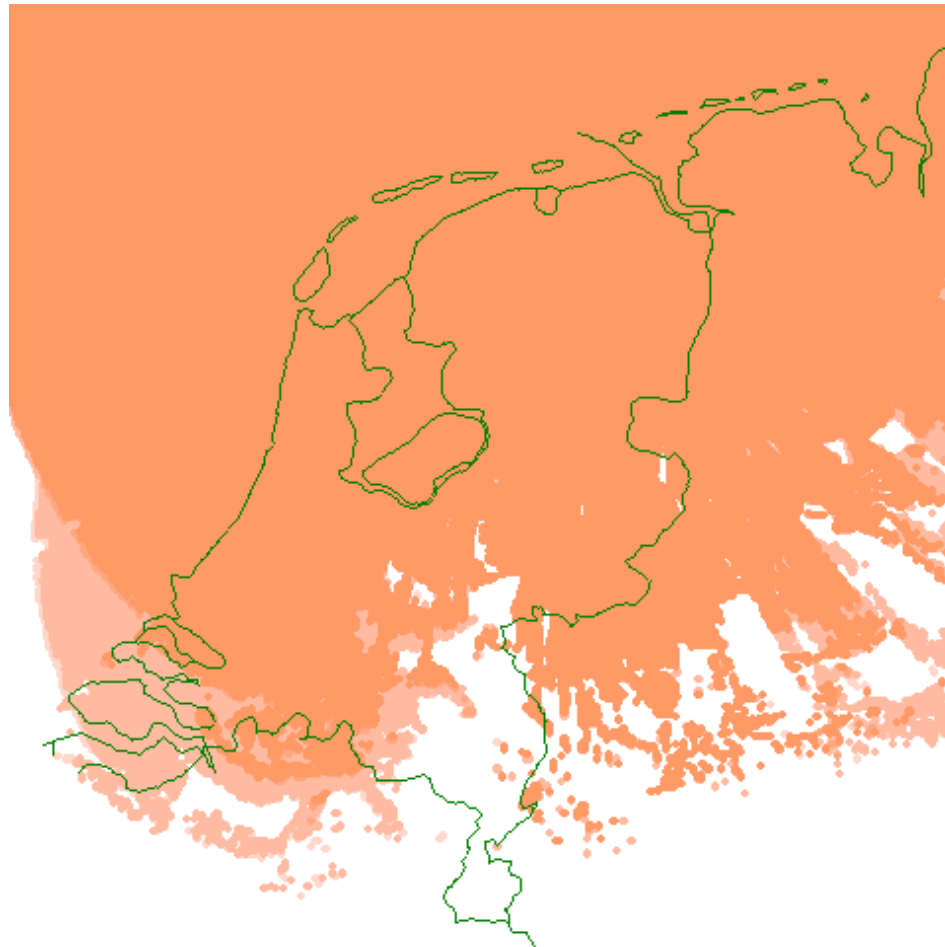


Figure 3.6: Exclusion zones of MOD-NL satellite ground terminals in Lauwersmeer.

In the Figure 3.6 the light orange coloured areas at the left bottom corner belongs to the exclusion zone of the satellite ground terminal operating over the Western satellite (SES-4, located at 22°W), while the light orange coloured areas at the right bottom corner belongs to the exclusion zone of the satellite ground terminal operating over the Eastern satellite (NSS-12, located at 57°E). The dark coloured areas belong to the exclusion zone of both satellite ground terminals.

The fact that e.g. Limburg - as compared to Zeeland - is not part of the exclusion zones is due to variations in terrain elevation.

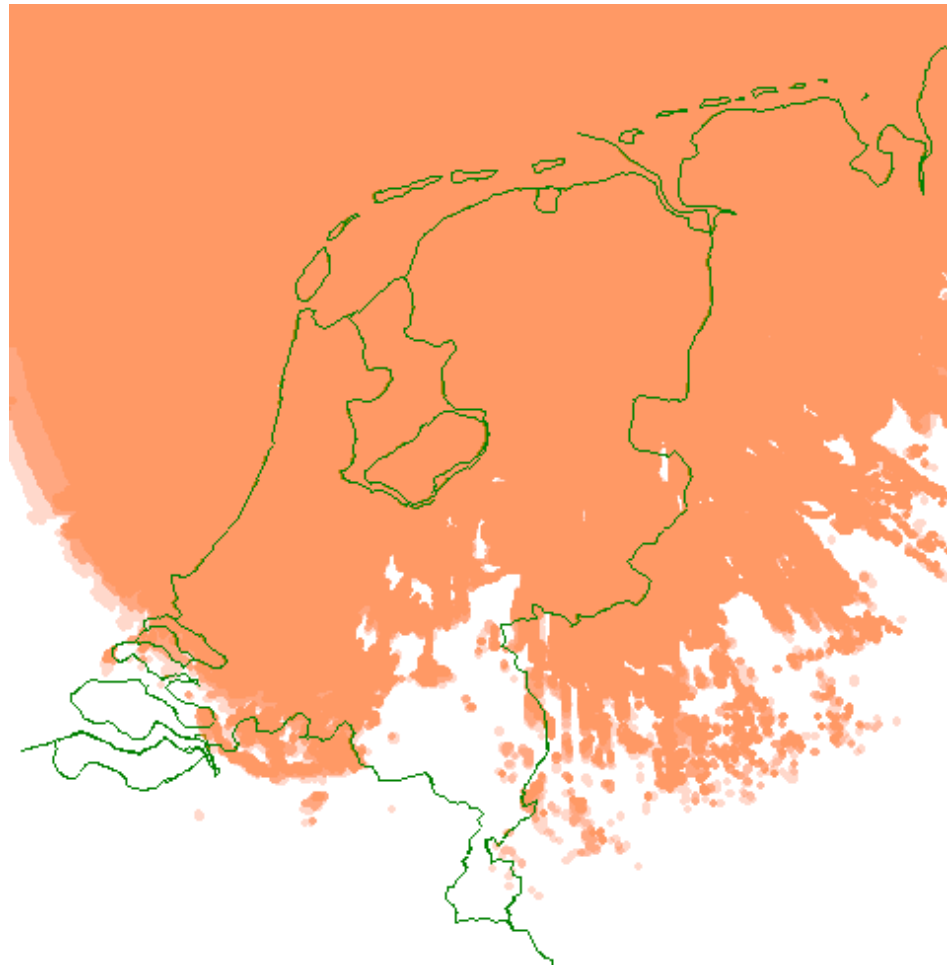


Figure 3.7: Exclusion zones of Castor Networks satellite ground terminals in Burum

The satellite ground terminals of Castor Networks are operating over Eastern satellites, located 17°E and 20°E respectively. Compared to MOD-NL, no satellite ground terminal is operating over a Western satellite, which is why the South-West part of Zeeland is not included in the exclusion zone.

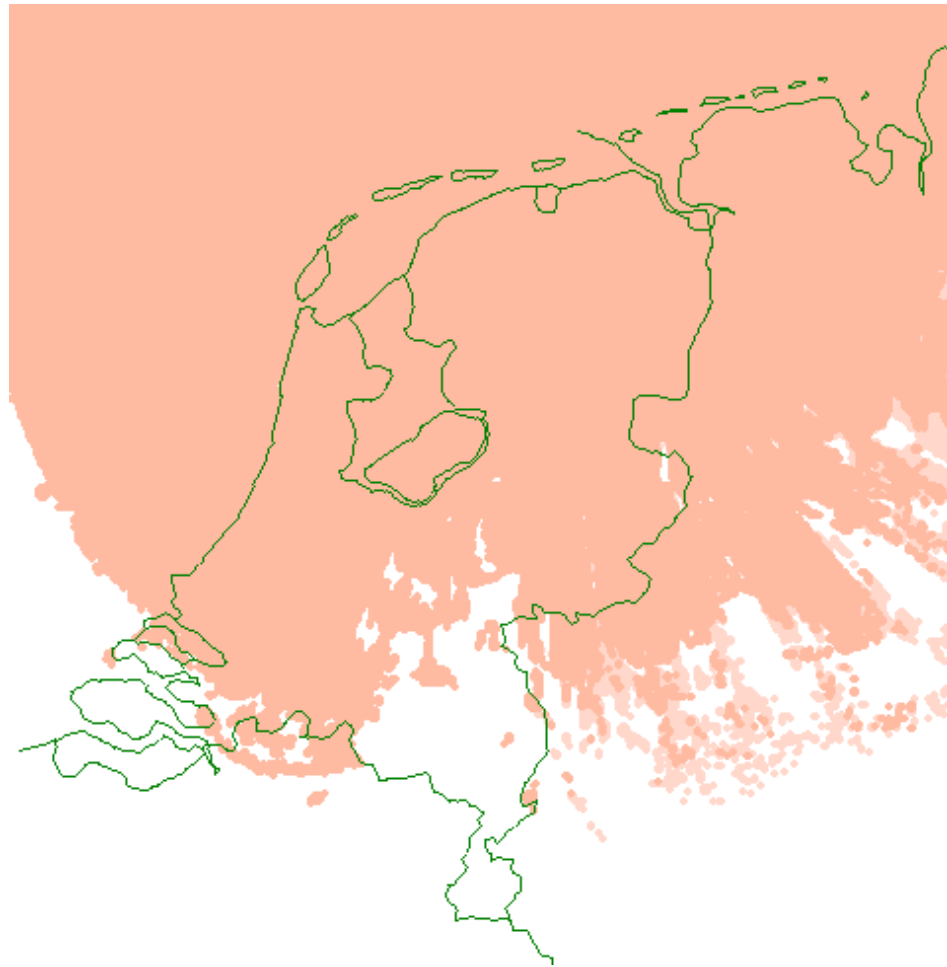


Figure 3.8: Exclusion zones of Inmarsat satellite ground terminals in Burum.

The satellite ground terminals of Inmarsat are both operating over Eastern satellites, located 57°E and 63.9°E respectively.

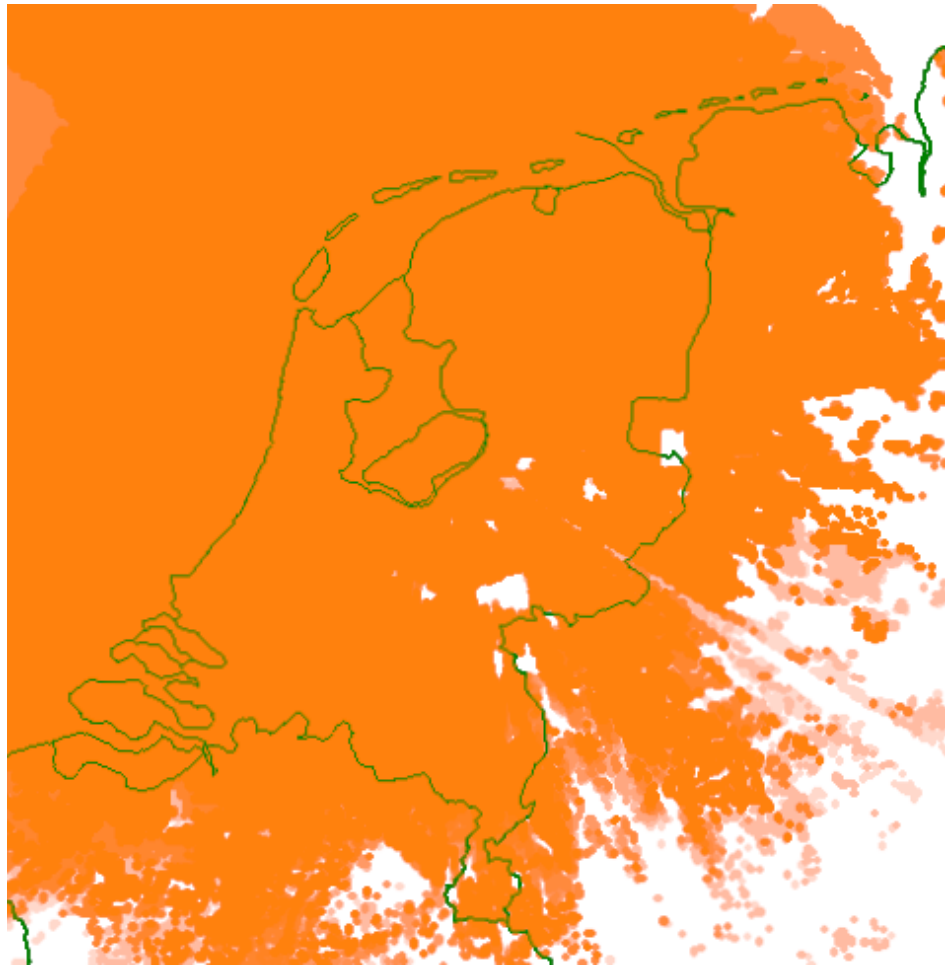


Figure 3.9: Exclusion zones of Speedcast satellite ground terminals in Biddinghuizen.

Speedcast has several satellite ground terminals (7) which can operate various satellites, located at 22°W, 3.1°E, 10°E, 17°E, 22°E, 49°E. Compared to MOD-NL, Inmarsat and Castor Networks, the satellite ground terminals of Speedcast are located more to the South and consequently the exclusion zones also extend more to the South.

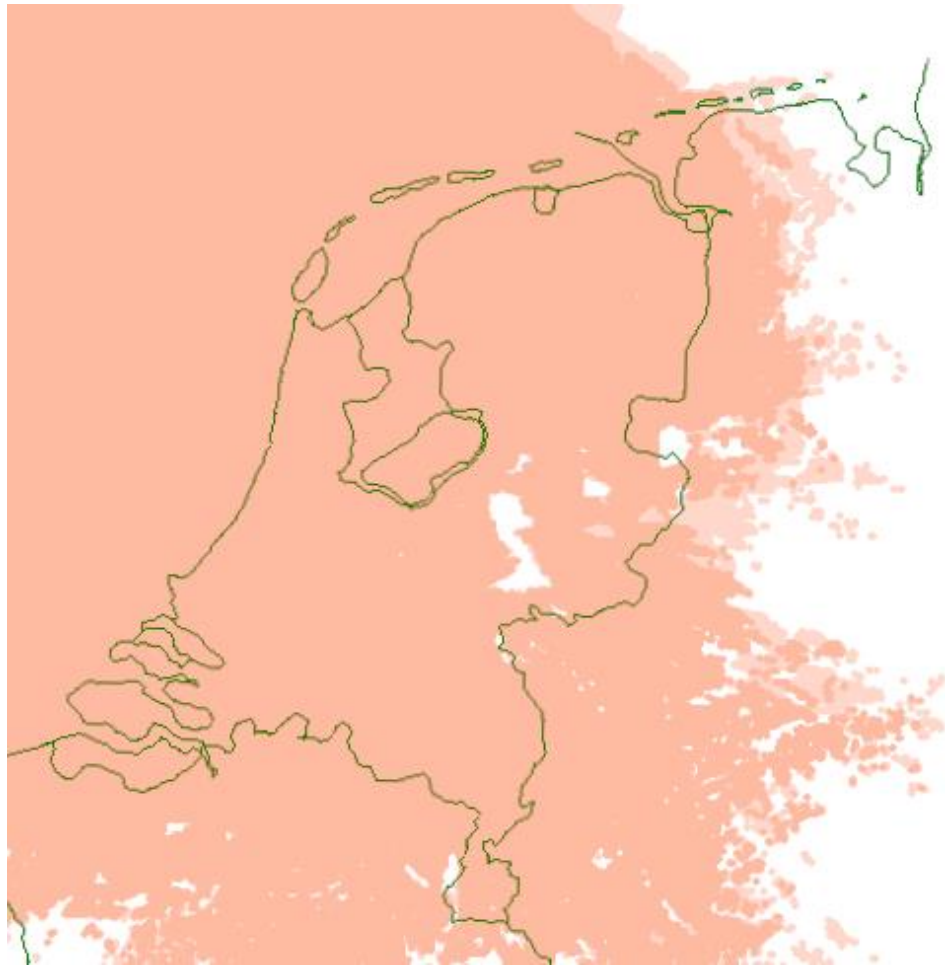


Figure 3.10: Exclusion zones of Signalhorn satellite ground terminals in Amsterdam/Amstelveen.

The two VSAT terminals of Signalhorn in Amsterdam and Amstelveen are located on top of buildings (at a height of 83 and 23 meter, respectively), due to which the exclusion zones are larger than the previously considered ones.

3.9.2 *Mitigation measures*

Various mitigation measures can be implemented to reduce the interference level experienced at the satellite ground terminals. The amount (in dB) by which the interference level is reduced at the satellite ground terminals will be called the mitigation effort, since a higher mitigation effort requires a combination of mitigation measures which are in general harder to be implemented or have a larger negative impact on cost and/or operational aspects.

Assuming a mitigation effort of 18 dB, the exclusion zones of the satellite ground terminals will become considerably smaller as shown in the figure below.

This figure also shows the effect of the pointing angles of the satellite ground terminals more prominently. For instance, in the North, three bulges are visible in the exclusion zones. The one pointing West belongs to the exclusion zone of the satellite ground terminal at Lauwersmeer pointing to SES-4 located at 22°W, the slightly detached bulge in the South belongs to the exclusion zones of the Castor

Networks satellite ground terminals, while the ones pointing East belong to the exclusion zone of the Inmarsat satellite ground terminals (light orange) and the satellite terminal at Lauwersmeer pointing to the NSS-12 satellite located at 57°E.

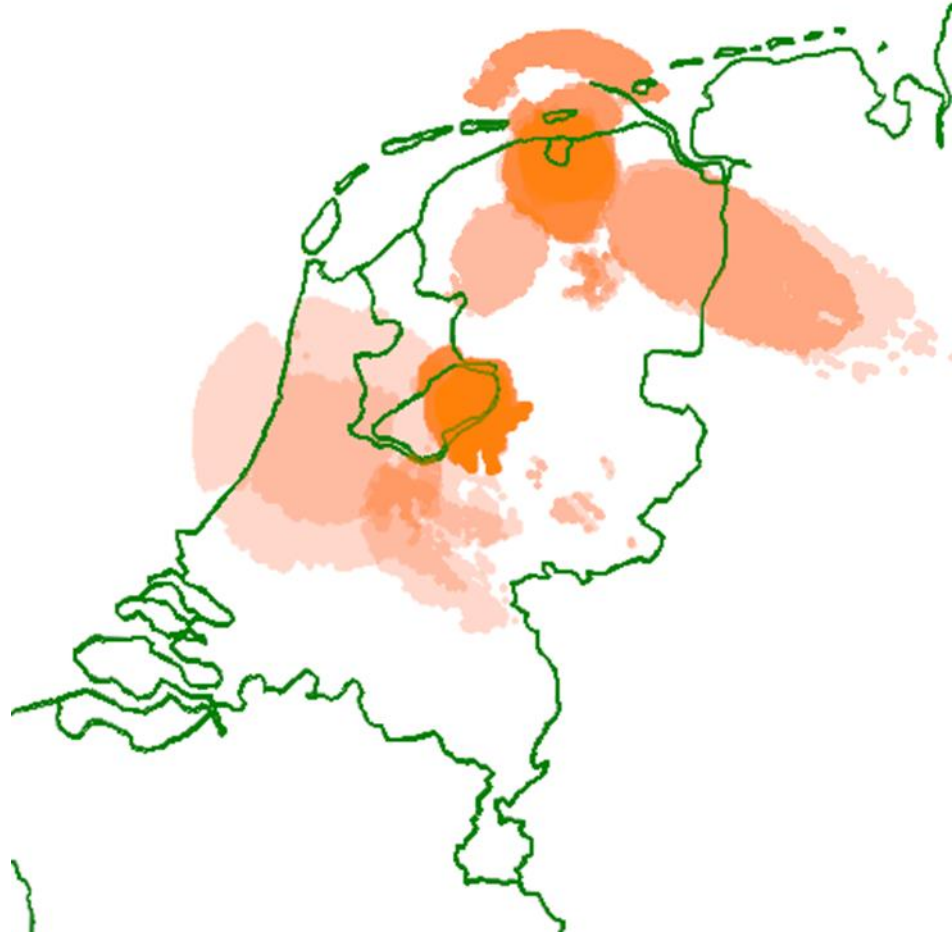


Figure 3.11: Exclusion zones for co-channel operation with 18 dB mitigation effort.

For co-channel operation a given mitigation effort can be realized in different ways, using any combination of any of the following mitigation measures available to IMT base stations:

- Lowering the EIRP density of the IMT base station(s).
- Using a down tilt of the IMT base station antenna.
- Using an IMT base station antenna which suppresses the emissions in the direction of the satellite ground terminals.
- Making use of Advanced Antenna Systems (beamforming, MIMO and cell shaping).
- Making use of clutter losses provided by e.g. high buildings in the neighbourhood of the IMT base station.
- Making use of already present shielding, for instance provided by the building when IMT is used indoor.

As an example, the clutter losses have been calculated for different clutter categories with a given nominal clutter height above ground level at a nominal

distance of the reference IMT base station mast with an antenna height of 10 meter. They are shown in Table 3.1.

Table 3.1 Clutter loss (according to Recommendation ITU-R P.452 [10])

Clutter category	Nominal height (m)	Nominal distance (m)	Clutter loss (dB)
Dense suburban	12	20	1.2
Mixed tree forest	15	50	7.0
Urban	20	20	16.1
Dense urban	25	20	18.5
High-rise urban	35	20	19.4
Industrial zone	20	50	15.6

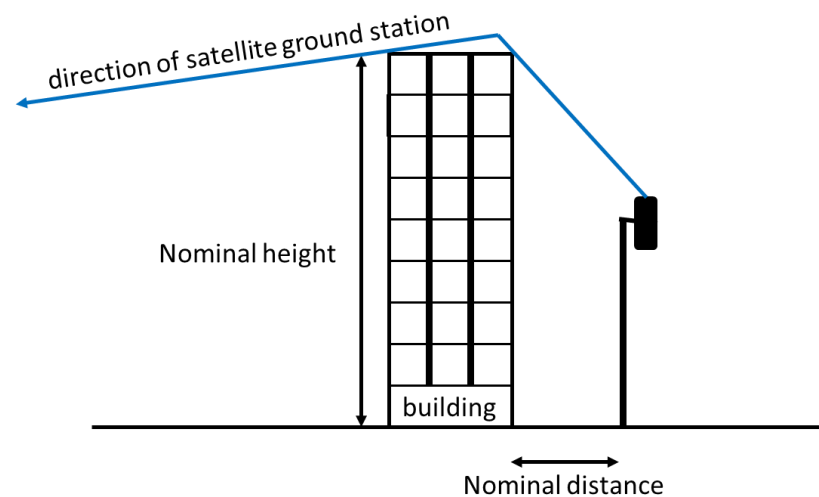


Figure 3.12: Geometry clutter loss (ITU-R P.452).

Since IMT networks are considered for local use, they will differ widely in objectives (like services to be supported) and environments in which they are deployed. For each specific IMT network, the most suitable combination of mitigation measures has to be tailored to meet the specific objectives and environments at the lowest cost and operational impact.

Similar, owners of the satellite ground terminals might be willing to contribute to, or accept the implementation of, mitigation measures on their side like:

- Using dishes with improved radiation patterns on their satellite ground terminals (or, if they have the actual measured radiation patterns of the dishes which are better than those used here, recalculate the exclusion zones to see what improvements can be obtained).
- Provide shielding.
- Accepting less stringent coexistence criteria (short-term criterion).

The replacement of dishes with ones having better radiation patterns (obtainable by e.g. an increased dish size) is less likely to be acceptable considering the cost,

available space on the site and the fact that some of the dishes already have a considerable size. Shielding has also been shown to be difficult to achieve, especially when multiple satellite ground stations are operated on the same site [11]. The acceptance of less stringent coexistence criteria (short-term criterion) could possibly be negotiated with the involved parties. This is out of scope of this study, but to indicate what it can contribute to the mitigation effort the following examples can be used.

As shown in Figure 3.13 and Figure 3.14, accepting a higher time percentage for the short-term criterion of 0.05% (instead of 0.005%) has about the same effect on the exclusion zone as a reduction of the reference IMT base station EIRP density from 43 to 38.2 dBm/5 MHz, corresponding to a mitigation effort of 4.8 dB.

Similar, if links are operated at a higher fading/link margin M_s of 3 dB instead of the 2 dB assumed for the short-term criterion, the maximum permissible interference level (not to be exceeded for more than 0.005% of the time) increases by 2.33 dB which is equivalent to a mitigation effort of 2.33 dB.

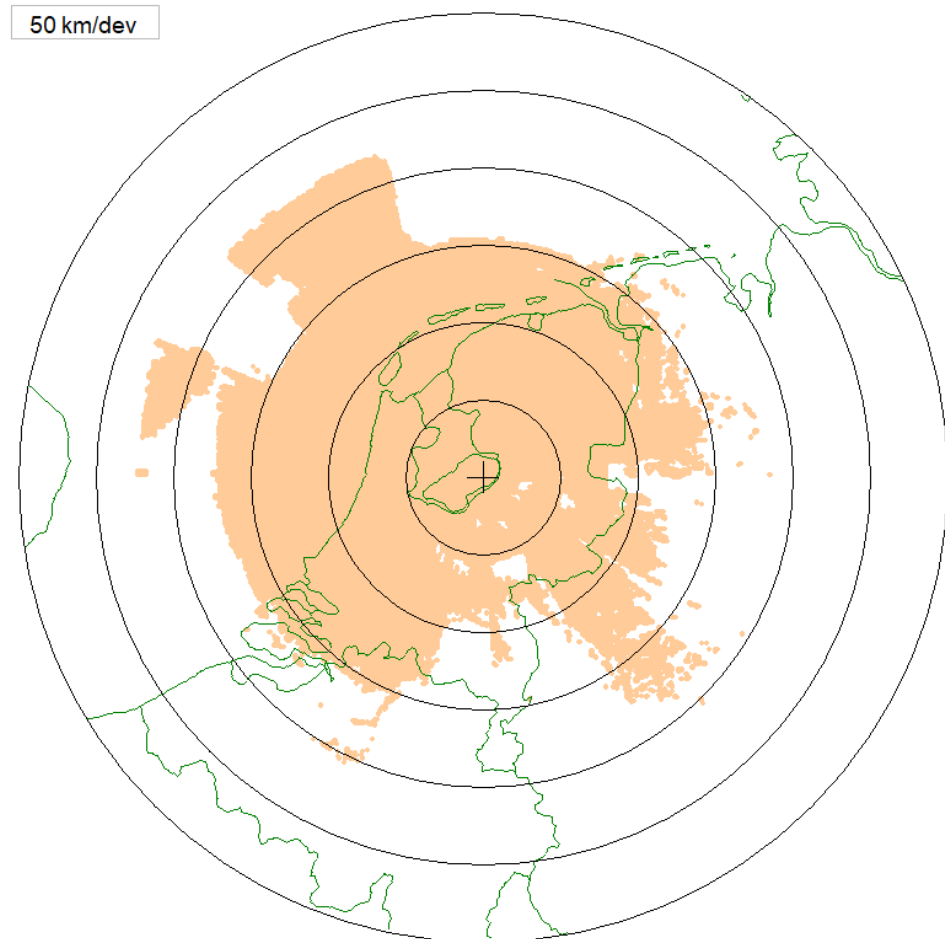


Figure 3.13: Effect of less stringent short-term criterion (0.05% instead of 0.005%) on the exclusion zone of the satellite ground terminal Type 1 operating over YAMAL-601 at Biddinghuizen (for a reference IMT base station).

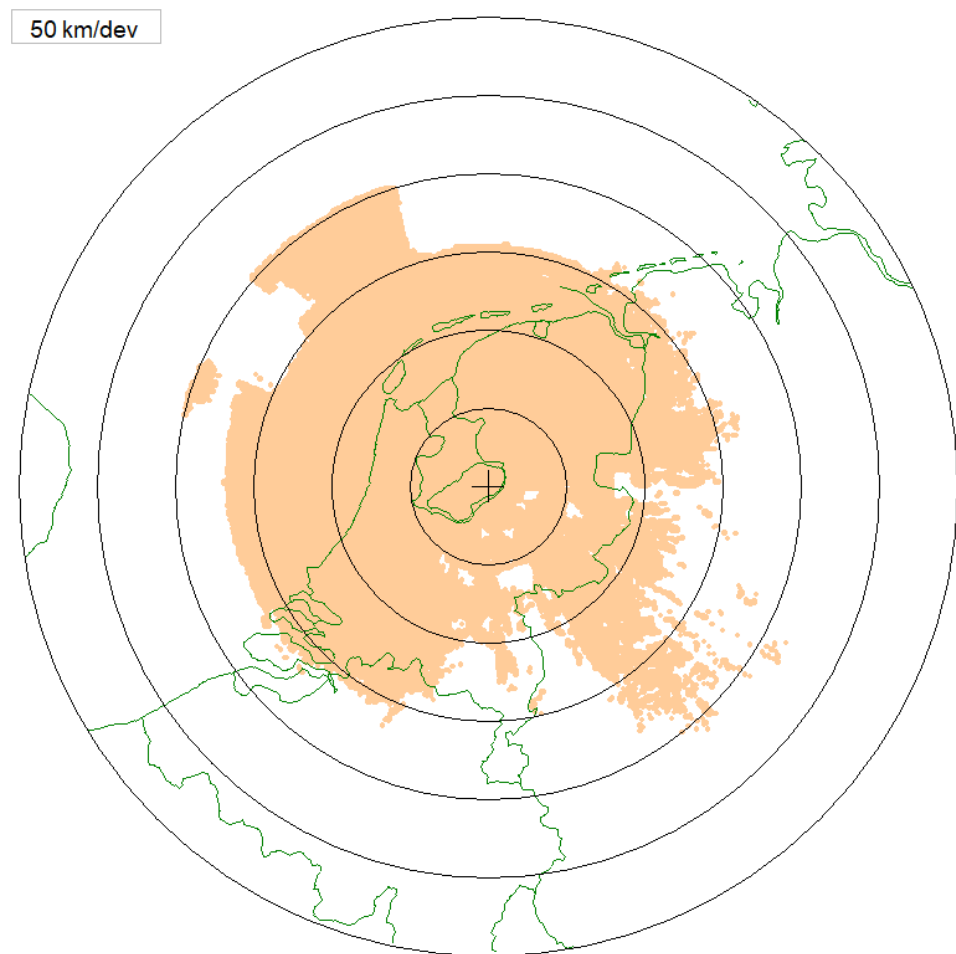


Figure 3.14: Exclusion zone of the satellite ground terminal Type 1 operating over YAMAL-601 at Biddinghuizen (short-term criterion of 0.005%) for a reference IMT base station with 4.8 dB mitigation effort.

3.9.3 Multiple IMT base stations

The exclusion zones shown in Figure 3.11 are for single IMT base station with a mitigation effort of 18 dB and co-channel operation. Co-channel operation allows the full 3800-4200 MHz band to be used by a single IMT base station. Alternatively, the 400 MHz wide bandwidth may be split up in e.g. 8 mutual exclusive 50 MHz sub-bands, which can then be allocated to 8 different IMT base stations. This will not change the exclusion zones and each of the 8 IMT base stations can simultaneously be deployed on the edge (or outside) of the exclusion zone.⁶

Depending on the number of IMT base stations to be accommodated in the 3800-4200 MHz band, just 8 (like in the above example) might not suffice. In this case it could be considered to let multiple IMT base stations use the same frequency sub-band. This will have an impact on the exclusion zones and the impact will be different for IMT base stations, using the same sub-band, being deployed at dispersed locations (such that propagation losses on each path can be assumed

⁶ Note that in both cases the interference density experienced at the satellite ground terminal remains the same in the whole frequency band.

uncorrelated) or in close vicinity of each other (such that propagation losses on each path can be assumed to be correlated).

As an example, five reference IMT base stations are considered using the same sub-band and assuming 18 dB mitigation effort (EIRP of 25 dBm/5 MHz). For this case the exclusion zone for the Type 1 terminal at Biddinghuizen, operating over the YAMAL-601 satellite (at 49°E), has been calculated as an example, which is shown in the figure below. In this case, each of the five reference IMT base stations is assumed to be located on the edge of the exclusion zone.

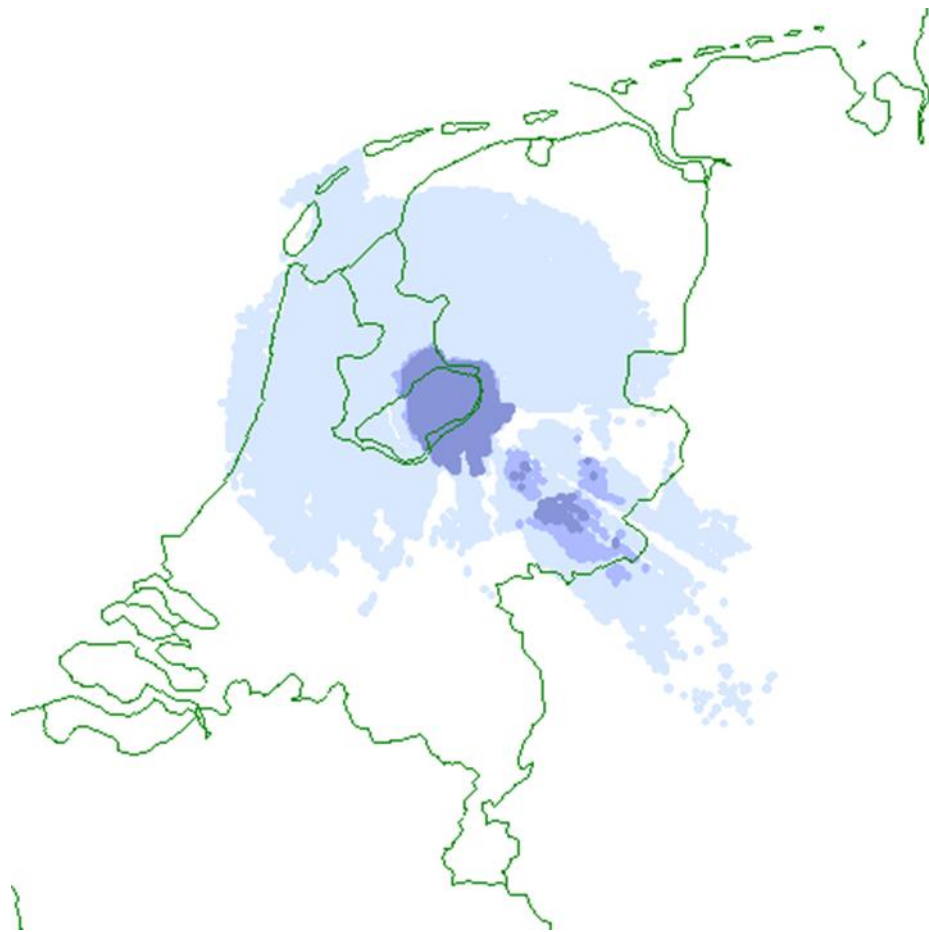


Figure 3.15: Exclusion zones for co-channel operation with a single reference IMT base station at a reduced EIRP density of 25 dBm/5MHz (darkest blue) and 5 reference IMT base stations base stations at a reduced EIRP density of 25 dBm/5MHz operating in the same sub-band, either at dispersed locations (medium blue) or approximately the same location (light blue).

As shown in this figure, the exclusion zone for five IMT base stations deployed at dispersed locations (medium blue) is only slightly bigger compared to the exclusion zone for a single IMT base station (dark blue). In case the five IMT base stations are deployed in close vicinity of each other (light blue), the exclusion zone is significantly increased.

This is caused by the (varying) propagation loss experienced on the paths between IMT base stations and the satellite ground terminal. In case the IMT base stations are deployed at dispersed locations, the propagation losses on the different paths are considered uncorrelated meaning that a low propagation loss is unlikely to occur on all paths simultaneously. Considering the short-term criterion this means that the maximum permissible interference due to each of the five IMT base stations should not be exceeded for more than 0.001% of the time. In case the five IMT base stations are collocated, the propagation losses on the paths are correlated (since all paths are nearly identical). Considering the short-term criterion, this situation is equivalent to one IMT base station with 7 dB more EIRP, which should not exceed the maximum permissible interference during 0.005% of the time.

Considering the results, it is therefore advantageous to allocate the same sub-band to dispersed deployed IMT base stations.

3.10 Exclusion zones for adjacent channel operation

3.10.1 *Single reference IMT base station*

A **single** reference IMT base station, operating in a sub-band not in use by a satellite ground terminal to receive satellite signals (adjacent channel operation), will cause the long-term criterion (which is dominating) to be exceeded when located in the exclusion zones (orange-coloured areas) shown in the Figure below. The exclusion zones corresponding to the blocking and short-term criterion, which also have to be met, are much smaller for all satellite ground terminals (for Signalthorn in Amsterdam/Amstelveen this is shown in Figure 3.16 by the tiny slightly darker orange spot in the middle of the larger exclusion zones)⁷.

⁷ These tiny spots also occur at the other location but are not visible due to the many overlays (one overlay for every terminal/satellite combination).



Figure 3.16: Exclusion zones of all satellite ground terminals.

The relatively large exclusion zones of the satellite ground stations of Signalthorn in Amsterdam and Amstelveen are due to the fact that these terminals are placed on top of high buildings (83 m in Amsterdam and 23 m in Amstelveen).

3.10.2 *Mitigation measures*

Although mitigation measures are usually aimed at reducing the large exclusion zones in co-channel operation, mitigation measures can also be implemented to reduce the already small exclusion zones in adjacent channel operation or to compensate the growth of the exclusion zones due to the deployment of multiple IMT base stations.

For adjacent channel operation, mitigation measures can be aimed at:

- Reducing the total aggregated received signal power originating from IMT base stations (blocking criterion). This can be achieved with the same mitigation measures as mentioned at co-channel operation and in addition by placing wave-guide filters before the LNA's of the satellite ground terminals (to filter out the IMT signals).
- Reducing the adjacent channel interference (long-term criterion), by lowering the spurious emissions of IMT base stations. It seems technically possible to reduce the spurious limit from -30 dBm/MHz to -50 dBm/MHz

and can significantly reduce the exclusion zone as shown in the figure below.



Figure 3.17: Effect of lowering the spurious of a reference IMT base station from -30 dBm/MHz (light orange) to -50 dBm/MHz (dark orange) on the exclusion zone (long-term criterion) of the satellite ground terminal Type 1 operating over YAMAL-601 at Biddinghuizen.

3.10.3 Multiple IMT base stations

The exclusion zones shown in the figures above are for single reference IMT base station and adjacent channel operation. Adjacent channel operation allows an IMT base station to be deployed in a very large part of the Netherlands. The disadvantage is that an IMT base station can only make use of the sub-bands that are not in use by any of the satellite ground terminals.

Assuming a sub-band is available for IMT, it could be considered to let multiple IMT base stations make use of this sub-band. This will have an impact on the exclusions zones. As an example, five reference IMT base stations are considered using the same sub-band, each with an EIRP density of 43 dBm/5MHz. For this case the exclusion zone for the Type 1 terminal at Biddinghuizen, operating over the YAMAL-601 satellite (at 49°E), has been calculated as an example, which is shown in the figure below. In this case, each of the five reference IMT base stations is assumed to be located on the edge of the exclusion zone.



Figure 3.18: Exclusion zones for adjacent channel operation with a single reference IMT base station (darkest orange) and 5 reference IMT base stations (lighter orange).

The exclusion zone in this case is mainly determined by the IMT base stations close to the satellite ground terminal⁸.

In this case it makes no difference whether the IMT base stations are dispersed or collocated (as it did in co-channel operation). This is caused by the large difference in time percentages between the short- and long-term criterion (0.005% versus 20%). Due to this, the short-term criterion has to deal with exceptional propagation conditions (like ducting, which occur more locally), while the long-term criterion has to deal with much more frequently occurring propagation conditions (line-of-sight or nearly line-of-sight).

⁸ The total interference density experienced by the satellite ground terminal due to five IMT base stations on the edge of the exclusion zone belonging to one IMT base station will be five times as high as for one IMT station (note that the interference is now caused by spurious, which is emitted in the whole frequency band and with the same level by each IMT base station). To compensate this (reduce this to the permissible level), the exclusion zone has to be slightly increased.

3.11 Coexistence

A single reference IMT base station operating in a sub-band within the 3800-4200 MHz band has to meet the coexistence criteria of all satellite ground stations simultaneously. This means that the IMT base station cannot be deployed:

- Inside any of the exclusion zones of the satellite ground terminals which operate in the same sub-band (co-channel operation), nor
- Inside any of the small exclusion zones of the satellite ground terminals which operate in different sub-bands (adjacent channel operation).

In co-channel operation IMT can make use of the full 3800-4200 MHz band, albeit at the cost of a very limited deployment area or a substantial mitigation effort.

In adjacent channel operation IMT can be deployed in the largest part of the Netherlands, albeit at the cost of a lower bandwidth being available for IMT since sub-bands in use by satellite ground terminals will have to be excluded from use by IMT.

In general, a combination of adjacent channel operation with part of the satellite ground terminals and co-channel operation with the other part of satellite ground terminals (simultaneously) is the most likely scenario to be considered for IMT deployment based on the considerations below.

Inmarsat

Considering Inmarsat, only a fairly small bandwidth of 9 MHz (3946-3954 MHz) is in use for TT&C links which carrier frequencies cannot be changed due to satellite limitations. Considering this small fixed frequency sub-band in use and the importance of these links for control of the satellites, it is advisable to exclude this sub-band from use by IMT (i.e. only adjacent channel use by IMT).

Signalhorn

Signalhorn intends to use the limited bandwidth within the 3800-3850 MHz band on the YAMAL-601 for a long period of time (until 2030 and beyond)⁹. Also considering the relative large coordination zone (see Figure 3.11) required for co-channel operation, even with 18 dB mitigation effort, it is advisable to exclude this sub-band from use by IMT (i.e. only adjacent channel use by IMT).

MOD-NL

Currently MOD-NL only uses a relatively small amount of bandwidth. This use may however change, depending on the missions which have to be supported. Adjacent channel operation of IMT could therefore be possible using Shared Access model which takes into account the dynamic use of the 3800-4200 MHz band by MOD-NL.

Speedcast

Speedcast is currently using a considerable bandwidth, a total of 289 MHz. In addition, it has a license application in progress for 12 blocks of 19.2 MHz (total of 230 MHz bandwidth) located within the 3801-4125 MHz band on the AMOS-17 satellite, which will result in a total bandwidth of 519 MHz¹⁰ being used by

⁹ Unless the satellite operator decides otherwise.

¹⁰ Spread in blocks over the 3800-4200 MHz band.

Speedcast in the near future. As noted in section 2.6, the actual use of spectrum by Speedcast is also highly dynamic. Sub-bands with sufficient bandwidth, which are also available for a reasonable amount of time, to be attractive for IMT use in adjacent channel operation can be expected to be limited to non-existing and co-channel operation might be the only option.

Castor Networks

Castor Networks is currently using only a limited amount of bandwidth, which suggest that adjacent channel operation by IMT is possible. However, this situation may change in the near future when a total of 356 MHz is expected to be needed (to support a project currently in the acquisition phase) due to which co-channel operation by IMT might become the only option.

Summarising, currently and in the near future, Speedcast and Castor Networks will be limiting the shared use by IMT of the 3800-4200 MHz band the most. Co-channel operation might be the only option for IMT. In this case, to obtain a reasonably large deployment area for IMT, a substantial mitigation effort is needed to reduce the exclusion zones of the satellite ground terminals of Speedcast and Castor Networks.

From an IMT point of view, it is difficult to determine in general whether a substantial mitigation effort can be easily achieved in each case and whether or not the impact of the required mitigation measures on the application/service (in terms of e.g. coverage) are acceptable. This will have to be further investigated in order to be able to grant licenses for future local IMT networks.

Considering future developments, the sharing of the 3800-4200 MHz band by IMT and satcom may get more complicated, for instance when:

- New satellite ground terminals are introduced and operated at other locations than considered in this report (for instance in Limburg, introducing new exclusion zones to take into account).
- More bandwidth is being used by satellite ground terminals, to accommodate new users (lowers possibilities for adjacent channel operation).
- More or other satellites are being used by satellite ground stations (introducing new, or affecting existing, exclusion zones).

If any of these changes occurs, already taken mitigation measures may no longer be sufficient to deal with the new situation. Of course, the reverse situation could also occur, like a decreasing number of customers or a transition to the use of higher frequency bands which would increase the opportunities for coexistence.

3.12 Shared Access Licence in the UK (Ofcom)

The criteria and conditions for shared access in the 3800-4200 MHz band in the UK can be found in [24]. Although this document covers shared access in several frequency bands and also contains criteria and conditions relevant to mutual interference between IMT networks, only those relevant for coexistence of IMT and satellite ground terminals in the 3800-4200 MHz band are relevant for this study and will be considered here.

For each licence application for a specific location, Ofcom will assess interference to and from other licensees in the band, based on the coordination parameters and methodology outlined in the document [24]. Assignments are made on a first come, first served basis with regards to other users in the band.

3.12.1 *Types of licence*

There are two types of licences to cater for different types of potential uses [24, par 2.4]:

- **Low power licence** for local connectivity (per area licence).
This allows users to deploy as many base stations as they like within a 50-metre radius circle without further authorisation from Ofcom. Licensees can apply for multiple licence areas if the required coverage area is larger than the coverage area defined by a single licence.
- **Medium power licence** for longer range connectivity (per base station licence).
Given the higher transmit power and larger potential interference area, medium power base stations are authorised on a per base station basis and deployments are limited to rural areas only.

Usage will be designated for indoor or outdoor use.

3.12.2 *Base stations*

The requested bandwidth (BW) for both low and medium power base stations can be either 10, 20, 30, 40, 60, 80 or 100 MHz [24, section 4].

The maximum EIRP of base stations is [24, section 4]:

- 24 dBm/BW for BW < 20 MHz or 18 dBm/5MHz for BW > 20 MHz for a low power licence
- 42 dBm/BW for BW < 20 MHz or 36 dBm/5MHz for BW > 20 MHz for a medium power licence

For bandwidths exceeding 20 MHz, the maximum EIRP of 36 dBm/5 MHz (medium power licence) is 7 dB below the 43 dBm/5 MHz used for the reference IMT base station in this study (see par. 3.3).

The antenna height of base stations is limited to 10 m for a low power licence only [24, section 4].

The transmit mask [24, section 3.8] indicates that the maximum spurious level (see Figure 3.1) is 53 dB below the maximum EIRP of 36 dBm/5MHz for a medium power licence, corresponding to a maximum spurious level (EIRP) of -17 dBm/5MHz or -24 dBm/MHz. This is 8 dB below the spurious level of -16 dBm/MHz of the reference IMT base station used in our study (see par. 3.3).

3.12.3 *Indoor/Outdoor*

Indoor use is assumed to provide an additional 12 dB attenuation (shielding provided by the building) [24, section 3.3].

3.12.4 *Licensing tool*

The licensing tool has a set coordination area per station type. For satellite ground stations (denoted by PES in [24]) the coordination area is the circular area with radius of 287 km around the satellite ground station [24, Annex A2].

Note: For a base station located within (each) coordination zone, an interference analysis calculation is performed as described below. In the Netherlands the coordination zones would encompass the whole country. This is why exclusion zones are considered in our study, to show what is possible within the coordination zones based on the criteria.

For inter-service coordination, where the Shared Access station (IMT base station) is the interferer, the interference analysis calculation will be derived from the affected station's (i.e. satellite ground stations) technical frequency parameters [24, par 3.6].

The interference analysis calculation checks if the following criteria are met:

- The short-term criterion, as defined in section 3.6.1, but with a maximum increase of the satellite receiver noise level of 100% (0 dB) instead of 73.6% (or -1.329 dB) as used in our study.
- The long-term criterion, as defined in section 3.6.2.

Although [24, par 6] states that proposed stations will be coordinated with co-channel and adjacent channel Earth stations (i.e. satellite ground stations), only the above co-channel criteria are stated. This may suggest that only co-channel operation is considered.

3.12.5 *Calculations*

The calculations are performed using the propagation model ITU-R P.452, which is the same model as being used in our calculations. Ofcom does take clutter losses into account, which is possible because the exact location of the base station is known (which has to be provided in the licence request).

3.12.6 *Comparison sharing opportunities UK and NL*

Ofcom has predicted the likely initial spectrum availability in the 3800-4200 MHz band based on their proposed protection criteria for incumbent services. They have taken account of the current deployments of satellite Earth stations, fixed links (after clearance of the 3.6-3.8 GHz band) and the currently coordinated UK Broadband deployments in 3925-4009 MHz. The predicted spectrum availability is shown in 'Consultation: Enabling opportunities for innovation', which together with other useful information can be found at: <https://www.ofcom.org.uk/consultations-and-statements/category-1/enabling-opportunities-for-innovation>.

Figure 28, concerning available spectrum for medium power outdoor base stations, is shown below with the Netherlands as overlay, just to show that in the UK sharing opportunities are better, because the UK covers a larger area than the Netherlands and almost all satellite ground terminals are located in the Southern part of the UK. In addition, terrain in the UK provides more shielding compared to the Netherlands.

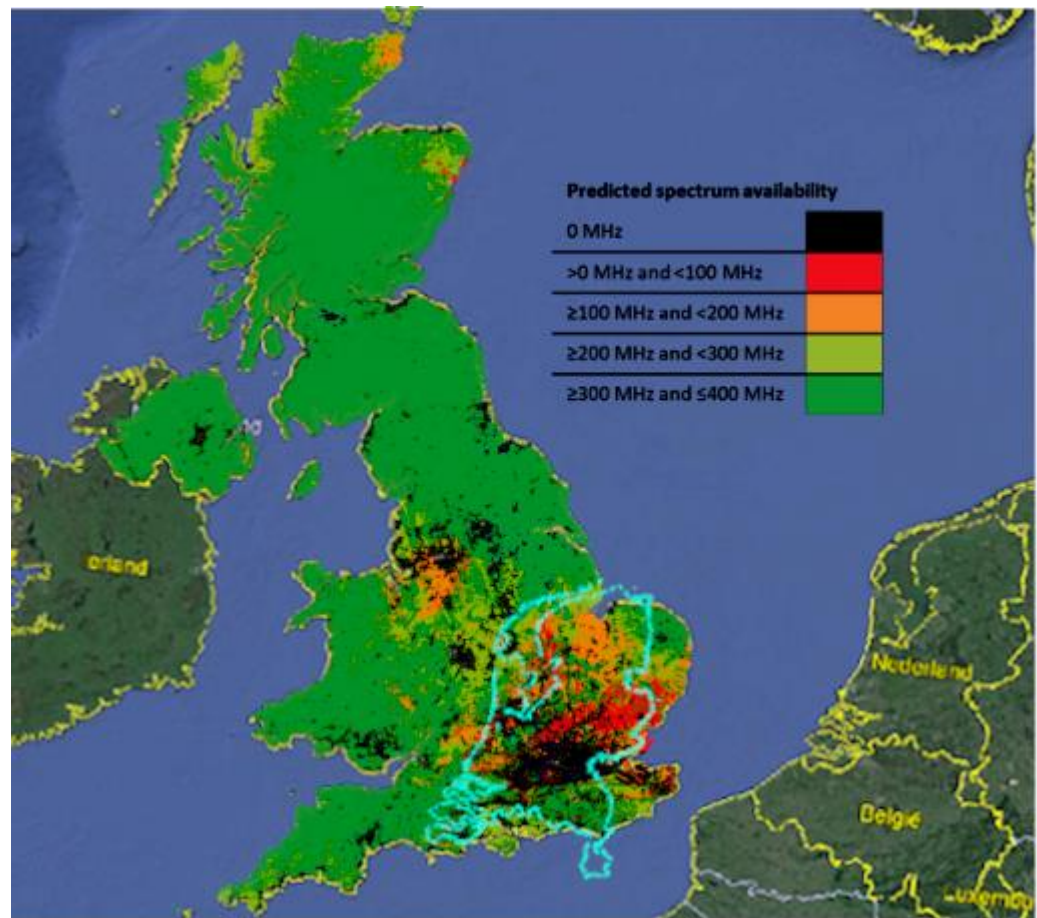


Figure 3.19: Predicted spectrum availability in the UK (by Ofcom).

3.13 Conclusions

Each IMT base station operating in a sub-band within the 3800-4200 MHz band has to meet the coexistence criteria of all satellite ground stations simultaneously. This means that the IMT base station cannot be deployed:

- Inside any of the exclusion zones of the satellite ground terminals which operate in the same sub-band (co-channel operation), nor
- Inside any of the exclusion zones of the satellite ground terminals which do not operate in the same sub-bands (adjacent channel operation).

Co-channel operation will allow the full frequency band of 3800-4200 MHz to be used by IMT. The area in which the IMT can be deployed will however be limited by the exclusion zones of the satellite ground terminals. These exclusion zones cover a large part, if not all, of the Netherlands, but can be significantly reduced by implementing mitigation measures.

Adjacent channel operation allows IMT to be deployed in the largest area within the Netherlands. However, sub-band(s) not in use by the satellite ground terminals with sufficient bandwidth to accommodate broadband applications (from 50 to 100 MHz) which are available for a sufficient period of time to be useful for IMT may be hard to find.

It should be noted that in this study the exclusion zones have been determined for reference IMT base stations with an EIRP of 43 dBm/5 MHz. In case of co-channel operation it is assumed that either a single reference IMT base station uses the full 400 MHz bandwidth (3800-4200 MHz) or that a number of reference IMT base stations each use a smaller mutual exclusive sub-band (e.g. the available bandwidth of 400 MHz may be divided in 8 mutual exclusive sub-bands of 50 MHz, to support 8 reference IMT base stations, each using one of these sub-bands of 50 MHz). In case of adjacent channel operation each available sub-band, not in use by a satellite ground terminal, is assumed to be only used by one of the reference IMT base stations.

Whenever multiple reference IMT base stations are deployed using the same sub-band, the exclusion zones have been shown to increase. Especially in co-channel operation, this re-use of the same frequency sub-band by a number of IMT base stations will have a large impact on the size of the exclusion zones when these IMT base stations are deployed at approximately the same location.

The current opportunities for IMT and satellite ground terminals to share the 3800-4200 MHz band can be summarized as follows.

Inmarsat and Signalthorn use only a small portion of the 3800-4200 MHz band which will hardly change in time. MOD-NL is also using a relatively small portion of the 3800-4200 MHz band, but this may change, depending on the missions which have to be supported. Adjacent channel operation of IMT could therefore be possible using e.g. a Shared Access model which takes into account the more dynamic use of the 3400-4200 MHz band by MOD-NL.

Speedcast and Castor Networks will however be limiting the shared use by IMT of the 3800-4200 MHz band, since they use a large portion (if not most) of the 3800-4200 MHz band. Co-channel operation might therefore be the only option for IMT. In this case, to obtain a reasonable large deployment area for IMT, a substantial mitigation effort is needed to reduce the exclusion zones of the satellite ground terminals of Speedcast and Castor Networks.

From an IMT point of view, it is difficult to determine in general whether a substantial mitigation effort (e.g. a lower EIRP or lower antenna height) can be easily achieved in each case and whether or not the impact of the required mitigation measures on the application/service (in terms of e.g. coverage) are acceptable. This will have to be further investigated in order to be able to grant licenses for future local IMT networks.

Shared Access in the UK provides incumbent users (satellite ground terminals) protection based on same principles as used in this report, albeit with some mitigation measures already included (7 dB lower EIRP, 8 dB lower spurious level and a slightly loosened short-term criterion). For each licence request (in order of arrival) the co-existence criteria are checked. If the co-existence criteria are met, the licence is granted.

Compared to the Netherlands, the sharing opportunities in the UK are better, due to the much larger size of the UK, the satellite ground terminals being mostly located

in the South of the UK and the more undulated terrain in the UK providing better shielding compared to the 'flat' terrain in the Netherlands. Applying the same shared access policy (and rules) as in the UK, may therefore result in much less opportunities for IMT networks in the Netherlands to make use the 3800-4200 MHz band.

At last, it should be noted that the results presented are valid for the assumed reference IMT base station (as defined in section 3.3). Allowing a higher EIRP density or higher antenna heights¹¹ to meet the needs of IMT networks, will increase the exclusion zones. In addition, the Interception Facility has not been taken into account in this study, as noted in section 2.2. In case this facility is required to be able to intercept all satellite signals within the 3800-4200 MHz band, co-channel operation will be the only option for IMT.

¹¹ Commercially available equipment allows the assumed characteristics of the reference IMT base station to be exceeded. This means that limitations should be included in the licences for IMT networks.

4 Interference of IMT networks on radar altimeters in 4200-4400 MHz band

This chapter addresses the interference study of local IMT networks in the 3800 – 4200 MHz band on radar altimeters making use of the 4200 – 4400 MHz band. In literature both “radio altimeter” and “radar altimeter” are used, in this report radar altimeter is used.

In this study, the ITU M.2059 recommendation is used as main reference and several parts are copied into this document. ITU M.2059 describes how radar altimeter studies have to be conducted and which parameters for altimeters should be taken into account. ITU M.2059 is “in force” and hence used for the study, it is the best document available. However, it has some shortcomings as is outlined in Appendix A (section 6.1). Note that, unless explicitly stated else, power levels in this chapter are in TRP (Total Radiated Power), since the interference on radio altimeters is related to the total power received on the front-end of the altimeter. The difference between EIRP and TRP (in dBm) is the antenna gain of 12 dBi, so $EIRP = TRP + 12$.

4.1 Usage of the band 4200-4400 MHz

The band 4200 – 4400 MHz is used almost exclusively for radar altimeters. More specific, its use is designated for and limited to airborne altimeters. Ground equipment is excluded, except transponders for airborne altimeters (should they be necessary).

Other allocated use by ITU-T of the 4200 – 4400 MHz band:

1. The band 4200 – 4204 MHz is used to send frequency and time reference signals from satellite to earth.
This is not investigated, the national frequency plan in The Netherlands did not copy this allocation.
2. Satellite earth observation is allowed, on a secondary basis (implying they cannot require protection from altimeter signals).

4.2 Radar altimeters

Radar altimeters are used to measure the altitude above ground. The “maximum reported height” is depending on the model and can be anywhere between 2,500 and 20,000 feet (762 – 6,000 meter). Above the transition altitude (which is not harmonized) aircrafts use “flight levels” that are based on barometric pressure rather than on actual altitude.

Radar altimeters have two antennas. They operate by a signal from the transmit antenna to be directed to the ground. When the signal hits the ground, it is reflected back to the receive antenna. The system measures the time it takes for the signal to travel from the transmit antenna to the ground and back to the receive antenna. The altitude of the aircraft is proportional to the time required for the transmitted signal to make the round trip.

Most radar altimeters operate at 4300 MHz center frequency. Only if aircraft have more than one altimeter, then center frequencies may differ 5 or 10 MHz.

Radar altimeters use two principles of operation:

1. Frequency Modulated Continuous Wave (FMCW) transmission
2. Pulse transmission

Both methods are explained in the paragraphs 4.2.1 and 4.2.2.

4.2.1 FMCW altimeter

The FMCW (Frequency Modulated Continuous Wave) altimeter uses a continuous transmit signal that is modulated in frequency. Due to the frequency modulation, the transmitter frequency will change during the time it takes for the signal to travel to the ground and return. The difference between the transmit and receive frequencies (Δf) is directly proportional to the height of the aircraft above the ground and depends on the exact slope of the FMCW modulation (span vs. period) as shown in Figure 4.1.

As illustrated by Figure 4.1, an altitude is calculated by determining the difference between the frequency f_1 of the reflected signal and the frequency f_2 of the signal being transmitted at the instant t_2 the reflected signal is received. This difference frequency Δf is directly proportional to the time Δt required for the reflected signal to traverse the distance from the aircraft to the terrain and back to the aircraft.

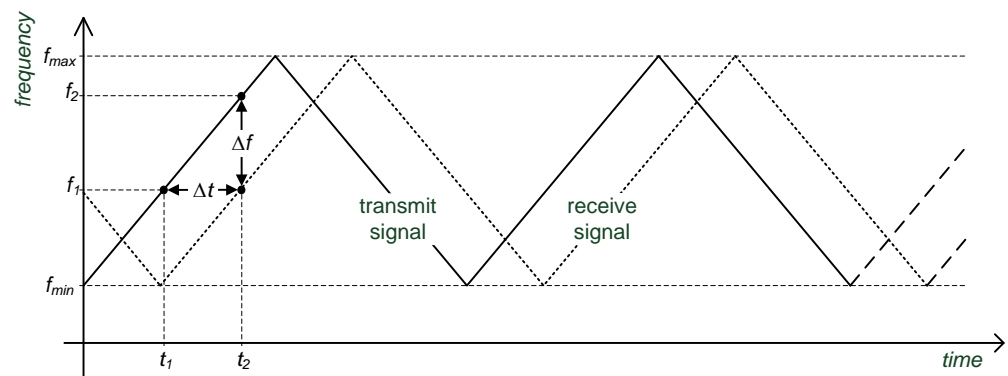


Figure 4.1: Typical frequency modulation carrier wave radar altimeter transmitted and received signals

The period of the triangle FMCW waveform can vary depending upon the altitude. At every instant, a beat signal is obtained by mixing the transmitted wave (with frequency f_2) and the received wave (with frequency f_1). The frequency Δf of this signal is equal to:

$$\Delta f = f_2 - f_1$$

Knowing either Δt or Δf , the height above terrain can be calculated using the following formula:

$$H_o = \frac{c\Delta t}{2} = \frac{c\Delta f}{2(df/dt)}$$

where:

- H_o: height above the terrain (m)
- c: speed of light (m/s)
- Δt: measured time difference (s)
- Δf: measured difference in frequency (Hz)
- df/dt: transmitters frequency shift per unit time (Hz/s)

The sweep frequency $f_{\max} - f_{\min}$ is around 100 – 180 MHz, according to ITU M.2059.

4.2.2 *Pulse altimeter*

The pulsed-type radar altimeter uses a pulse of radio frequency energy transmitted towards the earth to measure the absolute height above the terrain immediately underneath the aircraft. The time difference between the transmitted pulse and the received pulse is measured and proportional to the altitude (via the speed of light). The bandwidth of the transmitted pulse is around 7-31 MHz, according to ITU M.2059.

4.3 **IMT base station to altimeter interference**

4.3.1 *Previous studies on altimeter interference*

At the ITU WRC-19 a presentation of the International Civil Aviation Organization (ICAO) was given [20]. This presentation summarises the US regulations with respect to altimeters. Specific issues:

- They underline the severity of the interference potential.
- They advocate the execution of additional interference studies.
- They underline the risks for helicopters. However, it is virtually impossible to make all air space, including the zone below 150 m, fully interference free. In addition, also the band 3400 – 3800 and even LTE and 5G in lower bands (2600 MHz and below) poses a risk here.

The Radio Technical Commission for Aeronautic (RTCA) performed an extensive study with respect to interference of altimeters from 5G signals in the designated band for 5G in the US (3.7-3.98 GHz). The results are described in RTCA SC-239 paper [19]. The study is in great detail and has scenarios with specific locations of multiple aircrafts and multiple base stations. Moreover, they use real measurements on existing altimeters (types not specified) instead of artificial reference altimeters as used in ITU M.2059. Based on the scenario, the actual interfering signal is produced by a (large) set of generators.

The main conclusion of this paper is:

“The extent of the RF interference is summarized by the worst-case exceedance of the safe interference limit of radar altimeters by expected 5G signals in the 3.7–3.98 GHz band: 14 dB for commercial transport airplanes, 48 dB for business, regional, and general aviation airplanes, and 45 dB for helicopters”

Within the time frame of our TNO study, it is not possible to check all details of the analysis in the RTCA SC-239 paper. However, some remarks can be made:

- Deployment of AAS is assumed.
- IMT base station power levels are 67 dBm / 5 MHz, over a 100 MHz band (hence 80 dBm TRP).
- Strong defocusing of AAS antenna at altimeter frequency is assumed (pattern of 1 element, instead of that of a full antenna array). This removes the high gain of the AAS antenna for spurious, but that spurious is almost equally emitted in all directions.
- Spurious level is assumed to be -13 dBm/MHz. This level is allowed in the US but is limited to -30 dBm/MHz in Europe.
- The paper also considers altimeter to altimeter interference. This is realistic, but:
 - The interference problem also exists without 5G at 3800 – 4200 MHz
 - They lower the allowable level of 5G interference with the amount of interference already provided by other altimeters
 - They assume all aircraft below 200 ft (60 m) to be “at the airport” (hence increasing the interference potential). However, 60 meter altitude is equal to 1200 meter to touchdown. For all Dutch airports this is still outside the airport area
- The thresholds are lowered by 6 dB to account for tolerances (they use actual measurements and other altimeter samples of the same type may vary in performance), which effectively doubles the safe distances.

It is unfortunate that the RTCA study did not include interference from air surveillance radar.

Potential inference from 5G base stations in 3.4-3.8 GHz into radio altimeters in 4.2-4.4 GHz was also identified and discussed with CEPT ECC. A new work item proposal was discussed and developed during the CEPT ECC PT1#67 meeting in January 2021. This new work item was submitted to ECC for approval. The scope of this proposed study is on 5G base stations in the 3.4-3.8 GHz band, but the results are also of interest for the band 3.8-4.2 GHz.

4.3.2 *ITU M.2059*

ITU M.2059 is used as guideline for this altimeter interference study by TNO. It is the only available guideline that is widely accepted. However, this TNO study has revealed some potential shortcomings of M.2059 (see appendix A, section 6.1). Given that no other suitable guideline is available, M.2059 is used anyway, despite of its shortcomings.

All altimeters are assumed to have a 24 dB/octave input filter. This implies sensitivity for interference, not only for the band 3800 – 4200 MHz but also for the band 3400 – 3800 MHz, for radars in the band 2700 – 3400 MHz (S-band) and even for LTE and 5G at frequencies below 2700 MHz.

Following M.2059, calculations show that interference is also expected from S-band radars. Radar altimeters do exist from the '70s onwards and there has always been co-existence with air surveillance radar and ship radar. In this time period of more than 50 years apparently no interference issues have been reported. At least none of the interference studies ever mentioned air surveillance radar to altimeter

interference. Nevertheless, following M.2059 there should be severe risk of interference.

The fact that no air surveillance radar to altimeter interference ever is reported is a strong indication that some of the assumptions in M.2059 are too conservative. So most probably also the interference from IMT networks in 3800-4200 MHz is less severe as predicted in this document.

It is recommended to address this issue at ITU level as well as in the recently proposed study by CEPT ECC PT1.

4.3.3 *Altimeter interference*

Basically, there are three mechanisms following which an IMT base station can interfere with altimeters (definitions as in M.2059):

1. Receiver blocking: receiver front-end overload occurs when sufficient power from an interfering signal saturates the front-end of a radar altimeter receiver causing the inherent effects of non-linear behaviour; for example, harmonic distortion or intermodulation.
2. Receiver desensitization: the desensitization effect is related to the intensity of the interfering signal that falls into the so-called Intermediate Frequency¹² (IF) bandwidth of the radar altimeter.
3. False altitude reports: in the case of FMCW-based radar altimeters, false altitude reports occur when interference signals are detected as frequency components during spectral frequency analysis of the overall IF bandwidth.

These three mechanisms are discussed more in detail in the paragraphs 4.3.4 to 4.3.6.

4.3.4 *Receiver blocking*

Receiver front-end overload occurs when sufficient power from an interfering signal saturates the front-end of a radar altimeter.

Any signal within the RF bandwidth of the front-end can cause receiver blocking, also signals outside the operational band of the altimeter. The RF bandwidth of the front-end is design dependent, ITU M.2059 specifies the operational bandwidth of the RF front-end as 200 MHz (from 4200 to 4400 MHz), with a 24 dB/octave roll off on both band edges.

Receiver blocking is caused by the emissions of IMT base stations (in the 3800-4200 MHz band),

For example, an IMT base station transmitting at 4000 MHz gets an attenuation of (only) 2.5 dB because of roll-off of the RF front end (i.e. the frequency difference 4000 – 4300 MHz in combination with 24 dB/octave roll-off equals 2.5 dB. The low suppression of signals below 4000 MHz may not prevent receiver blocking caused by emissions of nearby IMT base stations.

¹² The receiver converts incoming signals to another frequency, the Intermediate frequency.

Receiver front-end overload causes two major effects:

- Saturation: if the front end is saturated by the strong interfering signal, its gain is largely decreased and causes “receiver blocking”.
- Intermodulation: the various signals present at the RF front-end input will cause intermodulation. The interfering signals themselves can be outside the radar altimeter band but the intermodulation products can be inside this band. Especially signals carrying multiple frequencies (as 5G signals do) will give rise to signals in the radar altimeter band and are hence processed

A radar altimeter is susceptible to interference both within its operational swept bandwidth as well as outside this bandwidth.

The potential interference to the radar altimeter front-end will exist whenever the total peak interference signal power at receiver input is higher than the Input power threshold at which receiver front-end overload occurs.

Intermodulation occurs when the total signal power at the receiver exceeds a given input power threshold (equipment dependent), while receiver blocking occurs at a higher level (also equipment dependent).

4.3.5 Receiver desensitization

Receiver desensitization occurs when interfering signals can enter the altimeter receiver. For the receiver, interfering signals have nothing to do with the transmitted radar signal and are hence equal to noise. In other words, interfering signals increase the noise level and hence desensitizes the receiver.

Interference is filtered by the IF filter (which is narrower than the RF filter in the receiver blocking part). Receiver desensitization is caused by IMT base station spurious.

Receiver desensitization is caused by interfering signals that are within the IF-bandwidth of the receiver (note that, due to the principle of operation, this IF band is swept through the operational swept bandwidth by FMCW radar).

The desensitization effect is related to the intensity of the interfering signal and manifest itself as an increase in input noise level.

The radar altimeter performance is considered degraded when the interfering signal causes a noise floor increase within the receiver of 1 dB. This is equivalent to an I/N of –6 dB. The effective receiver thermal noise power (N) is given by (ITU M.2059):

$$N = -114 \frac{\text{dBm}}{\text{MHz}} + 10 \log(B_{R,IF}) + N_F$$

Where:

$B_{R,IF}$: The IF-bandwidth of the radar altimeter (MHz)

N_F : Noise figure at receiver input (dB)

In determining compatibility based on desensitization within the IF bandwidth, the interference power threshold $I_{T,IF}$ at which the radar altimeter performance starts to degrade is defined as:

$$I_{T,IF} \geq N - 6dB$$

The Interference Duty Cycle R_s is the ratio of I (the interference power within the IF-bandwidth) to I_{RF} (the total interference power received). The Interference Duty Cycle is defined by:

$$R_s = \frac{2B_{R,IF}}{B_s}$$

Where:

B_s : Chirp bandwidth

$B_{R,IF}$ IF bandwidth

The amount of interference signal power that is captured by the IF of the receiver is proportional to R_s (the Interference Duty Cycle). Thus, the relation between $I_{T,IF}$ and the RF-referred interference threshold $I_{T,RF}$ is then defined by:

$$I_{T,RF} = I_{T,IF} - 10\log(R_s)$$

Should the calculated aggregated interference exceed the threshold at which desensitization of the receiver occurs ($I_{T,RF}$) then harmful interference would occur.

4.3.6 False altitude reports

False altitude reports occur if an interfering signal fulfils two conditions:

- It is strong enough,
- It mimics a radar altimeter signal that indicates a given (but false) altitude.

False altitude reports are caused by IMT base station spurious.

The interfering signal can cause the altimeter to report a false altitude. According to ITU M.2059, this can occur if the interference power in the detection bandwidth of 100 Hz is more than -143 dBm (see also section 6.1).

The interference power at the detector stage is given by:

$$I_D = I_{RF} - 10\log\left(\frac{2*100Hz}{B_s}\right)$$

Where:

I_D : The interference power at the detector

B_s : Chirp bandwidth

Note:

The formula above uses I_{RF} as input, which is the total amount of interference power. The text in M.2059 however explains only the Interference power within the chirp band B_s should be taken into account. The latter is logical, if 1) no front-end overload and 2) no receiver desensitization occurs, then the receiver is only sensitive to interference power in the band B_s . This approach has been used in this report.

If the magnitude of the spectral components caused by the interference signal rises above the detection threshold of the altimeter ($I_{T,FA}$), then they may falsely be regarded as valid altitudes by the altimeter and there will be no means to exclude them from the altitude calculation. The detection threshold is given by:

$$I_{T,FA} = -143 \text{ dBm, considering 100 Hz detector bandwidth}$$

A 100 Hz detection bandwidth is considered representative by ITU M.2059.

4.3.7 Sensitivity control

It is not addressed in [12], but all radar altimeters do reach their Input Power Threshold Receiver Overload $P_{T,RF}$ by their own transmission if they are close enough to the ground. However almost certainly all radar altimeters do have some means of sensitivity or gain control. For pulsed altimeters this will be STC (Sensitivity Time Control), for FMCW altimeters AGC (Automatic Gain Control).

If the aircraft reaches the altitude where its own transmission matches $P_{T,RF}$, it will start reducing its sensitivity and hence the risk for receiver blocking decreases.

The altitude where its own transmission matches $P_{T,RF}$, is the lowest altitude where the sensitivity to interference is at its maximum. Hence it correlates to the largest safe distance.

4.3.8 Reference radar altimeter parameters from ITU M.2059

The document M.2059 presents a list of six analogue and four digital altimeters. These reference altimeters and their parameters that are relevant to this study are presented in Table 4.1.

Table 4.1 ITU M.2059 reference altimeters

ITU Altimeters	A1	A2	A3	A4	A5	A6	D1	D2	D3	D4	Unit
M.2059											
Transmit power	0,6	1	0,25	100	5	40	0,4	0,1	1	5	W
Chirp bandwidth	104	132,8	133	8	7	15	150	176,8	133	31	MHz
40 dB emission bandwidth	180	180	191	130	108	131	180	190	196	195	MHz
Noise figure	10	6	6	10	10	10	8	9	8	10	dB
Input power threshold	-30	-53	-56	-40	-40	-40	-30	-43	-53	-40	dBm
IF bandwidth	2	0,25	2	9,2	6	16	0,312	1,95	2	30	MHz
Antenna gain	10	10	10	13	11	11	11	10	11	13	dBi
Cable loss	6	6	2	6	6	6	6	0	2	0	dB
Beamwidth	60	55	60	35	45	45	60	60	60	45	°

Note that the presented altimeters itself are not existing altimeters. Their specifications however are considered to represent the majority of altimeters in the market.

For the study, the specifications of existing altimeters have been viewed to see if the above parameters are available:

- Systems in use with the Dutch MoD:
 - ERT-160
 - AN/ASQ242
 - KRA-405B
- Civil systems
 - Garmin GRA55 and GRA 5500
 - FreeFlight Systems RA-4000 and RA-4500

Not all relevant technical parameters are available from the specifications of these altimeters. Especially the input power threshold is omitted in all cases. As a consequence, no safe distances could be calculated for these actual altimeters.

4.3.9 *Reference IMT base station as interfering source*

In this study the interference from an IMT base station with a maximum Effective Isotropic Radiated Power (EIRP) of 43 dBm/5 MHz is used as reference value.

With a total bandwidth of 200 MHz this equals 59 dBm EIRP. A bandwidth of 200 MHz is selected to create a realistic interference level. This bandwidth may be shared between multiple base stations (2*100 MHz, 5*40 MHz or 10*20 MHz for example). With an antenna gain of 12 dBi (non-AAS) an EIRP of 59 dBm results in a TRP of **47 dBm**.

However, commercially available IMT equipment may emit at larger EIRP values than the maximum of the reference IMT base station presented here. This is due to the maximum allowed transmit power limits presented in [14][15]. These IMT base stations are described as alternate interfering sources in Appendix A (section 6.2) - with a TRP of 59 dBm for non-AAS antenna and 56 dBm TRP for AAS antenna.

4.3.9.1 *Out-of-band emission limits*

The out-of-band emission limits of 5G base stations are given in [16]. Those out-of-5G-band limits are -30 dBm/MHz (TRP).

4.3.10 *Propagation*

The free space model is used to calculate the transmission attenuation of the path between IMT base station and the altimeter. Given that the aircraft has line-of-sight to the IMT base station, the use of the free space attenuation model is justified.

4.3.11 *Interference calculations*

Following the approach given in section 4.3, the interference of an IMT base station to an aircraft is calculated. The geometry (see also Figure 4.2) is chosen as follows:

- The aircraft is at height h .
- The distance over ground to the IMT base station is distance d .
- The aircraft is within the sector of the IMT antenna and the IMT (non-AAS) antenna is down tilted by 7.5° .

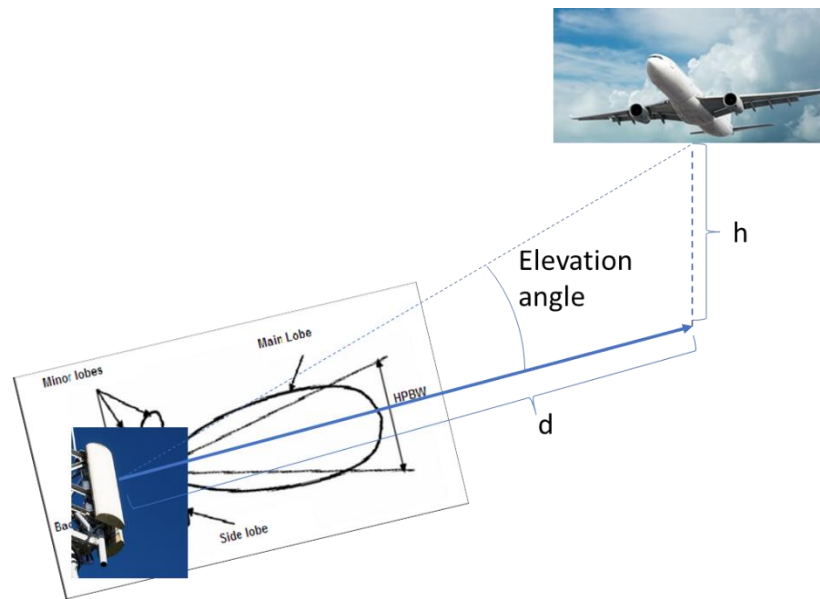


Figure 4.2: Geometry IMT base station and aircraft

For indicative purposes, also the safe distance is calculated at the altitude where the receiver sensitivity control becomes active, see also section 4.3.7.

The following basis assumptions are made:

- The non-AAS IMT antennas are down-tilted, having their – 3dB beam point on the horizon (for the stated antenna this is 7.5° down-tilt).
- The IMT base stations are transmitting at the maximum power possible within the license conditions as allowed for Medium Range base stations (43 dBm/5 MHz).
- IMT and radar altimeter frequencies differ approximately 10% (4000 MHz midband versus 4300 MHz) , so for the beamforming of the antennas no changes are considered due to detuning. (The radar and IMT antenna maintain their beamforming both at IMT and radar frequency).

4.3.12 The calculation sheet

An excel sheet is used to calculate the interference potential of a single IMT base station to a nearby aircraft. An example of the interference calculation sheet is shown in Table 4.2. On top in the right columns the center frequencies of IMT and radar altimeter are shown, as are used in the calculations. All calculations are made both for IMT frequency (the IMT signal) and altimeter frequency (the IMT spurious).

The interference calculation sheet shows several sections/parts:

- The geometry part in the example of the calculation sheet is used to calculate the relevant elevation angle, see also Figure 4.2.
- The 5G (IMT) part presents the transmitter energy, bandwidth and antenna gain, both at 0° and at elevation angle. The values are used to calculate the EIRP in the direction of the aircraft.
- The radio propagation part calculates the free space loss at both IMT and altimeter frequency.
- The altimeter part first provides the signal level at the altimeter input, taking into account the antenna gain and cable loss. It also summarizes altimeter

specifications. The altimeter part contains three sub-sections to calculate the margin towards the threshold for front-end overload, receiver desensitization and false altitude report. A positive margin implies the signal level is below the threshold and no interference will occur. For the I/N level, a maximum value of -6 dB is allowed (values above -6 dB, for example -4 dB, will cause desensitization).

The example in Table 4.2 shows the situation for a IMT non-AAS base station at 10 km distance from an aircraft at 1,000 m height using the A1 altimeter. It is clear that no interference occurs:

- The front-end overload is 42.2 dB below threshold
- The receiver desensitization I/N is -49.9 dB, 43.9 dB below the threshold of -6 dB.
- False altitude reports levels are 53.3 dB below threshold

Note that if the altitude of the aircraft is lower, the elevation angle is lower and hence the aircraft is closer to the main beam axis of the IMT base station. As a consequence, IMT base station EIRP and also its interference potential is higher.

Table 4.2 Example of interference calculation sheet

Power budget 5G induced on Radar Altimeter A1					5G	radar band	
			freq	[MHz]		4000	4300
Geometry	Altimeter Height			[m]	1000		
	Distance over ground			[km]	10,00		
	Elevation angle			degree	5,7		
5G	ofdm transmitter		power	[dBm]	59	59	
			spurious	[dBm/MHz]	-30		-30
			bandwidth	[MHz]	200		
			AAS	Y/N	N		
	antenna	gain	G(0)	[dBi]	12		
			G(13)	[dBi]	2,7	2,7	2,7
			EIRP	[dBm/MHz]		38,7	-27,3
radiopropagation			distance	[km]	10,05		
			FSA	[dB]		-124,5	-125,1
Altimeter		gain	G(0)	[dBi]	10		
ITU M.2059	A1		G(84)	[dBi]	-0,9	-0,9	-0,9
		cable	loss	[dB]	6	6,0	6,0
	power level at input altimeter			[dBm/MHz]		-92,7	-159,3
		Chirp	bandwidth	[MHz]	104		
		emission	bandwidth (-40 dB)	[MHz]	180		
		IF	bandwidth	[MHz]	2		
			noise figure	[dB]	10		
Front-end overload							
	Rf filter attenuation			[dB]	2,5	2,5	
	Power density after filtering			[dBm/MHz]		-95,2	-159,3
	Power after filtering (200 MHz)			[dBm]		-72,2	
	Power in emission band (180 MHz)			[dBm]			-136,8
	Input power threshold	P _{T,RF}		[dBm]	-30	-30,0	-30,0
	Margin			[dB]		42,2	106,8
Receiver desensitization							
	Interfering power (180 MHz)			[dBm]	-136,76		-136,8
	Interference duty cycle				0,0385		
				[dB]	-14,15		-14,1
	IF interference level			[dBm]			-150,9
	Equivalent input noise			[dBm]	-100,99		-101,0
	I/N			[dB]			-49,9
False altitude report							
	Power in chirp band (104 MHz)			[dBm]			-139,1
	Interference power@detector (100 Hz)			[dBm]			-196,306
	Protection threshold I _{T,FA}			[dBm]	-143		-143
	Margin			[dB]			53,3

4.4 Results of calculations

The sheet presented in section 4.3.12 is used to calculate the minimum distance for which none of the three mentioned interferences will take place: threshold for front-end overload, receiver desensitization and false altitude report. This is done by decreasing the distance up to the level where one of the thresholds is met.

As already mentioned, the interference increases with lower altitudes (see section 4.3.12). The safe distance is calculated at the lowest permissible altitude, which is 500 ft (152.4 m), the minimum altitude for VFR (Visual Flight Rules) flights above non-building areas, according to [21]. Above buildings, the minimum altitude is 1000 ft (304.8 m)

4.4.1 Safe distances to a reference IMT base station with EIRP of 43 dBm / 5 MHz

The safe distances are given in Table 4.3, assuming the minimum aircraft altitude of 150 m and a base station EIRP of 43 dBm/5 MHz.

Table 4.3 Safe distances to IMT non-AAS station at 150 m aircraft altitude, 43 dBm/5MHz EIRP

Altimeter	A1	A2	A3	A4	A5	A6	D1	D2	D3	D4
Altimeter height (m)	150	150	150	150	150	150	150	150	150	150
Distance over ground (km)	0	0.17	0.5	0.16	0.11	0.09	0	0.14	0.38	0.12
Front end overload margin (dB)	11.7	0	0	7.5	9	6.3	10.7	0	0	2.9
Receiver desensitization I/N (dB)	-7.3	-19.8	-22.5	-6	-6	-6	-9	-10.8	-20.4	-6
False Altitude report margin (dB)	10.8	22.1	25.1	16.7	18.1	15.4	9.8	12.1	22.1	12

Safe distances over ground vary from 0 m for altimeter A1/D1 to 0,5 km for altimeter A3.

Note that:

- For altimeter A1 and D1, the safe distance (over ground) is 0, implying the base station can be anywhere. In other words, altimeters A1 and D1 are safe for base stations with 43 dBm/5 MHz EIRP
- For altimeters A2, A3, D2 and D3 the front-end overload margin is 0 dB, any decrease in distance will cause front end overload (also called receiver blocking)
- For altimeters A4, A5, A6 and D4, the interference to noise ratio is at its limit of -6 dB, any decrease in distance will cause receiver desensitization.

We can also calculate the safe distance that is valid for all altitudes. At airports lower altitudes than 150 m are allowed¹³.

The safe distance is at its maximum for the altitude where the sensitivity control starts to operate. From that point onwards, the decrease in sensitivity due to the lower altitude is larger than the increase of IMT base station EIRP.

The safe distances for the aircraft at an altitude where the sensitivity control starts to operate are given in Table 4.4. These safe distances are valid at all altitudes.

Table 4.4 Safe distances to IMT non-AAS station at onset sensitivity control, 43 dBm/5MHz EIRP

Altimeter	A1	A2	A3	A4	A5	A6	D1	D2	D3	D4
Altimeter height (m) at onset sensitivity control	3.4	62	70	278	39	111	3.5	12	124	124
Distance over ground (km)	0.11	0.22	0.59	0.16	0.14	0.08	0.08	0.27	0.39	0.14
Front end overload margin (dB)	10.4	0	0	11.9	8.8	6.3	7.7	0	0	2.9
Receiver desensitization I/N (dB)	-6	-19.8	-22.5	-6	-6	-6	-6	-10.8	-20.4	-6
False Altitude report margin (dB)	9.5	22.1	25.1	22	21.1	15.4	6.8	12.1	22.1	12

It is shown that safe distances over ground vary from 80 (A6, D1) to 590 m (A3).

Note that:

- The safe distance of altimeter A4 is 0.16 km, even for aircraft altitude of 150 m, due to the fact that the sensitivity control is already active at 150 m altitude.
- The altitudes at which the sensitivity control becomes active do vary. This altitude is design dependent.

¹³ In [21] a complete list of conditions is given under which altitudes less than 150 m are allowed.

4.4.2 Safe transmitter power levels of IMT base station

In this section the approach is reversed: it is calculated what maximum transmission power levels of an IMT base station (in dBm TRP) could be allowed for the aircraft being at the most critical point: at 150 m altitude and a distance of 86 meter. At this point the elevation angle is 60 degree (implying maximum gain for the aircraft antenna, in concordance with ITU M.2059) and the IMT antenna gain is slightly higher than directly overhead. The values are given in Table 4.5, where also the I/N value is given.

Table 4.5 Safe transmission power levels of IMT base station for aircraft at 150 m altitude

Altimeter	A1	A2	A3	A4	A5	A6	D1	D2	D3	D4
IMT transmitter power (dBm TRP), non-AAS	58.7	35.7	28.7	45.7	47.7	47.7	57.7	39.7	30.7	39.7
Receiver desensitization I/N (dB), non-AAS	-7.4	-8.5	-4.2	2.3	2.1	2.1	-9	-3.5	-4.1	4.2

In this study we have used a maximum value of the TRP of 47 dBm to which the values of Table 4.5 can be compared.

- This value is safe for altimeters A1, A5, A6 and D1.
- The lowest safe power is for altimeter A3, being 28.7 dBm. This implies that base station power has to be lowered to 28.7 dBm to protect all altimeters. Note that, even with a power density of 25 dBm/5 MHz this implies a IMT bandwidth of just over 10 MHz.
- The I/N criterion of -6 dB is only met for altimeter A1, A2 and D1. In order to protect all altimeters, the base station spurious shall be -38.3 dBm/MHz or better (note that in operational IMT bands the spurious in -52 dBm/MHz).

Safe emission levels at lower altitudes are irrelevant, as the distance to the base station can be anything. A rescue helicopter can land in the immediate vicinity of the base station.

4.4.3 Evaluation of analysis results

Safe distance for reference IMT base stations

In Table 4.6 a summary of the results is given for the 10 reference radar altimeters for the reference IMT base stations. Note that for distances over 20 km, the height becomes irrelevant and that “at ground level” for larger distances shall be interpreted as “at the horizon”.

Table 4.6 Safe distances (in km) summary, from reference IMT base station

Altimeter	A1	A2	A3	A4	A5	A6	D1	D2	D3	D4
Safe distance over ground (km) - Reference IMT base station - 150 m aircraft altitude	0	0.17	0.5	0.09	0.11	0.09	0	0.14	0.38	0.12
Safe distance over ground (km) - Reference IMT base station - Aircraft at ground level	0.11	0.22	0.59	0.16	0.14	0.08	0.08	0.27	0.39	0.14

For almost all altimeters, the limiting factor for interference from a single IMT base station with a power levels of 43 dBm/5MHz is receiver blocking, although receiver desensitization also plays a role for lower IMT base station power levels (IMT spurious levels are specified as being power level independent).

There is a large variation of the safe distance over ground for the 10 reference altimeters. For aircrafts at the minimum altitude of 150 m the altimeters A1 and D1 are safe. The safe distances for the other altimeters are between 90 (A4/A6) to 500 m (A3).

At airports and immediately in front of runways, aircrafts fly lower than 150 meters. Already 3 km in front of the runway, aircraft cross the 150 m boundary. For these locations the safe distances have to be taken into account (for aircraft at ground level) and are (slightly) higher.

The distances are calculated for reference altimeters. The digital altimeters D2-3-4 appear to be more vulnerable than the altimeters A1-4-5-6. A reason could well be that processing is not taken into account. In general, digital radars use processing to maximize sensitivity and resolution while minimizing sensitivity to unwanted interference. However, it might well be possible that no overload condition will occur if actual altimeters and antenna parameters would be taken into account. Actual base station antenna sidelobes are lower than described in [18]. Moreover, filter characteristics might be better and the reference altimeters A1, A4, A5, A6 and D1 already have a good performance. It is anticipated that the actual performance of altimeter D2, D3 and D4 is much better if their digital processing is taken into account. Further study is recommended to verify the sensitivity for interference on actual altimeters.

Safe IMT transmission power levels

Safe IMT transmission power levels are calculated for each altimeter and are given in Table 4.7. If all reference altimeters are taken into account, the transmission power level should be limited to 28.7 dBm for non-AAS base stations, related to altimeter A3. If the five most sensitive reference altimeters A2, A3, D2, D3 and D4 are not considered, the safe transmission power level can be increased by 17 dB - to 45.7 dBm, over the full country, without any limitation in placement of the base station.

Table 4.7 Safe transmission power level summary

Altimeter	A1	A2	A3	A4	A5	A6	D1	D2	D3	D4
Safe IMT emission level (dBm), non AAS base station	58.7	35.7	28.7	45.7	47.7	47.7	57.7	39.7	30.7	39.7

Safe transmission power limits are calculated for very short distances. For cell radii of typically 2 km or more the implementation of more than one base station is expected to have little effect.

It should be noted that over built environment the minimum altitude is 300 m (instead of 150 m) so the safe IMT transmission power limit can be increased by 6 dB.

4.5 Conclusions and recommendations

The interference of a single IMT base station on radar altimeters in the 4200-4400 MHz band was studied. The ITU M.2059 recommendation is used as main source of reference, since it includes all relevant technical parameters for interference study of 10 reference altimeters (6 analogue, 4 digital). These technical parameters

of actual altimeters in aircrafts are not available from suppliers. The interference results of this study are calculated with 43 dBm/ 5 MHz EIRP for a single IMT base station. Higher power levels as allowed by the IMT standard, will result in higher interference risks.

The conclusions of the altimeter interference study are:

1. The safe distances of these 10 reference altimeters for an aircraft at 150 m (minimum flight altitude) vary between 0 and 500 m.
2. At airports and up to 3 km in front of runways where the altitude of aircrafts is below 150 m, a safe distance between 80 and 590 m is retrieved.
3. If the base station output power is limited to 28.7 dBm, the airspace is interference free for all reference altimeters at altitudes of 150 m and above.
4. However, the ITU M.2059 appears to be too conservative: following its guidelines, calculations show that also interference from lower frequency bands will pose an interference risk to the reference altimeters. However, to date, no interference reports from these lower bands below 3800 MHz seem to exist (see appendix A, section 6 for details). This may imply that safe distances in practice are lower than the values calculated here. It is recommended to participate to a proposed CEPT ECC PT1 study and advocate to study adjacent channel co-existence of IMT networks in both 3.400-3.800 MHz and 3.800-4.200 MHz and to study sensitivity of realistic altimeters.

5 References

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6 Appendix A – Background information on radar altimeter interference study

6.1 Remarks on ITU M.2059

The recommendation ITU M.2059 is “in force” implying all ITU members including The Netherlands have agreed to apply this recommendation. Many experts have contributed to this document and all ITU members, have had the opportunity to review it. As such, the recommendation is strictly followed.

The guidelines for the calculation of interference as given in ITU recommendation M.2059 do affect the obtained results, as is briefly discussed below:

- **Antenna characteristics:** the antenna characteristics are in concordance with ITU F.1336. The antenna diagrams are not real ones but provide for each angle the maximum (sidelobe) level that could be present in that direction. As a consequence, antennae have low directivity.
- **Altimeter antenna:** the altimeter antenna is assumed to have maximum gain for all angles up to 30° from the vertical. This translates in an increased vulnerability of the altimeter at high (>60°) elevation angles.
- **Processing:** the recommendation M.2059 does not address in any way advanced analogue and digital processing. This processing can increase immunity to noise and interference. As a consequence, some digital altimeters are more sensitive to interference as some of their analogue counterparts.
- **All altimeters are assumed to have a 24 dB/octave input filter.** This causes the altimeters to be vulnerable to interference, not only for the band 3800 – 4200 MHz but also for the band 3400 – 3800 MHz, for radars in the band 2700 – 3400 MHz and even for LTE and 5G at frequencies below 2700 MHz.
- **The specifications of the 10 reference altimeter address the upper boundary on interference and show a wide variation.** It might well be possible that real altimeters are (much) less sensitive for interference. As a consequence, from specifications in [12] it is hard to tell why $P_{T,RF}$ differs so much over the altimeters, from general radar design perspective there is no apparent need.
- **Altimeter specifications are composed by ITU members.** As composed now, they satisfy the need of all contributing (to the composing process) members. Industry partners do not want to reveal actual performance or specifications of their products. One option to achieve this is the use of non-realistic parameter sets.
- **As the reference altimeter specifications of ITU M.2059 are ‘composed’ rather than based on a specific design,** it is impossible to tell which altimeters of ITU M.2059 do represent the majority of the altimeters in use today.

During this study by TNO some issues arose that are not addressed in the recommendation, they are summarised in this section.

6.1.1 *Input Power Threshold Receiver Overload*

Although the phenomenon is not mentioned in ITU M.2059 [12], altimeters, especially those with a low Input Power Threshold Receiver Overload $P_{T,RF}$, need a kind of sensitivity control (input attenuation) to prevent their receiver from

overloading. For pulsed altimeters this will be STC (Sensitivity Time Control), for FMCW altimeters AGC (Automatic Gain Control). So, at lower altitudes, the risk for receiver blocking decreases.

Due to this sensitivity control, the safe distance will decrease, as will be shown for altimeter A4. The receiver of this altimeter will start to overload already at a height of close to 800 meter and a high reflective surface, see Table 6.1. The calculation assumes high reflectivity (loss 1 dB) of the surface below the aircraft, which is reality for the sea surface. Many airports have approach routes over water, as for example Nice airport, see Figure 6.1.

Table 6.1 Power budget radar altimeter A4 above sea

Power budget Radar Altimeter A4				
Altimeter Height			[m]	782,75
Altimeter power			[dBm]	50
Antenna gain			[dBi]	13
Radio propagation		FSA	[dB]	-109,0
Reflection loss			[dB]	-1,0
Antenna gain			[dBi]	13
Cable loss			[dB]	6
power level at input altimeter			[dBm]	-40,0
Input power threshold	$P_{T,RF}$		[dBm]	-40
Margin			[dB]	0,0



Figure 6.1 Nice airport (Courtesy Nice Côte d'Azur Airport)

Due to this sensitivity control, the safe distance for altimeter A4 will decrease. In Table 6.2 the altitude is given where sensitivity control “kicks in”, for a low reflective soil (e.g. dry sand) with 10 dB reflection loss. At this altitude of 278 meter the IMT AAS base station can be as close as 170 meter, as is shown in Table 6.3.

Table 6.2 Power budget altimeter A4 above sand

Power budget Radar Altimeter A4				
Altimeter Height			[m]	277,74
Altimeter power			[dBm]	50
Antenna gain			[dBi]	13
Radio propagation		FSA	[dB]	-100,0
Reflection loss			[dB]	-10,0
Antenna gain			[dBi]	13
Cable loss			[dB]	6
power level at input altimeter			[dBm]	-40,0
Input power threshold	$P_{T,RF}$		[dBm]	-40
Margin			[dB]	0,0

Table 6.3 Safe distance of altimeter A4, taking sensitivity control into account.

Power budget 5G induced on Radar Altimeter A4					5G	radar band	
			freq	[MHz]		4000	4300
Geometry	Altimeter Heigth			[m]	287		
	Distance over ground			[km]	0,17		
	Elevation angle			degree	59,4		
5G	ofdm transmitter		power	[dBm]	59	59	
			spurious	[dBm/MHz]	-30		-30
			bandwidth	[MHz]	200		
			AAS	Y/N	N		
	antenna	gain	G(0)	[dBi]	12		
			G(67)	[dBi]	-0,9	-0,9	-0,9
			EIRP	[dBm/MHz]	35,1	-30,9	
radiopropagation							
		distance	[km]	0,3336			
		FSA	[dB]		-94,9	-95,6	
Altimeter ITU M.2059 A4	gain	G(0)	[dBi]	13			
		G(31)	[dBi]	3,8	3,8	3,8	
		cable	loss	[dB]	6	6,0	6,0
	power level at input altimeter			[dBm/MHz]	-62,1	-128,7	
	Chirp emission	bandwidth	[MHz]	8			
		bandwidth (-40 dB)	[MHz]	130			
		IF	bandwidth	[MHz]	9,2		
		noise figure	[dB]	13			
Front-end overload							
	Rf filter attenuation		[dB]	2,5	2,5		
	Power density after filtering		[dBm/MHz]		-64,6	-128,7	
	Power after filtering (200 MHz)		[dBm]		-41,6		
	Power in emission band (130 MHz)		[dBm]			-107,6	
	Input power threshold	P _{T,RF}	[dBm}	-40	-40,0	-40,0	
	Margin		[dB]		1,6	67,6	
Receiver desensitization							
	Interfering power (130 MHz)		[dBm]	-107,56		-107,6	
	Interference duty cycle			2,3			
			[dB]	3,6173		3,6	
	IF interference level		[dBm]			-103,9	
	Equivalent input noise		[dBm]	-91,362		-91,4	
	I/N		[dB]			-12,6	
False altitude report							
	Power in chirp band (8 MHz)		[dBm]			-119,7	
	Interference power@detector (100 Hz)		[dBm]			-165,6917	
	Protection threshold I _{T,FA}		[dBm]	-143		-143	
	Margin		[dB]			22,7	

The other altimeters have a higher Input Power Threshold Receiver Overload $P_{T,RF}$ and hence sensitivity control “kicks in” at a lower altitude. The safe distance is already met at a point where sensitivity control is inactive, hence the safe distance is unaltered.

6.1.2 Operational altitude

It is argued to evaluate interference up to the operational attitude of the altimeter. Altimeters have a range of reported altitude; outside this range they do not report altitudes. The maximum reported altitude is less than 2500 meter for all altimeters, except A3 and D3, that report up to 6 km.

Above the reported altitude, altimeters do not provide output, however they are still operational and might report an altitude if an interfering signal is exactly mimicking a reflected radar signal at lower altitude.

In this report, this effect is evaluated as “false altitude report”.

Aircraft only use the barometric altimeter above the transition altitude. The transition altitude is a published height above which pilots change their barometric altimeter datum from the regional pressure setting to the common international standard setting of 1013.2hPa. This means all altimeters above that altitude read the same at any given level, despite constant natural meteorological changes in atmospheric pressure, or the passage of the aircraft from a region of high pressure to low pressure or vice versa.

Above the transition altitude, altimeter readings are communicated as flight levels, not as height or altitudes.

As a consequence, barometric readings and radar altimeter readings do not align above the transition altitude, which forces the pilots to ignore the radar altimeter above this transition altitude.

Transitional altitudes are local, regional or national and vary considerably between about 3,000ft and 18,000ft. The Netherlands uses 3000 ft (914 m), the USA and Canada have a common one of 18,000ft (5486 m).

6.1.3 False Altitude reports

The section on false altitude reports is less elaborated, it contains e.g. no design specific properties, implying all altimeters are equally sensitive to false altitude reports.

Already mentioned is the improper use of the interfering power I_{RF} , see section .

Moreover, no motivation is provided for some choices, for example:

- why the detection bandwidth is 100 Hz
- why $I_{T,FA}$ is -143 dBm at 100 Hz.

6.1.4 Altimeters

The altimeters in the study do vary in vulnerability to interference. As the altimeters themselves are non-existing it is difficult to verify why these differences do exist.

6.1.5 Processing

Processing and processing gain are not addressed in the recommendation.

6.2 Interference calculations for alternate IMT base stations

To be able to put this study in perspective, results are given for two alternate IMT interference sources:

- Alternate non-AAS IMT base station with TRP of 59 dBm (TRP = 43 dBm/5 MHz, 200 MHz bandwidth and antenna gain of 12 dBi)
- Alternate AAS IMT base station with TRP of 56 dBm

Another approach in interference studies is to use the maximum Total Radiated Power (TRP) of an IMT base station, together with the maximum antenna gain. In a related ITU-study on compatibility of IMT systems maximum TRP of a single IMT base station were used: 43 dBm/5 MHz (TRP) for a macro cell (non-AAS) and 24 dBm for a small cell (see Table I of ITU report M.2481-0 [15]).

The resulting EIRP for a single IMT base station is related to the type of antenna. Base stations can have two types of antennas:

- A “normal” sector antenna.
This antenna covers a fixed sector, usually 120°. Due to the beamforming, those antennas have 12-18 dBi gain. Base stations using normal antennas are referred to as non-AAS.
- An active antenna system (AAS).
This antenna can actively (i.e. under computer control) shape and direct its beam over an area. Due to the narrow beam, the antenna gain can be high, for example 26 dBi.

Safe distances for radar altimeters from alternate IMT base stations based on a maximum TRP, with non-AAS and AAS, are included for information purposes, in case it is decided that standard IMT base stations are more appropriate to fulfil the needs of local IMT networks.

6.2.1 *In-band emission limits for alternate IMT base stations*

For non-AAS base stations, power limits (TRP, at antenna connector) are given as 43 dBm/5 MHz (36 dBm/MHz) [14][15] which equals 55 dBm/ 5 MHz EIRP (at 12 dB antenna gain, resulting in **59 dBm TRP** for 200 MHz. This is used as the power limit for non-AAS macro base stations with sector antennas.

For AAS, there is no limit for TRP for wide area base stations [16], although administration wishing to include a limit in their authorisation or to use a limit for coordination purpose may define such limits on a national basis. In Table 6.4 and Table 6.5 the limits are given as in [16].

Table 6.4 Base Station (BS) type 1-C rated output power limits for BS classes
Table 6.2.1-1 from [16]

BS class	$P_{\text{rated,c,AC}}$
Wide Area BS	There is no upper limit for the $P_{\text{rated,c,AC}}$ rated output power of the Wide Area Base Station.
Medium Range BS	$\leq 38 \text{ dBm}$
Local Area BS	$\leq 24 \text{ dBm}$

Table 6.5 Base Station type 1-H rated output power limits for BS classes
Table 6.2.1-2 from [16]

BS class	$P_{\text{rated,c,sys}}$	$P_{\text{rated,c,TABC}}$
Wide Area BS	There is no upper limit for the $P_{\text{Rated,c,sys}}$ or $P_{\text{Rated,c,TABC}}$ of the Wide Area Base Station	
Medium Range BS	$\leq 38 \text{ dBm} + 10\log(N_{\text{TXU,counted}})$	$\leq 38 \text{ dBm}$
Local Area BS	$\leq 24 \text{ dBm} + 10\log(N_{\text{TXU,counted}})$	$\leq 24 \text{ dBm}$

Meaning of the symbols in Table 6.4 and Table 6.5, taken from [16]:

- $N_{\text{TXU,counted}}$
The number of active transmitter units that are taken into account for conducted TX output power limit and for unwanted TX emissions scaling
- $P_{\text{rated,c,AC}}$
The rated carrier output power per antenna connector
- $P_{\text{rated,c,sys}}$
The sum of $P_{\text{rated,c,TABC}}$ for all TAB (Transceiver Array Boundary) connectors for a single carrier
- $P_{\text{rated,c,TABC}}$
The rated carrier output power per TAB connector

According to Table 6.5, for a Medium Range BS the TRP with a 64 elements array is for an array of 64 elements is $38+18 (10\log 64) = 56 \text{ dBm}$. This results in a value of **56 dBm TRP** or 82 dBm EIRP at 26 dB antenna gain.

6.2.2 Antenna characteristics

As is recommended by [12], the IMT antenna characteristics are used as described in [18]. This document is also used to model the altimeter antenna, although for angles up to 30° from the antenna axis maximum gain is assumed, as required by [12]. The recommended diagrams are given in Figure 6.2 for non-AAS, in Figure 6.3 for AAS and Figure 6.4 in for a radar altimeter antenna.

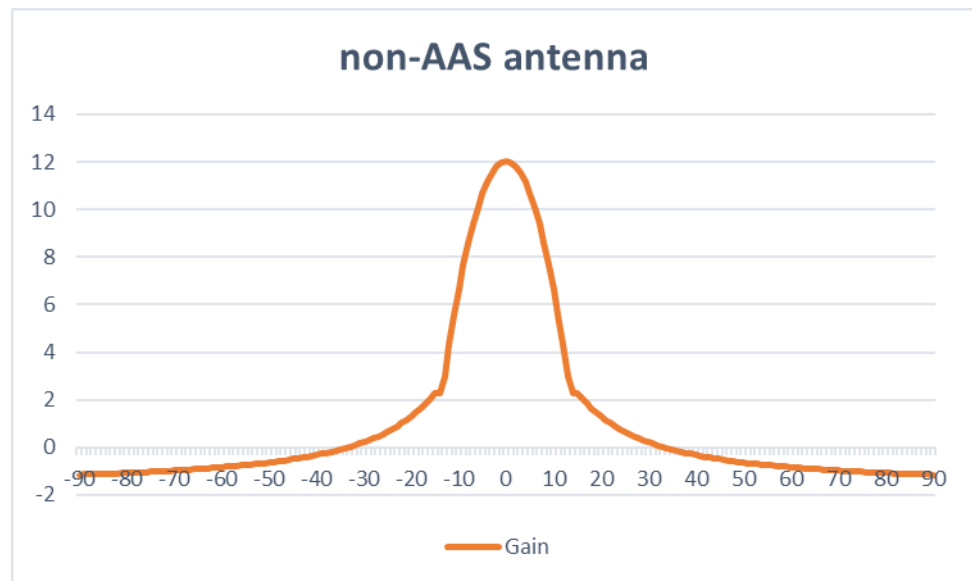


Figure 6.2 Non-AAS (elevation) antenna diagram according to [18] , beam width 15°

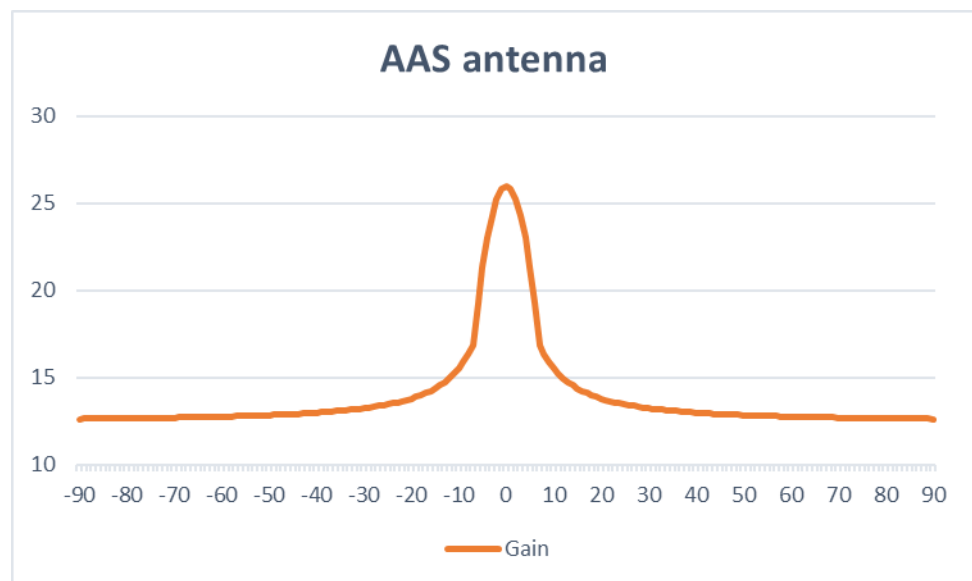


Figure 6.3 AAS antenna diagram according to [18] , beam width 8°

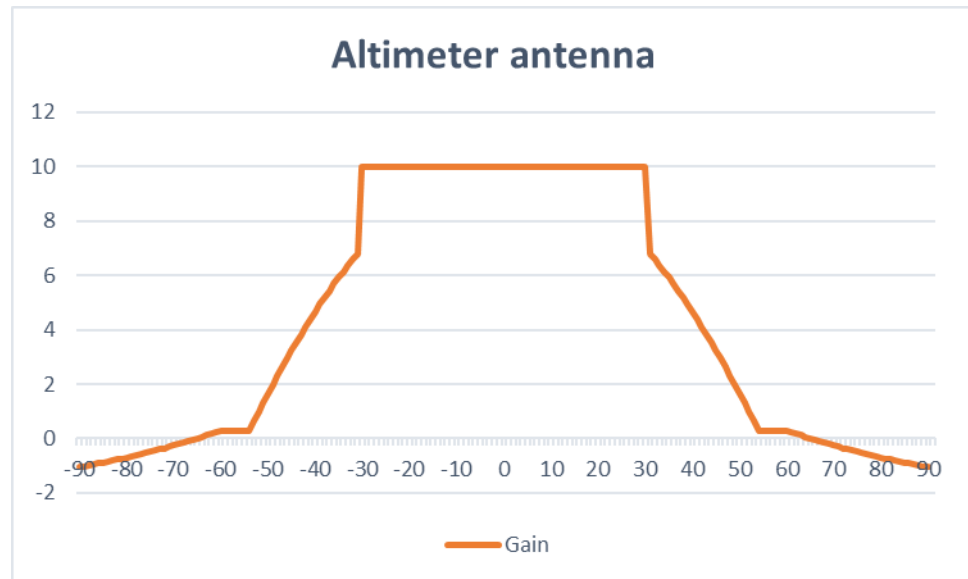


Figure 6.4 Radar altimeter antenna diagram according to [18], beam width 60°

6.2.3 Safe distances to an alternate non-AAS IMT base station with a TRP of 43 dBm / 5 MHz.

Table 6.6 provides the safe distances in case 43 dBm/5 MHz TRP (Total Radiated Power) is used, being the maximum allowable power level. Also, here the altitude is 150 m. It is shown that safe distances vary from 90 m (D1) to 4.0 km for altimeter A3. Note that for altimeters A4, A5, A6 and D4, the dominant interference changes from receiver desensitization to receiver overload, due to the higher power level.

Table 6.6 Safe distances to IMT non-AAS station at 150 m aircraft altitude, 43 dBm/5MHz TRP

Altimeter	A1	A2	A3	A4	A5	A6	D1	D2	D3	D4
Altimeter height (m)	150	150	150	150	150	150	150	150	150	150
Distance over ground (km)	0.1	0.99	4.02	0.16	0.15	0.15	0.09	0.58	2.88	0.51
Front end overload margin (dB)	0	0	0	0	0	0	0	0	0	0
Receiver desensitization I/N (dB)	-7.3	-31.8	-34.5	-11	-9.2	-11.7	-12.1	-22.8	-32.4	-15.1
False Altitude report margin (dB)	10.7	34.1	37.1	21.1	21.1	21.1	12.8	24.1	34.1	21.1

The safe distances for the aircraft at an altitude where the sensitivity control starts to operate are given in Table 6.7 for 43 dBm/5 MHz TRP. These safe distances are valid at all altitudes.

In Table 6.7 it is shown that safe distances vary from 140 m (A1) to 4.6 km for altimeter A3.

Table 6.7 Safe distances to IMT non-AAS station at onset sensitivity control, 43 dBm/5 MHz TRP

Altimeter	A1	A2	A3	A4	A5	A6	D1	D2	D3	D4
Altimeter height (m)	3.4	62	70	278	39	111	3.5	12	124	124
Distance (km)	0.14	1.77	4.6	0.16	0.23	0.17	0.16	1.34	3.15	0.54
Front end overload margin (dB)	0	0	0	0	0	0	0	0	0	0
Receiver desensitization I/N (dB)	-7.7	-31.8	-34.5	-6.1	-9.3	-11.7	-10.3	-22.8	-32.4	-15.1
False Altitude report margin (dB)	11.1	24.1	37.1	22	21.1	21.1	11.1	24.1	34.1	21.1

6.2.4 Safe distances to an alternate AAS IMT base station with 56 dBm TRP

Although AAS base stations for local IMT networks are not expected to be deployed in the band 3800 – 4200 MHz, calculations are made just to show the critical interference situation that will emerge upon application.

The safe distances are given in Table 6.8, assuming an aircraft height of 150 m. It is shown that safe distances vary from 200 meter for altimeter A1 and D1 to 25 km for altimeter A3.

Table 6.8 Safe distances to IMT AAS station at 150 m aircraft altitude

Altimeter	A1	A2	A3	A4	A5	A6	D1	D2	D3	D4
Altimeter height (m)	150	150	150	150	150	150	150	150	150	150
Distance over ground (km)	0.2	10.75	25	0.75	0.75	0.75	0.2	6.85	19.83	6.25
Front end overload margin (dB)	1.3	0	0	0	0	0	0	0	0	0
Receiver desensitization I/N (dB)	-6	-28.8	-31.5	-8	-6.2	-8.7	-7.3	-19.8	-29.4	-12.1
False Altitude report margin (dB)	9.4	31.1	34.1	18.1	18.1	18.1	8.1	21.1	31.1	18.1

The values in Table 6.8 are based on line of sight and a “flat” earth. It is checked with the program CARPET [22], which uses accurate modelling of the earth curvature that at 25 km distance the aircraft is still above the horizon and hence line of sight conditions still exist. Changes in actual distance and elevation angle due to earth’s curvature are negligible.

The safe distances at the altitude where sensitivity control starts to operate are given in Table 6.9. It is shown that safe distances vary from 750 m (A4) to 25 km for altimeter A3.

Table 6.8 provides safe distances to aircraft at 150 m altitude, whereas Table 6.9 shows safe distances to aircraft at low altitudes and hence close to airports.

Table 6.9 Safe distances to IMT AAS station at onset sensitivity control

Altimeter	A1	A2	A3	A4	A5	A6	D1	D2	D3	D4
Altimeter height (m)	3,4	62	70	278	39	111	3.5	12	124	124
Distance over ground (km)	0.92	10.9	25.02	0.75	2.55	2.16	0.89	7.05	19.85	6.33
Front end overload margin (dB)	1.3	0	0	0	0	0	0	0	0	0
Receiver desensitization I/N (dB)	-6	-28.8	-31.5	-8	-6.2	-8.7	-7.3	-19.8	-29.4	-12.1
False Altitude report margin (dB)	9.4	31.1	34.1	18.2	18.1	18.1	8.1	21.1	31.1	18.1

6.2.4.1 Interference from IMT base station in other bands

For IMT base stations in the 3400 – 3800 MHz band, the safe distances are 70% of those summarized in Table 2.17. Safe emission levels are 3.7 dB higher, for example 31.4 dBm for the A3 altimeter.

For 5G/LTE frequencies below 2700 MHz safe distances are a factor 4.5 lower and safe emission levels are 14.9 dB higher. For the reference altimeter A3 the safe emission limit is 39.9 dBm at 2600 MHz. The reference altimeter A3 is even at risk for interference from IMT base stations in these bands.

6.2.4.2 Interference from (S-band) radars

Radars, especially in the S-band, also pose a threat to altimeters. As an example, a Furuno FAR-2238S-BB ship radar [23] is taken. This radar has 30 kW or 74.8 dBm.

The antenna SN36CF has a gain of 29.2 dB. Note that this radar is taken as example, other radars have similar specifications.

The safe distance to the ship radar for altimeter A1 is 4.43 km, see also Table 4.1. For altimeter A3 this would even be 140 km (line of sight).

Table 6. Safe distance to ship radar

Power budget 5G induced on Radar Altimeter A1					5G	
			freq	[MHz]		3050
Geometry	Altimeter Height			[m]	150	
	Distance over ground			[km]	4,43	
	Elevation angle			degree	1,9	
Radar	Furuno FAR-2238S-BB		power	[dBm]	74,8	74,8
			spurious	[dBm/MHz]		
			bandwidth	[MHz]	2	
	antenna	gain	G(0)	[dBi]	29,2	
			G(2)	[dBi]	29,1	29,1
			EIRP	[dBm/MHz]		100,9
radiopropagation			distance	[km]	4,4278	
			FSA	[dB]		-115,0
Altimeter ITU M.2059 A1		gain	G(0)	[dBi]	10	
			G(88)	[dBi]	-1,0	-1,0
		cable	loss	[dB]	6	6,0
	power level at input altimeter			[dBm/MHz]		-21,1
		Chirp	bandwidth	[MHz]	104	
		emission	bandwidth (-40 dB)	[MHz]	180	
		IF	bandwidth	[MHz]	2	
			noise figure	[dB]	10	
Front-end overload						
	Rf filter attenuation			[dB]	11,9	11,9
	Power density after filtering			[dBm/MHz]		-33,0
	Power after filtering (2 MHz)			[dBm]		-30,0
	Power in emission band (180 MHz)			[dBm]		
	Input power threshold	P _{T,RF}		[dBm]	-30	-30,0
	Margin			[dB]		0,0

S-band ship radars are only required for large ships and hence can only be expected at the large waterways (Noordzeekanaal, Kanaal van Gent naar Terneuzen, Nieuwe Waterweg). However, air surveillance radars have comparable specifications (not to be disclosed here) and as a consequence, all altimeters have to be considered to be at risk close to airports (that is where the air surveillance radars are), following the rules as outlined in M.2059.

7 Appendix B - Filtering satellite ground terminals

The existing C-band satellite ground terminals in the Netherlands are designed to receive satellite signals in the 3625-4200 MHz band (standard C-band) or 3400-4200 MHz (including the Super Extended C-band).

Since C-band satellite ground terminals are designed to also receive signals below 3800 MHz, they may experience blocking due to signals radiated by 5G mobile networks once these are deployed in the 3400-3800 MHz band. Blocking occurs when the total aggregate signal power received at the input of the Low Noise Amplifier (LNA) causes saturation.

To prevent saturation of the LNA to occur, the signals received from 5G networks below 3800 MHz have to be attenuated before they enter the input at the LNA (filtering after the LNA will not prevent saturation). For this waveguide filters can be used. A waveguide is a structure that guides electromagnetic waves and waveguide filters are devices based on waveguide technology used to allow signals at some frequencies to pass (the passband), while others are rejected (the stopband). An example is shown in Figure B.1 and the location to insert this filter is shown in Figure B.2.



Figure B.1: Example waveguide (band-pass) filter (MFC 13961WE-I)

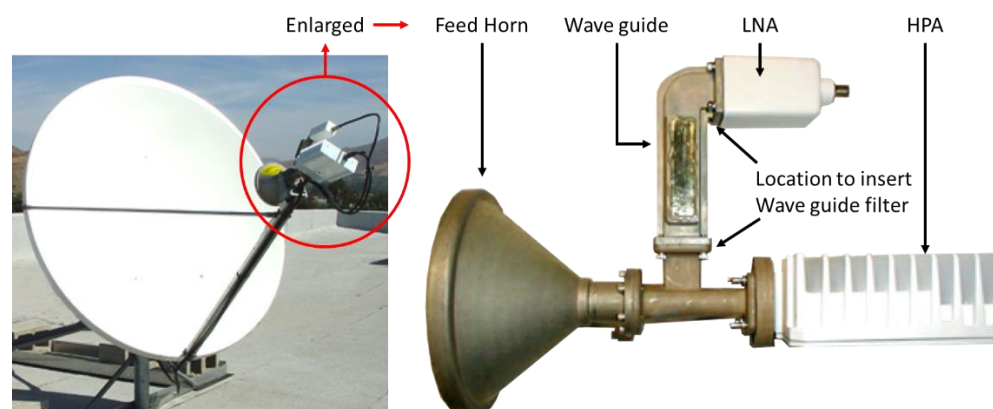


Figure B.2: Location to insert waveguide filter.

Waveguide filters offer sharp filtering with low insertion loss. An example is shown below.

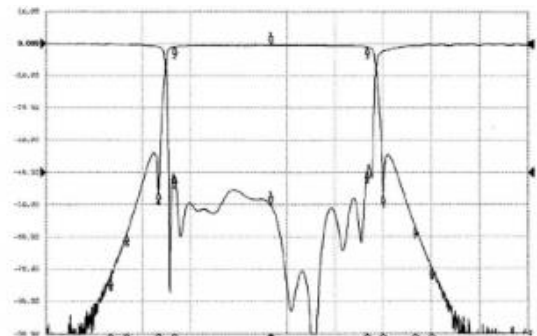
Specification (MFC 13961WE-I C-band Interference Elimination Filter¹⁴)

Specifications:

Passband:	3.6 - 4.2 GHz
Passband Loss:	0.5 dB Typ @ center band; 0.5 dB Typ roll-off @ band edges
Passband VSWR:	1.5:1 Typ
Group Delay Variation:	8 nS Max
Rejection:	45 dB Typ @ 3.55 GHz / 4.25 GHz 55 dB Typ @ 3.45 GHz / 4.35 GHz 70 dB Typ @ 3.40 GHz / 4.40 GHz
Flanges:	CPR229G (Input), CPR229F (Output)
Length:	5.49" (13.9 cm)
Weight:	1.125 lbs. (0.51 Kg)
Finish:	Gloss White Lacquer

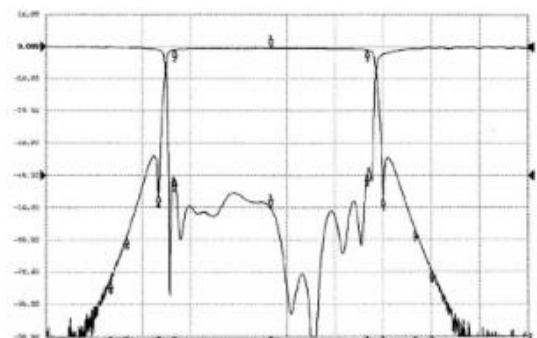
Marker

1	3.900000 GHz -0.4294 dB
2	3.600000 GHz -0.9639 dB
3	4.200000 GHz -1.0166 dB
4	3.550000 GHz -46.347 dB
5	4.250000 GHz -47.026 dB
6	3.450000 GHz -59.164 dB
7	4.350000 GHz -56.917 dB
8	3.400000 GHz -72.863 dB
9	4.400000 GHz -69.391 dB



Marker

1	3.900000 GHz -0.4294 dB
2	3.600000 GHz -0.9639 dB
3	4.200000 GHz -1.0166 dB
4	3.550000 GHz -46.347 dB
5	4.250000 GHz -47.026 dB
6	3.450000 GHz -59.164 dB
7	4.350000 GHz -56.917 dB
8	3.400000 GHz -72.863 dB
9	4.400000 GHz -69.391 dB



¹⁴ <https://788689.app.netsuite.com/c.788689/SSP%20Applications/NetSuite%20Inc.%20-%20SCS/SuiteCommerce%20Standard/Data%20Sheets/MFCO-13961WI.pdf>