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Final report for the Danish Energy Agency

Award of 700MHz, 900MHz and 2.3GHz spectrum in Denmark – spectrum for PPDR use

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Confidentiality notice

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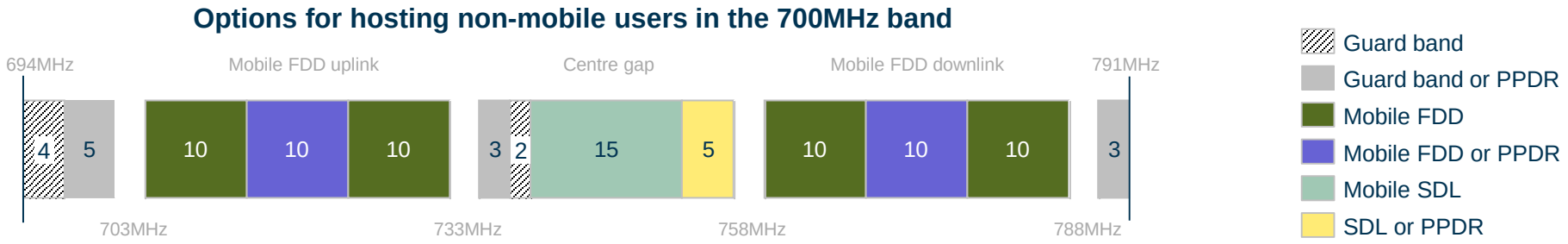
In preparation for upcoming spectrum awards, the DEA has asked us to consider the potential to use some spectrum in the 700MHz band for PPDR

- The Danish Energy Agency (DEA) is preparing the award of licences for the use of radio frequencies in the 700MHz, 900MHz and 2.3GHz bands by means of an auction process
- The spectrum available in the 700MHz band includes 2 × 30MHz FDD and up to 20MHz in the centre gap, which could be used for supplemental downlink (SDL) alongside the FDD spectrum – for example, in accordance with 3GPP specifications:
  - the paired frequencies will form a contiguous duplex frequency block comprising 703–733MHz paired with 758–788MHz
  - the centre gap runs from 733–758MHz, with the spectrum potentially usable for SDL forming a contiguous frequency block from 738–758MHz
  - the majority, if not all, of this spectrum will likely be in demand for mobile broadband use, although there is a possibility for some of the spectrum to be put to other uses, for example, for public protection and disaster relief (PPDR), either in the duplex portion of the band or in the centre gap
- An additional 17MHz of guard band spectrum is available in three contiguous blocks (694–703MHz, 733–738MHz and 788–791MHz), part of which may be assigned for other services, including but not necessarily limited to PPDR
- There are trade-offs to using parts of the various guard bands in different ways
  - for example, whilst 694–698MHz will remain as a guard band between the 700MHz band and digital terrestrial television (DTT), the option of using 698–703MHz for PPDR would incur increased requirements on the RF performance of the PPDR terminal in order to protect the DTT below 694MHz, potentially impacting the viability of this option for PPDR
  - alternatively, a reservation of 2 × 10MHz in the duplex portion of the band for PPDR might be possible, but would reduce the availability of spectrum for mobile broadband

* *As stated in ECC report 242, "Considering a separate SDL transmitting unit … designed for 738–758MHz, it is possible to design an internal 10-pole filter providing sufficient rejection to fulfil the least restrictive technical conditions (LRTC) namely -52dBm/3MHz and -64dBm/200kHz below 736MHz, with 2MHz frequency separation"*

PPDR could potentially make use of parts of the 700MHz band, influencing the amount of spectrum available for mobile broadband



- **Mobile (mobile broadband) FDD**: 2 × 20MHz or 2 × 30MHz (depending on PPDR usage)
  - 703–733MHz paired with 758–788MHz, though we understand that Motorola has suggested to the DEA that 713–723MHz paired with 768–778MHz is dedicated to PPDR
- **Mobile SDL**: 15 or 20MHz (depending on PPDR usage)
  - 738–758MHz, though 753–758MHz could potentially be used for PPDR
- **PPDR**: possible 2 × 3MHz, 2 × 5MHz or 2 × 10MHz (alternatively, could just be provided over commercial mobile networks). The DEA has identified four possible options for PPDR:
  - Option 1: 733–736MHz paired with 788–791MHz
  - Option 2: 698–703MHz paired with 753–758MHz
  - Option 3: 713–723MHz paired with 768–778MHz – an alternative 2 × 10MHz in the mobile FDD spectrum is also possible
  - Option 4: no dedicated PPDR spectrum

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This report focuses on the demand for spectrum in the 700MHz band for PPDR use

- Given the different options for assignment of parts of the 700MHz band, it is necessary to assess the likely demand from these services
- we understand that it has been suggested to the DEA that the middle 2×10MHz of the FDD spectrum in the band is reserved for PPDR
- Analysys Mason has carried out an assessment of demand for the spectrum, taking into account the different service provision options (both using dedicated spectrum around 700MHz or providing the services by other means)
- In this report we focus on the economic considerations regarding the establishment of a new broadband PPDR service
- Our aim will be to establish the economic costs of different approaches
  - although we do qualitatively discuss some wider economic benefits, as well as social costs and benefits, combining these factors to reach a conclusion on the future use of the spectrum is ultimately a policy decision
- The present report provides a comprehensive overview of our demand analysis and results for the use of the 700MHz spectrum for PPDR
  - we analyse the costs of providing a PPDR service either over a dedicated network using dedicated spectrum (for which there are various options), or making use of an existing commercial mobile network
  - at the end of this report we provide a summary of our main conclusions and recommendations

Opportunities for broadband PPDR services are being considered in Denmark currently

- PPDR has stringent coverage, quality of service and reliability requirements, which for narrowband voice and data use have traditionally been met through a privately run network using dedicated spectrum
- The central question that we seek to address in this section is *how is a broadband PPDR service best provided?*
  - we consider two main approaches: the use of a dedicated broadband PPDR network and the use of capacity on a commercial mobile network (operated by an MNO)
- Our approach is to model the economic costs of providing the service using these different methods
  - we qualitatively consider some other strengths and weaknesses of the different approaches, which we do not attempt to quantify
- It should be noted that the scope of our task extends only to considering these economic costs and that detailed assessment of unquantified costs and benefits of the different approaches, including social costs and benefits, should also be made
  - the combining of these factors and drawing of conclusions on the best option is ultimately a policy decision (and one that is unlikely to rest solely on an economic cost assessment)
- Our conclusions and recommendations in this report are based on our quantified assessment of economic costs, supported by our unquantified assessment of other costs and benefits
- This section is structured as follows:
  - we begin with a discussion of the requirements of a broadband PPDR service
  - we then discuss options for the provision of a broadband PPDR service
  - we carry out an assessment of the costs of service provision under these different options, including a description of our modelling approach, the input data relied upon and the outputs of our modelling
  - we provide a high-level analysis of other, unquantified, costs and benefits of the different options
- In the following sections we summarise our findings and present our conclusions and recommendations

The Danish PPDR network will need to accommodate a number of service requirements and must provide suitable coverage and resilience

PPDR service requirements

- The PPDR service must be capable of providing for a number of use cases:
  - voice
  - video
  - push-to-talk group communications
  - texting
  - transfer of location information for fleet management purposes
  - direct mode communications between terminals without the use of a network
  - transfer of still images and live video in near real time (picture / video taken and then transferred)
  - land-based communications and communications to aircrafts
  - prioritisation of traffic (if network carries non-PPDR traffic)
- Voice is considered to be the most important feature and is the basic part of emergency communications, but the demand for text, data, pictures and video is expected to increase

Network resilience

- Resilience is of key importance in networks for PPDR and has to exist in all levels in the network
- Depending on the technology, resilient coverage could ideally be established by overlapping cells[1] or by the use of independent networks, though there are of course cost implications to the degree of resilience
  - if independent networks are used it is important that they are not co-located at the same sites
  - the level of overlapping cells present in a mobile network today is considered sufficient for the purposes of modelling
- Resilience at higher levels in the network (i.e. transmission and switching) is also important
- In practice we assume that whether provided over a dedicated network or a commercial mobile network, the following features would be required:
  - a dedicated and tailored core network
  - resilience in backhaul links
  - additional robustness at sites in the access network (relative to a commercial mobile network)

[1] *By overlapping cells we refer to 'double coverage' whereby any part of the coverage area can be covered by (at least) two independent base stations*

Source: Danish Energy Agency, Danish Centre of Emergency Communication

The network used to provide the service must meet extensive coverage requirements and provide sufficient capacity for around 30 000 terminals

Coverage requirements

- The current narrowband TETRA service has the following coverage requirements, which we assume should apply to the broadband PPDR service:
  - **99.5 %** geographical area coverage for devices fitted to vehicles
  - **97.6 %** geographical area coverage for handheld devices
  - indoor coverage in the **143** largest cities (equivalent to **62%** geographical area coverage or **86%** population coverage)
- Although detailed analysis of the data speeds required at these levels of coverage has not been provided to Analysys Mason, we assume that the following coverage parameters should apply in a lightly loaded cell:
  - minimum 1Mbit/s uplink speed (to allow for the upload of video from ground forces back to a control centre[1], with a some capacity remaining available for simultaneous voice communications)[2]
  - minimum of 10Mbit/s downlink speed[3]
  - 90% cell edge probability (equivalent to greater than 97% cell area probability), reflecting a higher quality of coverage than on a standard mobile network

Current number of users of the narrowband PPDR service

Users	Number of devices
Police	11 000
Fire and rescue	8500
Defence (Danish Home Guard)	1100
Ambulance services	2500
Civil defence (Danish Emergency Management Agency)	1100
Others	1500
Total	25 700

- It is assumed that the current number of users may rise rapidly to a total of 30 000 terminals (with the same split between user types as above being assumed)

Source: Danish Energy Agency, Danish Centre of Emergency Communication

[1]: Typically about 800kbit/s; estimated at 768kbit/s by CEPT in ECC report 199

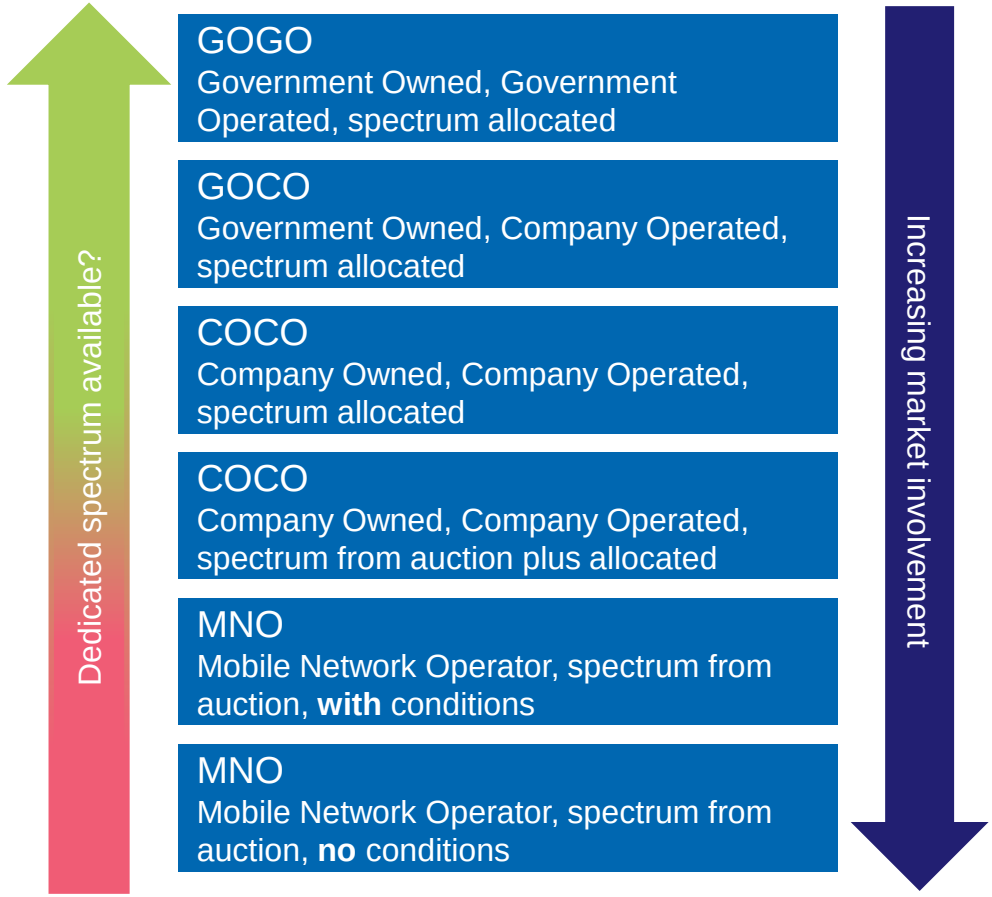
[2]: A higher uplink requirement is possible, but would tend to reduce cell radius and exaggerate the cost differences between the dedicated and commercial networks

[3]: A lower downlink speed than 10Mbit/s may be possible, but it is not the limiting factor in determining cell radii and has been chosen for this reason

There are two broad options for the provision of broadband PPDR services: over a dedicated network or over a commercial mobile network

- Narrowband PPDR services have traditionally been provided over networks that are government owned and run
- Over time there has been a shift towards these networks being company owned and run
- Now, in the broadband PPDR world, using LTE technology, there is a possibility for MNOs to own and operate the networks
- There are currently two main network approaches for providing a broadband PPDR service
  - construct and operate a **dedicated network**, making use of dedicated spectrum
  - provide the service over the **network of a commercial MNO**, with suitable adaptations made to the network to enhance coverage and resilience, and to allow for appropriate prioritisation of traffic
- Under the dedicated network approach there are various different options for the spectrum that could be used (with different associated costs and benefits)
- Under the commercial network approach there may be differences in the costs different established MNOs would incur to provide the service and there are different models for the commercial basis on which the service is provided (e.g. through licence obligations or on a purely market-driven basis)

Options for the provision of PPDR services



Source: Analysys Mason, 2017

A number of provision models have emerged for PPDR services across Europe*

Slovenia uses a hybrid MVNO solution with a combination of commercial and dedicated networks

- Broadband PPDR service
- Non-mission-critical LTE services on commercial operator networks and 2×5MHz of dedicated spectrum at 700MHz used for mission-critical services and extended coverage
- Operators winning any 700MHz spectrum will be under obligation to offer national roaming to a 'PPDR MVNO' and will have to enable traffic prioritisation
- 5G solution as a 5G 'plug-in' to the 4G network

Sweden is likely to adopt a hybrid system (though no final decision has yet been taken on the approach)

- Current MNO coverage in rural areas is poor
- A hybrid system using public and private networks aims to provide the best of both worlds
- Roaming agreement with commercial operators
- 2×10 700MHz MFCN on the public network and MNOs on 2×20 700MHz (+800, 900, etc) on the private network
- Communication solution in which MSB supervises and imposes requirements

In the UK, EE has been awarded the management of the Emergency Service Network (ESN)

- Benefits from a dense network which is already in place
- Provides mobile data capabilities and service prioritisation
- Opportunity for new applications, services and technologies
- 4G coverage layer based on LTE1800, 800MHz added in rural areas and 2.6GHz in urban areas
- Ensures further investment in quality of service
- Dedicated core network and a 'coverage-on-wheels' approach to provide extra coverage if needed

Commonalities across these models

High coverage

Guaranteed quality of service

Voice and data capabilities

Access to new technologies

Savings on set-up costs

Source: Analysys Mason, 2017

* *Further details on each of these emerging provision models are described in the Appendix*

Parts of the 700MHz band are being considered for dedicated PPDR networks in some European countries, although not in a harmonised way

- Although advances have been made in LTE-PPDR standardisation (3GPP has adopted new features in its Release 14 specification), the situation in relation to spectrum for PPDR is less clear
  - the Asia–Pacific Wireless Group (APT-AWG) approved a new recommendation on harmonising spectrum in its 700MHz band (Band 28 – 703–748MHz paired with 758–803MHz) for broadband public safety networks
  - spectrum for PPDR in the 700MHz band is not currently harmonised in Europe
    - spectrum for PPDR in the 700MHz band is described as an "option" in the current ECC 700MHz decision[1]
    - hence implementation is subject to national market needs and national decisions
- We therefore see a fragmented global picture in relation to spectrum for PPDR
- There have however been some implementing decisions within individual European countries for PPDR in the 700MHz band
  - the proposed approaches in Sweden and Slovenia are described on the previous slide
  - in France there are plans to use a total of 2 × 8MHz (encompassing two of the options described previously for Denmark) across 698–703MHz paired with 753–758MHz and 733–736MHz paired with 788–791MHz – though there is a chance that these plans will not reach fruition
  - Norway is consulting on a proposal of full assignment of 700MHz FDD to mobile operators (all of 2 × 30MHz) but may decide to impose some PPDR-related obligation on the operator licences in the 700MHz band (available from mid-2021)

[1] *Source: http://www.erodocdb.dk/Docs/doc98/official/pdf/ECCREP218.PDF;*

The different spectrum options for a dedicated solution have associated costs and benefits

2×10MHz (e.g. 713–723MHz paired with 768–778MHz)

- This spectrum option does not cause any significant interference problems
- However, this option removes spectrum from commercial mobile networks, which means that associated economic benefits are also lost
- This option offers the highest capacity, which could be of benefit in the event of a major emergency

2×8MHz

- This spectrum option is an aggregation of the 2×3MHz and 2×5MHz options described below
- It has the potential to cause interference with broadcast TV below 694MHz, as well as potential interference with SDL and/or other uses above 736MHz
- Coverage is more costly than using 2×10MHz, whilst capacity is also slightly lower

2 × 5MHz (698–703MHz paired with 753–758MHz)

- This spectrum option could potentially result in interference with the uppermost broadcast TV channel (as noted in ECC Report 218[1]) – this could have an economic impact
- Reduces the 700MHz SDL spectrum availability by 5MHz, which has an opportunity cost (even if lower than for 700MHz FDD spectrum)
- Coverage is more costly than using 2 × 10MHz and capacity is only around half the level offered by 2 × 10MHz

2×3MHz (733–736MHz paired with 788–791MHz)

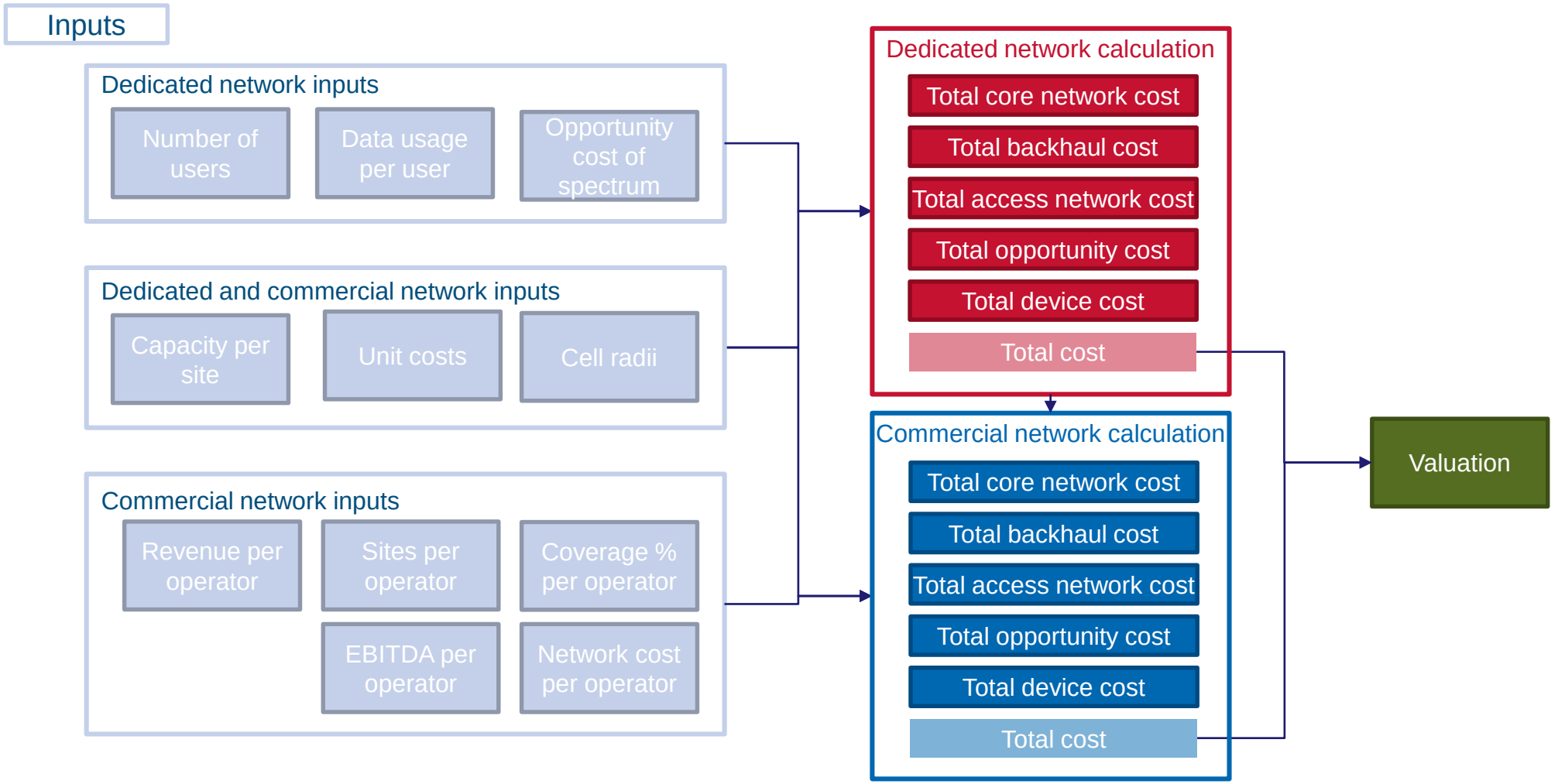
- Using this spectrum for PPDR rather than as a guard band will result in interference with the bottom 5MHz of the 700MHz SDL in the centre gap (see IoT and PMSE section), resulting in limited usability of the centre gap spectrum, and the bottom 5MHz no longer being suitable for mobile use
- It offers the lowest capacity, which might cause problems in the event of a major emergency
- Coverage is the most costly of all the dedicated spectrum options

1 *Sources: ECC Report 218 (see http://www.erodocdb.dk/Docs/doc98/official/pdf/ECCREP218.PDF), Analysys Mason*

The scope of our model is to calculate the economic costs of different options for provision of a broadband PPDR service

- The model measures the economic cost of setting up and running the PPDR service over a set period of time (20, 22 or 25 years)
  - by establishing a **dedicated nationwide PPDR network** with different amounts of spectrum previously set out; or
  - by buying access to an **established mobile network,** upgraded to offer similar quality of service to nationwide PPDR network
- The cost of hybrid solutions such as those discussed for Slovenia and Sweden is not directly calculated, though it would likely lie between the cost of a dedicated network and the cost of using a commercial mobile network
- We consider different options for each network approach:
  - in the dedicated model, we consider:
    - different amounts of **spectrum,** which have different **cell radii** for **indoor** and **outdoor** coverage as well as offering different amounts of **capacity**
    - different percentages of **greenfield** and **co-location** sites to account for uncertainty over re-use of existing sites
  - in the commercial network model, we consider the costs for each of the current Danish mobile operators
    - there may be synergies for mobile operators in both providing a PPDR service and meeting certain types of coverage obligations, but we do not explicitly take this into account in our calculations
- The costs associated with the dedicated network and commercial network are considered in five sections:
  - core network costs
  - backhaul costs
  - access network costs
  - device costs
  - opportunity costs associated with the use of spectrum and network capacity
- However, as already discussed, the model does not take into consideration wider economic and social costs and benefits

Overview of model calculation flows



Source: Analysys Mason, 2017

Our model contains five cost categories, with calculations for each undertaken separately for the dedicated and commercial network options

Cost category	Dedicated network	Commercial network
Core network	A PPDR-dedicated core network is required in either case, and with the same assumed cost 1	
Backhaul	Each new site requires two fibre backhaul links for resilience and a metro node and transport link to the core network is required for every five sites 2	**New sites** have the same requirements as the new sites in the dedicated network, but **existing sites** only need a second fibre backhaul link to increase resilience 2
Access network	**Coverage**: 3 In order to fulfil both the indoor (62% area) and outdoor (97.6% area) coverage requirements, a certain number of sites have to be built according to the cell radii, which vary for outdoor and indoor coverage and for different amounts of spectrum **Capacity:** Additional sites (beyond the coverage layer) could be needed to provide the required capacity. This depends on the traffic generated by the PPDR users	**Coverage:** 3 The number of additional sites needed to fulfil the coverage requirements depend on the existing coverage at the required speed for each existing operator. The number of additional sites required to enhance coverage is determined using the applicable cell radii
Devices	Devices have to be split between handheld and vehicle devices, which incur different costs. Additionally, we assume the cost per device is higher for the 2×3, 2×5 and 2×8 options, than for 2×10MHz 4	The cost per device is the same as for the 2×10MHz option in the dedicated network 4
Opportunity cost	The opportunity cost is an estimate of the value of the amount of 700MHz spectrum denied to mobile operators by its use of a dedicated PPDR network 5	Using the percentage of traffic that is generated by PPDR, a capacity-based approach calculates the share of MNO network costs that should be paid by the PPDR service provider in lieu of the MNO being able to sell the capacity to mobile users 5

1 Details of approach and key input data: Core network costs

- In this section we consider two components of the PPDR network:
  - the core network itself
  - the service platform
- We assume that in the case of both the dedicated network and the commercial network, a core network (and service platform) dedicated solely to PPDR will be required
  - we note that in the commercial network case it is possible that an alternative, lower cost, solution may be possible
- The capex and opex estimates used for both components are derived from a similar study undertaken recently on behalf of the Norwegian regulator NKOM by Nexia and Menon[1]
  - the **core network** is assumed to have a ten-year lifetime, with opex modelled to represent 10% of the initial capex per annum
  - the **service platform** is also assumed to have a ten-year lifetime, with opex consisting of the staff costs to operate the platform (it is assumed that five full-time members of staff are required)

Component	Total capex (DKK thousand)	Total opex (DKK thousand)
Service platform	28 000	4000
Core network	60 000	6000

1 *Source: Anvendelse av 700 MHz-båndet, Nexia and Menon, July 2017 (see https://www.nkom.no/aktuelt/nyheter/_attachment/27620?_ts=15a7fd5fdd8)*

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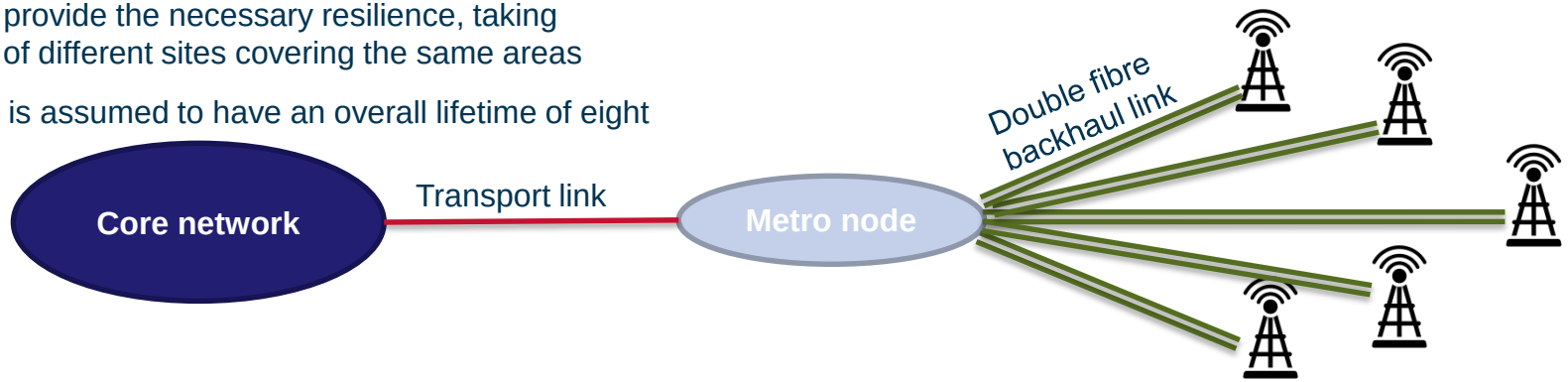
2 Details of approach and key input data: Backhaul

- In order to fulfil the resilience requirement of the PPDR service, all sites need to be equipped with two backhaul links
  - we have assume that these are fibre backhaul links
- In the **dedicated network**, all sites require two fibre backhaul links and a metro node and transport link is required for every five sites (as shown in the diagram below)
- In the **commercial network**:
  - all new sites require two fibre backhaul links and a metro node* and transport link is required for every five new sites
  - all existing sites (which are already equipped with one backhaul link) require an additional fibre backhaul link in order to add resilience – we note that this is a conservative assumption since alternative approaches could potentially be used to provide the necessary resilience, taking advantage of different sites covering the same areas
- The backhaul is assumed to have an overall lifetime of eight years

Unit costs of backhaul cost components

Component	Capex (DKK thousand)	Opex (DKK thousand)
1 fibre backhaul link	80	6
Metro node (per 5 sites)	160	16
Transport link (per 5 sites)	–	35

- The unit costs are sourced from the Danish operator's responses to our data request and from the Nexia/Menon report for Norwegian regulator, NKOM



* *Metro nodes are used to provide a more cost-efficient network structure in the form of a ring to route and switch IP packets without always needing to route traffic right into the core network*

Source: Nexia and Menon report, Analysys Mason

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3 Details of approach and key input data: Access network – coverage

Dedicated network

- For the dedicated network we calculate the number of sites needed to fulfil both the outdoor and indoor coverage requirements
- The outdoor requirement is **97.6%** of the area of Denmark whereas the indoor is **62%** (covering 143 major cities)
- The number of sites being built is determined by the cell radii; the cell radii varies between spectrum options and depending on whether indoor coverage is also required (the latter has a significant impact)
- The cell radii are derived from a link budget model using a cell edge probability assumption of 90% (reflecting high-quality coverage); in this model we account for interference from neighbouring cells as well as white noise through the inclusion of an interference margin (2dB in urban, 1dB in suburban and 0dB in rural areas)
- The 2 × 10 option has the largest cell radii and therefore requires a smaller number of sites to be built, however the 2 × 3 option has the smallest cell radii and requires the largest number of sites

Commercial network

- For the commercial network we calculate the number of additional new sites needed to fulfil the outdoor coverage requirements. The new sites are added to the sites the operator already possesses
- The outdoor requirement is **97.6%** of the area of Denmark
- The number of new sites being built depends on the operators' geographical coverage of the area of Denmark (consisting of the existing coverage area augmented by the addition of a 2 × 10MHz carrier of 700MHz on each existing site)
- The commercial operator with the greatest coverage has to build the least new sites. Similarly, the commercial operator with the lowest coverage has to build the largest number of sites
- The same cell radii as used for the 2 × 10MHz dedicated network scenario are used for all commercial operators

Cell radii are somewhat higher for all operators in the commercial network due to a lower cell edge probability

Outdoor cell radii (km)

Spectrum (MHz)	Urban	Suburban	Rural
2×10	0.68	1.36	4.40
2×8 and 2×5	0.64	1.20	3.86
2×3	0.64	0.95	3.07

Indoor cell radii (km)

Spectrum (MHz)	Urban	Suburban	Rural
2×10	0.36	0.74	2.82
2×8–2×5	0.33	0.65	2.47
2×3	0.33	0.52	1.97

Source: Analysys Mason

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3 Details of approach and key input data: Access network – other features

Dedicated network

- The network has to be able to carry the traffic generated by users, and the sites required for coverage may not be sufficient to do this
  - it is assumed that there are **30 000** users (as described in an earlier section of this report)
  - the data usage per user is assumed equal to mobile users and is used, along with user numbers, to derive the total busy-hour traffic*
  - the capacity per site depends on the spectrum option, 2 × 10MHz having the highest capacity and 2 × 3MHz the lowest
  - if the busy-hour traffic generated by users exceeds the capacity offered by the sites built to fulfil the coverage requirement, then additional sites need to be built
- The sites built for both coverage and capacity are split between new **greenfield** sites and sites **co-located** with existing sites (at lower cost)
- The proportion of greenfield sites has a significant impact on costs and is an assumption we sensitivity test (our starting assumption being that 30% of sites are greenfield)

Commercial network

- The new sites required to fulfil the PPDR coverage requirement are added to the existing operator sites
- We assume a 700MHz deployment on all existing sites to ensure that no more new sites than necessary are deployed
- Whilst new sites incur the same unit costs as in the dedicated network scenarios, existing sites need only to be upgraded to fulfil the PPDR robustness requirements
  - in particular, we have assumed that all existing sites require additional battery back-up to be installed

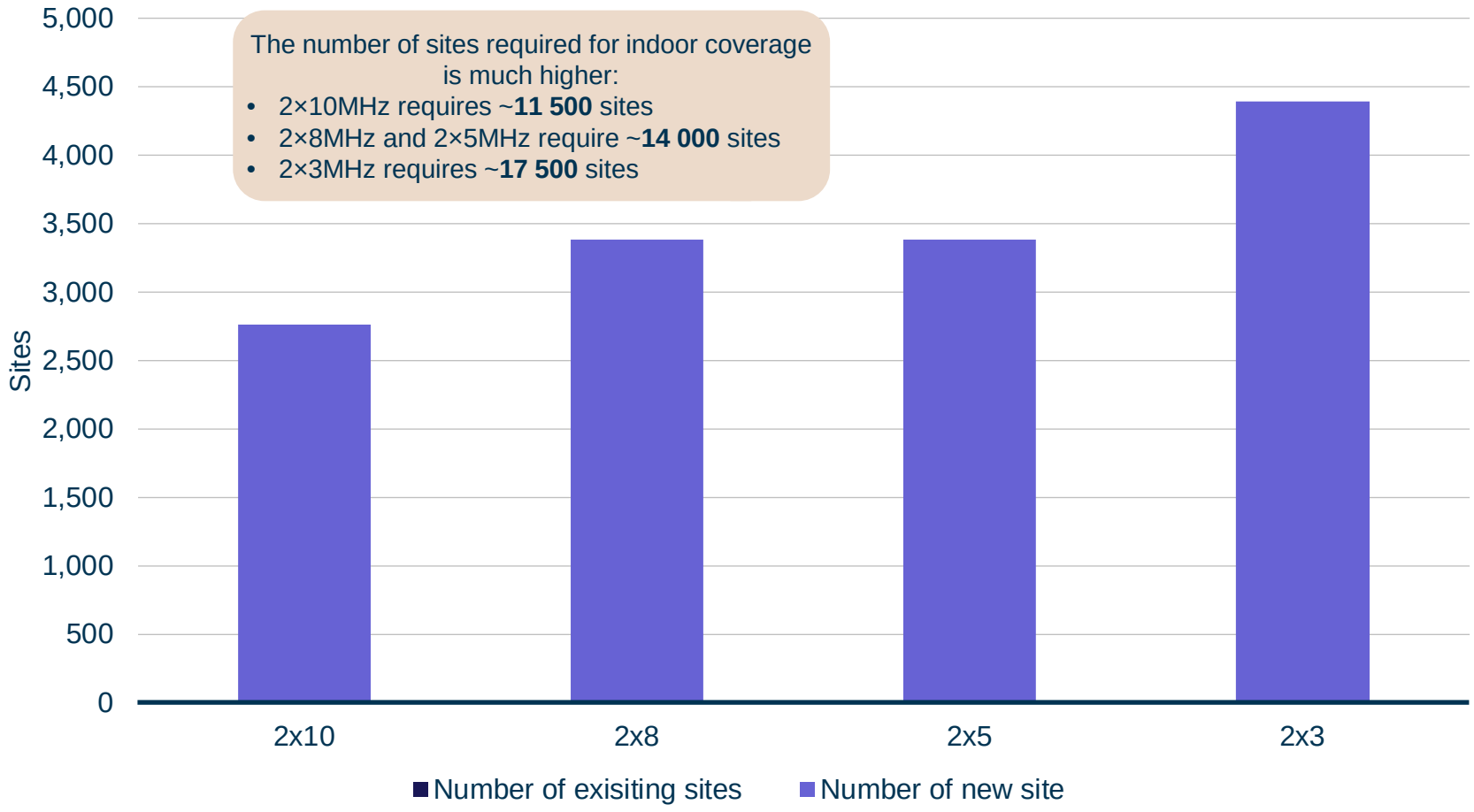
Due to the extremely high number of sites required to provide indoor coverage at 10Mbit/s downlink and 1Mbit/s uplink in 143 cities, we assume in our base case that the outdoor cell radius for these speeds continues to apply and a lower speed with potentially more patchy indoor coverage is provided in both the dedicated and commercial network scenarios

We sensitivity test providing indoor coverage at 10Mbit/s downlink and 1Mbit/s uplink in the dedicated network case, but do not assume that this requirement could practically be met in the commercial network case due to the nature of existing site grids

* *This is likely an aggressive assumption for PPDR traffic per user, although conversely it is possible that the proportion of traffic in the busy hour is greater than for a mobile network. Our analysis ultimately demonstrates that capacity-based costs for PPDR are not high, despite potentially aggressive traffic assumptions such as this*

To fulfil PPDR outdoor requirements, new sites have to be built for the dedicated network in particular

Total number of sites required for outdoor coverage using a dedicated network (25-year valuation period)



Source: Analysys Mason

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3 Details of approach and key input data: Access network – costs

Dedicated network

- All new **greenfield** sites incur five main capex items:
  - site acquisition and civil works costs
  - a base station
  - antennas in each of three sectors
  - a 700MHz carrier
  - a back-up battery
- All of these cost components, apart from the carrier, also incur opex
- **Co-located** sites have a lower capex and opex as they only require new active equipment (antennas, carriers and base stations) as well as lower civil works costs
- The percentage of greenfield and co-located sites therefore has a significant impact on the total cost of the network
- The average lifetime for all components of a site is assumed to be 16 years

Commercial network

- In addition to the standard capex and opex relating to sites, existing sites need to be upgraded to increase resilience
  - this incurs additional capex and opex for each site related to battery back-up
- The new sites that need to be built by the operators have the same component cost and lifetime as the new sites being built in the dedicated network

Component	Capex (DKK thousand)*	Opex (DKK thousand)*
Greenfield site	1 105	179
Co-located site	434	57
Back-up battery	80	8

Also used for the operator's existing sites upgrade

Source: Analysys Mason, Nexia/Menon report

* *All capex and opex unit costs are expressed in 2017 real terms*

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Details of approach and key input data: Devices

- The end-user devices (or terminals) can be broken down into **handheld devices** and **vehicle devices**
  - we have been provided with a ratio for the Danish police force of 73% handheld devices and 27% vehicle devices, and have applied this ratio for the projected 30 000 users*
- The vehicle devices also require an installation cost
- All devices are assumed to have a four-year lifetime
- In the dedicated network, the costs differ between spectrum options
  - for the 2 × 10MHz option, which is part of the harmonised mobile band, devices (whilst still needing to be customised) are likely to be available at significantly lower cost (e.g. due to making use of components used in mobile devices with significant economies of scale)
  - on the other hand, although the 2 × 8MHz, 2 × 5MHz and 2 × 3MHz are also harmonised and covered by 3GPP standardisation, the frequency bands used for these options are outside the core bands used for mass market equipment and are therefore likely to incur substantially higher unit costs; we assume a 50% increase on the cost of the 2 × 10MHz devices
- The devices in the commercial network have the same cost as devices in the 2 × 10MHz spectrum option in the dedicated network

Spectrum option	Unit cost handheld (DKK thousand)	Unit cost vehicle (DKK thousand)	Installation cost (vehicle only) (DKK thousand)
2×10MHz	7	11	2
2×8 / 2×5/ 2×3MHz	11	16	2

Source: Nexia/Menon report, Analysys Mason

* *The ratio we have assumed relates to voice terminals and it is possible that a different split could apply for broadband terminals and/or a different lifetime could apply for vehicle mounted terminals, although we have no direct evidence to support a different assumption. A different assumption here would not be a key driver of the costs.*

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5 Details of approach and key input data: Opportunity cost – dedicated network

- The opportunity cost in the dedicated network relates to the spectrum that has to be foregone by mobile operators
- The opportunity costs we use are estimates of the values for the relevant amount of spectrum, which we do not discuss in this report due to sensitivity of such numbers in relation to upcoming auctions
- The relevant amounts of spectrum are as follows:
  - for the 2 × 10MHz network – 2 × 10MHz of spectrum in the 700MHz FDD band
  - for the 2 × 8MHz network – 10MHz of spectrum in the 700MHz SDL band
  - for the 2 × 5MHz and 2 × 3MHz networks – 5MHz of spectrum in the 700MHz SDL band

5 Details of approach and key input data: Opportunity cost – commercial network

- The opportunity cost calculation for the commercial network scenarios is designed to reflect ongoing payments that the PPDR service provider would be required to make to the MNO to compensate for the capacity that is being used on the MNO's network
- The pricing may be the outcome of a commercial negotiation or could be mandated (or at least specified in principle) through regulation; as such it is hard to predict accurately
- We have therefore followed **three** alternative approaches to try and estimate a reasonable price reflecting the opportunity cost of the MNO not being able to use the capacity for additional or existing mobile customers, or alternatively incurring costs to add capacity to its network
  - all three approaches are based on the percentage of traffic that the PPDR network represents compared to the total traffic of the chosen operator
    - the level of PPDR traffic is derived in the dedicated network capacity calculation and is compared to our estimate of total traffic on each MNO network
- The **first approach** looks at the future **network costs** of each operator from the base case of our spectrum valuation modelling and multiplies this by the percentage of traffic on each operator's network that would be made up by PPDR
  - this approach is likely to represent a lower bound for the opportunity cost as it only takes the access network costs into account
- The **second approach** looks at the **EBITDA** of the mobile business of each operator (within Denmark) and multiplies this by the percentage of traffic on each operator's network that is generated by PPDR
- The **third approach** looks at the **total revenue** of the mobile business of each operator (within Denmark) and multiples this by the percentage of traffic on each operator's network that would be made up by PPDR and a 50% factor to represent a typical retail margin (e.g. in deals with mobile virtual network operators (MVNOs))
- We note that the opportunity cost calculated by all three methods is similar for each operator and only represents a small part of the total cost of providing the PPDR service

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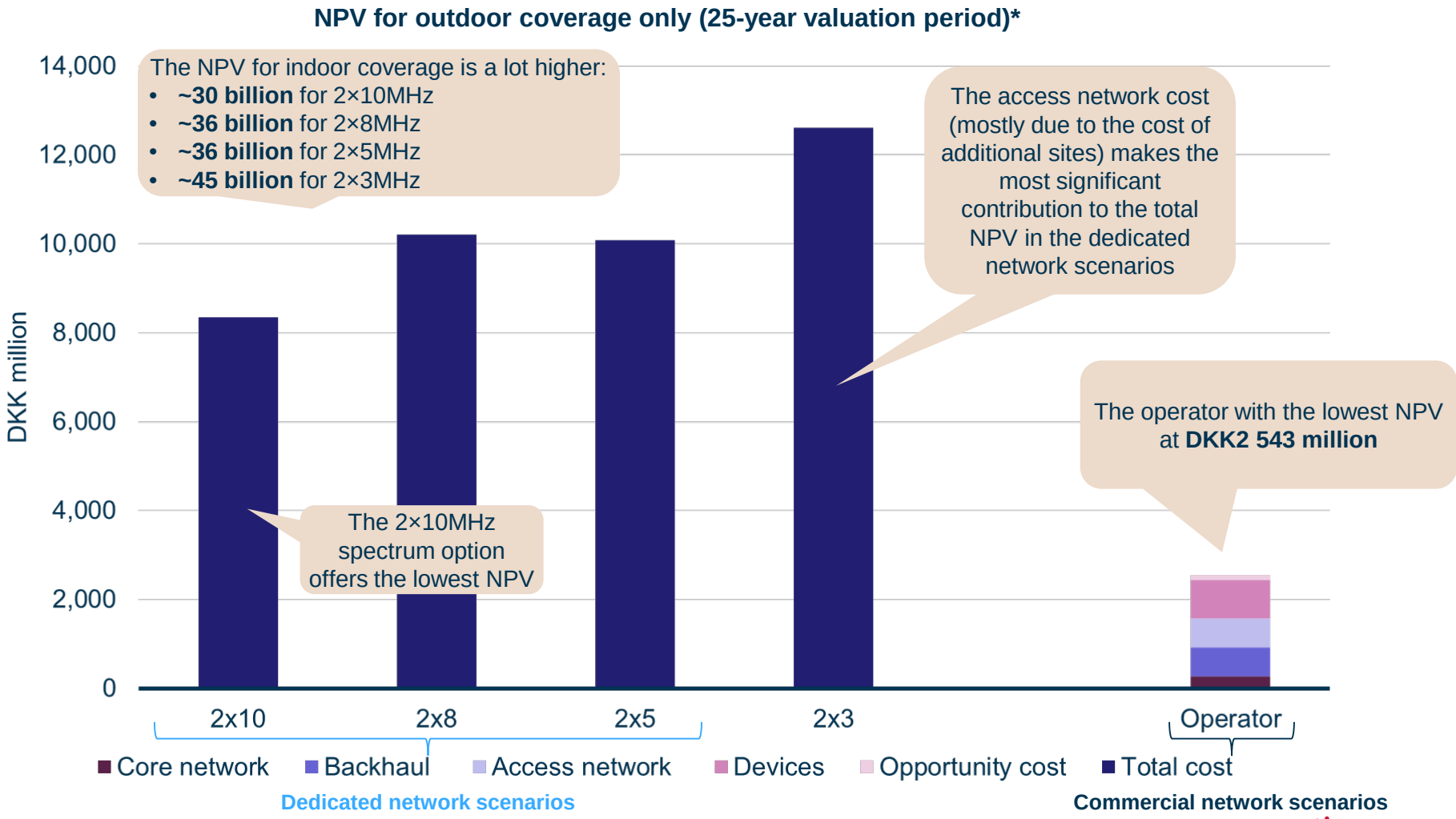
The model outputs show that the cost of a dedicated network solution is significantly higher than the costs of using a commercial mobile network



Source: Analysys Mason

* *The results shown for the commercial network option are fort the operator with the lowest costs*

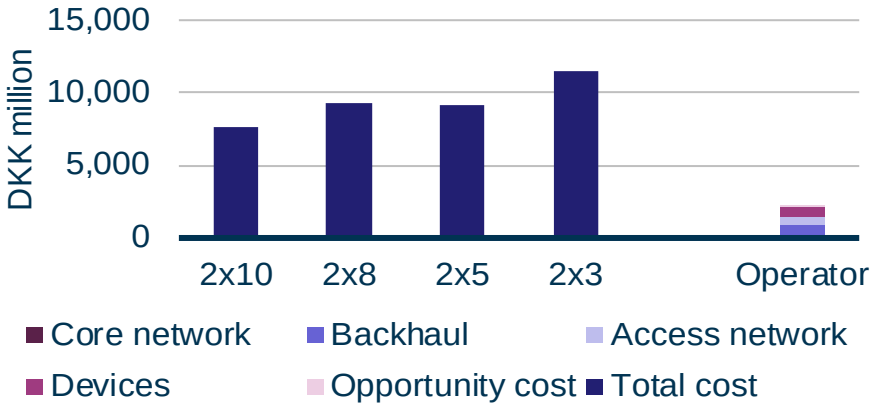
We have sensitivity tested different valuation periods in both the dedicated network and the commercial network scenarios

- Our sensitivities reflect the potential licence durations we have used in our mobile spectrum valuation modelling work
  - 20 years
  - 22 years
  - 25 years
- A longer valuation period is potentially relevant for assessing the best option for a future broadband PPDR network, but would not change our conclusions
  - we have used the same valuation periods as in our mobile spectrum valuation model so that we have access to accurate opportunity cost estimates, but have focussed on the longest of these (25 years) in our base case
- There are only very slight variations in NPV between different valuation periods

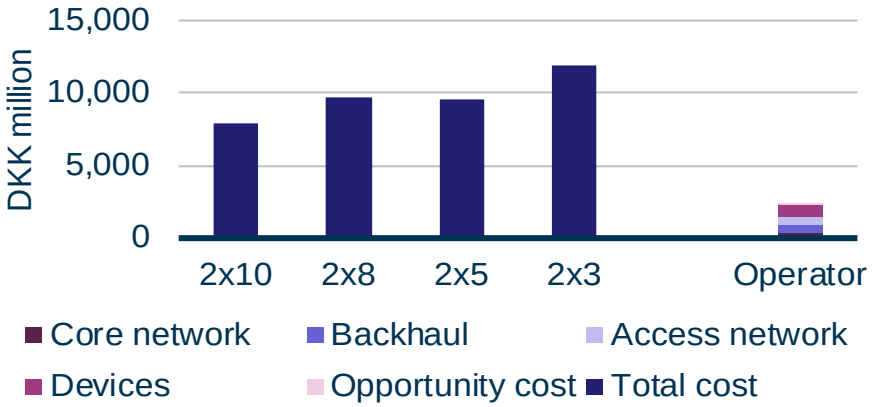
Total cost for each dedicated PPDR network scenario (DKK millions, expressed as NPV)

Spectrum option	25 years	20 years
2×10MHz	8 345	7 595
2×8MHz	10 215	9 266
2×5MHz	10 082	9 155
2×3MHz	12 604	11 472

NPV outdoor only 20-year valuation period*



NPV outdoor only 22-year valuation period*

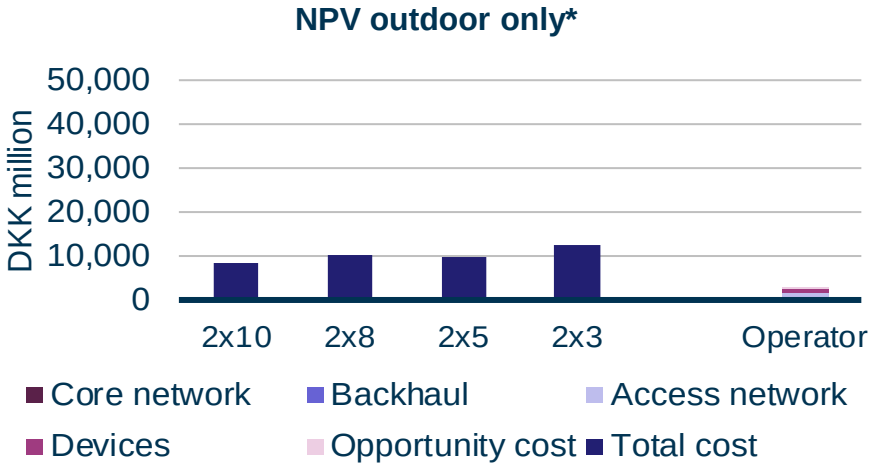


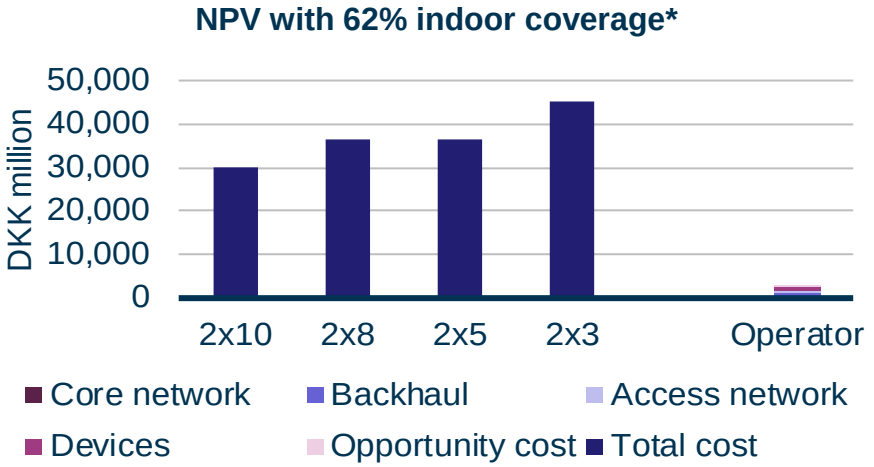
Source: Analysys Mason

* *The results shown for the commercial network option are fort the operator with the lowest costs*

Applying an indoor coverage requirement to 62% of the area of Denmark is significantly more costly than the outdoor-only coverage requirement

- The outdoor coverage requirement is **97.6%** of the area of Denmark
  - **62%** of this area, which represents 143 major cities in Denmark and 86% of the population, should also be covered indoors
- In the dedicated network scenarios, we assume the same high levels of coverage in urban and suburban geotypes indoors as are provided outdoors, and a **56.9%** indoor coverage in rural areas to achieve the 62% average
- Assuming a different breakdown of the coverage by geotype could have some impact on this cost, but it is likely to be small
- Due to the indoor cell radii being very small, a high number of sites are required for indoor coverage of **62%** of the area
- The high number of sites incurs very high costs and so the total NPV of the dedicated network is too high to be realistically affordable
- However, lowering the speeds that is offered and allowing for a larger cell radius would lower costs and could generate a more realistic NPV
  - this alternative might not suit the PPDR service requirements





Source: Analysys Mason

* *The results shown for the commercial network option are fort the operator with the lowest costs*

The proportion of greenfield sites has a big impact on the cost of the access network (demonstrated by reducing the greenfield proportion to 10%)

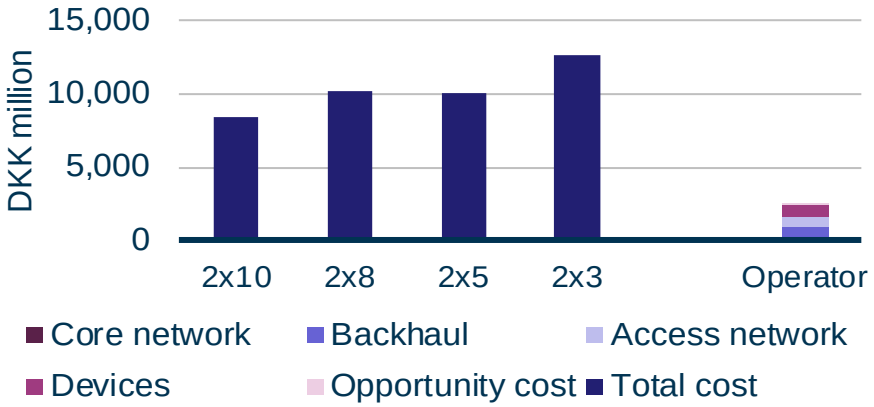
- In the dedicated network scenarios, the proportion of greenfield sites and co-located sites has a significant impact on costs
  - this is due to co-located sites having lower capex and opex
- Reducing the proportion of greenfield sites from **30%** to **10%** induces a significant decrease in the cost of the access network, which in turn has a big impact on the total NPV

Total cost for each dedicated PPDR network scenario (DKK millions, expressed as NPV)

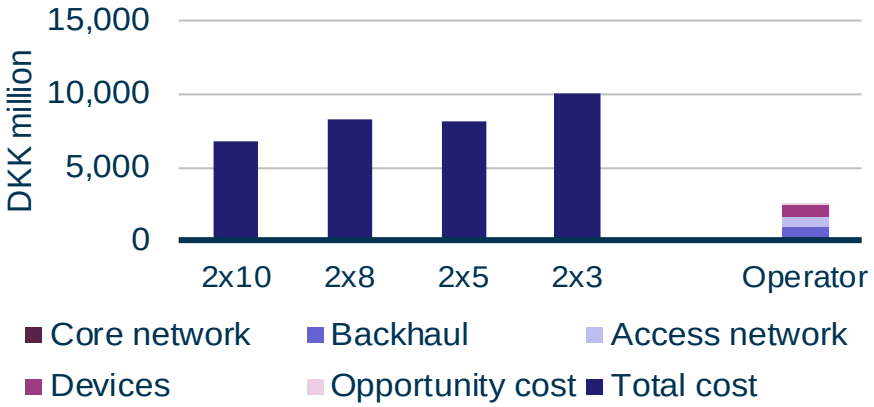
Spectrum option	30% greenfield	10% greenfield
2×10	8 345	6 742
2×8	10 215	8 256
2×5	10 082	8 122
2×3	12 604	10 055

- A low greenfield site proportion relies on being able to re-use sites currently used in mobile networks
  - an inability (or a lesser ability) to do so would significantly increase the costs of an outdoor as well as an indoor coverage-capable dedicated network

NPV outdoor only 30% greenfield sites*



NPV outdoor only 10% greenfield sites*



Source: Analysys Mason

* *The results shown for the commercial network option are fort the operator with the lowest costs*

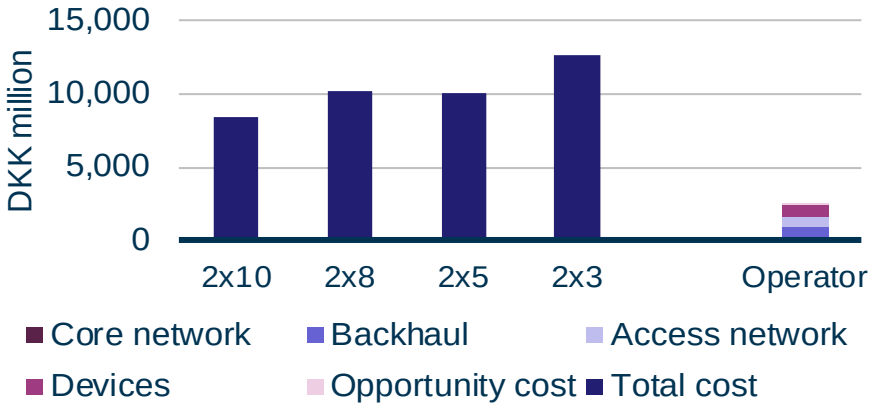
The model behaves in a predictable way as assumptions on the proportion of greenfield sites are changed to other alternative levels, such as 20%

- Reducing the proportion of greenfield sites by 10% points from **30%** to **20%** also induces a decrease in the cost of the access network, which in turn has an impact on the total NPV
- As expected the impact of a reduction in the proportion of greenfield sites from 30% to 20% has roughly half the impact of a reduction from 30% to 10%

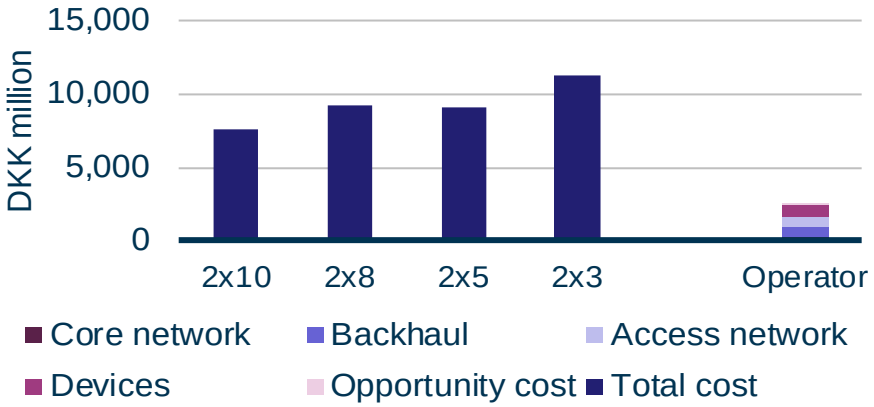
Total cost for each dedicated PPDR network scenario (DKK millions, expressed as NPV)

Spectrum option	30% greenfield	20% greenfield
2×10	8 345	7 544
2×8	10 215	9 236
2×5	10 082	9 102
2×3	12 604	11 330

NPV outdoor only 30% greenfield sites*



NPV outdoor only 20% greenfield sites*



Source: Analysys Mason

* *The results shown for the commercial network option are fort the operator with the lowest costs*

There are additional costs and benefits of the different approaches to providing a broadband PPDR service, which we have not quantified

- Our model analysis only assesses a specific set of costs relating to the set-up and operation of the PPDR network
- The different approaches considered will also exhibit a number of other advantages and disadvantages, which we have not sought to quantify but which can nonetheless be considered as further costs and benefits
- These unquantified effects could include the following:
  - network coverage (assumed equal in our analysis, but quality of coverage within covered areas could vary)
  - network capacity (assumed satisfactory in all scenarios, but networks with greater excess capacity may provide benefits during major incidents)
  - grade of service (assumed higher for the dedicated network than for the commercial network, though in practice more spectrum and overlapping coverage areas of sites on a commercial mobile network could also lead to a higher grade of service)
  - futureproofing (new technologies and their benefits not explicitly considered in our modelling)
  - interference with other services (e.g. broadcasting or other mobile services – not considered in our modelling)
  - customer surplus (we account for the opportunity cost of using less spectrum for mobile by estimating the value foregone by mobile operators, but there may also be substantial consumer surplus associated with additional spectrum allocation to mobile broadband services)
  - quality of service
- The parameters have varying degrees of importance in terms of their effect on the PPDR network
- Our model analysis also does not attempt to quantify social costs and benefits
  - e.g. benefits such as lives being saved by a superior quality of service provided by the broadband PPDR service offered by each technical solution

On balance (without considering weightings) a greater number of these unquantified factors point to a commercial network route being favoured

Parameters	Dedicated network		Commercial network	
Coverage	Full outdoor coverage with a possibility of indoor coverage (although costs are high)	✓✓	Full outdoor coverage but indoor coverage within existing footprint may be challenging	✓
Capacity	Capacity is limited to the spectrum dedicated to PPDR. This could be a significant problem when dealing with major incidents, particularly where smaller amounts of spectrum are used (e.g. 2×3)	✗	There is effectively no capacity threshold as operators can shift capacity from their commercial services to the PPDR service	✓✓
Grade of service	Higher grade of service as the network is purpose built	✓	Lower grade of service is likely, though overlapping cell areas could mitigate this	✗
Futureproofing	Reliant on a steady, but uncertain, stream of investment	✗	Mobile operators continuously invest in technological development to stay competitive	✓✓
Interference	Depending on the spectrum option there could be a risk of interference with broadcasting channels 2×10MHz carries no risk; other options do carry a risk	✗ —	No risk of interference	✓
Customer surplus	Less spectrum available for commercial uses as some dedicated to PPDR	✗	Increased spectrum for mobile services	✓
Quality of service	Purpose-built network, no need for traffic prioritisation involving commercial traffic. In addition, the network is built to fulfil the PPDR resilience and security requirements	—	Need for traffic prioritisation between the commercial and PPDR part of the network and need for an upgrade to PPDR resilience and security requirement – these requirements are achievable	—

Source: Analysys Mason

✓ Advantage of the parameter ✗ Disadvantage of the parameter — Neutral effect of the parameter

Dedicated 700MHz spectrum (and a dedicated network) for PPDR is a more expensive solution than using a commercial mobile network

- Different MNOs will incur varying levels of cost when providing a broadband PPDR service; the MNOs may also have varying appetites for doing so due to the impact on their networks. A summary of the NPV of costs (DKK millions) for the operator with the lowest costs is shown in the table below for each time period:

Operator	20 years	22 years	25 years
Lowest cost	2 274	2 396	2 543

- There are several ways that the service could be provided over a commercial network, which need to be considered to help understand how best to achieve this
  - a **market-driven** approach occurred in the UK, where EE won a public tender to provide the broadband PPDR service
    - this approach has associated risks, however
  - an alternative would be to **mandate** the provision of PPDR services; this could take the form of a licence condition when awarding 700MHz, or other, spectrum
    - the operators would offer the service by adhering to certain pricing and non-pricing conditions (e.g. cost-oriented provision of required coverage and quality of service)

- The dedicated network approach incurs significantly higher costs, which vary depending on the spectrum option
- If the service is to be provided using a dedicated network, then 2 × 10MHz seems to be the most suitable spectrum option as it is the cheapest and least risky option
  - it provides a higher capacity, which could be needed in the case of major emergencies
  - it also avoids causing interference with other existing services such as broadcasting
  - it does, however, entail the greatest opportunity cost due to removing the largest amount of prime spectrum from mobile broadband services

NPV (DKK million)

Spectrum	20 years	22 years	25 years
2×10MHz	7 595	7 898	8 345
2×8MHz	9 266	9 652	10 215
2×5MHz	9 155	9 531	10 082
2×3MHz	11 472	11 918	12 604

Source: Analysys Mason

Other factors, which are beyond the scope of this report to quantify, should be taken into account to form the basis for any policy decision

- From an economic cost perspective, providing a broadband PPDR service over a commercial mobile network appears more attractive
- Although our model analysis offers good insight into the economic costs of dedicated versus commercial network solutions, it considers only the costs of service provision and not the wider economic benefits afforded by the alternative approaches (e.g. consumer surplus decreasing were less spectrum to be allocated to mobile broadband)
- There are also numerous factors relating to the difference in quality or other characteristics of the services provided using a dedicated network or over a commercial network, all of which could have either economic or social costs or benefits associated with them

Dedicated network

Benefits	Costs
• Benefits from possibility of indoor coverage • Fully dedicated network that offers a tailored solution • No traffic prioritisation • High grade of service, with high quality of service, reliability and security	• High set-up costs • Cost to upgrade • Lack of incentive to upgrade • Limited capacity in the event of a major emergency • Risk of interference • Decrease in consumer surplus

Commercial network

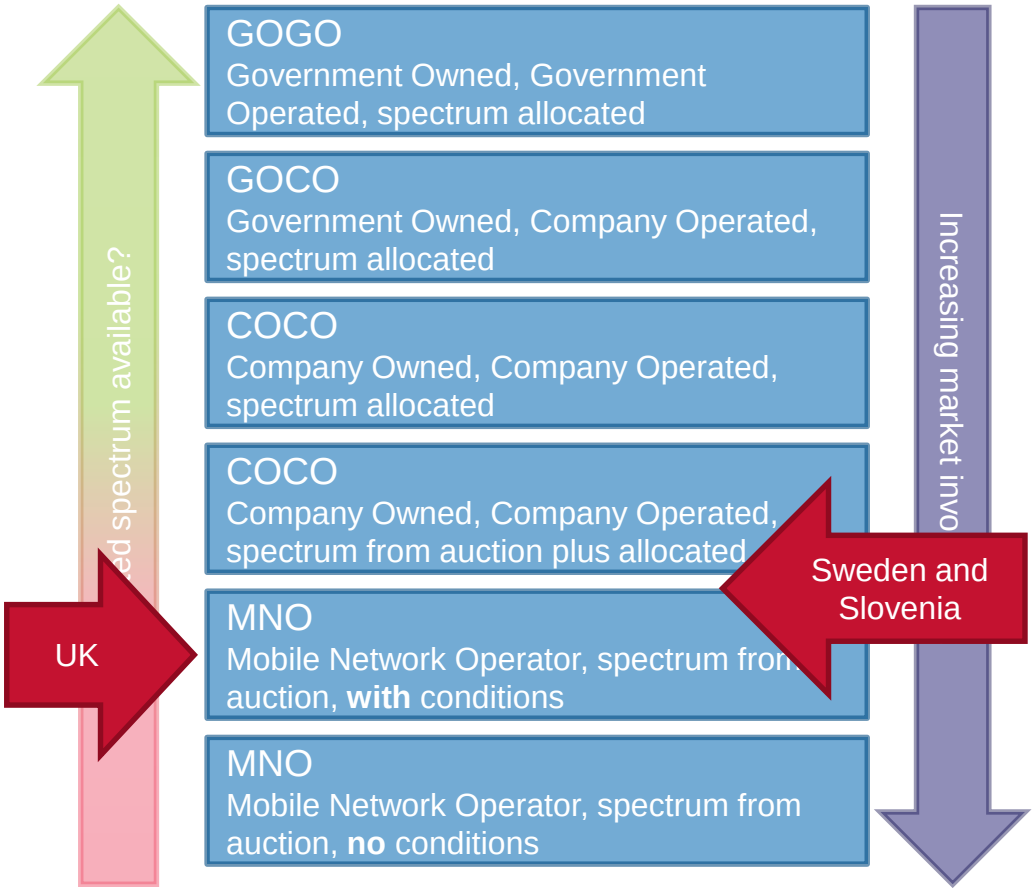
Benefits	Costs
• Lower set-up costs • Continuous upgrades • Access to operator resources and expertise • High capacity in case of emergency • No risk of interference • Increase in consumer surplus	• Likely to be a lower grade of service • Ensuring that coverage is added to support PPDR service even where it is not commercially profitable • Service to retail mobile customers may occasionally suffer

- Similarly, our analysis does not attempt to quantify social costs and benefits, e.g. benefits arising due to lives being saved by a superior quality of service provided by the broadband PPDR service offered by each technical solution
- We recommend that these issues are considered further, though this is beyond the scope of the present report

Source: Analysys Mason

Requirements and provision options

Options for the provision of PPDR



- In this Appendix we describe the broadband PPDR approach being followed in three European markets:
  - Slovenia
  - Sweden
  - the UK

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Slovenia plans to use a hybrid broadband PPDR solution with a combination of commercial network and dedicated network

- Combination of non-mission-critical services on commercial operator networks and dedicated spectrum used for mission-critical services and extended coverage
- In the 700MHz auction, operators winning any spectrum will be under obligation to offer national roaming to a 'PPDR MVNO' and will have to enable traffic prioritisation
- For mission-critical LTE, there will be dedicated spectrum in addition to the commercial networks, 2 × 3MHz in 700MHz, 2 × 5MHz in 450MHz to 470MHz and possibly 2 × 5MHz in 410 to 430MHz
- A rapid introduction of 5G is being encouraged by the regulator, AKOS
  - the intention is that it will be supported by PPDR users, co-operation between the entities concerned as well as a sound regulatory and development environment
  - the use of a commercial mobile network means that upgrades to a 5G solution should be a relatively straightforward 'plug-in' to the existing 4G network, and one which is likely to enhance the functionality of the PPDR service

Pros:

- Benefits from a relatively low cost set-up, high coverage from the combination of commercial and dedicated network and from the access to MNO resources, expertise and technologies

Cons:

- Risk of a lack of investment in the dedicated network and reduction in the service to retail customers in case of emergency

Sweden is also planning to adopt a hybrid system using public and private networks, though no final decision on the approach has yet been taken

- Requirements set by Swedish Civil Contingencies Agency (MSB) are: need for public control; capacity requirements; specific PPDR functionality; coverage requirements; information security; traffic prioritisation; robustness; international connectivity; interoperability
- Currently, mission-critical voice and data is being offered through the TETRA network, RAKEL (Radio Communication for Effective Management) and non-critical data is being offered through commercial networks (PS core, LTE-3G)
- RAKEL is expanding and will eventually replace many of the more than 200 various analogue systems still in use, offering mission-critical voice as well as data (PS LTE, RAN, LTE -5G) – it is meant to merge all civil protection agencies and organisations into one common forum, increasing information exchanges across organisational and sector boundaries
- Current MNO coverage in rural areas is poor due to low population density, some have therefore considered there to be a need for a purpose-built network for PPDR
  - the MSB proposal will see the public network complemented by roaming agreements with commercial operators
- The envisaged PPDR service is intended to be able to make use of 2 × 10MHz of 700MHz on the public network and 2 × 20MHz of 700MHz (+800MHz, 900MHz, etc.) on the MNO networks
  - MSB suggested a 2 × 10MHz allocation to the dedicated PPDR network in the lower part of the 700MHz band
  - however, the government has so far only decided to extend the broadcasting licence in this spectrum and a final decision on how to provide the broadband PPDR service has not yet been announced

Pros:

- Benefits from a low cost set-up, high coverage from the combination private and public network and from the access to the operator resources, expertise and technologies

Cons:

- Risk of a lack of investment in the dedicated network, reduction in the service to retail customers in case of emergency

In the UK, EE has been awarded the management of the ESN, which will benefit from the dense network which is already in place

- The connectivity is based on a network shared with all other EE (mobile) customers but PPDR traffic will have priority and pre-emption
- The ESN will use the same RAN as the commercial mobile network but with a dedicated core network
- EE's 4G coverage layer is based on LTE1800 but almost 4000 sites will have 800MHz spectrum carriers added to enable greater reach into rural area and enhance indoor coverage
  - 2.6GHz spectrum will be added in urban areas and aggregated with 1800MHz spectrum to enhance data speeds
- EE has a portfolio of ~18 500 sites, which will all use LTE by the end of 2017
  - in addition to this, 450 new sites will be acquired to target gaps in the coverage

Pros:

- This solution benefits from a dense network that is already in place and offers coverage and resilience to match if not exceed that of the previous Airwave (narrowband PPDR) network
- Provides mobile data capabilities and service prioritisation
- Offers the opportunity for new applications, services and technologies
- The ESN funding is added to the existing private funding provided by EE's shareholders which EE estimates enables the tax payer to save around GBP1 million per day and ensures continuous and further investment
- The ESN has access to a global ecosystem of standardised technologies and benefits from EE's expertise and experience in radio architecture and service management

Cons:

- Service to retail customers may suffer in case of high PPDR demand
- It is not clear whether the ESN service will deliver to the full requirements of a PPDR service

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