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5G BLUEPRINT

Next generation connectivity for enhanced, safe & efficient transport & logistics

D5.7: Study on the use of public and private fibre infrastructure in a 5G landscape

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Abstract

The introduction of 5G New Radio equipment in the RAN is expected to require densification of radio sites when 3.5 GHz and 26 GHz frequency bands are used. For roadside deployment, this site densification will require significant CAPEX investments. Providing optic fibre connectivity to the new sites will therefore probably be a key cost driver. Consequently, the idea of allowing mobile network operators to utilise a road operator's unused optical fibres to lower CAPEX costs for roadside 5G coverage, has become popular in the 5G community. In this report, we assess the feasibility of using this type of public fibre infrastructure. We present an overview of the field, looked at identifying of overcapacity, studied the technical feasibility, reported upon the organizational aspects, defined a potential broker role, and investigated the idea of a field trial.

Keywords: 5G, Mobility, CCAM, Fibre, Densification, Public Networks, Network Broker

Version	Date	Description of change	List of main contributors
V1.0	31-01-2022	Final version	Menno Driesse, Adriaan Smeitink, Marc Hulzebos, Wim Vandenberghe, Jeroen Avau, Matthijs Klepper, Kris Dillemans, Besian Kuko, Freek van der Valk, Francois Verwilghen
V2.0	11-05-2023	Reworked version after feedback EC. The main changes are: restructured document to clarify relation between content and the task description in the grant agreement, added extra content where possible on the different subtasks, took outcome of other EU-funded projects into account, further analyses added of involved road operators on which information is available, and which is not, further investigation and description of trial feasibility.	Menno Driesse, Adriaan Smeitink, Marc Hulzebos, Wim Vandenberghe, Jeroen Avau, Hans Nobbe

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EXECUTIVE SUMMARY

Research context

The 5G-Blueprint project is a research project carried out by an international consortium of 26 parties. These partners investigate several topics within the Cooperative, Connected and Automated Mobility (CCAM) domain in relation to digital (5G) connectivity. Together they aim to build a European Blueprint for 5G CCAM use and value cases, such as tele-operated transport. One of the key questions here is how the various existing fibre optic networks can be interconnected in order to create a safe and cost-effective basis for future 5G applications. 5G (also) places higher demands on the connectivity beyond the antenna site (backhaul in fact), which increases the demand for fixed connectivity along transport corridors. The realisation of fibre-optic access to these sites is a major cost component. If existing (public) fibre-optic networks could be used for this access, this would have a positive effect on the feasibility of the business case for new roll-out and thus facilitate new use cases.

Research goals

The introduction of 5G New Radio equipment in the Radio Access Network (RAN) is expected to require densification of the radio sites when the 3.5 GHz and 26 GHz frequency bands are used. For roadside deployment, this site densification will require significant CAPEX investments. Providing optical fibre connectivity to the new sites is expected to be one of the key cost drivers. Therefore, the idea of allowing mobile network operators to utilise the road operator's unused optical fibres to lower the CAPEX costs for roadside 5G coverage has become popular in the 5G community. The task will involve a multi-stage approach: first identify overcapacity, then conduct a technical feasibility study, investigate how this could be organized technically, and finally define how the broker role could facilitate the execution of that technical integration process, and if successful, lead to a final field trial.

Public fibre network sharing and its role in 5G

The construction of more (5G) antenna sites as well as an increase in mobile network bandwidth have boosted the demand for fibre. The capacity of mobile networks is determined by the spectral efficiency of the technology applied, the amount of spectrum deployed and the extent of network densification. If the available amount of spectrum and (development of) spectral efficiency are fixed for a longer period, the third parameter, network densification, becomes the primary 'dial' for a mobile operator to increase capacity at specific locations. Potentially, public networks could contribute to the feasibility of new 5G cross-border use cases and other value cases since the networks sometimes have a unique footprint and could therefore meet unfulfilled demand in the process of network densification. From both the demand and supply side, there are various reasons for offering or using the public networks.

Legal framework

Providing access to public physical infrastructure (including ducts but not cables or dark fibre) is already mandatory under the Broadband Cost Reduction Directive (BCRD), the European Electronic Communications Code (EECC) and certain conditions. The BCRD lists several criteria for refusing requests to access infrastructure. These legal criteria relate to, among other things, the capacity of the network, safety and security concerns. Examples of denied requests to access existing infrastructure based on these criteria are well documented. The EECC contains several articles on sharing existing infrastructure, including access to certain public infrastructure for deploying small cells, general principles on the co-location and sharing of network elements, the obligation to grant access to ducts, cables, specific network facilities and regulations regarding access tariffs.

The importance of the BCRD for access to physical infrastructure differs between countries. In some countries, access regulations were already in place before the BCRD. In the Netherlands and Belgium, the national transposition of the BCRD adheres closely to the text in the Directive (transposition was more difficult in Belgium because it had to be done on multiple levels). The impact of the BCRD on access to infrastructure seems limited in both countries. Contributing factors include the availability and accessibility of information, regulations enabling access providers to benefit from granting access and access pricing.

Identification of overcapacity

The main cases studied were the fibre networks belonging to Rijkswaterstaat (RWS, Dutch Directorate-General for Public Works and Water Management) and Agentschap Wegen en Verkeer (AWV, the Flemish Agency for Roads and Traffic).

The RWS fibre optic network has a length of approximately 5,000 km (we expect to find this network along all (major) highways and waterways). The network is primarily designed for internal use and is – by design – not intended to be shared with other parties. It consists of a core network and a local distribution network, which is created for the last mile at specific locations that are of limited use for third parties. The AWV fibre optic network consists of over 2,600 km of routes (mainly along motorways, certain regional roads and important waterways). This fibre optic network has branched out into major Belgian cities such as Hasselt, Antwerp, Ghent, Ostend, Brussels, Leuven and Bruges. In the Netherlands and Belgium, public and private networks play a role in the shared task of providing connectivity to end users.

The RWS fibre optic network was not designed with extra capacity to share with other parties and redundancy is one of the key objectives for this evolving network. Overcapacity may only be available at a limited number of connections and the identification of overcapacity requires further analysis. The required level of detail of the available network capacity (number of fibres, dark fibres,empty ducts, etc.) is currently not available for the entire network. It requires a level of detail in Digital Asset Management which is work in progress. That makes it difficult to have good insight in RWS overcapacity. Regarding AWV's overcapacity, there is an overview showing which routes have at least one duct as well as the number of optical fibres and the occupancy of these optical fibres per route. However, there is no overall overview of the number of ducts, whether there are microducts, how many and how the fibre optic cables are distributed. Each requested route must be analysed for available (micro)ducts, by studying the detailed plans or conducting a site survey. It was therefore not possible to provide a numerical estimate of the overcapacity across the AWV and RWS networks.

Such a lack of Digital Asset Management which is needed to determine the actual roadside overcapacity at the road operator side was an unexpected outcome of this activity. During project proposal phase it was thought of as a much more straightforward task than what it turned out to be. These two practical case study do bring an important lesson though: in the context of public/private fibre infrastructure sharing, it is wrong to assume that any road operator can easily determine its available fibre overcapacity. Which can be an important element holding back the real-life feasibility of the concept.

Technical feasibility study

The degree to which public fibre networks are equipped or designed to be shared with other organisations differs across networks. The RWS network is not designed and might also be difficult to share because of the potentially limited speed to the PoP locations. Another factor that impedes RWS sharing its infrastructure is that the organisation's current legal framework (internal guideline) does not allow for sharing dark fibre. Sharing does take place with services such as IP or VPN connections, but this is only for public bodies and as an exception to the legal framework. On the other hand, AWV has been sharing capacity/bandwidth and fibre optics with other governments. This is done for investigating the sites that have to be connected in relation to the current Flemish fibre optic network, and if feasible, the costs are estimated for excavation and connection works to the existing network (otherwise, a leased line from another party can be used).

We expect that the public network owner will face considerable legal hurdles when sharing their network. These include various legal frameworks, such as procurement law (what kind of partnerships are allowed and how should the capacity be offered to the market), telecommunications law (can the co-deployed network be used for commercial telecommunications activities) and European Directives (how should the network owners interpret the BRCD). We provide more insight and given the importance and potential impact of such matters, the public network owners indicated they would also like to investigate these further. Another relevant factor is security and safety in vital infrastructure. For organisations dealing with highly intrinsic security measures (defence, police), it is less obvious to forfeit a little extra vulnerability for extra income. Regarding technical issues, such as an unfavourable location or uncertainty about a network's exact location, a business case for sharing overcapacity simply cannot be made from both the owner and the access seeker's perspective.

Organisational feasibility study

From both the demand and supply side, there are various reasons, perceived and factual, whether or not to offer the use of public fibre or duct capacity. We identified issues relating to business economics, macro-economics, organisational aspects, security concerns, legal frameworks and technology. Ultimately, when deciding whether to open their network to third parties, the owner has to weigh up the arguments for and against sharing. One of the factors that further determines an owner's degree of openness to sharing is the absolute economic value (for a public network owner, the value case). A certain 'return'[1] must be expected on the investment to justify overcoming the organisational and legal barriers.

Another issue to consider is how the fibre-optic network is embedded in an organisation. Some organisations place these networks with an internal organisational unit that is responsible for providing IT and telecommunications services to other units. Other organisations outsource the management of their fibre-optic network to a third party. In the internal management model, even though the number of available staff might be limited, the organisation may have the knowledge and expertise to share the network. However, this observation applies particularly to smaller public network owners, and not necessarily to larger public organisations such as RWS and AVW.

These, combined with the technical, security and legal arguments, determine whether or not to grant access to third parties. If the issues were only technical, these would be resolved if the economic or social value justified the required investments. The more (perceived) barriers there are, such as legal uncertainties or lack of internal support, the harder it will be to facilitate further network sharing. External pressure, such as a new European framework, may have a positive effect and lower the barriers.

[1] In the case of a public owner, returns are not usually measured in terms of monetary profit (or cost reduction) since these are non-profit organisations. They base their investment decisions primarily on to what extent they can fulfill their public mission effectively and efficiently.

Neutral Host Infrastructure Provider

We identified diverse sharing strategies among the various owners in Belgian and Dutch road operators' fibre networks. Their current approach to network sharing, adopted strategy and overall organisational culture largely determine their openness to new partnerships and new value chain functions. As part of this study, we explored a neutral host infrastructure provider (NHIP) model to potentially overcome these (perceived) limitations.

The neutral host strategy involves a third-party infrastructure provider operating shared infrastructure, such as fibre optic connections or small cell networks, for multiple service providers to offer 5G services. This model is particularly useful in EU member states with challenging geographical or other factors that can impede connectivity. The NHIP model can reduce costs for 5G providers, improve service quality, and is effective in environments like stadiums, airports, and shopping malls.

The technical integration process for fibre operators or Open Access Network providers involves network analysis, interface design, development and maintenance. The primary goal is to deliver reliable and efficient 5G services. The neutral host plays a prominent role in connecting networks, capacity management, and ensuring compliance with industry standards. The NHIP entity design can address the challenges identified in this study and create a level playing field for all service providers.

Neutral host services can be acquired through public tender processes, with potential requirements such as technical capability, compliance, financial stability, service level agreements, innovation and added value. Operators looking to build NHIP network sharing propositions should be aware of the challenges in technical integration, as well as the complexity of interworking with government bodies.

Introducing new value chain functions

Introducing new value chain functions such as a neutral host or broker, could potentially lower the transaction costs between the stakeholders involved, for instance by supporting the information exchange on demand and available capacity, streamlining legal processes (providing standardised procedures and agreements) and pooling public capacity. Such functions could maximise the public infrastructure value case by facilitating more use cases (general 5G, smart mobility, tele-operated transport, rural connectivity etc.). To what extent these functions are truly beneficial and feasible still has to be determined in a field trial after this research phase. Furthermore, determining demand and overcapacity proved to be much more complex than presented in the initial task description. Too many local circumstances determine whether a public network can meet the demands of a third-party access seeker.

The idea of introducing new value chain functions has led to much debate. It has proved difficult to reach consensus on the preferred approach to using public and private infrastructure. We distinguish on the one hand the public owners who are actively seeking new partnerships and private investment (SOFOCI); and on the other hand, the public owners with all sorts of (perceived) limitations and more restricted views. This differentiating perspective on the part of the dialogue partners demonstrates that the concept of sharing co-deployment networks is not trivial. Therefore, a general blueprint for deploying 5G for CCAM use cases such as tele-operated transport, is to assume that building a value case for public network sharing is complex and requires intensive collaboration between owners (supply) and access seekers (demand). Public network sharing should therefore be perceived as an optional extra tool to potentially reduce costs in specific local situations, but not as a silver bullet that can structurally reduce the roadside 5G deployment cost. It is also highly dependent on MNO demand to assess whether this effort is worthwhile. Every individual deployment initiative has to investigate how the arguments for and against sharing and introducing new value functions can help build a stronger value case, also bearing in mind the societal benefits when working towards local consensus. The details described in this report can provide the necessary guidance for such an investigation.

Field trial

For the final step in this project, KPN and Telenet explored the viability of a field trial to assess using road operator fibre for 5G deployment. KPN identified a few dozen potential sites along Dutch motorways where this could be the case, while Telenet found none in Flanders. Our study revealed that the demand for road operator fibre sharing was lower than anticipated and providing the required fibre capacity was challenging. Furthermore, growing cybersecurity concerns around critical infrastructure and shifting perspectives on 5G network cell densification reduced the value of a field trial. Ultimately, the main value of the trial was to confirm earlier insights through a practical lens; connecting a KPN site through the road operator's fibre infrastructure was deemed unnecessary due to the lack of scalability.

Conclusion

A general blueprint for deploying 5G for CCAM use cases such as teleoperation needs to assume that building a value case for public network sharing is complex and requires intensive collaboration between owners (supply) and access seekers (demand). It greatly depends on the MNO to assess whether this is worth the effort. It is up to each individual deployment initiative utilising this blueprint to investigate how the arguments for and against sharing and the introduction of new value functions can help build a stronger value case and achieve local consensus. But the concept of public network sharing should definitely not be seen as the silver bullet to speed up the deployment of roadside 5G infrastructure fast and cost-efficient across the entirety of Europe.

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ABBREVIATIONS

5G NR	5G = 5th generation mobile networks, NR = New Radio
ACM	Autoriteit Consument en Markt (Dutch Authority for Consumers & Markets)
AWV	Agentschap Wegen en Verkeer (Flemish Agency for Roads and Traffic), part of MOW
BCRD	Broadband Cost Reduction Directive
BEREC	Body of European Regulators for Electronic Communications
CAPEX	Capital Expenditures
CCAM	Cooperative, connected and automated mobility
EECC	European Electronic Communications Code
FttH	Fiber to the Home
FttO	Fiber to the Office
GSM	Global System for Mobile communications
HDPE	High Density Polyethylene (HDPE) ducts
IRU	Indefeasible Right of Use
KLIM-CICC	Federal Cable and Pipeline Management Database (BE-BR, BE-WL)
KLIP	Kabel- en Leidinginformatieportaal (BE-FL)
LTE	Long Term Evolution (4G)
MNO	Mobile Network Operator
MOW	Departement Mobiliteit en Openbare Werken (Department of Mobility and Public Works in Flanders, Belgium)
NAFIN	Netherlands Armed Forces Integrated Network
NRA	National Regulatory Authority
OPEX	Operational Expenditures
OPWG	Optical Ground Wire
PoP	Point of Presence
RAN	Radio Access Network
RWS	Rijkswaterstaat (Dutch Directorate-General for Public Works and Water Management)

SLA	Service Level Agreement
SMP	Significant Market Power
SPW	Service public de Wallonie, Mobilité et Infrastructures (Walloon Department of Mobility and Infrastructure)
TSO	Transmission System Operator (electricity grid)
UMTS	Universal Mobile Telecommunications System
URLL	Ultra-reliable low latency
VLAN	Virtual local area network
VPN	Virtual Private Network
WDM/DWDM	(Dense) Wave Division Multiplexing
WIBON	Wet informatie-uitwisseling bovengrondse en ondergrondse netten (NL)
WM&O	Dutch Market and Government Act

1 INTRODUCTION

1.1 Background

The 5G-Blueprint project is being carried out by an international consortium of 26 parties. Together, these partners are investigating several topics within the mobility domain in relation to digital (5G) connectivity. These include enabling real-time data exchange between vehicles, between terminals and vehicles, and between vehicles and distribution centres. The question is how these solutions can contribute to greater efficiency in the supply chain, and help solve driver shortages by remotely controlling and supporting vehicles and ships. These developments are expected to improve the accessibility of a key logistics corridor between the Netherlands and Belgium (Vlissingen - Ghent - Antwerp), create more jobs (although the number of drivers will drop) and strengthen the region's competitive position. New 5G technologies are (potentially) useful tools here, for example the ultra-reliable low latency communications (URLL) feature from 5G New Radio (NR).

An important question is how to interconnect the various existing fibre optic networks, and thus create a safe and cost-effective basis for future 5G applications; 5G also places higher demands on connectivity beyond the antenna site (backhaul), creating a greater need for fixed connectivity along transport corridors. The realisation of fibre optic access to these sites is a major cost component. If existing (public) fibre-optic networks could be used for such access, this could have a positive effect on the feasibility of the business case for new roll-out and thus facilitate new use cases. An example is the RWS (Directorate-General for Public Works and Water Management network along the Netherlands' main roads. Currently, the RWS network is not accessible for use by third parties, except those working on behalf of RWS. There is a network in Belgium, namely the Vlaams Glasvezelnetwerk, managed by the Roads and Traffic Agency (MOW). This network is primarily intended for telematics, but its dark fibre (over)capacity is available to a wider range of parties, albeit all public. Examples are the collaboration with the Facility Management Agency for interconnecting buildings used by the Flemish Government, and the Economics, Science and Innovation Department for high bandwidth interconnection in university buildings.[2]

In the run-up to this study, the parties involved indicated there was a potential for sharing overcapacity, provided good governance, orchestration and an adequate legal framework were in place. The introduction of new roles in the value chain, such as a (neutral) broker between supply and demand, could be a good solution, if this was legally, organisationally, and financially feasible. This research elaborates on these preconditions.

1.2 Research questions and goals

The introduction of 5G New Radio equipment in the RAN is expected to require densification of the radio sites when 3.5 GHz and 26 GHz frequency bands are used.[3] For roadside deployment, this site densification will require significant CAPEX investments. Providing optical fibre connectivity to the new sites is expected to be a key cost driver. Therefore, the idea of allowing mobile network operators to utilise the road operator's unused (optical fibre) capacity to lower CAPEX costs for roadside 5G coverage has become popular in the 5G community. The main

[2] See: [overheid.vlaanderen.be]

[3] The 3.5 GHz frequency bands will probably be most relevant for roadside and C-ITS applications.

research question is thus:

How can public and private fibre infrastructure contribute to the 5G roll-out for mobility use cases?

The research aims to identify overcapacity and understand the technical and organisational feasibility of using public and private networks. It also examines potential new roles in the value chain (such as a broker or virtual operator). We assess whether these roles can mitigate technical or organisational burdens, and if so, under what preconditions. The focus of the research and underlying evidence is the Dutch and Belgium context, in line with 5G-Blueprint and its consortium members' overall goals.[4] Through this process, we aim to deliver generally applicable lessons (a blueprint) for other member states.

If the process is successful, there will be a field trial to validate the findings in practice as part of the pilot activities scheduled for the second half of the project.

We attach the terms of reference (task descriptions) for this research in Annex C. The corresponding findings will form part of the governance guidelines for MNOs, vendors and national authorities under D5.8, planned by the end of the project.

1.3 Research approach

For our approach to this project, we applied various research methods as explained below. The first was **desk research**. This included a literature review to gain initial insight into the dynamics of cross-border connectivity, the openness of public and private networks and the various value chain roles. We consulted several sources: earlier studies conducted by Dialogic on fibre networks, online sources, results from other 5G Blueprint work packages (if available), as well as sources provided by work package members and the technical steering committee. In addition, related studies (5G-MOBIX, research on the brokerage role in integrated satellite-5G networks) provided insights on the role of a broker and sharing (public) infrastructure. These works offered useful starting points as the brokerage role study is not autonomous. The section below describes this study's relationship with earlier 5GAA publications.

After the desk research, we gained further insights by organising **workshops and interviews.** Several validation workshops were held with the individual work package members and additional interviews to gather specific input from stakeholders. In total, five workshops were organised with 13 participants. At these workshops, the work package members discussed and validated the findings from the desk study. The participants discussed whether public infrastructure could improve the effectiveness of cross-border fibre use cases and they also gave additional written input. Along with these workshops, both RWS and AWV provided additional input regarding the identification of overcapacity, a technical feasibility study, an investigation of the technical organisation and the new value chain functions. The contributing authors discussed this additional content during several online meetings. Interviews were held with representatives of BIPT and Smart Energy & Network (SEN) to gather additional insights. The list of interviewees and contributors is in Appendix A.

[4] See: [5gblueprint.eu/about]

1.4 Connection with earlier 5GAA publications

This study builds on earlier research and publications related to 5G and automotive use cases, for instance by 5GAA and within 5G-Carmen, focusing on public-private partnerships between an MNO and road authorities. Examples of such work are:

- **MNO Network Expansion Mechanisms to Fulfil Connected Vehicle Requirements** [1] This White Paper contains findings by a 5GAA "NetExp" working group. Section 3.2.1 of this paper is an excerpt from the 5G-Blueprint proposal, showing that research on the reuse of road operator fibre was planned in the Netherlands. Other relevant outcomes concerned:
    - Cost drivers: providing fibre connections to existing (public) fibre networks, shared use of ducts, etc. could significantly reduce costs.
    - Cross-border connectivity: though cross-border network reselection is already technically feasible, there is still a lack of incentives to implement this in networks. It is therefore essential to find the right incentives for mobile network operators to embed this functionality, for example through public-private cross-border programmes or as a requirement in auction obligations, but supported by bi-national agreements.
    - Introducing a broker: providing new sites with optical fibre connectivity is expected to be a key cost driver. Allowing mobile network operators to utilise road operators' unused optical fibres to lower the CAPEX costs for roadside 5G coverage has therefore become a popular notion in the 5G community. Though simple in its concept, it is not yet known what complexities have to be overcome when deploying 5G new radio equipment. More research is needed to establish whether this is a feasible approach, how it should be organised, and what are the main challenges when putting this into practice. For example, the fibre may not belong to the road operators but to the state and is sometimes reserved for state services like defence, national intelligence or the police.
    - A neutral host infrastructure model: unlike vertically integrated networks that accommodate one technological solution, neutral host infrastructure is a shared platform, capable of supporting all MNOs and technologies, giving their customers what they are looking for – seamless coverage and high capacity. This approach allows operators to focus on service delivery and infrastructure companies to focus on real-estate development and capital investment. By shifting investment from an upfront, CAPEX-heavy model where MNOs shoulder all deployment costs to a neutral host model, sharing helps to spread costs across multiple parties and converts a CAPEX burden to an easier to manage OPEX.
- **Cooperation Models enabling deployment and use of 5G infrastructures for Connected and Automated Mobility (CAM) in Europe** [2] - This White Paper outlines five non-mutually exclusive options for ecosystem cooperation models relevant to 5G CAM infrastructure deployment and use.
    - Potential synergies: road operators can provide easy and predictable access to passive infrastructure such as ducts and poles, dark fibre and power to allow cost-effective construction of mobile networks The proposed five options for ecosystem cooperation are:

        1. Investment by MNO in fully active 5G network (along the roads)
        2. Investment by road/rail operator in passive infrastructure

3. Investment by single Neutral Host infrastructure Provider (NHP) in passive infrastructure
4. Co-investment by a consortium of interested parties (NHPs, MNOs, road/rail operators) in active combined mobile network and RSU infrastructure
5. Commercial Agreements.

  - Related to the second option, the white paper suggests brokering road operator fibre and utilities, since "*Providing optical fibre connectivity to the new sites is expected to be one of the key cost drivers. Therefore, the idea of allowing mobile network operators to make use of road operators' under-used optical fibres capacities to lower the CAPEX costs for roadside 5G coverage has become a popular one in the 5G community*". The paper then refers to our task/work package, since *"it is unknown today what complexities may need to be overcome when deploying 5G new radio equipment using this paradigm".*
  - The White Paper concludes that a more integrated model involving ROs, MNOs, NHPs and OEMs should be considered, as from 2024 onwards, we anticipate the large-scale introduction of advanced safety and automated driving use cases supported by C-V2X.

- **Cost Analysis of V2I Deploymen**t [3]. This document was prepared on behalf of 5GAA. It includes cost comparisons of long-range and short-range rollout of infrastructure to vehicle communication use cases that may be of interest. Its other relevant outcomes are:
  - It shows the importance of high fibre coverage, since fibre is implemented as backbone in all four infrastructure deployment options.
  - <u>Roll-out costs:</u> The highest costs are incurred in fibre installations, where expensive laying of fibre (backhaul capex) accounts for the bulk of the total cost. The expenditures on fibre backhaul installation also differ significantly […], which account for the large variation in costs.
  - <u>Recommendations to road operators</u>: consider novel business models and engagement with organisations such as MNOs that have the added benefit of technical skills and experience in deploying and maintaining communications equipment.
  - <u>Recommendations to MNOs</u>: work with the public sector and vehicle manufacturers to identify viable business models that can support the delivery of cellular V2I services and the integration of new cellular development (NR, MEC etc) in the V2I ecosystem. Analyse the synergies of joint small cell/RSU deployment.
- **Road Operator Use Case Modelling and Analysis** [4]**.** A study into C-ITS use cases based on mobile network technology revealed that even with a high penetration rate and high data rate applications (such as Data Collection and Sharing for HD Maps), 4G is actually sufficient. The summary of this study has also been published separately. [5]
- **Techno-Economic Analysis of MEC Clustering Models for Seamless CCAM Service Provision** [6]
  - <u>Abstract:</u> The latency requirements of delay-sensitive applications such as cooperative, connected and automated mobility (CCAM) services challenge the capabilities of traditional vehicular radio access technologies (i.e., IEEE 802.11P and cellular networks). To this end, the 5G cellular network is adopting the multi-access edge computing (MEC) paradigm. However, this technology comes with

several challenges. The analysis examines these MEC placement challenges and their impact on network deployment costs. It proposes three MEC clustering models and compares them from a cost perspective. The outcome shows that all the MEC clustering models outperform the non-clustering approach. In addition, the conditions are analysed where specific clustering models yield optimal results. The aim is to provide insights into cost-effective MEC deployment models.

- Reduce costs via network sharing: the analysis showed that network sharing in both its active and passive forms significantly reduces the cost of MEC deployments by 31 and 25 percent, respectively.

In summary, these earlier publications identify the potential benefits of further network sharing and introducing new Cooperation Models to lower the cost of supporting future mobility/connectivity use cases. The brokerage role is also mentioned as potentially beneficial, but more research is needed to assess the viability of these new value chain functions. Our study aims to provide answers to the earlier raised questions.

1.5 Report structure

Starting in Chapter 2, we introduce the concept of public fibre networks and their owners, elaborate on network sharing and explain the relationship with the roll-out of 5G and 5G use cases. In Chapter 3, we provide an overview of the existing public and private parties in the Netherlands and Belgium and discuss public parties' overcapacity in both countries. Chapter 4 presents the technical feasibility study on sharing overcapacity, while Chapter 5 contains the investigation on the technical organisation of sharing overcapacity. In Chapter 6 we elaborate on how and in what form new value chain functions such as the broker role could strengthen the arguments for using public infrastructure and facilitating the technical integration process. Chapter 7 looks at organising a field trial as part of this project. Lastly, Chapter 8 presents our conclusions.

2 PUBLIC FIBRE NETWORK SHARING AND ITS ROLE IN 5G

The primary goal of this research is to examine how public and private fibre infrastructure contributes to the roll-out of 5G for mobility use cases and what the potential contribution of new roles in the value chain (such as a broker/neutral host or virtual operator) would entail. Before answering this question, we need to better understand public fibre networks and their relationship with 5G. We introduce the concept of public fibre networks and their owners, then delve deeper into network sharing (types of openness and availability to third parties). Lastly, we explain the relationship with the roll-out of 5G and 5G use cases.

2.1 Types of public fibre networks

Public networks are best classified according to the reasons why the public owner constructed the networks in the first place, i.e., the original incentive for their realisation. The assumption here is that public networks are built to meet a specific need for connectivity that is not offered by the market (nor under the desired conditions). This can be a public organisation or a consortium's need. We identify three types of public networks:[5]

- **Co-deployed networks** - these are constructed (simultaneously) with other types of linear infrastructure such as roads, railways or electricity networks. The purpose of laying fibre-optic connections is often to realise simple and cheap connectivity between different nodes in the network. Examples include connections between substations in high-voltage networks or between railroad switches and stations on railway lines. These connections are meant to facilitate all kinds of monitoring and control operations. Co-deployed networks are usually very well protected against (human) influences from outside; it is rare that someone pulls the cables out of a high-voltage pylon or opens up the ground under a railway embankment. Often, the road or rail manager also owns the land or other infrastructure where the network is located and already has legal access to the land. The additional costs for fibre rollout are negligible compared to the infrastructure costs (roads, rail, electricity cables, etc.) where fibre is laid. RWS and MOW networks are textbook examples.
- **Municipal and provincial networks** – these types of networks are installed to connect a municipal or provincial organisation's (real estate) objects. These could be a fibre-optic connection between the town hall and the municipal workshop for generic network traffic, but also application-specific connections such as to and from traffic control installations, bridges, locks or camera installations. The networks are in fact an extension of the internal ICT infrastructure. The connections are made specifically for the municipality or province and full ownership therefore lies with these parties. In many cases, these connections are located on their own land or in their infrastructure such as roads.
- **Demand aggregation networks** – in the past, (semi) public parties often sought cooperation in the form of a demand aggregation initiative, unlike the previous examples of networks initiated and financed by one public organisation. Especially from 2000 to 2005, the Netherlands established several 'city rings': an urban or regional network achieved jointly by various (semi)public parties between their properties. These were mainly municipalities and healthcare or educational institutions. The advantage of this

[5] Networks not owned by a public or semi-public party but used by them (for example, by purchasing a dark fibre connection from a commercial provider) are beyond the scope of this study.

approach is that the realisation costs can be divided among the various entities. At a time when the commercial network coverage was still limited, this approach was an efficient way to develop the required connections. Matters such as management, maintenance and expansion are usually placed in an independent entity, while the initiators, as shareholders, members or participants, retain control over the activities this entity undertakes.

Whereas private entities have a strong incentive to sell/share their fibre-optic infrastructure (over)capacity to monetise the economic value of these assets, public networks like RWS are not usually shared with third parties. We will discuss this in more detail below.

2.2 Openness to others

For all sorts of strategic, legal and historic reasons, network owners prefer to share their network with different types of parties. We identify in what sequence parties are granted access to a network, as shown in Figure 1.

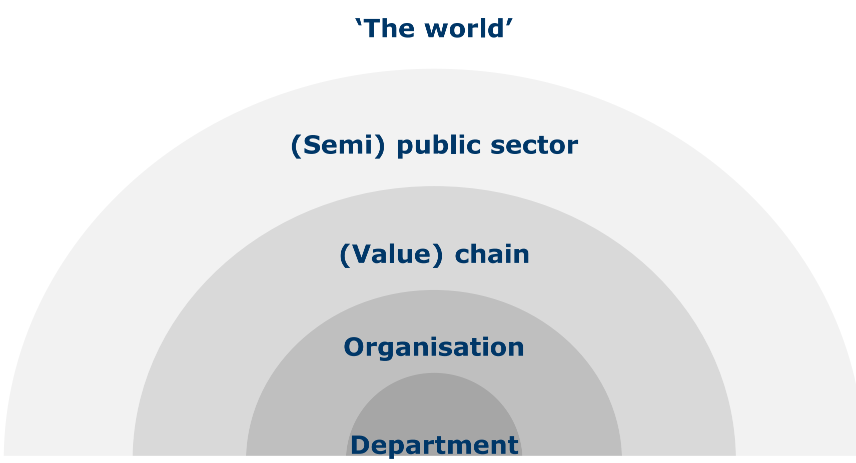

Figure 1. Sequence in which parties are granted access to the (public) network [7]

- **Own department** – in the most basic model, the network is only used by the department that initiated the installation. Think of networks to and from traffic control installations, control networks for bridges and locks and connectivity to car parks for camera security and payment systems. In some cases, departments deliberately decide to create their own new infrastructure. In practice, however, various departments unknowingly create duplicate networks.
- **Own organisation** - In this case, the public organisation such as a municipality or province applies a more integrated approach whereby in addition to traffic lights, cameras and other sensors in the public space are accessed via the same network. This avoids unnecessary investments for the organisation and achieves more efficient management and coverage.
- **Within the 'value' chain** - third parties can also gain access to the network, but only if they are part of the chain of parties that cooperate with the public organisation to achieve its goals. Examples are suppliers of physical elements or services in the public space, such as traffic management or security applications. As these third parties provide a certain value or service to the network owner, they require access to the network.

Box 1: Example of network sharing within a value chain: RWS and Port of Amsterdam

In 2012, RWS commissioned a new shore radar system in collaboration with the Port of Amsterdam, called the Walradar system. [8] The new system covers the area between the Oranjesluizen at Schellingwoude up to some 40 km off the coast of Ijmuiden and includes the IJ channel and the Buiten-IJ. The 'Centraal Nautisch Beheer Noordzeekanaalgebied' operates a system that helps ships sail smoothly and safely across the North Sea Canal from IJmuiden to Amsterdam, with a complete package of information and communication tools, and an up-to-date shipping traffic image. For the Walradar system, 27 radar posts are connected by fibre-optic cable installed on the north and south sides of the canal. [9]

- **(Semi)public sector** - Currently, the organisational and functional boundaries are blurred, and third party (semi)public organisations are allowed access to the network. All parties can use the network for the same or their own applications and purposes. A good example is the TeleMANN network in Nijmegen, the Netherlands. This network is owned by an association of public and semi-public organisations in and around Nijmegen, which have made their objects accessible via this network. Another example is the mutual exchange of fibre infrastructure between the Flemish government and the city of Antwerp. The Flemish public fibre network is also shared with parties such as universities and research institutions.

Box 3: Examples of network sharing within the (semi)public sector

RWS, AWV and Port of Antwerp

The Port of Antwerp's shore radar system 'Schelderadarketen' uses both RWS and the Flemish AWV fibre infrastructure. This radar system enables safe and smooth navigation in the Scheldt area (between the ports Zeebrugge, Vlissingen, Terneuzen, Ghent and Antwerp) and uses various technical systems. [10] The vessel traffic services offered to ships are radar observation, telecommunications, an information processing system and an automatic identification system. [11] This radar system is a cross-border collaboration that involves exchanging dark fibre.

- **The world** - In this case, the network is shared with 'everyone', which means it is placed in the market for wholesalers or large business customers just like a regular telecom network. The only difference is the incentive for initially building the network. Private networks are primarily built for commercial reasons. In contrast, public networks only involve selling overcapacity when fulfilling a public need. However, public organisations constructing new pipeline routes should consider installing additional ducts to cope with potential future demand for fibre from the private market.

Box 3: Examples of network sharing with all interested parties

TenneT and ProRail

In 2003, TenneT and ProRail established Relined, a joint venture that put the overcapacity from their co-deployed public fibre networks on the market if they could not fully utilise their glass fibre cable capacity. In 2017, ProRail sold its stake in the joint venture. [12] Relined's services are directed at putting unused dark fibre on the market. [13] Relined has expanded its network over the years and now also operates in Germany and Denmark. The venture rents out capacity but does not offer additional services such as hosting.

2.3 Types of access

There is a great deal of diversity in how (third) parties can get access to a network, particularly how 'deep' this access is allowed in the network architecture. Figure 2 shows the various layers where third parties can currently gain access to (public) networks. We use a classification inspired by the OSI model, the reference model for data communication standards.

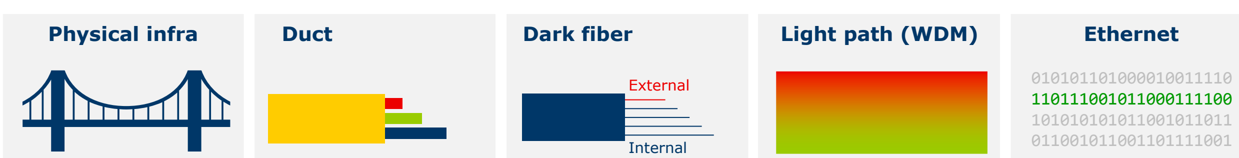

Figure 2. Types of network access [11]

The various types of access are:

- **Access to physical infrastructure** - this type of access addresses the lowest level of the network, namely the physical space in, on or through which the public networks are created. The realisation costs are driven up significantly by routes that pass along, under or over specific points in the physical space, such as waterways, complex road crossings, or close to other underground infrastructure. At these points, the landowner or party commissioning a civil engineering structure such as a bridge or tunnel may already have made provisions during construction so that third parties can add their network infrastructure later. Examples include joint cable and pipeline routes under busy roads and junctions or in a tunnel tube where all the technical installations are brought together. In Brussels (Noordwijk), underground galleries have been constructed for fibre-optic cables. Also, when drilling under waterways, a complex and costly operation, groundworkers and network owners coordinate to take stock of others intending to make the same crossing at that time so that they can share costs and efforts.[6]

Figure 3. Example of inspection manholes in a shared pipeline route [14]

[6] In Belgium, co-deployment and co-investment by diverse infrastructure owners are stimulated via online information sharing platforms Gipod (Flanders), Osiris (Brussels) and PoWalCo (Wallonia). The idea is to share construction plans and stimulate co-deployment of infrastructure.

- **Access to ducts, tubes or pipes** - an empty pipe (HDPE) or multiduct provides space for multiple cables or cable ducts. Network owners can give third parties access to these tubes, who can then install their own cable or duct. Figure 4 shows the installation of such a multiduct system where the owner can thus pass on one or more ducts to third parties.

Figure 4. Installation of a multiduct system [15]

- **Dark fibre** - the fibre-optic network created in (underground) physical space and through ducts, usually consists of multiple glass layers. In a casing or multi-duct, fibre-optic cables consisting of one or more fibres are blown into the network. Cable sheaths buried directly in the ground can also contain several fibres. The owner only needs a few fibres, so can therefore sell or lease the remaining ones to third parties. The cables in main lines contain up to 96 fibres (sometimes even up to 192), of which the public owner only uses a few (roughly 4 to 8 fibres).

Figure 5. Cross-section of a fibre-optic cable [16]

- **Lightpaths (WDM)** – in order to transmit more capacity over individual fibre-optic cables, parties use (among other things) wave division multiplexing (WDM) technology. As shown in Figure 6, several signals with different wavelengths, i.e., in different colours, are sent via the fibre-optic cable. This creates up to 88 different lightpaths (in DWDM's case) that can be used for various data connections. It is possible to distribute these separate lightpaths to different customers, without them being able to interfere with others' information flows. However, this solution is only used in exceptional situations where the number of fibres is limited, for example at sea.[7]

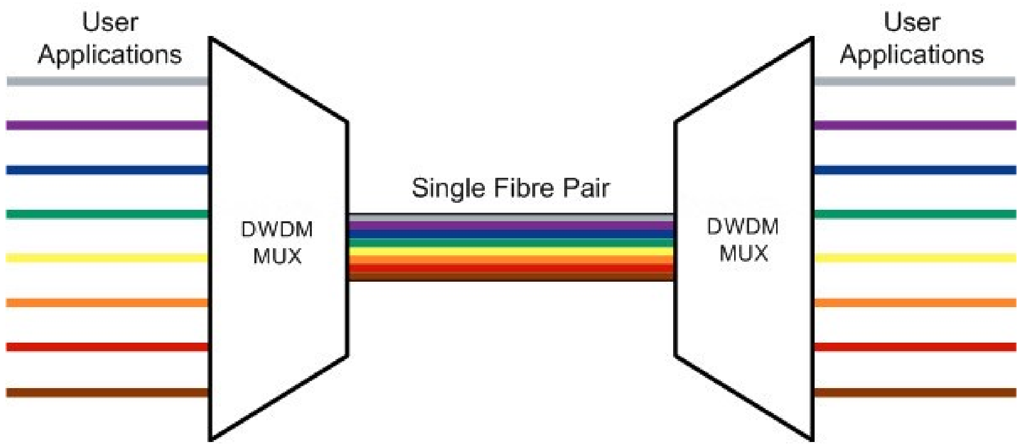

Figure 6. Schematic explanation of WDM technology [17]

- **Ethernet and other services** – although less relevant for the type of openness discussed here, an external supplier may be able to connect certain components in an internal or external ICT infrastructure, or use certain (software) platforms in the public organisation it serves. A VLAN is the common and safe way to segregate users on this network level.

2.4 Fibre infrastructure and 5G roll-out

Now that we know more about the types of networks, extent of openness and current availability, we need to understand the link between these networks and 5G roll-out. In short, the increasing demand for fibre networks is on account of the rising need for high-capacity mobile data networks. To meet this growing demand, operators continually invest in their networks to increase coverage and capacity — factors which determine the quality and throughput a customer experiences. As well as deploying newer technologies, an operator can acquire additional radio spectrum (as it becomes available) or place more antennas. Extra antennas increase coverage and capacity in each area. Recent work by the European Court of Auditors suggests that 5G roll-out is an ongoing process which is lagging behind in the EU. [18]

The capacity of mobile networks is basically determined by three parameters: 1. the spectral efficiency of the technology used (expressed in bits/s/Hz); 2. the amount of spectrum deployed; and 3. the degree of network densification (which allows reuse of the frequency space). Figure 7 explains the relationship between the parameters.

[7] An example: The Flemish fibre network uses a DWDM colour from Infrabel (The Belgian Rail operator) as part of an exchange contract between the Flemish Government and Infrabel.

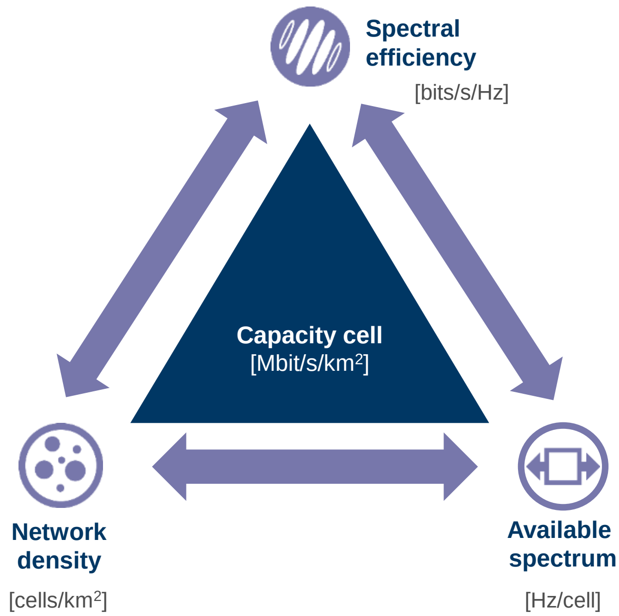

Figure 7. Mobile network capacity parameters [19]

So, to increase capacity in the cell, an operator needs to invest in one or more parameters. To what extent is this possible?

- The **amount of spectrum** available to an operator is a parameter that is fixed for the long term: only through an auction (such as the recent multiband auction and 3.5 GHz band auction in 2022) and the 'refarming' of old technologies (GSM, UMTS and in the future LTE) can spectrum be freed up for more efficient use. Spectrum only becomes available occasionally. A substantial amount of spectrum (300 MHz) in the 3.5 GHz band will become available in the Netherlands; however, the timing is still hotly debated. [19]
- **The efficiency of radio technology** is largely determined by the relevant technical standard (UMTS, LTE or 5G NR). These standards are developed worldwide by 3GPP and adopted in Europe by ETSI. The efficiency achieved in practice depends on how the parts of the standard perform that are implemented by manufacturers of network equipment, terminals and their extensions. Because the terminal is also a determining factor, end users' adoption of more modern terminals plays an important role.

  The 5G NR radio protocol is slightly more efficient than LTE, the radio protocol used for 4G. However, this is not sufficient to realise substantially higher capacity; modern technologies are getting closer to the theoretical maximum of a radio channel, according to the Shannon-Hartley theorem. However, within a certain standard, an operator can deploy certain optional technologies. The use of beamforming and Massive MIMO is becoming more and more common, albeit still costly. Both techniques allow for a higher degree of frequency reuse within a cell. Operators will probably prefer to equip selected antenna installations with these techniques.
- When the available amount of spectrum and (development of) spectral efficiency are fixed for a longer period, the third parameter, **network densification**, becomes the primary 'dial' for an operator to realise capacity growth at specific locations. In addition to achieving coverage (which an operator does in principle with the macro network), an operator will want to ensure that sufficient capacity is provided at specific locations with high traffic (hotspots). At the 'normal' district and neighbourhood level, an operator can usually still

achieve this in the macro network: by placing more antenna installations, larger macro cells are split into smaller ones, the number of users per cell drops and the average available capacity per user rises.

The parameter **network densification** is of most interest for this specific research. Selecting and building new macro sites require an investment of around EUR 50,000 for a multicarrier base station. [20] This not only includes constructing the actual site (e.g., building a new radio tower or preparing a rooftop installation), but also providing the backhaul (fibre) connectivity. In some cases, the expensive laying of fibre (backhaul CAPEX) accounts for a significant amount of the costs of fibre roll-out, as highlighted in the 5GAA study regarding the cost analysis of V2I deployment. In practice, there are several business models for site sharing: the tower can be built by a specialized company (e.g., Cellnex) and one or more MNOs rent a space on it. The MNO invests in the network equipment but apart from this CAPEX, a multiple year commitment to the tower's owner is required (OPEX). Without such a commitment, a tower might not prove profitable for the owner and thus will probably not be realized.

In the urban context, a lot of fibre connectivity is usually available in close proximity, although not always enough to meet the demand for fibre due to local government restrictions on cable digging in dense urban areas. The footprint in more isolated and rural areas is usually low. In rural Flanders, the demand for fibre is relatively high along highways and railways because many cell sites were installed alongside such infrastructures. Even high-capacity point-to-point radio links are common in rural areas.

Operators follow different strategies regarding the backhaul connectivity for their mobile networks. Some operators (e.g., KPN) have a strong preference for using their own fibre network. They are therefore more likely to construct new network routes to new antenna sites. Others have a more diverse strategy and use existing third-party networks, such as the Eurofiber network.

In this respect, BEREC (Body of European Regulators for Electronic Communications) explained the relevance of **fixed-mobile convergence** back in 2017 already [21]. At the infrastructure level, fixed-mobile convergence translates into the use of fixed network infrastructures to transit mobile data streams, as part of the mobile backhaul service. Operators can adopt an integrated fixed-mobile strategy. This encompasses using core and backhaul network infrastructure to provide both fixed and mobile services, because the synergies can lead to improvements in efficiency and competitiveness in a highly dynamic electronic communications market. Convergent operators who emerged typically focus on self-owned infrastructure since they commonly have the highest fixed and mobile networks coverage.

For this research, we are keen to find out whether public networks could meet an unfulfilled demand in the process of network densification. This could be as a result of their unique footprint (e.g., close to highways) or for reasons such as price and reliability. As highlighted in multiple recent 5GAA papers, network sharing (both active and passive infrastructure in existing (public) fibre networks such as ducts, poles and dark fibre) could significantly reduce the costs of constructing mobile networks. [1] [2] [6] The question is whether both sides (demand from the market and supply from the public network owner) are willing and able to use or offer the public network, and if not, whether a broker or neutral host has a potentially positive impact on this supply and demand exchange.

Box 3: Small cell infrastructure

If the demand for capacity is very high at a specific location, macro cells can come up against limitations; an approach based on small cells is therefore relatively more efficient. In a regular 'macro network', antennas at high and high-powered set-up points together form a cell structure. Small cells overlap a 'macro cell' and due to their smaller height and power, cover a limited area. The small cell in fact functions as an inverted "umbrella": the traffic within the small cell does not come at the expense of the macro network. Small cells realised with one small cell installation can cover a radius of a few dozen metres, such as a town square. In multiple small cell installations, they can cover a larger area like a football stadium.

In the longer term, conceivably an operator will roll out large-scale small cell structures that cover more than one 'hot spot'. The small cells then become the primary 'radio layer' for realising capacity, while the macro network remains active in the background for among other things, indoor coverage.

2.5 Current legal framework for sharing public infrastructure

In this section, we analyse the legal framework regulating the sharing of public fibre infrastructure. Starting with an overview of the main EU directive, we then provide examples of its national implementation, including cases where sharing public infrastructure is based on or is a result of these legal frameworks.

2.5.1 BCRD and EECC stipulate sharing infrastructure

Sharing (public infrastructure) is already required to some extent in the EU under current legislation: the European directive 2014/61/EU, which came into effect in 2016. Known as the Broadband Cost Reduction Directive (BCRD), this directive may help to reduce required upfront investments in fibre networks and the use of (public) physical infrastructure for 5G wireless applications such as tele-operated transport.

This directive's objective is to reduce the cost of deploying high-speed electronic communications networks by facilitating the shared use and coordinated deployment of physical infrastructure such as ducts and poles within the electronic communications sector and across other sectors including energy, transport and water. [22] Network operators[8] are required to share their physical infrastructure with an undertaking that provides or is authorised to provide public communications networks under reasonable conditions with a view to deploying elements of high-speed electronic communications networks.

Notably, this directive's definition of physical infrastructure includes ducts and poles but does not include cables, dark fibre, DWDM or ethernet.[9] This is an important point, since for RWS and MOW, the main concern with this directive is a potential widening of the scope to shared use of cables and dark fibre instead of only physical infrastructure such as ducts. The directive also

[8] Defined in the directive as: "an undertaking providing or authorised to provide public communications networks as well as an undertaking providing a physical infrastructure intended to provide: (a) a service of production, transport or distribution of: (i) gas; (ii) electricity, including public lighting; (iii) heating; (iv) water, including disposal or treatment of wastewater and sewage, and drainage systems; (b) transport services, including railways, roads, ports and airports".

[9] Physical infrastructure is referred to as "any element of a network which is intended to host other elements of a network without becoming itself an active element of the network", such as inspection chambers, masts, pipes, manholes, cabinets, buildings or entries to buildings, antenna installations and towers.

contributes to more openness of the existing infrastructure, since network operators are required[10] to provide the following minimum information on existing physical infrastructure to every undertaking providing or authorised to provide public communications networks that requests access to the infrastructure: 1) Location and route; 2) Type and current use of infrastructure; 3) A contact point. In 2020/2021, the European Commission organised a public consultation to potentially change the directive based on stakeholders' feedback. [23]

The directive states that if more specific regulatory measures apply in conformity with Union law, these should prevail over the minimum obligations and rights under what the BCRD entails (the *lex specialis* principle). The directive states that the BCRD should be without prejudice to:

- The Union regulatory framework for electronic communications (Directive 2002/21/EC)
- Access to, and interconnection of, electronic communications networks and associated facilities (Access Directive) (Directive 2002/19/EC)
- Universal service and users' rights relating to electronic communications networks and services (Universal Service Directive) (Directive 2002/22/EC)
- Commission Directive 2002/77/EC, including adopted national measures pursuant to that regulatory framework.

Moreover, if access to physical infrastructure is already imposed by obligations pursuant to the Union regulatory framework for electronic communications such as on significant market power (SMP) operators, then this is already covered by the specific regulatory obligations and is not affected by the BCRD. Therefore, access to infrastructure according to the BCRD should not impair asymmetrical obligations that address SMP operators. [22]

According to article 57 of the European Electronic Communications Code (EECC), MNOs should be able to access certain public infrastructure for deploying small cells: "*Member States shall, by applying, where relevant, the procedures adopted in accordance with Directive 2014/61/EU, ensure that operators have the right to access any physical infrastructure controlled by national, regional or local public authorities, which is technically suitable to host small-area wireless access points or which is necessary to connect such access points to a backbone network, including street furniture, such as light poles, street signs, traffic lights, billboards, bus and tramway stops and metro stations."* [24] This obligation for Member States refers to the BCRD (Directive 2014/61/EU). Furthermore, article 44 of the EECC lists general principles on the co-location and sharing of network elements for providers of electronic communications networks, while article 61 (paragraph 3) states that National Regulatory Authorities (NRAs) can impose obligations to grant access to ducts and cables. Other relevant EECC articles are 72 on access to civil engineering, 73 on obligations of access to and use of specific network facilities and 74 regarding prices of access to existing physical infrastructure). [25]

2.5.2 Valid reasons for refusing to share infrastructure

Network operators are not required to share their physical infrastructure in all cases. First, other directives take precedence over the minimum rights and obligations imposed by the BCRD. Second, the BCRD lists valid reasons for refusing to share existing infrastructure, such as:[11]

[10] Except if sharing this information compromises the security of the networks and their integrity, national security, public health or safety, confidentiality or operation and business secrets.

[11] According to the directive, refusing access to physical infrastructure should be based on transparent, objective, and

- The technical suitability of the physical infrastructure to which access has been requested for hosting any of the elements of high-speed electronic communications networks
- The space available to host elements of high-speed electronic communications networks, including a network operator's future space requirements
- Safety and public health concerns
- The security and integrity of a network (especially critical national infrastructure)
- Interference from the planned electronic communications services with other services provided over the same physical infrastructure
- Availability of viable alternatives for wholesale physical network infrastructure access provided by the network operator and suitable for the provision of high-speed electronic communications networks (given that such access is offered under reasonable and fair terms and conditions).

For their national implementation, many Member States have made use of the exclusions allowed in the directive, for example by excluding access obligations for physical infrastructures considered not technically suitable for high-speed electronic communications networks, or where there was a threat to safety or public health, interference or viable alternatives were available. Denied requests for accessing existing physical infrastructure are widely reported, the main reason being lack of capacity and sometimes security concerns. [26] Numerous disputes have arisen regarding denied access. One example of a recent dispute is when a municipality in Germany argued that an exclusive contract with a party to make use of the network justified refusal based on lack of capacity. However, this was overruled by the German regulatory authority BNetzA since lack of capacity as a criterium for refusing access refers to technical capacity, not the capacity reserved in existing contracts.

2.6 Current sharing of physical infrastructure in the EU (implementation of BCRD)

Table 1 summarizes the implementation of the EU directive in certain EU countries.[12] It shows the date of initial access legislation, as well as whether there are clear rules on infrastructure access pricing (as in Italy and Portugal) and on cost and profit sharing (found in Italy and Germany). The table also shows the requests for access in terms of kilometres of duct and to what extent access requests are reported as refused. It also demonstrates the perceived improvement in access conditions after implementation of the BCRD (highest in Austria, Ireland, Italy and Spain) and the perceived satisfaction with access conditions (in Italy and Portugal). Some countries already had legislation or rules in place for granting access to existing physical infrastructure before implementation of the BCRD. This is the case for France, Poland and Portugal (where access was granted to extensive networks of physical infrastructures belonging to the significant market power operator), Austria, Germany and Italy. [27]

proportionate criteria. This reason must be stated by the network operator within 2 months of receiving the complete request for access.

[12] This is the most recent report on the implementation of the BCRD (2018).

Table 1: Summarized rules and outcomes for access to existing infrastructure (Article 3 of the BCRD). [26]

		AT	BE	DE	FR	IE	IT	PL	PT	ES	SE	
Transposition	Date of initial access legislation/rules**	**2009-07**	2017	**2012-06**	**1927**	2016-07	**2012-01**	**2010-05**	**2009-05**	2014-09	2016-06	Bold-early application
Application	Clear rules on infrastructure access pricing, contractual terms						CO/RO		CO (law)			G=yes, Y=partly
	Clear rules on cost and profit sharing between utility/telco											G=yes, Y=partly
	Number of dispute requests received by authority (2015 - Q2 2017)	4	0	1	0	0	3	8		9	3	
Outcome (quantitative)	Requests for access 2015-Q2-2017 (km duct and aerial deployment)				>4,000		>9,000		>20,000			G=high use Y=medium use, O=limited use reported
	Degree to which access requests are reported as refused			Mixed	Mixed		Mixed			Mixed		R=all respondents report refusa O=most report refusals
Outcome (qualitative)	Perceived improvement in access conditions post CRD					Mixed	Mixed			Mixed		G=Significant improvement, Y=no change
	Perceived satisfaction with access conditions			Mixed								G=very satisfied, Y=neutral, R= very dissatisfied
	No. telco respondents	1	1	7	2	3	5	0	3	3	3	
	No. utility respondents	0	3	0	2	0	0	0	2	0	1	

* Data from utility operators

** Sources are desk research, NRA survey, BEREC 2016 report on implementation of the BB CRD, Europe's Digital Progress Report 2017

Blank indicates no information

CO=Cost Orientation, RO=Reference Offer

Shaded cells represent the views of 1 operator

Table 2 summarises the relative importance of the BCRD for access to existing infrastructure. Relative importance refers to how important the directive is considered for sharing infrastructure (i.e., if regulatory requirements for sharing infrastructure are already in place, the relative importance of the BCRD is lower). NRAs in 10 member states (including the Netherlands) regard this relative importance as low for the following reasons:

- In the Netherlands there are relatively few owners of ducts and infrastructure. Parties seeking access already informally share some infrastructure. The shared use of physical infrastructure between telecom operators is also common practice, while shared use across sectors is limited. [28] Providers of electronic communication services and mast sites in the Netherlands must comply with reasonable requests for shared use of their sites, antenna systems or antennas. [29]
- In Austria, the relevance of access to physical infrastructure defined by the BCRD is considered low because most access requests concern dark fibre (included in Austria's national legislation), which is currently outside the scope of the BCRD. Dark fibre has been mandated for use in mobile backhauls (under market 4: high quality access). [30]
- In Spain, Portugal and the UK, the SMP (significant market power) operators were already obliged to grant access to their physical infrastructure (ducts and poles) before the transposition of the BCRD. Despite the UK's minimal approach to implementing the BCRD, like Austria, the NRA in the UK has mandated dark fibre backhaul for the high-quality access market (for areas where there is no competing supply). [31]

In 10 countries, however, the BCRD is of relatively high importance for access to existing infrastructure because:

- In Germany, Denmark, Finland and Poland, there is only a limited availability of SMP operators' infrastructure or access is restricted by several conditions.
- In Czechia and Romania, access to the SMP operators' infrastructure was not regulated

before the BCRD transposition. Therefore, the only way to gain significant access to physical infrastructure is with the BCRD (except infrastructure built with state support).

Table 2: Relative importance of the BCRD access regime in several EU countries (Art. 3). [27]

Rel. importance	High	Low	N.A. / no information
Countries	CZ, DE, DK, FI, HU, IT, MT, PL, RO, SE	AT, BG, CY, EE, ES, FR, IE, NL, PT, UK	BE, GR, HR, SI
No. of countries	10 (42%)	10 (42%)	4 (16%)

Several countries, including the UK, largely follow the BCRD and do not go beyond the minimum requirements, while others go further. Denmark and Czechia have expanded the scope beyond network operators to include other investors that own infrastructure (like municipalities). NRAs in Czechia must create and publish sample contracts for access to physical infrastructure. In Romania, NRAs must establish maximum tariffs for access to public property, based on a cost method. Legislation in Portugal that predates the BCRD also mandates that tariffs for access to physical infrastructure are cost-oriented. Austria includes an obligation of access to dark fibre. In Slovenia, telecom operators can apply for access to use optical fibre.

In Italy, Ireland, Belgium and Sweden, dark fibre is sometimes offered as an alternative if access to existing infrastructure is refused. Some countries pursue the option of reciprocity, whereby access is requested to telecommunication network operators' infrastructure for installing non-telecommunication infrastructure.

Countries with limited use of access to existing physical infrastructures are Germany, Ireland and Spain. [32] However, a greater demand for physical infrastructure is emerging in Germany, Austria, Poland, Spain and Sweden, as evidenced by requests and disputes regarding access. France, Italy and Portugal make more use of existing infrastructure, having requested more pole and duct access (in km/year) from 2015 to 2017.[13] However, the lower use of existing physical infrastructure in Germany and Sweden may be because their municipalities and utilities provide alternatives such as dark fibre or bitstream access.

2.6.1.1 Factors that affect access to existing infrastructure

The report on the implementation of the EU directive found that regarding access to existing infrastructure, the main regulatory issues are [26]:

- Lack of information about the location and availability of existing infrastructure
- Lack of clarity or perceived lack of fairness over how the costs of shared infrastructure will be allocated between the telecom operator renting access and the owner of the infrastructure – as well as lack of potential for access providers to derive cost savings and/or additional profit
- Disputes over the level of access pricing. These include cases where the supplier deploys their own fibre and has concerns that providing access would undermine their business

[13] As no information was available from NRAs concerning requests or actual km of access to existing physical infrastructure, the data in this graph is derived from a limited number of network operators' responses.

case

- Contractual terms, which can limit autonomy and flexibility for the access seeker and/or impose one-sided liability conditions.

Lack of awareness of the existing regulations might be another factor limiting the access to existing infrastructure, but this is not mentioned in the implementation report. The greatest use of existing infrastructure is in countries with effective information provision and well-developed rules or recommendations about pricing and contractual terms. Factors that increase access to existing infrastructure include:

- The development of a single information point
- Rules on access pricing
- Reference offers
- Rules enabling regulated utility companies to at least partially derive the benefits of providing access.

2.6.1.2 Pricing methodologies for access to existing infrastructure

Since (a lack of) rules on access pricing are an important factor in determining the extent of access provided to existing infrastructure, we elaborate on the pricing methodologies.

The BCRD's main principle regarding pricing is that this should be "fair and reasonable"[14] [27]. Article 3 states that access to existing infrastructure should be made available under fair and reasonable conditions, which include price. For example, the price could be cost-oriented, ranging from incremental costs to those that include a contribution to common costs and network expansion, or value based. A cost-oriented approach means that the access provider should be able to recover their costs incurred by providing access to their physical infrastructure, considering the national conditions and tariff structures in place. Sunk cost, ongoing costs and network expansion costs must be considered and allocated between the host and recipient of physical access. Any previous imposition of remedies by a national regulatory authority (NRA) should be considered, as well as the impact of the requested access on the business plan, including investments in the physical infrastructures for which access is requested.

The article states that in the case of physical infrastructures owned by public communications network providers, free riding can influence downstream competition. Access obligations should therefore consider the economic viability of investments in infrastructure based on the risk profile, the return on investment and the impact of access on downstream competition.

In most countries, no pricing decisions were made when the BCRD was transposed into national legislation. In Portugal, cost-orientation of access to physical infrastructure is a legal requirement. In 10 countries (BE, CZ, HR, EE, ES, FR, GR, IE, MT, NL), the national transposition of the directive gave no indication beyond the directive's "fair and reasonable pricing". On the other hand, in 14 countries (AT, BG, CY, DE, DK, FI, HU, IT, PL, PT, RO, SI, SE, UK) the law does include further guidelines on pricing. [27] Legislation provides extensive guidance on access pricing in Germany and the UK, while most countries refer to cost recovery or cost orientation when interpreting fair and reasonable prices. Table 3 shows the price benchmark for duct access

[14] As described in Art. 3 (5) subpara 3 and Recital 19.

in France, Germany, Portugal, Spain and the UK.[15] These prices consist of one-time monthly fees per metre, monthly charges per metre and (if applicable) monthly ancillary charges. The total price for duct access in these five countries varies from EUR 0.046 to 0.084 per metre per month. A report by BEREC also compared prices for the use of ducts in Italy, Poland and Portugal. [27] Interestingly, they found that the price in Poland is substantially higher (EUR 0.32 per month per metre). In Italy, the recurrent price component for ducts is an IRU with a duration of 20 years. The price for duct access in Portugal also differs between the two reports (BEREC reports a monthly fee of EUR 0.0314 per metre).

Table 3: Price benchmark for duct access in several countries (monthly price per metre). [33]

Country	One-time fee, €/month/metre	Monthly charge, €/metre	Monthly charge (ancillary), €/metre	Total, €/month/metre
France	0.0034	0.0688		**0.072**
Germany	0.0069	0.0400	0.0026	**0.050**
Portugal	0.0002	0.0461		**0.046**
Spain	0.0033	0.0280	0.0522	**0.084**
UK	0.0005	0.0587	0.0186	**0.078**

2.6.2 Implementation in the Netherlands and Belgium

We describe the implementation of the BCRD in the Netherlands and Belgium in more detail below. The implementation of the EU directive in the Netherlands was delayed by several years. The 18 month-period allotted for its implementation was considered too short to draft legislation that all stakeholders could agree on. Another reason was that the implementation should not incur unnecessary costs for network operators.[34] Government documents outline the Dutch implementation plan. [35] The Dutch Telecommunications Law was adapted to implement the EU directive (chapter 5a, articles 5.2 and 20.5 on unused cables and chapter 12). [36] Other existing articles on the shared use of physical infrastructure were incorporated in chapter 5a. Similar to other member states, the legislative text in the national transposition overlaps the text in the Directive. A slight difference in the wording is the term ‘shared use’ instead of ‘access’ to existing infrastructure, to avoid confusion with Chapters 6 and 6a and since the scope of the Directive is passive, not active physical infrastructure. The directive has also been transposed in the law ‘Wet informatie-uitwisseling bovengrondse en ondergrondse netten en netwerken’ (WIBON). RWS uses an extensive public fibre network in the Netherlands and this network is not open to third parties.

In Belgium, the transposition of the BCRD into national legislation was more complicated because it had to be done on different levels: interfederal, federal and regional. [37] At the interfederal level, the Cooperation Agreement established a dispute settlement body for network

[15] This benchmark indicates duct access prices; however, these are difficult to compare EU-wide because costs differ per country depending on the type of basic infrastructure work, surface (underground), salaries, taxes and so on.

infrastructures. [38] At the federal level, among other things the Telecom Act was amended. Furthermore, there are several provisions for BCRD implementation at the Flemish, Walloon and Brussels Capital Region level. This transposition with all the right authorities was thus slower than in other countries. In general, the BCRD was transposed into national law without adjustments to the text in the directive. Regarding the Flemish public fibre network, MOW is the primary user. Other public parties are welcome on the network (not for profit): the Flemish government, universities, universities of applied sciences, local government and governmental institutions. Operational costs are shared among all users. Agentschap Wegen en Verkeer (AWV) is responsible for maintenance. Dark fibre is shared and exchanged with other public network owners if there is no market interference. Currently, the Flemish government is also looking at providing excess microduct to private parties (non-public) under the BCRD. The BCRD's impact on access to physical infrastructure appears to be limited in the Netherlands and Belgium. For example in Belgium, the dispute settlement body has not received any disputes regarding a request for access to physical infrastructure. This may of course be down to the limited number of ducts available in Belgium and some relevant stakeholders might not be fully familiar with the BCRD. There are also relatively few ducts in the Netherlands, and infrastructure owners or parties seeking access already share infrastructure informally.

2.6.3 Public consultation on the BCRD

A public consultation on the BCRD was held from December 2020 to March 2021. [39] This evaluation aimed not only to gather stakeholders' views and input on the implementation of the Directive, but also support potential future adjustments with a view to preparing a revised legislative proposal. [40] This includes adaptations to technological, market and regulatory developments and other improvements in order to foster a more efficient and fast deployment of sustainable, very high capacity networks (VHCN), including fibre and 5G and possibly reducing the administrative burden and increasing the potential for simplification. One question is whether to change the definition of physical infrastructures to include dark fibre, for example. The consultation respondents were companies, business organisations and public authorities. BEREC also provided an opinion report. The Commission will analyse the various stakeholders' input.

The European Competitive Telecommunications Association (ECTA) thinks the BCRD needs to be reformed to make it more fit-for-purpose and more consistent with the EECC. According to the association, the BCRD should not replace obligations such as solid existing asymmetric regimes for SMP operators. The directive has not had a significant impact (except for example in Italy). A further critique is that the listed criteria for refusing access encourage transport services to seek reasons for denying access.

The European Telecommunications Network Operators (ETNO) published a discussion paper on how the BCRD is meeting its objectives, and in light of the consultation, offers recommendations. These include expanding the notion of "network operator" to provide uniformity and consistency throughout the EU and ensuring this definition includes both private and public organisations. [41] ETNO also recommends that certain countries' inclusion of dark fibre in the definition is monitored and addressed at the European level and that the term "physical infrastructure" should be updated and widened to include any kind of resource that is potentially useful for deploying VHCN.

BEREC's contribution to the consultation is that the reasons for access refusal are well developed and no more specific rules are needed to justify refusals in the BCRD. [42] According to some market parties, physical infrastructure's scope should include dark fibre. Currently, electronic communications networks (ECN) operators may get access to dark fibre based on EECC provisions (SMP regulation, Art. 61,3) but this is not included in the BCRD. [43] The EECC article states that NRAs may impose obligations on ECN providers or infrastructure owners to grant access to ducts and cables upon reasonable request, if replicating such network elements would be economically inefficient or physically impracticable. [24]

BEREC argues that a parallel access regime to dark fibre under the BCRD does not seem proportionate since the regulatory EECC instruments already provide such access for interested operators. Some parties argue that including dark fibre in the BCRD might cause market distortions. Changes in the revised legislative proposal for the Directive remain to be seen.

Box 4: Case study of infrastructure sharing, Luxconnect and Creos in Luxembourg

In Luxembourg, infrastructure was already shared by Luxconnect and Creoa before the launch of the EU directive. [26] Luxconnect, a private limited company owned by the Luxembourg government, has provided dark fibre (1,700 km since December 2020) and data centre services. Creos is the largest network distributor for gas and electricity in Luxembourg. Creos owns a duct system and dispersed fibre connections, shown in the left panel of the figure below.

The right panel shows Luxconnect's dark fibre network (red indicates the existing dark fibre network in 2014 and green the projected expansion in 2014 in collaboration with Creos). Creos and Luxconnect reached a co-deployment agreement whereby Creos rents out its ducts to Luxconnect, who rents back dark fibre to Creos. This is based on costs, whereby 1 km of duct equals 6 km of logical fibre path (12 fibres).

This agreement greatly reduces costs: Luxconnect realised 90% cost savings because the company could use Creos ducts. The company achieved a faster time to market in terms of fibre roll-out. Creos reduced EUR 115 million in costs by not having to deploy 1,300 km of fibre. These cost reductions led to a positive business case for fibre roll-out in Luxembourg's underdeveloped areas.

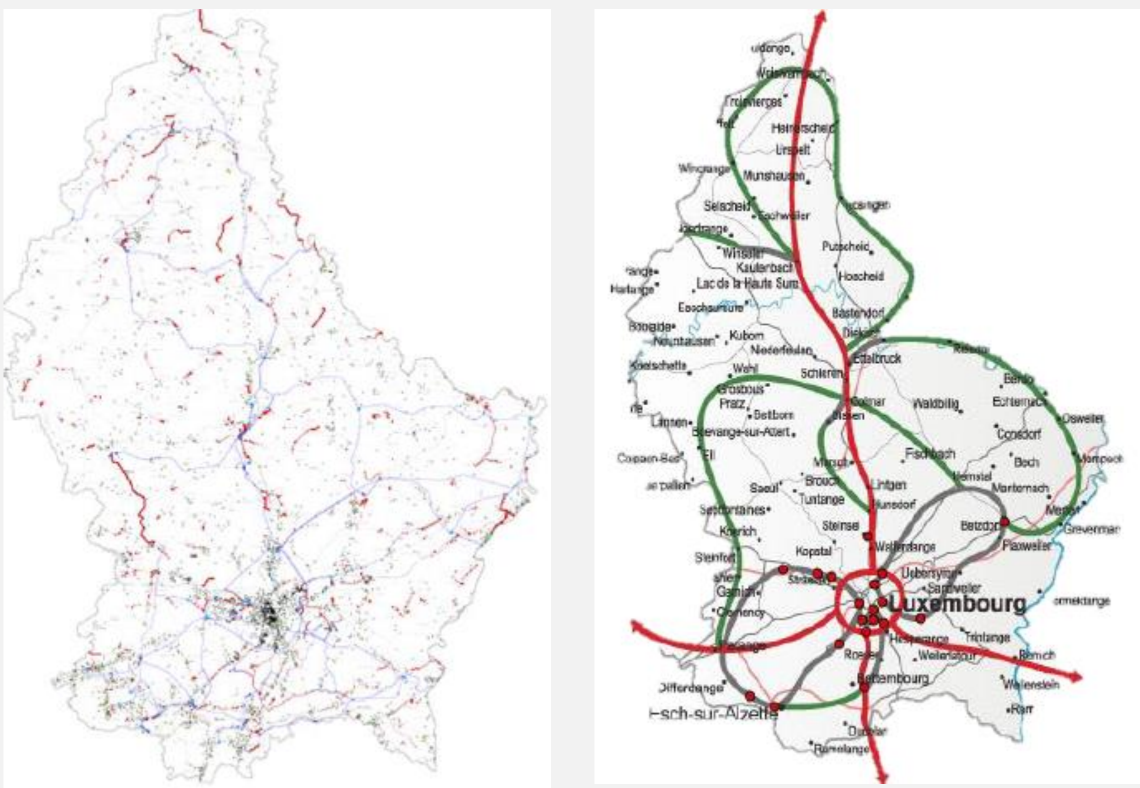

Figure 8. The Creos duct system and dispersed fibre connections (left) and the Luxconnect dark fibre network (right) [23]

2.7 Conclusions

Co-deployed networks are the most interesting type of network for this study. They are constructed (simultaneously) with other infrastructure such as roads, railways or electricity networks. Of the other networks we identified, municipal and provincial networks aim to connect their organisations' (real estate) objects, whereas demand aggregation networks are the result of collaboration between (semi) public parties. The latter two networks usually have a limited/local footprint serving local organisations/objects.

Public network owners, when it comes to sharing their network, prefer different types of parties. There is a sequence of parties that a network owner can grant access: their own department (no sharing), their organisation, parties within the (value) chain, within the (semi) public sector or 'the world' (third parties). Currently, sharing co-deployment networks is mostly limited to the (semi) public sector. Third party access for 'the world' is not yet common practice, with some exceptions such as the Relined (TenneT/ProRail) network. The ways (third) parties can get access to a network are highly diverse, particularly how 'deep' the access is allowed in the network architecture. The types of access distinguished in this research are: access to physical infrastructure, ducts, tubes or pipes, dark fibre, lightpaths (WDM) or ethernet and other services.

Prominent parties with a large footprint in the Netherlands (in terms of metro networks and backbone) are Eurofiber, KPN, VodafoneZiggo and T-Mobile. In Belgium, Proximus and Telenet are by far the largest operators on the market. In addition to the private market, there are various public network owners: RWS, Ministry of Defence, ProRail and TenneT and demand aggregation networks in the Netherlands; and in Belgium, the Flemish public fibre network, Fluvius, Fluxys, Elia, SOFICO, SPW, Infrabel and the Ministry of Defence. Each network plays its own part in the shared task of providing connectivity to end users. As a result of extensive FttH-related fibre roll-out, we observe and expect further fibre densification in the Netherlands. We also observe a further roll-out of fibre in Belgium.

The installation of more (5G) antennas as well as an increase in mobile network bandwidth have increased the demand for fibre. The capacity of mobile networks is determined by the spectral efficiency of the technology used, the amount of spectrum deployed, and the degree of network densification. When the available amount of spectrum and (development of) spectral efficiency are fixed for a longer period of time, the third parameter, network densification, becomes the primary 'dial' for an operator to realise capacity growth at specific locations. Potentially, public networks could contribute to the feasibility of new 5G (cross-border) use cases since some have a unique footprint and therefore could meet unfulfilled demand in the process of network densification. From both the demand and supply side, there are various reasons for offering and using public networks or not.

We have described that access to physical infrastructure is already required under certain conditions and to a certain extent (the level of access includes ducts but not cables or dark fibre). The BCRD lists criteria for refusing requests to access existing infrastructure including network capacity, safety and security concerns. Requests denied on the basis of these criteria are widely reported. The EECC contains articles on access to certain public infrastructure for deploying small cells, general principles on the co-location and sharing of network elements, obligations to grant access to ducts, cables, specific network facilities and regulations regarding access tariffs.

The importance of the BCRD for access to physical infrastructure differs among countries. In some countries, regulations were already in place before the BCRD was implemented. Elsewhere, the BCRD is more important for access to infrastructure due to a lack of previous regulation. Some countries transposed the BCRD into national law without any notable adaptations to the minimum requirements in the directive. Other countries went beyond the minimum requirements and broadened the scope of definitions such as network operator and physical infrastructure (to include dark fibre, for example). In the Netherlands and Belgium, the national transposition of the BCRD closely follows the text in the directive. The impact of the BCRD on access to infrastructure seems limited in these two countries.

Factors that impact gaining access to existing infrastructure include availability and accessibility of information, rules enabling access providers to partially benefit from granting access and rules on access tariffs. Regarding pricing, the BCRD states that it should be 'fair and reasonable'. The price may be cost-based or value-based. In ten countries, no further regulation was drafted regarding access pricing beyond the conditions in the directive. In fourteen other countries, the national laws include pricing guidelines (mostly cost-based) where, for example, ducts are rented out for a certain price per metre per month (or year).

A public consultation on the directive took place from December 2020 to March 2021, to gather input from stakeholders and possibly adjust the BCRD (including technological, market and regulatory developments and other improvements). ECTA suggests that the directive has not yet had a significant impact (except in a few countries) and that the criteria for refusing access encourage transport services to find reasons to deny access. ETNO's recommendations include expanding the definition of network operators and monitoring certain countries' inclusion of dark fibre. According to BEREC, it is not necessary to include dark fibre in the BCRD because other regulatory instruments already provide such access. It is not known what changes will feature in the revised legislative proposal for the directive.

3 IDENTIFICATION OF OVERCAPACITY

3.1 Availability of (public) fibre infrastructures

Here we provide a quick scan of the existing public and private parties in both the Netherlands and Belgium. Most data regarding market shares is related to private networks, which is logical given most public network owners' scale (limited) and focus (no market activities). The private market is however relevant since we are trying to identify whether the public footprint could offer exclusive segments where there is no private entity.

3.1.1 The Netherlands

To understand the potential value and uniqueness of the public fibre footprint, we first present a brief overview of the private market for dark fibre in the Netherlands. Prominent parties with a large footprint (in terms of metro networks and backbones) are Eurofiber, KPN, VodafoneZiggo and T-Mobile. Together, they represent 80-85% of the total market for business fibre connections and their market shares are stable. The remaining 15-20% is covered by small to medium network owners. Besides this dark fibre access, there is a wide range of (active) network sharing, such as lightpaths and ethernet access. Given the scope of our research, we will not elaborate on this.

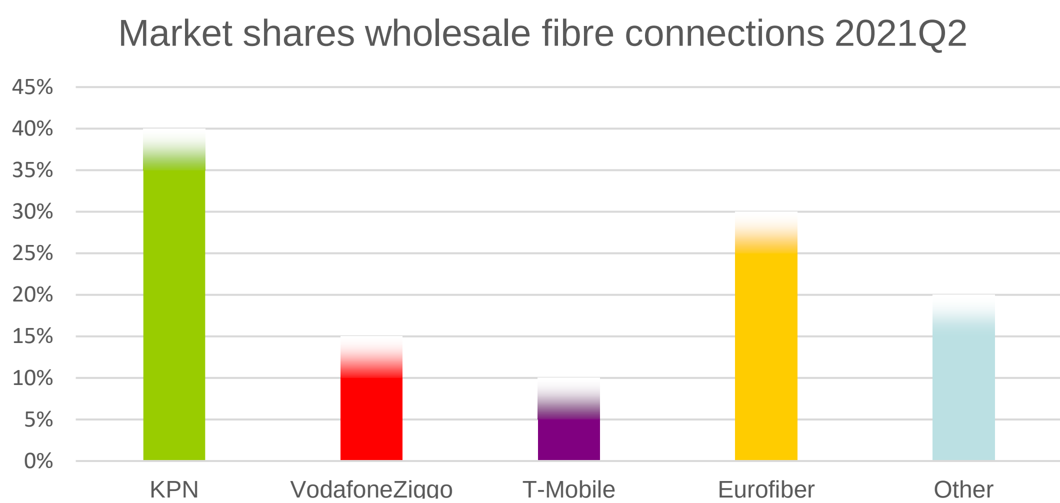

Figure 9. Market shares of wholesale fibre connections, with +/- 5% margin [44]

As a result of extensive FttH-related fibre roll-out, we observe and expect further fibre densification in the Netherlands. In 2020, over 500,000 households were equipped with fibre optics, compared to 180,000 in 2019. [45] This number further increased in 2021, mainly due to uptake from KPN, DELTA Fiber Netwerk, Primevest, T-Mobile (via Open Dutch Fiber), Glasdraad, E-Fiber and Digitale Stad. [46] In addition to rural areas, fibre is now being rolled out in urban areas on an increasingly large scale. Clearly the market is experiencing a strong positive trend in terms of roll-out rate. Throughout the Netherlands, almost 3.7 million of the more than 8 million households are currently connected to fibre optics. If the current roll-out rate continues, the entire Netherlands could be connected to fibre optics (well) before 2030. We discuss the relevance of these densification efforts in light of fixed-mobile convergence in section 2.4.

Using the typology in section 2.1, we identified various public network owners (not exhaustive):

- **Rijkswaterstaat (RWS)**: the RWS optic fibre infrastructure has a total length of approximately 5,000 km. It connects two Data centres and two PoP locations with Central

Network Facilities. The optic fibre infrastructure connects 1,157 manned and unmanned locations, of which 330 are via leased lines. The network functions as a Wide Area Network (WAN) and is not intended - by design - to be shared with other partners.

- **Ministry of Defence**: The Netherlands Armed Forces Integrated Network (NAFIN) is a dedicated, heavily secured Dutch Ministry of Defence fibre-optic network. It is managed by JIVC, the Ministry of Defence's IT Command. In 1996, PTT (now KPN) delivered the cable network, in total approximately 3300 km of fibre-optic cable. Since 2004, NAFIN has also been the backbone for OOV (Public Order and Safety) services' C2000 communication network. This network is not open to third parties.
- **ProRail and TenneT**: networks in railway embankments (ProRail) and Optical Ground Wire, or OPWG (TenneT). In 2003, these parties established a joint venture, Relined, to put the public fibre network overcapacity on the market. Over the years, the networks expanded, including extra connections between ground stations and other (private) fibre networks. Relined also initiated partnerships with other (metro) network owners, enabling them to offer end customers better solutions since most customers are not located on the rail route or at ground stations.
- **Demand aggregation networks**: at the start of this millennium, city rings were deployed in several cities and municipalities such as Arnhem, Leiden and Dordrecht. These networks were initiated by a consortium of (public) entities, including municipalities, schools and health care organisations.

Figure 10 shows several Dutch public network owners' footprint based on public information. The RWS network is not on this map since its coverage is confidential information (further strengthened by current geopolitical risks). We expect to find its network along all major highways and waterways. The map shows a nationwide network of (backhauls of) public networks. However, this coverage would be completely overshadowed if we added a layer with all the private network owners' backhaul and fronthaul fibre connectivity. Each network plays a part in the shared task of providing connectivity to end users.

The Rijkswaterstaat network is designed primarily for internal use. It consists of a core network connecting major hubs, and a local distribution network connecting offices and operating rooms in traffic centres, for bridges, locks, etc., often in remote places of no particular interest to other users. A distribution network is created for the last mile(s) to connect roadside units, traffic lights, cameras and other digitally connected assets along the roads and waterways. These are very specific locations and may be of limited use for third parties. In many locations, more traditional copper lines are used for the last mile(s).

Figure 10. Public network owners' fibre backbones [7]

3.1.2 Belgium

In Belgium, Proximus and Telenet are by far the largest operators on the market. Market shares are shown in Figure 11. Although Proximus is a private company, the Belgian federal government is the largest shareholder. Recently, Proximus set up two fibre joint ventures: Fiberklaar (together with EQT Infrastructure) and Unifber (together with Eurofiber), aiming to deploy fibre to more customers. Orange Belgium recently acquired Walloon telecom provider Voo (December, 2021).[16] [48]

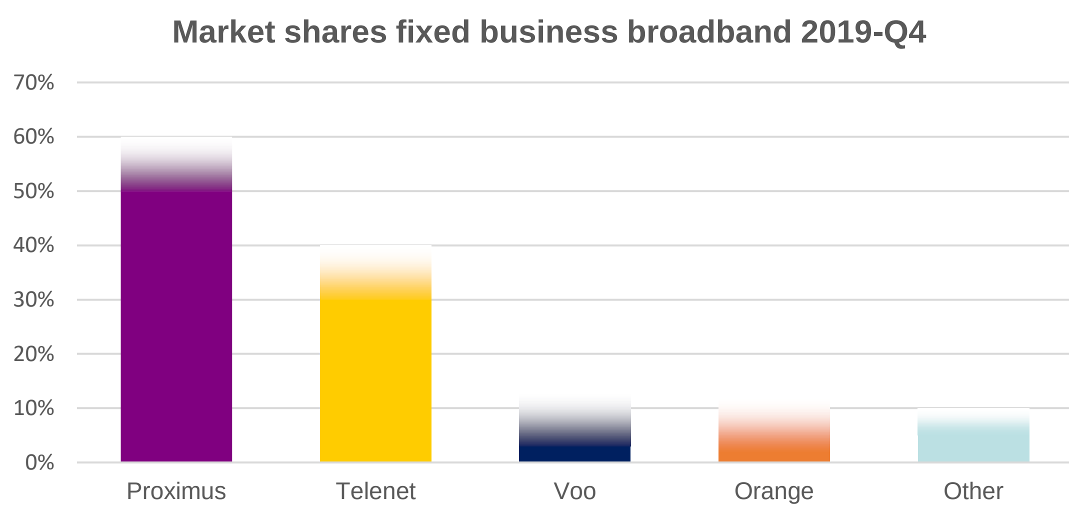

Figure 11. Market shares in fixed business broadband [48]

Regarding public networks, most relevant are the following parties:

- **Flemish public fibre network** (Vlaams Glasvezelnetwerk) - The Agency for Roads and Traffic (AWV) has constructed an extensive copper and glass fibre network. Its main purpose is to connect a large number of installations along freeways and some regional roads and that must be able to communicate with each other or with central systems and applications. The Flemish fibre optic network consists of more than 2600 km of fibre optic routes. These are mainly located along motorways, certain regional roads and important waterways. More than 60 percent of these routes were financed by the Roads and Traffic agency, with the main aim of remote control of their telematics applications. The Flemish administration sites are also connected. As a result, the fibre-optic network has branched out into major cities such as Hasselt, Antwerp, Ghent, Ostend, Brussels, Leuven and Bruges. After several expansions, and with the help of a transparent communication layer using the fibre-optic network, this network has become the backbone of the Flemish administration and the access layer (to the Belnet Network) for High Bandwidth connections for Flemish University buildings. It is developed, managed and operated by the Agency for Roads and Traffic, Department of Traffic, Road Systems and Telematics. Like in the Netherlands, Belgian public and private networks play their part in the shared

[16] This is the most recent data found on market shares in fixed business broadband, published before Orange acquired Voo.

task of providing connectivity to end users.

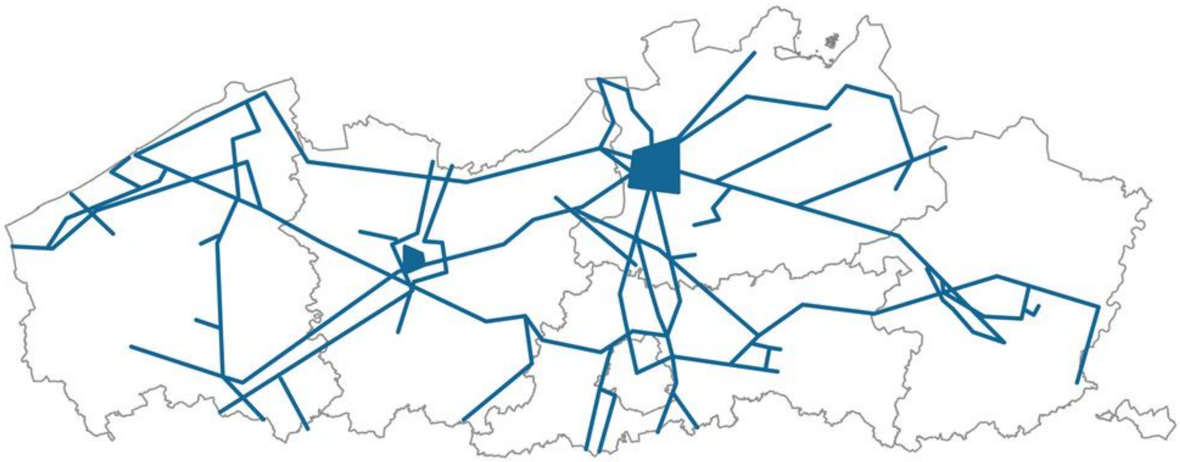

Figure 12. Schematic overview of the Flemish public fibre network [49]

- **Fluvius** is the Belgian grid operator of electricity and gas in all the Flemish region's municipalities. It is a publicly owned company and all cities and municipalities in Flanders are (indirect) shareholders of Fluvius (intercommunal). Telenet and Fluvius have signed an agreement to form a new infrastructure company, **NetCo**. This company will exploit the fibre network with an open access model. NetCo's goal is to evolve the network infrastructure and make it accessible to households and businesses in urban and rural areas of Flanders. [50] Other organisations with fibre networks are Fluxys and Elia.
- In Brussels there is a public initiative to integrate the network assets of Vivaqua, Sibelga, STIB/MIVB, IRISnet and Bruxelles Mobilité. These public network owners have agreed to pool their infrastructure and create a single large network in Brussels in order to market the overcapacity. [51]
- **SOFICO** has managed and developed Wallonia's optical fibre network since 2002, and the network's primary goal is to be able to manage traffic, deploy fibre in areas with low profitability and provide broadband access to customers through telecommunications operators. [52] SOFICO handles the commercial management, while the Department of Telecommunications is responsible for technical management. **SPW** (Service public de Wallonie, Mobilité et Infrastructures) manages the development, maintenance and operation of the optical fibre and telecommunications network. The network covers Wallonia, Brussels and a small part of Flanders, with a footprint of approximately 4,000 km, of which 600 km are exchanged. Figure 11 shows SOFICO's fibre network. SOFICO plans to expand its fibre network in the coming years (118 km along the structuring network and 147 km along the waterways) and deploy more fibre to the office (FttO). Since 2002, the organisation has been marketing the fibre network's overcapacity to private operators, companies and public sectors. SOFICO offers local dark fibre access for partners (telecom operators) in certain areas.

- Other organisations with public networks are **Infrabel** and the **Ministry of Defence**. Infrabel is the railway operator in Belgium and first deployed fibre infrastructure along the railways for its own use. The fibre network was transferred to Syntigo, which then sold its fibre network (B-Telecom department) to Eurofiber.

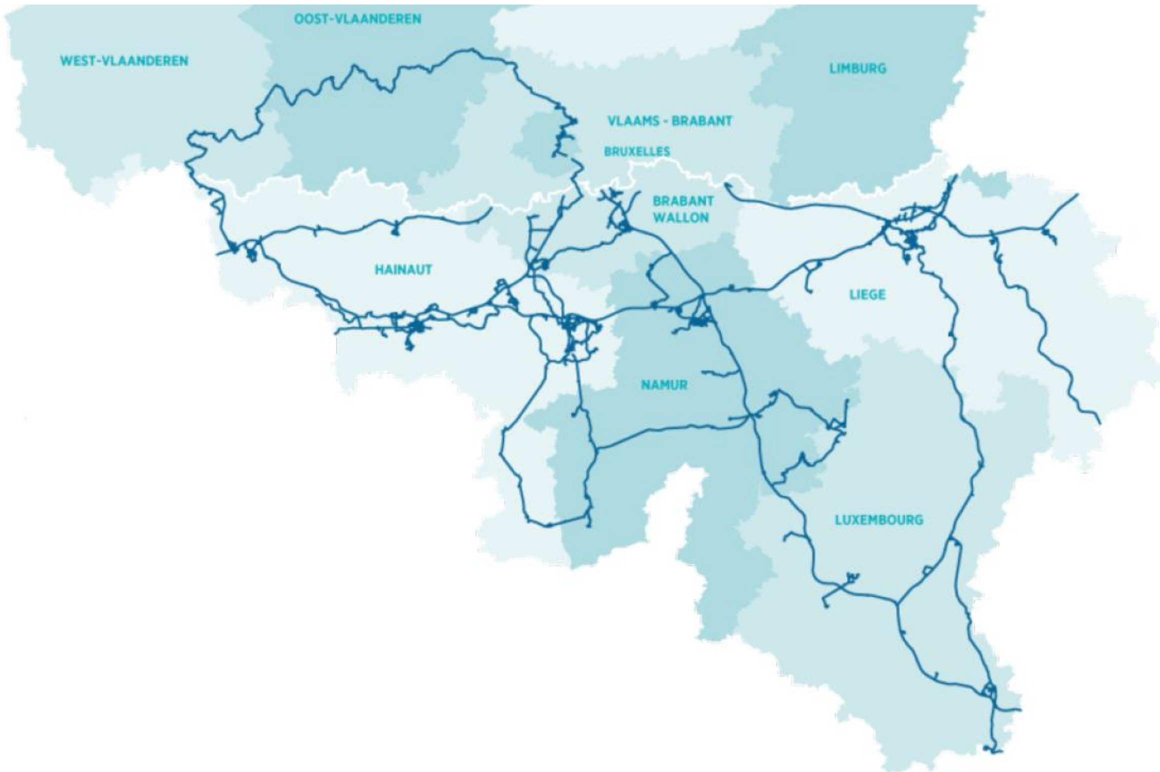

Figure 13. Schematic overview of Wallonia's public fibre network managed by SOFICO [53]

3.2 RWS and AWV overcapacity of public fibre infrastructure

3.2.1 RWS

The Rijkswaterstaat (RWS) fibre optic network has been rolled out over several decades. Some of the design principles were “fit for purpose” and “ready for the future”. RWS is not an entrepreneur, so ready for the future did not provide extra fibre optics to share with others or to gain a market position. The growth of IP-based devices in turn led to the growth of the optic fibre network, as did the increased need for bandwidth for digital cameras or other high bandwidth equipment. The current optic fibre network is still expanding and redundancy is one of its key objectives. Overcapacity may only be available at a limited number of connections and requires further analysis. The required level of detail of the available network capacity (number of fibres, dark fibres,empty ducts, etc.) is currently not available for the entire network. It requires a level of detail in Digital Asset Management which is work in progress. That makes it difficult to have good insight in overcapacity. Such a lack of Digital Asset Management which is needed to determine the actual roadside overcapacity at the road operator side was an unexpected outcome of this activity. During project proposal phase it was thought of as a much more straightforward task than what it turned out to be. This practical case study does bring an important lesson though: in the context of public/private fibre infrastructure sharing, it is wrong to assume that any road operator can easily determine its available fibre overcapacity. Which can be an important element holding back the real-life feasibility of the concept.

3.2.2 AWV

Regarding AWV overcapacity, an overview shows on which routes there is at least one duct as well as the number of optical fibres and their occupancy per route. However, there is no overall overview of the number of ducts and microducts, or how the fibre optic cables are distributed. The lack of an overview is because AWV has not needed this analysis in the past. For each application to provide a microduct in accordance with the BCRD, the requested route must first be analysed for any available ducts and microducts. This is done by studying the detailed plans and/or conducting a site survey. Thus AWV cannot currently provide an estimate of its overcapacity across the entire network.

3.3 Articulating demand for capacity

What does the user or use case require: a separate duct, dark fibre, or are active services (DWDM or ethernet) an option? It is up to the owner to determine whether the network can meet the specific requirements.

The MNOs in our work package argued that there is no one fits all solution for their third-party capacity demand. This is understandable, especially in light of their considerations for installing antennas and potential fibre-optic compaction. The radio planning process for densification is as follows:

- Based on usage measurements, usually visualised on a heatmap, operators determine where densification is needed
- A network team seeks suitable locations in that specific area
- The owners ("landlords") of those locations are approached in order of preference
- Only once a contract has been signed with a landlord will the site be designed and built. The design is largely standardised for management purposes.
- When the site is being developed, the MNO first checks their own database for any fibre coverage in their own fixed network. Where there is no or limited coverage, the MNO starts a procurement procedure for third party capacity. Based on this information, a buy or make decision must be made. In extreme (expensive) situations, a wireless radio link provides a fall-back scenario.

MNOs and especially incumbents KPN and Proximus, focus strongly on using their own fibre infrastructure. If a survey for a new site shows that its glass is not (easily) available, a procurement process is started to decide whether third parties have more attractive offers. It can be worthwhile to add public capacity, in many cases ducts, to this search. At the same time, we know that operators are currently only adding antennas in areas of demand congestion, i.e., where there are many active users. This is typically in urban areas, with an already higher network coverage. This does not mean it is always easy to install a piece of new fibre (such as in historic city centres), but the same problem will apply when using a public network. Another reason for densification is to improve coverage because of the new coverage obligation. This is very much spread out over the country and not necessarily concentrated around motorways.[17]

The degree to which public and private networks complement each other, i.e., have unique

[17] For a more in-depth analysis of site densification in the Netherlands, see [19].

locations where an MNO decides to use public capacity, differs from operator to operator. For example, many operators have a high fibre density in urban areas and not often along highways. At the same time, antenna sites have already been installed along motorways and are being served (sometimes wirelessly, but also with fibre). In a scenario where a small cell network (e.g., for C-ITS applications) is rolled out along highway corridors, the road operator's (duct) network might be of value. Recent trials proved it was challenging to use this existing infrastructure in a cost-effective manner, according to our interviewees.

The earlier mentioned increase in fibre-to-the-home deployment in both NL and BE could further reduce the chances of a public network offering a unique footprint. We note the regional differences between the Netherlands, Flanders, Brussels and Wallonia:

- Netherlands: high existing density of both antenna sites and fibre optic. Chance of unique and suitable offerings from public networks is therefore low.
- Flanders: reasonably high existing density of antennae and fibre optic, but still a considerable step when it comes to converting wireless backhauls to fibre. Due to FttH soaring in this region, the glass density will further increase and the opportunities for fixed-mobile convergence will grow accordingly.
- Brussels area: High density of networks. Owners of public networks have been working for years on a plan to house the networks in one public operator. This pooling of capacity will probably lower transaction costs for future access seekers by providing them with a one stop shop.
- Wallonia: lower glass and antenna density. SOFICO serves business parks and has been seeking public investors for some time to further exploit its network. In these regions, further and more active opening up of (duct) capacity on the public networks is seen as a policy intervention to solve a market failure. This applies particularly to white areas where coverage of both mobile and fixed networks is limited. In our Dutch and Belgium case study, this is particularly the case in Wallonia and especially in the Ardennes. See also SOFICO's efforts.

In the recent 5GAA publication regarding the cost analysis of V2I deployment, a recommendation for road operators and MNOs is to explore novel business models through collaboration. [3] A more integrated model involving also neutral host infrastructure providers (NHPs, or brokers) should be considered. [2] A broker could, just as in real-estate, provide support for MNOs' procurement processes where using their own network is not economically feasible. This would only be relevant in situations where the public network owner is willing to share capacity, but is not able or sufficiently staffed to provide the MNOs with the required footprint data in a timely or suitable manner.

3.4 Capacity management

Capacity management concerns the owner and external users' current and future demand. For each specific case it must be determined whether excess capacity is available at that location. For a proper assessment, the network owner needs to have insight in the type of network, the current route occupancy (are there still ducts and/or fibres available) and also estimate future use, preferably based on a roadmap. Usually, these assessments are based on capacity management tools data (COCON[18] and so on), but require proper registration and updating of the network properties. We expect this is not yet common practice for all public network owners. Along with all this information, a framework also needs to be in place to decide what to do in case the demand for ducts is higher than the available capacity. Will there be some sort of prioritisation based on economic or societal value? Do prices rise when capacity becomes more limited? Will there be a roll-out to cover additional future (internal) demand? It is also important to understand that typical IRU contracts can last up to ten years, enabling both the owner and the user to make long term investment decisions. On the other hand, it is hard to predict future demand over a period of ten years.

3.5 Conclusions

We presented an overview of the existing public and private parties in the Netherlands and Belgium. In both countries, public and private networks play a role in the shared task of providing connectivity to end users. We identified the overcapacity of the largest public networks in the Netherlands (RWS) and Flanders (AWV).

The RWS fibre optic network is approximately 5,000 km long and consists of a core network and a local distribution network created for the last mile at specific locations that are of limited use for third parties. The network is primarily designed for internal use and is not intended - by design - to be shared with other parties. The AWV fibre optic network consists of over 2,600 km of routes (mainly along motorways, regional roads and important waterways) and has branched out into major cities.

The RWS fibre optic network was not designed with extra capacity to share with other parties and redundancy is one of its key objectives. Overcapacity may only be available at a limited number of connections and the identification of overcapacity requires further analysis. Regarding AWV overcapacity, there is an overview of which routes have at least one) duct as well as the number of optical fibres and their occupancy per route. However, there is no overall overview of the number of ducts or microducts and how the fibre optic cables are distributed. Each requested route must be analysed for available (micro)ducts, by studying the detailed plans or conducting a site survey. There is therefore no numerical estimate of overcapacity across the entire AWV network.

Such a lack of Digital Asset Management which is needed to determine the actual roadside overcapacity at the road operator side was an unexpected outcome of this activity. During project proposal phase it was thought of as a much more straightforward task than what it turned out to be. These two practical case study do bring an important lesson though: in the context of public/private fibre infrastructure sharing, it is wrong to assume that any road operator can easily determine its available fibre overcapacity. Which can be an important element holding back the real-life feasibility of the concept.

[18] COCON is a widely used fibre registration application in the Netherlands.

4 TECHNICAL FEASIBILITY STUDY

4.1 Technical feasibility of sharing overcapacity

This chapter presents the technical feasibility study on sharing overcapacity. It details current RWS and AWV overcapacity sharing, including existing barriers to sharing the network with other parties. We outline the networks' technical accessibility then discuss the arguments (technical, business economics, macro-economics, security and legal) for and against sharing overcapacity.

4.1.1 Sharing of overcapacity by RWS and AWV

The RWS network can best be described as a nationwide internal network. Imagine the Netherlands as one large office building with network connections on every desk and on every level. When you look at the architecture of the fibre optic network, this is reflected in the basic layout with only two PoP locations and two data centres with central network facilities. The network was never designed to be shared with others. It may be difficult to share because of limited speed to the PoP locations (the slowest network sector defines the connection's maximum throughput). The current legal framework for Rijkswaterstaat does not allow sharing of dark fibre. This operational framework is an internal guideline based on the "Wet Markt en Overheid" (Dutch Market and Government Act). The current interpretation of the Dutch Market and Government Act gives only room to provide access to governmental organisations, such as ministries and their related governmental agencies. And only on the basis of an exception on the legal framework. Examples of services provided is facilitating the use of gantries and access to the fibre optic network to support enforcement by the Public Prosecution Service for speed control along highways. In the near future it is expected that access will be granted to public agencies for Truck Tolling.

AWV has been offering capacity/bandwidth (preferred) and fibre optic to other governments for a long time. As soon as a party wants connectivity between two sites, AWV will sit down with them to discuss the possibilities. First, AWV looks at where the sites to be connected are located in relation to the current Flemish fibre optic network. For sites that are not too far away, it will make a rough cost estimate for excavation and connection works to the existing Flemish optic fibre network. These costs will be borne by the customer later with any order. For sites further away, it is possible to work with another party's leased line.

Subsequently, the cost price is determined for the connection between the two sites. Preferably this is a capacity over the transport network (= the AWV layer 2 network). In this way, AWV does not lose fibre to the customer. The cost is determined by a model that distributes the costs fairly among the customers, taking into account the connection costs already paid by the customer. If capacity is not possible for the customer, a complete dark fibre pair can sometimes be made available, on routes where there is sufficient free fibre. These dark fibres are invoiced annually according to the number of meters purchased. In the past, AWV hardly had any requests for an entire duct. If the customer wishes to proceed on this basis, AWV will order a detailed estimate from the fibre optic contractor and/or network management contractor for the work required. As soon as the customer orders their connection, the works are carried out and the connection is put into operations.

4.1.2 Access to the network

The accessibility of the networks must be specifically addressed: What needs to be done technically to connect the road operator's infrastructure with that of the access seeker? And how will the network be integrated? This is relevant for both installation and maintenance.

At MOW/AWV (Flemish Road operator), the engineers in their telematics network have already worked out a possible integration strategy, shown in Figure 14. They propose that the third party installs its own handhole near the road operator's handhole (but always outside the highway perimeter), and introduces the glass fibre tube (green) into this. In this handhole, the microducts from the access seeker's (orange) glass fibre tube will be coupled to the road operator's microducts. After this coupling, a task which may only be performed by the road contractor, the access seeker can blow glass fibre cable through the microducts over the entire route. For sections that exceed the maximum blowing distance, additional handholes can be installed for inserting in the road operator's duct.

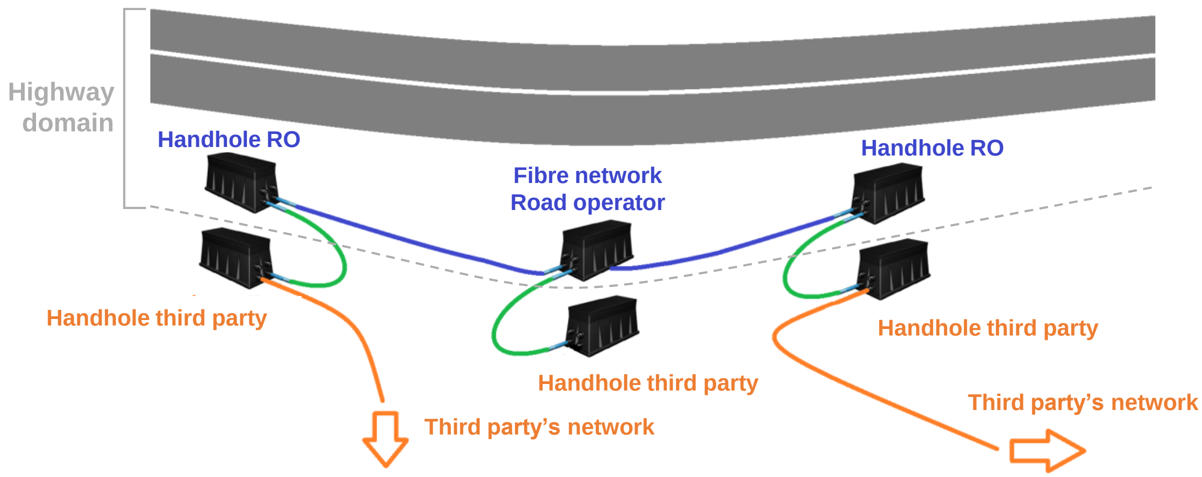

Figure 14. Schematic overview of access strategy (design: MOW/AWV)

This proposal stipulates a very strict physical separation between the public and private network, respecting current legal frameworks (e.g., highly restricted access to the highway domain for all third parties) and procurement contracts (network management contractor). It is still uncertain whether this model will be (economically) feasible in practice, since the extra handholes introduce more complexity and investments that will (directly or indirectly) lead to a higher cost profile for the access seeker. Other models could investigate potential legal or security issues where third-party contractors have direct access to the road operator's handholes. Another option is a certification scheme for which contractors can apply (if not yet in place).

RWS also shared its ideas regarding physical access to the network. They prefer to arrange the access via an outside demarcation point, so that the access seeker does not have to access RWS technical areas (PoP). This avoids the need for contracts and agreements related to access control (key management) and service levels. The access seeker can offer their own duct or fibre at an existing RWS demarcation point (handhole). RWS will couple this fibre to the corresponding fibre on the RWS network. In places where there is no existing handhole, but interconnection is required, a handhole will have to be installed. This may also require a large section of glass fibre to be blown into the network. Such additionally required investments will be charged to the access seeker. RWS has also developed guidelines regarding the active equipment, encompassing laser safety requirements and testing protocols (allowing RWS to assess and ban equipment if requirements are not met).

4.2 Technical arguments

The technical arguments about offering overcapacity are predominantly against sharing infrastructure. We focus on sharing ducts and fibres (see section 2.3 for all other types), since this is presumably the type of sharing mostly discussed in connection with the legal obligations mentioned in chapter 3.

There are all kinds of technical arguments why offering overcapacity may be less suitable than (1) completely blocking third parties from using your network, and (2) a customer using dedicated fibre networks. The arguments below are not all equally strong, and in some cases can easily be worked around. Our study revealed that technical arguments are often generated simultaneously, thus increasing their strength.

In the case of co-deployed networks, the complexity of creating new connections such as handholes on the network plays a role. Fibre-optic networks lying in, under or above motorways, railways, high-voltage networks, low-voltage networks, metro lines, etc. are much more difficult to reach physically than a regular fibre-optic network 60 cm below the paving stones. In some cases, the primary infrastructure must even be made temporarily unavailable to realise connections. Technical and safety limitations mean that disconnections can only be made at certain locations or at certain times. In addition, creating these disconnections often requires specific expertise and certification. A technician not only has to deal with fibre optics but must also be able to deal with primary infrastructure and its risks.

Another influential factor in networks realised through co-laying is that management is dependent on the primary user. The network's primary user determines when preventive maintenance is undertaken. This might be less in line with market demand. Furthermore, the main user has priority when it comes to fibre-optic network repairs. If one cable breaks, most likely all fibre-optic cables will be damaged, but this is not a law of averages. If a customer connection's fibres are damaged, but the main user's are not, these fibres will probably not be repaired immediately. This means that the main infrastructure (high voltage, rail, road, etc.) must be temporarily (partly) taken out of operation. Contracts can be made regarding the repair of shared fibre (e.g., 24/7 service), but the ability to repair damages depends on different factors. For road operators such as RWS and AWV, this includes permission for traffic measures (taking a road out of operation temporarily), localisation of the damage and assessing possibilities for repair. In addition, access to the road for maintenance is restricted to a limited number of contractors. Usually only the contractor that won the tender has access and may carry out maintenance. These organisations therefore cannot guarantee the repair time for damages to shared fibre infrastructure, although they may provide service level agreements (SLAs) with response times.

The reliability of networks based on shared operations, what we label co-deployed networks, differs from that of regular networks. This creates an eclectic supply profile that not all customers can accept. Compared to regular fibre-optic networks, the networks based on shared access are expected to have a low probability of failure (MTBF – Mean Time Between Failures), but a much longer failure duration (MTTR – Mean Time to Repair). The fibre-optic cables in high-voltage pylons are a case in point. We know of only a few occasions of high voltage line breakage in the Netherlands: black ice in 1969, 1987 and 2005; Apache helicopter in 2007 and 2017. Similar arguments apply for infrastructures such as railways, motorways and gas pipelines. There is a very small chance that a fibre optic line co-deployed to these networks will break down. However, if there is extensive damage, it can take a long time to repair the lines. And this work requires certified installation companies. Apart from their technical "skills", these companies provide security that the network is reliably secure. We see the opposite in regular networks. A fibre-optic line at a depth of 60 cm can be damaged by an over-enthusiastic farmer and cables break regularly. Repairs, however, are relatively simple and quick.

Some networks may have older fibre types that are less attractive to use. Older fibre types require different, unusual equipment that is less readily available and manageable. Older fibres also have technical limitations that reduce capacity and limit the use of lightpaths. If the fibre network consists of direct-buried segments, it is not possible to add new duct capacity without civil engineering work (unlike ducts).

A network's unfavourable location may result in low market demand. Dark fibre customers typically want connections between locations with relatively high traffic flows. If the public network connects locations with little data traffic, market demand will be low. In corridors where commercial 5G coverage is poor due to low consumer demand, third (public) party transmission might allow the deployment of an additional 5G site which would otherwise not be viable for the MNO.

A technical argument from organisations providing access to their network is future overcapacity. Organisations must know their infrastructure's long-term needs. A possible concern is that these parties may need the shared overcapacity for their own use in the future, which is why contracts should include clear agreements about such issues beforehand.

Owners of network infrastructure may also impose technical restrictions on parties using their network, for example regarding the type of active equipment and laser power. An issue for public organisations is that granting access to their infrastructure should not affect their primary tasks, for which agreements must be also made.

Furthermore, sharing fibre infrastructure may require demarcation points (handholes) in the backbone. Third parties ensure that a breakout cable is laid to the handhole, while the infrastructure owner ensures this is coupled to the right microduct in the handhole. However, in places where there is no existing handhole but a coupling is needed, a handhole will have to be installed. This requires additional fibre cables, and the client (the user requesting access to the infrastructure), would accrue the cost, which links back to the business economics.

Relatively short pieces of network are not attractive to purchase. Customers typically want a single line between two points. It is, of course, possible to connect many smaller routes from different parties to make one connection. However, this could result in reduced technical performance (higher attenuation), relatively high costs and a complex network management situation.

With some parties, the network location is not clear precisely clear. Many networks were established some twenty years ago and data on the location may have been lost. Besides, if networks function well, there is little incentive to put much energy into determining their exact location.

4.3 Security arguments

This section looks at the security aspects of network sharing. We focus on cyber security. The risks include third parties reading data, manipulating data, breaking data streams and gaining access to systems. When it comes to security, most arguments are against making excess capacity available since each additional party gaining access provides more exposure to the outside world.

Various parties indicate they do not provide overcapacity because leasing it increases the risk of a data breach. We believe this argument is regularly misinterpreted. The data stream in fibre A does not radiate to the adjacent fibre B. If you rent fibre B, you cannot pick up any signal from adjacent fibre A. This type of crosstalk does occur in copper networks, but is not characteristic of optical fibre. Of course, this argument also applies to wireless networks, which involve a public medium, the ether.

On the other hand, we do see a risk if third parties can bring equipment close to an organisation's fibres at any location. At places where an interconnection is necessary, it may be possible to physically access other fibres. With all kinds of techniques such as bending the glass fibre (coupling), making a v-groove, evanescent-coupling, catching Rayleigh scatter, data can be read from another glass fibre connection. Obviously, these are not easy operations to perform (and remain undetected). They require a great deal of expertise and, to execute them properly, a great deal of capital. Moreover, parties with these capacities will probably also be able to access data via other, much simpler methods than renting overcapacity. Still, a large number of disconnections on the network creates more risks.

Because of these potential risks, organisations that consider sharing infrastructure must decide how to grant access to third parties while maintaining the highest level of security (e.g., zero trust principles with VPN). If an organisation shares dark fibre with third parties, it should make clear agreements regarding the demarcation points (fibre connection points for these third parties). Another related issue is to what extent access can be granted to technical areas (e.g., should there be a key policy?), which also touches on technical aspects.

Another argument is the increased vulnerability when overcapacity is offered, since the location of the fibre optic network then becomes known. After all, you want to market the overcapacity. The better the location is known, the easier it is to physically reach the fibres. Third parties are thus able to deliberately damage fibres or install equipment to read or manipulate data (without taking up fibres). However, we believe this argument is often overstated. When it comes to co-laying, it is obvious where the fibre-optic network is located. The ProRail network is near the railway, the TenneT network is near the high voltage line, et cetera. The WIBON regulation in the Netherlands and consequent KLIC notifications (of digging), make it easy to find the location of many networks, precisely to protect them against unwanted disruptions. In Belgium, this is organised via KLIP (Flanders) and KLIM-CICC (Wallonia and Brussels).

Ultimately the security arguments seem to indicate either a lack of knowledge (also a fair argument not to share infrastructure) or the earlier discussed capacity issue in the organisation. But nevertheless, even if some of the security arguments against sharing don't have a profound technical foundation, they can't just be ignored or disposed. Even just in the time that this project has been ongoing, and for a big extend driven by the war in Ukraine, Europe has gone through quite an important increase of significance of both cyber- and homeland security. Military surveillance agencies reported recently that espionage and foreign interference are on the highest level since the Cold War [61]. Road networks, and al digital infrastructure that belongs to it, are now also seen as critical infrastructure that needs to be protected accordingly. In this context, the existence of any security related argument not to share will most likely be of concern to policy makers deciding on the decision to share or not.

4.4 Legal arguments

Numerous organisations have indicated that uncertainty about the legal aspects of marketing their network as a (semi)public party raises barriers to putting their overcapacity on the market.

It is not exactly clear to what extent RWS in the Netherlands must comply with the Telecommunications Act, is bound by the requirements set by the Authority for Consumers & Markets (ACM) or is allowed to offer these telecommunications services within their own specific frameworks. WM&O (Dutch Market and Government Act) and state aid rules must be considered. Other legal aspects are how the cooperation with third parties relates to procurement law, to the organisation's procurement policy and to government procurement policy (regarding the management of data connections). Also, road operators like RWS and AWV are bound by legal frameworks regarding the ability to close lanes and carry out repairs, affecting the conditions of third-party access to infrastructure. It is of course usually possible to find out within which legal construction parties may put overcapacity on the market. The question is, however, whether the costs of this legal process will outweigh the benefits.

Another legal aspect of sharing public fibre infrastructure is whether parties may resell capacity in network segments deployed on privately owned land. In the Netherlands, the ‘Federatie Particulier Grondbezit’ (FPG) asked ACM to conduct an investigation into TenneT and Relined commercially co-using the fibre network. [54] FPG argues that private landowners must give permission for co-use where the network runs through private land, and if a public network is shared with private parties, landowners should receive compensation. [55] According to Belgian law on ‘the restructuring of some of the economic public organisations’ (Art. 99),[19] every operator of a public telecommunications network has the right, free of charge, to lay cables, overhead lines and related equipment, to permanently support walls and facades retaining the public highway, to use open and undeveloped land and to span or cross properties without attachment or contact. [56] The question is whether a road operator with a fibre network is included in the scope of this definition since they do not operate a public telecommunications network. Furthermore, in Belgium, it must be possible to remove fibre installed in the public domain at any time for public interest reasons, such as widening a highway. On the other hand, investments in fibre are large and operators want long-term certainty.

There is, however, also an argument for organisations opening up their own infrastructure: under the Broadband Cost Reduction Directive (BCRD), telecommunications providers should have access to other networks’ physical infrastructure: "This means that telecommunications providers - under reasonable conditions - will be given access to the physical infrastructure (such as ducts, masts, cable trays, street cabinets, antenna sockets) of almost all utilities that provide infrastructure (telecom, electricity, gas, heating, waste and sewage water and operators of railways, roads, ports and airports)." Thus, to comply with the legislation, physical infrastructure must be shared under certain conditions. Utilities, if they must give other parties access to ducts anyway, can make the trade-off within their own organisation of extending overcapacity to fibre. RWS must assess which infrastructure it is required to share and which infrastructure is technically feasible to share (ducts, dark fibre, etcetera).

4.5 Conclusions

The degree to which public fibre networks are equipped or designed to be shared with other organisations differs across networks. The RWS network was not designed to be shared and it may also be difficult to share if the speed to the PoP locations is limited. Another factor that impedes RWS sharing infrastructure is that the organisation’s current legal framework (internal guideline) does not allow sharing the fibre optic network (dark fibre, IP services, VPN services, etc). It does share with services such as IP or VPN connections, but only for public bodies related to their legal duties and as an exception to the legal framework. AWV has been sharing capacity/bandwidth and fibre optic with other governments. This is done by investigating the sites in relation to the current Flemish fibre optic network and if feasible, the costs for excavation and connection works to the existing network are estimated (otherwise, another party’s leased line can be used).

We expect the public network owner will face considerable legal hurdles when sharing their network. These include various legal frameworks, such as procurement law (what kind of partnerships are allowed and how should the capacity be offered to the market), telecommunications law (can the co-deployed network be used for commercial

[19] This law is, Wet betreffende de hervorming van sommige economische overheidsbedrijven.

telecommunications activities) and European Directives (how should the network owners interpret the BRCD). We provide more insight and given the importance and potential impact of these matters, the public network owners indicated they would also like to investigate them further. Another relevant factor is security and safety in vital infrastructure. For organisations dealing with highly intrinsic security measures (defence, police), it is less obvious to forfeit a little extra vulnerability for extra income. Regarding technical arguments, such as an unfavourable location or uncertainty about a network's exact location, a business case for sharing overcapacity simply cannot be made from both the owner and the access seeker's perspective.

5 ORGANISATIONAL FEASABILITY STUDY

5.1 Technical organisation of sharing overcapacity

5.1.1 RWS

Rijkswaterstaat applies certain internal rules for the deployment of its network. The first priority is safety, which is important during construction (mainly physical safety) and during operation (mainly digital safety or resilience to misuse). However, physical safety is also an important element during network operations since many technical rooms are at locations with limited access (traffic-centres, data-centres, technical rooms as part of critical infrastructure as bridges, locks, sea-defence systems and roadside units). Those locations come under a very restricted access policy, also for management and maintenance. Shared use of technical rooms is not provided nor desirable. This can be a serious limitation for operations if third parties require 24/7 access. Another limitation is that the organisation is not ready for sharing overcapacity. A dedicated unit should be set up as a point of contact for third parties, like a broker. There is no provision for such a unit in an already fully loaded organisation.

5.1.2 AWV

The Flemish Government's entire fibre optic network is managed by the Roads and Traffic Agency (AWV). To this end, the agency directs a number of contractors for the technical network management and the fibre optic works. These contracts are renewed every 4 years.

Public customer contacts are handled by the agency's project engineers. As soon as a customer is interested, the project engineer has a quote drawn up by the contractor. The supervisor and project engineer check the quote, then the customer can order directly from the contractor. The supervisor and the project engineer monitor and finally approve the connection works.

The cable works contractor then documents the work carried out and the occupation of the optical fibres in the AWV applications, such as AWVInfra for the location of optical fibre pipes and Kabelnet for the occupation (use) of the fibres. The network management contractor keeps track of the network connections. The contractors monitor the network and ensure its availability 24/7. They are subject to an SLA for this. However, there is no overall overview of the number of ducts or microducts and how the fibre optic cables are distributed.

5.2 Organisational arguments

A frequently mentioned argument for not offering overcapacity is that an organisation is not equipped to operate fibre-optic networks and share or offer overcapacity to third parties. Parties that co-locate fibre-optic cables by definition engage in other activities: public transport, electricity, roads, railways, et cetera. They may handle the fibre-optic network for their own use, but are not equipped for fibre-optic customers who call with questions about maintenance, sales managers who sell the surplus capacity and a financial department that sends invoices to all kinds of small fibre-optic customers. The organisation's employees have to carry out additional tasks such as deciding which parties get access to the network or assessing the technical feasibility of sharing infrastructure. Unlike a commercial operator, (semi) public organisations may have to develop certain policies for sharing overcapacity at a high management level.

We can question how the overcapacity came to exist in the first place. Did the owner install additional ducts or fibres for their own future demand or to serve other parties' needs? This all determines whether the 'overcapacity' is only of a temporary nature, or even a 'coincidence', and probably an indication that the public owner is open to new partnerships or customers.

An argument against sharing overcapacity is if the network owner does not have sufficient staff and resources to deal with this new task. Even though the organisation is equipped to share overcapacity with third parties, it may need additional employees. The same could be said for registration software: is this designed to share information with third parties? This argument is therefore also linked to the business economics of sharing fibre infrastructure with third parties.

Another argument for not offering overcapacity is the fear of losing control. The organisation currently manages a certain overcapacity, but by allowing other parties to use it, the organisation will lose control over this capacity. What will happen in the future if the organisation suddenly needs much more fibre? Can the organisation still maintain its fibre-optic network, or will it have to start taking on other users? Such arguments may cause reluctance to share public infrastructure with private parties.

Nevertheless, there is also an organisational argument for offering overcapacity: external pressure might ensure even better management of the network, because the obligation to other parties puts more pressure on the organisation. If part of the network fails, the network management department is notified not only by its internal organisation, but also by external users of the network. Customers sometimes report disturbances sooner than the internal organisation because they are more active users of the fibre route or have a greater dependency on the infrastructure.

5.3 Business economics

If an organisation has overcapacity in its networks, this has economic value. Monetising the economic value is therefore an obvious argument for sharing overcapacity with third parties. This can be done by leasing fibres to other parties, exchanging with other parties or parts of its organisation using the overcapacity. The value of dark fibre depends very much on the location of the lines. Market prices in the Dutch context are currently EUR 0.10 to 0.50 per fibre pair per metre per year.[20] A dark fibre connection from The Hague to Utrecht will therefore yield EUR 7,000 to 35,000 a year. Tariffs vary greatly depending on the length of the route (shorter is more expensive per metre), duration of the contract (longer is cheaper per year), available capacity (unique routes with limited capacity are expensive), et cetera. This can therefore be an interesting way for some organisations to obtain additional financial resources. Also, when new partnerships are formed that exchange capacity, it is easier for the public network owner to use (lease) these partners' networks since the interconnections are already in place.

For more insights on duct access tariffs, we refer to the earlier discussed 2017 WIK international benchmark. It provides several cases from France, Germany, Portugal, Spain and the UK [33]. Prices varied between EUR 0.046 (Portugal) and 0.084 (Spain) per metre per month.

Some organisations indicate that revenues are limited. This certainly applies to parties with short stretches of network. Nonetheless, this can also be an argument for parties that manage and realise other infrastructures. As an example, the realisation of a kilometre of motorway in the Netherlands can cost up to EUR 100 million in a complex environment. The average investment is EUR 20 million per kilometre [57]. Leasing one kilometre of dark fibre alongside the motorway, based on the above estimates, yields EUR 100 to 500 a year. With annual revenues at least a

[20] Price estimates provided by Eurofiber, validated in various Dialogic research projects. Dark fiber is commonly leased as a 10 to 20-year (mostly 20) Indefeasible Right of Use (IRU).

million (!) times lower than realisation costs, revenue remains relatively limited. The business argument thus loses a lot of strength and can soon be outweighed by other arguments.

Another emergent argument is that there is a positive business case even without additional revenue. This is of course an inherent characteristic of overcapacity on networks. Why should we do our best to make an already positive business case even more positive? Especially for (semi)public organisations, the incentive may be low. Accordingly, some parties say that the additional revenue does not benefit their organisation. The disadvantages of sharing infrastructure typically end up with the part of the organisation that manages the network, while the financial benefits are for the organisation as a whole or society. The incentive for offering overcapacity is therefore low.

The disadvantages of sharing infrastructure include costs related to providing technical access (e.g., constructing handholes). Thus, a relevant question for parties that share their network is how the costs are determined and allocated to the access provider or third party being granted access. Related issues are state aid rules to ensure costs are allocated correctly and the consideration whether the network capacity will eventually be used by a limited (private) user group or for a much broader societal use case, for example providing better network coverage and capacity or enabling more diverse and more advanced network services. The type of user and use case could lead to different tariff structures (offer a discount in return for specific services).

5.4 Macro-economics

Earlier research showed that some parties share their overcapacity because, as a (semi)public organisation, they feel a responsibility to maximise the societal value of these connections. From a macro-economic perspective, it is efficient if all forms of capital, including overcapacity of glass fibre, are used to their maximum extent. The 5GAA publication regarding the cost analysis of V2I deployment emphasises the importance of high fibre coverage, because fibre is implemented as backbone in all four infrastructure deployment options. [3] Unused fibres contribute nothing. Some parties, however, indicate they do not want to distort the market by bringing overcapacity onto the market. They argue that overcapacity competes unfairly with market parties' fibre-optic networks. These parties have created fibre-optic networks and borne the full costs. They have to compete with (semi) public parties that have realised the overcapacity at a lower cost.

The discussion about market forces is, in our opinion, not black and white. There are examples where most stakeholders believe the market is being distorted. One is the deliberate creation of overcapacity on routes where the market is already very active and putting this on the market at dump prices. However, many stakeholders believe the market is not being disrupted and that there are major societal benefits. Examples include projects with no active market players, where realisation costs are very high and overcapacity is offered at market rates. For example, TenneT, the Dutch Transmission System Operator (TSO), has achieved overcapacity on fibre-optic cables between the Netherlands (Eemshaven) and Denmark (Endrup). This has created a unique route between Northwest Europe and Scandinavia, which can increase the total availability of international backbone networks. The Walloon government has collaborated with telecom providers to lay ducts to new mobile network sites because either the rocky soil or remote population made it too expensive for operators to do it alone.

Once the decision is made to share fibre infrastructure with other parties, the question arises which users to grant access. How do we prioritise (potential) public or private users of the infrastructure, given a network's limited capacity? There are various ways to decide this such as maximising societal value. However, determining societal value is not straightforward: how do you compare the value of using the network for 5G use cases, public organisations including universities, rural broadband projects and so on? A certain selection process can grant users access to infrastructure, such as on a 'first come first served' basis, auctions or potential users' societal value rankings.

5.5 Overview of the arguments

An important part of this research is the question whether and under what conditions the owners of public fibre-optic infrastructures are prepared to open their networks to third parties, like an MNO with a 5G network densification strategy. We have elaborated on the main enablers and barriers for owners to share their networks and provide an overview in **Error! Reference source not found.**.

Table 4 Arguments for and against sharing public fibre-optic infrastructures [7]

Arguments for sharing	Arguments against sharing
1. Business economics	
• Monetising overcapacity via leasing or selling to third parties • Access to more capacity via new partnerships	• Relatively limited returns (compared to total infrastructure investment), regulated tariffs (state aid rules) • Positive business case (or profit) not required for public entity • Additional income not automatically accrued to (part of) own organisation • Additional investments in the public network to facilitate sharing
2. Macro-economic	
• Maximising the societal value of public infrastructure by facilitating more use cases (general 5G, smart mobility, rural connectivity etc.)	• No market distortion • How to prioritise new users in case of limited access?
3. Organisational	
• External pressure ensures better management of entire network (capacity management, maintenance, etc.)	• Own organisation not set up to operate glass-fibre network for third parties • No capacity (FTE) available for new tasks and responsibilities • Fear of losing control • Current registration tools not designed to share data with third parties
4. Security	
• External pressure ensures better security management by articulating and formalising underlying processes/ agreements	• Higher probability of a data breach (but still limited) • Higher vulnerability due to known location of network • Telecom providers need access to other networks' physical infrastructure
5. Legal	
• Writing and signing SLAs helps to streamline internal and external processes/agreements.	• (Uncertainty about) legal framework and liability • Restrictions in public-private cooperation
6. Technical	
• Exchange of fibre possibly improves network coverage for public network owner	• Complexity of making interconnections on the network; network not designed for third party access • Access to technical areas (PoPs) and road perimeter restricted to small number of contractors • Management and maintenance windows depend on main user • Different reliability profile (old fibre types, direct buried vs. ducts)

Arguments for sharing	Arguments against sharing
	• Relatively short lengths

5.6 Conclusions

From both the demand and supply side, there are various reasons, both perceived and factual, for and against offering the use of public fibre or duct capacity. We have identified arguments related to business economics, macro-economics, organisational aspects, security concerns, legal frameworks, and technology. Ultimately, when deciding whether to open their network to third parties, the owner has to weigh up the pros and cons of . We have elaborated on technical, security and legal arguments in the previous chapter. One of the factors that further determines an owner's degree of openness to sharing is the absolute economic value (for a public network owner, the value case). A certain 'return' must be expected on the investment to justify overcoming the organisational and legal barriers.

We also need to examine how the fibre-optic network is embedded in an organisation. Some organisations place these networks with an internal organisational unit that is responsible for providing IT and telecommunications services to other units. Other organisations outsource the management of their fibre-optic network to a third party. In the first model (internal management), even though the number of staff available is limited, the organisation may have the knowledge and expertise to share the network. However, this observation applies to smaller public network owners and not necessarily to larger public organisations such as RWS and AVW.

The combined technical, security and legal arguments determine whether or not to grant access to third parties. If the only arguments at play are technical, these issues would be resolved if the economic or social value justified the required investment. The more (perceived) barriers there are, such as legal uncertainties or lack of internal support, the harder it will be to facilitate further network sharing. External pressure, such as a new European framework, may have a positive effect and lower the barriers.

6 NEW VALUE CHAIN FUNCTIONS

Given all the insights gathered here, the question is whether introducing new roles or functions in the value chain could stimulate the use of public fibre infrastructure. We discuss how and in what form these new value chain functions could strengthen the arguments for using public infrastructure and counteract the arguments against sharing the network.

6.1 What could new value chain functions contribute

Some of the arguments against sharing capacity, especially regarding technical and organisational FTE/capacity, can potentially be mitigated by introducing new value chain functions, such as a neutral broker or 'virtual fibre operator'. Like a realtor in the housing market, a neutral broker or intermediary could reduce transaction costs because they: (1) gather insight on the road operator and other public parties' available overcapacity and where the new demand (from the use case or MNO) is coming from; (2) can facilitate contracts between parties. Previous 5GAA publications highlight the potential benefits of a neutral host (or broker) model where sharing infrastructure helps to reduce costs. [1] [2]

From our interviews (see Annex A), we concluded that public institutions have limited incentive and capacity for providing connectivity services to third parties. Lower transaction costs would mean less fine-tuning with individual parties, and there are standards for use by third parties.

Introducing new value chain functions to the existing ecosystem of private and public stakeholders also raises questions. For example, this function can be allocated to an existing or a new entity. If an existing party is selected, how do their interests relate to others? Is it a private or individual party or can multiple parties perform this role? Will it be a new implementing organisation or a public party? What about tendering rules such as the Market & Government Act? Does this broker also work across national borders or do several national brokers work on an international solution? Tension may arise as soon as the new functions are entrusted to a party with several roles in the value chain.

6.2 Concepts for stimulating the use of public infrastructure

Based on our study and discussions with project stakeholders, a range of models or scenarios can be considered for stimulating the future use of public fibre infrastructure. A brief overview:

- **No new functions or entities** – as a reference scenario, network owners could conclude, based on the advantages and disadvantages (see previous chapters), that they do not want to open up their network to new users or use cases. In this case, the network will primarily serve its internal organisation's needs, and limit its partnerships to for example the collaboration between RWS and MOW for the Port of Antwerp's radar system.
- **Reselling (lease or full sale) of overcapacity by the public network owner** – the public network owner could decide to broaden their scope and start offering the network (over)capacity to private third parties. AWV does not limit its services to (semi) public organisations. At the moment, AWV is investigating sharing ducts with private parties (such as MNOs), in line with the BCRD.
- **Reselling (lease or full sale) overcapacity by a third party** – this is the model we see with TenneT and ProRail in the Netherlands, where Relined was introduced to resell the overcapacity available in these co-deployed networks. As we understand from BIPT (the Belgian NRA), a consortium of public network owners in the Brussels region is also considering introducing such a network operator. This could be interpreted as a more

thorough version of the Relined model, since it not only involves overcapacity, but the entire network and its operations will be transferred to this joint public operator.

- **Introducing a neutral host or connectivity broker** – this new function could, regardless of its positioning and legal status, support the owner and users in exchanging information and the underlying processes for them to reach an (use/lease/sell) agreement. Ideally, this new role would help maximize the positive impact of further network usage and minimize the transaction costs (and therefore maximise the benefits for both the owner and users.
- **Selling the entire network** – in a more extreme scenario, network owners might decide that operating a fibre network is neither feasible nor part of their organisation's core activities. Selling the network to a commercial operator and leasing the capacity required for their use could be worth considering. We do not expect this will be a relevant scenario for a national road operator given the strategic importance of the network, or any owner expecting to have an internal / public use case for the network; but for smaller public network owners such as the city rings discussed in 2.1, these selling strategies are already common practice in the Netherlands. The more logical option for most owners is to have external organisations perform the operation for them through public tenders.

6.3 Facilitating the neutral host model

A neutral host strategy is a business approach that involves the deployment of a shared infrastructure that can be used by multiple (wireless) service providers or MNOs to offer their services to customers. Although the cross border corridor in the Netherlands and Belgium has not presented challenging locations that MNOs are unable to feasibly connect, it is worth considering this model in EU member states that face arduous geography, long distances or other issues that factor in difficult business cases. In a neutral host strategy, a third-party infrastructure operator, known as a neutral host infrastructure provider (NHIP), operates the shared infrastructure, such as fiber optic connections or even a small cell network. This infrastructure is then made available as an Open Access Network for multiple (wireless) service providers who can use it to provide their own 5G services to customers.

The neutral host strategy can benefit 5G service providers by reducing the costs associated with building and maintaining their network infrastructure. This is because the neutral host infrastructure operator assumes responsibility for the infrastructure and all associated costs. Additionally, the NHIP model can help to improve the quality of service for customers by providing access to multiple service providers and reducing network congestion. Wireless neutral host strategies have proven their usefulness in environments such as stadiums, airports, shopping malls, and other public venues, and are often used in situations where multiple wireless service providers may have to provide comprehensive coverage.

In the sense of sharing publicly owned fibre infrastructure with third parties, it is important to develop a thorough understanding of the neutral host proposition to the market. We use the arguments for and against sharing networks that were raised at work package workshops on technical and organizational feasibility, to look at how the NHIP could facilitate the execution of that technical integration process.

Infrastructure operations

Fibre operators or Open Access Network providers have a natural fit with the NHIP competence profile. From their perspective, the technical integration process involves several steps that must be completed to ensure integrated passive networks can communicate effectively with each other.

- Network Analysis: this involves identifying the technical requirements of the networks that need to be integrated. Our study helps to identify the areas of compatibility and incompatibility between the networks, and also identifies potential technical challenges and risks.
- Interface Design: since the technical requirements have been identified, the next step is to design the interfaces that will enable communication between networks. This involves determining technical requirements to interface between networks and operators, cost modeling, implementing standard operating procedures and developing monetization.
- Development: once the interconnection between networks has been designed, the actual development work begins. This may involve implementing the network coupling, testing the functionality and delivery of documented and tested end-to-end connections, ready for service.
- Maintenance: the final step is to ensure the integration in production and maintain this over time. This involves ongoing monitoring and troubleshooting to ensure that the integration continues to function correctly and that any issues that arise are addressed in a timely manner.

In essence, the primary goal of telecom infrastructure operations is to ensure that 5G services are delivered reliably and efficiently to customers. In our model, the neutral host has a prominent role in a range of activities, such as connecting networks, capacity management, monitoring network performance, GIS and asset management, diagnosing and resolving issues, performing regular maintenance and upgrades and ensuring compliance with industry standards and regulations. Fibre operators and telecom subcontractors are well equipped for such tasks, thus unburdening public bodies such as the road operator to focus on their main remit.

NHIP entity design

The neutral host may very well be the solution to many of the arguments identified in the study. Provided an infra operator can assume the right legal entity if necessary and is recognized by all relevant players to connect and interact, it can still create a level playing field of secure and reliable open access to all interested service providers. The proposition to the European road operator entails identifying overcapacity, high-level future capacity designs, cost and revenue modeling and crucial insights in the monetization of networks. For MNOs and 5G service providers and other parties, the NHIP offers cost benefits, ease of use and IRU models that provide stable and reliable connections closely resembling ownership.

Public tender bid requirements

The Neutral Host services may be acquired through a public tender process. This study found potential NHIP requirements that meet the stringent demands. Eurofiber as fibre operator describes these as follows:

1. Technical Capability: the NHIP will need to demonstrate their technical capability to meet the requirements of distributing shared infrastructure capacity to the market efficiently and safely. This might include providing information about their network infrastructure, experience with network integration projects and ability to scale their services to meet market demand at the right price.
2. Compliance: the NHIP will need to demonstrate that they are compliant with relevant industry standards and regulations. This might involve providing evidence of certifications, licenses, and compliance with security and data protection requirements.
3. Financial Stability: the NHIP will need to demonstrate financial stability and their

competency to deliver projects within budget. This might involve providing information about their financial status, revenue and profitability, and their ability to secure financing if needed.
4. Service Level Agreements: the NHIP business will need to provide service descriptions and service level agreements (SLAs) that outline the expected service levels for the integration task. These could include guarantees around network availability, response times and service restoration times in the event of an outage.
5. Innovation and Value-Add: the neutral host Infrastructure operator should also be evaluated on their ability to innovate and provide value-add services that go beyond the basic requirements of network sharing. This might include providing additional features, services, or insights that enhance the customer experience or provide additional societal value.

Any operator seeking to start or expand NHIP network sharing propositions should bear in mind the challenges demonstrated in this study, not only in technical integration, but also the enormous complexity of nationwide interwoven government bodies in terms of manpower provided and costs incurred relating to the outflow of generated revenue streams.

Technical and organizational feasibility

Chapters 4 and 5 focused on the technical and organizational feasibility of network and capacity sharing. Our study found compelling arguments for and against sharing duct and fibre capacity. The neutral host infrastructure provider model provides mitigation possibilities for all practical and many organizational obstacles. Qualified NHIP business modeling accommodates and settles the most pressing arguments.

NHIP Competence profile

The neutral host infrastructure provider can be found in the regular telecommunications domain or birthed as a specialist entity. By design, companies such as fibre operators, vendors, carriers and telecom subcontractors subscribe to agnostic technology design and interoperability principles. This philosophy is central to such companies' competence in designing and delivering solutions for any physical network challenges that arise regarding network sharing. Minimal NHIP requirements should entail:

- Telecommunication know-how and pedigree
- Full access to both (fibre)technical and sectoral ecosystems
- Agnostic by design and interoperation principles
- Compliance with industry standards and certifications
- Fibre optic networking knowledge and competence accreditation
- Experience in strategic partnership designs and business modeling.

The tender process for finding a suitable NHIP organisation should focus predominantly on combining both the value case and the business case for public capacity sharing, to create a more complete picture of the potential benefits, associated risks and how to proceed. After assessing the (regional) value case of using public and private fibre infrastructure for 5G for societal value and benefits, the NHIP can focus the bid on financial viability and technical feasibility.

The study found that neutral host infrastructure provider (NHIP) models are a useful way of mitigating arguments in an elegant and cost efficient way, if there is a compelling business case to be made due to a discrepancy in supply and demand. Although our study suggests there is no evidence for a useful business case in the densely populated Belgian-Netherlands cross border corridor, the neutral host proposition is valuable. It is worth considering the NHIP as a new value chain function overall, and more to the point as an efficient solution to local and regional complexity in its relevant (cross border)geography.

The most important advantage of a neutral host infrastructure provider as new addition to the value chain is that it allows 5G service providers to use the same shared infrastructure to deliver their services. Smaller operators can access the same infrastructure as larger operators, allowing them to compete more effectively in the market. MNOs can also compete better for customers through competitive pricing and offering better service. It improves coverage in areas previously underserved or unserved by a single service provider, and by sharing infrastructure, service providers can reduce expenditures, resulting in lower costs for end-users. Leveraging the NHIP shared public and private fibre infrastructure should lead to improved reliability, faster data speeds, and better overall 5G performance.

6.4 Considerations for all scenarios

Given the aforementioned concepts, certain technical and operational aspects should be considered when allowing third parties to access a network. We suggest how a broker could help tackle the issues.

Legal aspects

First and foremost, there are many legal aspects to consider when designing and exploring functions or introducing new entities. We introduced (see 4.4) some of the challenges posed by state aid rules, telecommunications law and the particularly challenging regional policy guidelines in Belgium. A broker could support public network owners by developing standard documents that take account of these legal frameworks. Initiated by the new European Framework (see chapter 3) and this 5G Blueprint research, both MOW/AWV and RWS have already conducted extensive research into the legal possibilities and limitations for further opening their networks. Both expressed their willingness to share their insights with the 5G Blueprint consortium or other parties.

Articulating demand

What does the user or use case require: a separate duct, dark fibre, or are active services (DWDM or ethernet) an option? It is up to the owner to determine whether the network can meet the specific requirements.

The MNOs in our work package argued that there is no *one fits all solution* for their third-party capacity demand. This is understandable, especially in light of their considerations for installing antennas and potential fibre-optic compaction. The radio planning process for densification is as follows:

- Based on usage measurements, usually visualised on a heatmap, operators determine where densification is needed
- A network team seeks suitable locations in that specific area
- The owners ("landlords") of those locations are approached in order of preference
- Only once a contract has been signed with a landlord will the site be designed and built. The design is largely standardised for management purposes.
- When the site is being developed, the MNO first checks their own database for any fibre

coverage in their fixed network. Where there is no or limited coverage, the MNO starts a procurement procedure for third party capacity. Based on this information, a buy or make decision has to be made. In extreme (expensive) situations, a wireless radio link provides a fall-back scenario.

MNOs and especially incumbents KPN and Proximus, focus strongly on using their own fibre infrastructure. If a survey for a new site shows that their fibre is not (easily) available, a procurement process is started to decide whether third parties have more attractive offers. Adding public capacity, in many cases ducts, to this search can be worthwhile. At the same time, we know that operators currently only add antennas in areas of demand congestion, i.e., where there are many active users. This is typically in urban areas, with an already higher network coverage. That does not mean it is always easy to install a piece of new fibre (such as in historic city centres), but the same problem will apply when using a public network. Another reason for densification is to improve coverage because of the new coverage requirement. This is very much spread over the country and not necessarily concentrated around motorways.

To what extent public and private networks complement each other i.e., have unique locations where an MNO decides to use public capacity, differs from operator to operator. For example, many operators have a high fibre density in urban areas and not often along highways. A base of antenna sites has already been installed along motorways and is being served (sometimes wirelessly, but also with fibre). In a scenario where a small cell network (e.g., for C-ITS applications) is rolled out along highway corridors, the road operator's (duct) network might be valuable. According to our interviewees, recent trials showed it was challenging to use this existing infrastructure cost-effectively .

The earlier mentioned increase in fibre-to-the-home deployment in both NL and BE could further reduce the chances of a public network offering a unique footprint. We note the regional differences between the Netherlands, Flanders, Brussels and Wallonia:

- Netherlands: high existing density of both antenna sites and fibre optic. Possibility of unique and suitable offerings from public network is therefore low.
- Flanders: reasonably high existing density of antennae and fibre optic, but still a considerable step when it comes to converting wireless backhauls to fibre. Due to FttH soaring in this region, the glass density will further increase and the opportunities for fixed-mobile convergence will grow accordingly.
- Brussels area: High density of networks. Owners of public networks have been working for years on a plan to house the networks in one public operator. This pooling of capacity will probably lower transaction costs for future access seekers by providing a one stop shop.
- Wallonia: lower glass and antenna density. SOFICO serves business parks and has been seeking public investors for some time to further exploit its network. In these regions, further and more active opening up of (duct) capacity on the public networks is seen as a policy intervention to solve a market failure. This applies particularly to white areas where coverage of both mobile and fixed networks is limited. In our Dutch and Belgium case study, this is particularly the case in Wallonia and especially in the Ardennes. See also SOFICO's efforts.

The NHIP connectivity broker could, just as in real-estate, provide support for mobile network operators' procurement processes where using their own fibre network is not economically feasible. This would only be relevant in situations where the public network owner is willing to share capacity, but is not able or sufficiently staffed to provide the MNOs with the required footprint data in a timely or suitable manner.

Capacity management

Capacity management concerns the owner and external users' current and future demand. Whether excess capacity is available at that location must be determined for each specific case. For a proper assessment, the network owner needs to have insight in the type of network, the current occupancy of the route (are there still ducts and/or fibres available) and estimate future use, preferably based on a roadmap. Usually, these assessments are based on capacity management tools data (COCON[21] and so on), but require accurate registration and updating of the network properties. We expect this is not yet common practice for all public network owners. Along with all this information, a framework also needs to be in place to decide what to do if the demand for ducts exceeds the available capacity. Will there be some sort of prioritisation based on economic or societal value? Do prices rise when capacity becomes more limited? Will there be a roll-out to cover additional future (internal) demand? It is also important to understand that typical IRU contracts can last up to ten years, enabling both the owner and the user to make long term investment decisions. On the other hand, it is hard to predict future demand over a period of ten years.

Together with the road operators involved in this project, we concluded that it is not easy to calculate the entire overcapacity that a road authority could open to third party private users such as MNOs. Therefore, no general assumptions can be made about the impact of the road authority's overcapacity in reducing the CAPEX of potential roadside densification.

In a Blueprint for 5G deployment of Teleoperation and CCAM, the use of public fibre is best understood as a process where MNOs lead with their standard process for network densification. Public network owners should be regarded as a partner and potential supplier in this process. Together, these partners can investigate whether the available ducts can be used to reduce costs, for instance at exceptionally difficult locations such as bridges and tunnels.

Service levels and maintenance

As with any service, the contract between the user and the network owner needs to include a service level agreement whereby both parties agree on the processes and timescales associated with faults and maintenance. Since the access seeker (such as an MNO) might also resell the capacity to another entity, they will probably 'forward' their own SLA to the access provider (the public network owner). For a public network owner only experienced in serving internal clients, the definition of these SLAs (and responsibility for the potential ensuing risk) might be a challenge. A broker could work on drafting these agreements and sharing them as standard documents with the network owners involved.

Degree of risk bearing

With the introduction of new functions or even new entities, the question is to what extent this new entity will bear the risks and responsibilities. Chiha Ep Harbi et al. [58] describe various brokerage models where the risk increases depending on whether the entity is a pure negotiator (no risk), leasing (limited risk) or acquiring assets (most risk). In a basic broker scenario, where only supply and demand are matched, the business model focusses on information exchange and therefore the broker's business risk is limited. If the new entity leases or even owns network capacity, the business risk increases significantly. These models require up-front investments and are best compared with a 'normal' private network operator. The extent of investments and risks also affects the tariff structure offered to potential users. Models can vary from a fixed membership

[21] COCON is a widely used fibre registration application in the Netherlands.

fee, to a supplement on the standard IRU prices or common leasing tariffs we see at regular private operators.

6.5 Conclusions

We identified the various sharing strategies adopted by the owners of Belgian and Dutch road operator fibre networks. Their current approach and strategy, or rather overall organisational culture, determine to a large extent their openness to new partnerships and an NHIP value chain function.

Determining demand and overcapacity proved to be a lot more complex than suggested in the initial task description. We cannot simply say there is *A* demand for capacity by operator *B* and network owner *X* has *Y* percent of spare duct capacity. As in regular fibre procurement processes, this differs per antenna site or fibre route. In some cases, the MNO can easily use their own network, in other cases, a third (public) party could make a suitable offer. The regional context (urban/rural, Netherlands/Flanders/Wallonia, etc.) and the stakeholders involved, whether the MNO is incumbent/mobile only or an open/closed public network, to a large extent determine the success of using public networks.

Introducing a neutral host fibre operator role could potentially lower transaction costs between stakeholders, for instance by supporting the information exchange regarding demand and available capacity, streamlining legal processes (providing standardised procedures and agreements) and pooling public capacity. Whether these functions are truly beneficial and feasible has to be determined after this research phase. The idea of introducing new value chain functions has led to much debate by our dialogue partners, making it difficult to find consensus among stakeholders. The conclusion is that there is still a lot of work to be done in describing *added value propositions* for all stakeholders in the sharing concept, allowing them to test and validate this through a field trial.

7 FIELD TRIAL

In an attempt to validate the various findings in this study with practical experience, we investigated organising a field trial as part of this project. The first step was to identify the concrete demand of the two mobile network operators involved in the project – KPN and Telenet. Both operators analysed their ongoing 5G deployment activities and further plans. For their entire nationwide coverage in the Netherlands, KPN identified a few dozen sites next to highways that have no fibre connections, and where road operator capacity could be a valuable alternative to the currently envisaged solution – upgrade the existing microwave links to higher bandwidth to facilitate 5G. The fact that after careful study only such a limited amount of potential sites could be found on a total highway road network of 2,500 km, is an important indicator confirming earlier insights from interviews that the demand side for road operator fibre sharing is lower than initially anticipated. Telenet did a similar exercise, but could not identify sites in the Flemish highway network where they saw real value in utilising road operator fibre.

Consequently, the further preparations for the field trial concentrated on the Netherlands. After carefully inspecting the identified locations, road operator Rijkswaterstaat concluded that it would actually be challenging to provide most of them with the two 10 Gbps dark fibres identified by KPN as the desired technical approach to capacity sharing. Again we see this as significant confirmation of earlier insights from interviews. In this case the supply side for road operator fibre sharing is lower and more complex than anticipated.

In further discussions about the value of conducting a field trial on connecting one of the very few valuable and possible KPN sites to RWS fibre infrastructure, other new insights emerged. For instance, due to the changed geopolitical conditions as a result of the war in Ukraine, the emphasis has shifted more to protecting critical infrastructure from a cyber-security perspective. As the Dutch road network is considered critical infrastructure, it is therefore even more challenging to approve providing third party access to the digital part of that infrastructure. We also appreciate the fact that, according to the MNOs involved, the need and desire for network cell densification has diminished in recent years of 5G experience and roll-out.

The conclusion was that the main value of the field trial, always considered a conditional activity within the scope of the project, lies in the preparatory steps described here. These steps confirmed the findings obtained through the desk research and interviews, but from a different practical perspective. The added value of actually connecting one of the KPN sites through the RWS fibre infrastructure was considered negligible, since there was no potential to scale up this action. The decision was therefore made not to go ahead with that final step of the field trial.

8 CONCLUSIONS

- For this study, we examined national road operators' fibre networks in Belgium and the Netherlands to gain insight in their potential contribution to 5G roll-out and 5G related use cases. These lessons can be relevant for all public network owners and co-deployed networks (rail and waterway), but also for demand aggregation and municipal/provincial networks, although these usually have a limited and local footprint.
- Currently, public network owners mostly share these co-deployment networks for the benefit of the public sector. Third party access is not yet common practice except for the Relined (TenneT/ProRail) network. We conclude from our interviews that public network owners have limited incentive and capacity for providing third parties with connectivity services. The investments in fibre and duct infrastructure are negligible compared to complete (road) works. The (perceived) benefits and added value for providing access are limited.
- The installation of more (5G) antennas is increasing the demand for fibre. Potentially, public networks could contribute to the feasibility of new 5G (cross border) use cases since some networks have a unique footprint. We cannot specify precisely where and how often this will be the case since MNOs prefer to use their own fibre footprint for their antenna sites. Only where the distance to their infrastructure is high, will there be a make or buy decision that could be a potentially unique proposition for the public network owner. The fact that compared to a few years ago, the need for site densification seems to be less clearly stated today by MNO's in their communication or internal discussions, it can be questioned if we could call this a cooldown of the site densification requirements? If so, this would be an element to also be taken into account in the future.
- From both sides (supply and demand) there are various (perceived) reasons (not) to offer or use public fibre or duct capacity. We have identified arguments related to business economics, macro-economics, organisational and technical aspects, security concerns and legal frameworks.
- Even though the (perceived) societal or economic value is high, we expect considerable legal hurdles for the public network owner. These include legal frameworks such as procurement law (what kind of partnerships are allowed and how should the capacity be offered to the market), telecommunications law (can the co-deployed network be used for commercial telecommunications activities), European Directives (how should network owners interpret the BCRD), et cetera. This report aimed to provide more insights, and given the importance and potential impact of these issues, the network owners indicated they would also like to investigate them.
- Other relevant factors are security and safety. For organisations that take high security measures across the board (defence, police), it is less obvious to trade (admittedly small) vulnerability for extra income. Likewise, in organisations with additional safety relevance (high voltage operators, railways, highways, oil and gas), it is less understandable to add extra risks. The importance of this factor further increased since the start of the war in Ukraine.
- We presented different options for introducing new value chain functions, depending on whether the new role or entity is willing and able to bear the risks (up-front investments).
- There was a great variety in the type of stakeholder involved in this research project (public, private, small, enterprise, etc.). This also meant a variety in interests and organisational cultures. The research process was therefore at least as important as this

report. The idea of introducing new value chain functions has led to much debate. It has proven difficult to reach consensus on the preferred approach to using public and private infrastructure. We describe on the one hand public owners who are actively seeking new partnerships and private investment (SOFOCI), and on the other hand, all sorts of public owners' (perceived) limitations and much more restricted views. The dialogue partners' differentiating perspective clearly shows that the concept of sharing co-deployment networks is not trivial. This was confirmed by further case study work performed by both the involved road operators and MNO's. Those activities revealed that it cannot be expected that a road operator is able to objectively determine the exact overcapacity it could share, and that the real demand size at the MNO part for some MNO's can be negligible.

- A general blueprint for deploying 5G for CCAM use cases such as teleoperation therefore assumes that building a value case for public network sharing is complex and requires intensive collaboration between owners (supply) and access seekers (demand). It greatly depends on the MNO to assess whether this is worth the effort. It is up to each individual deployment initiative utilising this blueprint to investigate how the arguments for and against sharing and the introduction of new value functions can help build a stronger value case and achieve local consensus. But the concept of public network sharing should definitely not be seen as the silver bullet to speed up the deployment of roadside 5G infrastructure fast and cost-efficient across the entirety of Europe.

APPENDIX A - INTERVIEWEES AND CONTRIBUTORS

We present the interviewees involved in the research, also indicating who reviewed the final draft of this report.

Organisation	Interviewee	Reviewer
BIPT	Laurence Hoflack, Steve Van Den Bossche	No
Ministry of Infrastructure and Water Management	Wim Vandenberghe	Yes
Department of Mobility and Public Works	Jeroen Avau, Laurens Lemaire, Koen Wardenier	Yes
Eurofiber	Marc Hulzebos, Ivo Veerman	Yes
IMEC	Dries Naudts, Asma Chiha Ep Harbi, Vasilis Maglogiannis	No
Independent consultant	Francois Verwilghen	Yes
KPN	Matthijs Klepper, Geerd Kakes	Yes
Rijkswaterstaat	Hans Nobbe	
Room40	Kris Dillemans, Besian Kuko	Yes
Swarco	Freek van der Valk	Yes
Telenet	Johan Vandenbergh, Lieven Vanhaverbeke, Arthur Xiangyu Lian, Dimitri Vanhove	No

APPENDIX B - BEST PRACTICE FOR PASSIVE INFRASTRUCTURE ACCESS

WIK Consult - Best practice for passive infrastructure access [59]

Minimum List of items to include in a Reference Offer for Physical Infrastructure Access	
Products to be provided	Access to ducts, cable trays etc., manholes, handholes, cabinets, MDF locations, building entry facilities, mutualisation points.
Technical guidelines	Technical characteristics of the physical infrastructure elements, minimum number or size of network elements, technical and operational guidelines regarding access to physical infrastructure, installation of cables, decongestion, enhancement or installation of new physical infrastructure connected to the access provider's network, safety and security standards.
Information	Details of the central information system so that access seekers can get information on the location and availability of physical infrastructure. Where proportionate, this system should be automated. All data should be up-to-date. Processes to ensure the accuracy of information and rectify any inaccurate or incomplete information.
Space reservation	Rules concerning the allocation of space, where this is limited, and the space the access provider should reserve for potential access seekers. Conditions for access seekers to inspect locations where physical infrastructure access has been refused on the grounds of lacking capacity.
Conditions enabling unsupervised access to physical infrastructure	Conditions such as accreditation whereby engineers working on behalf of the access seeker are permitted to access physical infrastructure unsupervised to conduct a survey, install or repair cables and conduct decongestion, enhancement or bypass works.
Process and service levels for the access provider	Processes and associated timescales (SLAs) concerning: • Availability of the information system and/or provision of any additional information. Processes to ensure accuracy of information. • (Where applicable) Approval of the access seeker's or competitor's plans for a (joint) survey or viability analysis. • Acknowledgement and approval of the specific order for infrastructure access (i.e., the route or area to be covered). • Removal or reorganisation of cables under the access provider's responsibility. • (Where applicable) Deadlines for responding to requests by the access seeker for permission to access the infrastructure. • Providing confirmation of final installation plans. • Repair of physical infrastructure under the access provider's responsibility.
Process and service levels for the access seeker	Processes and associated timescales (SLAs) concerning at least: • Advance or subsequent notification of works to conduct a survey, install or repair cables and conduct decongestion, enhancement or bypass works. • Period within which construction must be completed. • Submission of the final installation plan.
Compensation	Consequences, including where relevant financial compensation, or failing to meet service level requirements (for the access provider) or installation and notification requirements (for the access seeker).
Pricing	Prices or pricing formulae for each facility, feature and function listed above. Mechanism whereby costs incurred by the access seeker for the augmentation or enlargement of the physical infrastructure network are compensated or shared.

APPENDIX C - TASK DESCRIPTION OF 5G BLUEPRINT PROPOSAL

Study on the use of public/private fibre infrastructure in a 5G landscape (Contributors: EUROFIBER, KPN, TELENET, MIW, MOW; M03-M15)

The introduction of 5G New Radio equipment in the RAN is expected to require densification of the radio sites when the 3.5 GHz and 26 GHz frequency bands are to be used. For roadside deployment this site densification will require significant CAPEX investments. Providing optical fibre connectivity to the new sites is expected to be one of the key cost drivers. Therefore, the idea of allowing mobile network operators to make use of unused optical fibres of the road operator to lower the CAPEX costs for roadside 5G coverage has become a popular one in the 5G community. The task will be organized in a stepped approach: first identification of overcapacity, secondly technical feasibility study, thirdly an investigation on how this could be organized technically, finally a definition on how the broker role could facilitate the execution of that technical integration process, if successful, there will be a field trial.

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