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Title:

Can local 5G networks using local spectrum be used as platform for digitalization of industrial systems and services?

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Abstract

Local 5G spectrum licenses has recently attracted a great deal of attention and expectations from both industry and governments all over the world. One reason is the expectation that 5G local industrial networks using local spectrum can be used to support digitalization of industrial processes, and hence increase productivity of industrial use cases. In support of these expectations, governments all over the world have allocated spectrum for local 5G licensing in the 3.5GHz band with various conditions.

This paper focuses on local 5G networks for "private" use, these non-public networks are commonly referred to as Non-Public Networks (NPNs). We present results and discussion about implications in three areas:

- Network capacity and cost for 5G NPN for industrial use
- Allocation of local spectrum licenses
- Ecosystem analysis of business models and value networks

For the two first areas our analysis indicates that previously identified questions related to radio-interference and co-existence between NPN and operator macro cell networks still seem to be challenging. It is unclear if 5G NPN using Time-Division Duplex (TDD) at the 3.5 GHz band can satisfy performance and operational needs in the field of industrial radio systems. Hence, the value of this type of local 5G licenses need to be further discussed.

For the third area and the question "what actor is doing what?" we see a need to look more into solutions where different types of actors cooperate and contribute to different parts of the value network. This is in contrast to what is described in many papers and reports where the assumption is that one type of actor will take care of all or most of the roles.

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1. Introduction

1.1 Digitalization of industry and 5G mobile systems

"Industry 4.0" is an established term for the transformation that is currently underway in the manufacturing industry worldwide where machines and products continuously communicate with each other and the internet provides the conditions for more cost-effective production [1][2][3],

Today, the industry's connectivity is primarily wired, alternatively, they use "proprietary" or WiFi based systems in non-licensed bands (or narrow industrial bands specifically dedicated to different industrial processes).The company HMS networks annually presents an analysis of the industrial network market, focusing on new installed nodes within factory automation globally[1]. The study for 2022 shows that wireless technologies still represent a small market share (7%). Industrial Ethernet is the major type of solution with 66% of all new installed nodes followed by fieldbuses at 27%.

Hence, wireless technology, cellular systems and 5G is still a "new" feature for industrial systems. Manufacturers and users of industrial production systems must prepare in the long term to migrate from point-to-point communication to the use of cellular networks. In this context, it is expected that technology in the form of 5G networks will be able to offer increased performance in the form of increased capacity and data rate as well as very short latency [4]. The introduction of cellular technology also involves a change in "system thinking" as wired and point-to-point connections are replaced by equipment connected to a network.

The use of 5G, of course, requires access to spectrum. For industrial applications, it is relevant to study both the national spectrum licenses that the mobile network operators obtain as well as local spectrum licenses that can be given to user companies themselves, Facility owners or to other types of operators. Mobile operators offer industrial networks, usually as part of their national public mobile networks. Alternatively, you can build local networks for "private" use, these non-public networks are commonly referred to as Non-Public Networks (NPNs).

Local 5G spectrum licenses has recently attracted a great deal of attention and expectations from both industry and governments all over the world. One reason is the expectation that 5G local industrial networks using local spectrum can be used to support digitalization of industrial processes, and hence increase productivity of industrial use cases which to date have been complicated to connect using tethered solutions. In support of these expectations, governments all over the world have allocated spectrum for local 5G licensing in the 3.5GHz band with various conditions.

[1] Industrial networks keep growing despite challenging times (hms-networks.com)

E.g. the FCC has allocated 150 MHz in the so called CBRS band for shared use with a three-tier usage model ensuring interference protection and uninterrupted use by the incumbent users. In Europe several countries, e.g. Sweden, have followed the ECC recommendation to allocate the 3.7-3.8 GHz band, making up to 100MHz available for local licensing[2]. However, Norway has decided to go even further and make 400MHz available[3].

What we now see is a fairly steady growth of deployment of new local industry networks using cellular techniques. However, at the same time we see that in many cases 5G is not the chosen standard but rather 4G. The reasons for that choice may be both technical and business driven but it is an observation that leads us to the aim of this study and the research questions to follow.

1.2 Industry needs and challenges with local 5G licenses

NPN is a global phenomenon with great support and interest from existing ecosystems in industry and telecom, but also from brand new players from the IT industry. NPN is driven by the industry's need for secure and reliable connectivity for digitizing and automation of its processes and that it wants complete control over its systems and data.

The 5G technology used in the 3,5 GHz band is based on Time Division Duplex (TDD) and poses a number of challenges for local networks for the industry that uses local licenses. The local TDD networks need to be synchronized with the operators' macro networks in outdoor use and also use the same distribution of traffic between up and downlink as these networks. However, the industry's capacity needs are mainly in uplink, while the operator networks mainly provide video in downlink. In addition to question marks about the capacity that can be achieved, the impact of radio interference between different networks needs to be taken into account in order to ensure coexistence. It is therefore currently unclear whether, via only TDD permits at 3.5 GHz, it will be possible to satisfy all needs in the field of industrial radio systems and non-public networks.

In addition to these technology related aspects there are exist a number of other challenges with industrial 5G networks. This includes what actor that is responsible for what in the value network, e,g. the industrial users usually want to have full control of both the infrastructure as well as the data. On the other hand, many companies wants to outsource the deployment and operation of the own NPN.

[2] https://docdb.cept.org/download/3a143dbe-7cbc/ECCRep287.pdf
[3] https://www.nkom.no/aktuelt/nkom-nkom-inviterer-industriaktorer-til-testing-av-lokale-nett-i-3-8-4-2-ghz-bandet

1.3 Problem areas and research contributions

In the paper we will focus on local 5G networks that use a local spectrum license where the network should not be used publicly but refers to private use for a company's own needs, i.e. a 5G-NPN. We will present results and discussion about implications in three areas of contribution:

1. Network capacity and cost NPN for industrial use
2. Allocation of local spectrum licences
3. Ecosystem analysis of business models and value networks

Taking into consideration different real life aspects of NPNs one question, related to network capacity and costs, is if it "worthwhile" investing in an own local 5G network? Will different technical challenges mentioned above result in performance degradations compared to what can be achieved in a mobile operator driven network? In order to ensure network capacity the NPN may need to be densified with a number of additional 5G base stations, which will increase networks costs.

The willingness to invest also depends on the time frame, e.g. when you can get access to the local license and for how long period? A research question related to this area is:

RQ1. Is a 5G NPN a cost-efficient way to solve the mobile communication needs?

Discussing regulation and spectrum allocation a number of questions can be identified:

- Will a bandwidth of 40/80 MHz be sufficient to satisfy needs of industrial companies and/or can this band be used in a better way?
- Can we identify other solutions and frequency band for industrial use ((TDD or FDD) with less technical challenges, and/or better cost-benefit performance?

Hence, we can formulate another research question:

RQ2. Is the current allocation of local 5G licenses an efficient way to use these bands?

For the third problem area of “Ecosystems and value networks” we can identify the following quite open research question:

RQ3. What are the pros and cons of different ways to configure the value network for planning, deployment and operation of 5G NPN?

The motivation for this research question is to question the common statement that one type of actor will take care of everything in the value network. However, in real life, it turns out that the value network can be configured in a multitude of different ways involving a mix of actors. Besides identification of different roles another research contribution is an overview of drivers and obstacles for user companies to take care of NPN deployment and operation themselves.

2. Related work

In this section we summarize some papers and reports in the areas; NPN networks and systems, spectrum allocation, radio interference and co-existence, and business aspects.

NPN networks and systems

A number of recent papers provide good overviews of solutions for and research on private 5G networks [5][6][7]. These overview papers include key requirements and benefits of 5G, examples of use cases, options for spectrum use and descriptions of different network architectures e.g. shared RAN and isolated NPN. In [5] you can also find an overview of operational scenarios, including options for functional architectures and spectrum allocation, and also distribution of roles and responsibilities. When it comes to challenges, the mentioned papers bring up different aspects like; the co-existence between Wi-Fi and cellular technologies [5], spectrum agile & robust use, cyber threats and data sharing [6], network slicing for private 5G and integration with time-sensitive networking [7]. However, none of these papers mention issues related to the need for synchronization of NPN and other networks, or problems related to radio interference and co-existence between NPN and the macro cell networks of operators. These topics will be discussed later on in this section.

Another overview paper discusses cost-efficient 5G NPN [8]. The cost-efficiency is based on a business model with shared networks operated by a neutral host. Two papers look into how 5G NPN solutions can support Industry 4.0 scenarios and use cases [9][10]. The integration of deployment options for NPN with public networks of mobile operators are discussed in [9]. The paper includes a comparative analysis of stand-alone NPN with different options for Public network integrated NPN (PNI - NPN). The following aspects are included in the comparison; QoS customization, autonomy, isolation and level of sharing, security, service continuity, NPN management for verticals and the level of own control. One conclusion is that full QoS customization and high level of control in either an isolated network or in a PNI NPN implies very high entry barriers.

A complete 5G solution for two real-world Industry 4.0 use cases is proposed in [10]. Also a comparison between 4G and Non-standalone 5G is presented, these benchmark results include E2E latency, packet loss, and user data rate in uplink and down link. One interesting discussion on challenges can be found in this paper saying that the selection of the architectural option that best suits the needs of a NPN is a challenge itself "as it possibly involves multiple parties and different options on how the infrastructure is shared. This depends on whether the 5G network is perceived as part of the factory infrastructure or as a connectivity service offered by an MNO, as well as the degree of dependability from the MNO"

Spectrum allocation

In an Ericsson white paper on 5G for local networks for industry you can find world wide summaries on local spectrum allocation, the last version is published April 2021 [11].
An analysis of recent 5G spectrum awarding decisions for local networks in different countries is presented in [12]. The analysis indicates that the spectrum bands and the available bandwidths for local 5G networks vary significantly between different countries. This implies potential business challenges, especially for "non-MNO stakeholders".
Micro licensing for local networks and innovations is discussed in [13] where guidelines for the development of the key micro licensing elements are presented. A key contribution is the comparison of micro licensing with individual authorization and general authorization.

Radio interference and co-existence

Time division duplex (TDD) multiple access systems has long been popular for use in both cellular and Wi-Fi systems. Its main advantage is the possibility of non-symmetrically allocating capacity in down- and up-link [14][15]. However, it has also been long known that co-existence of multiple TDD networks in the same geographical area is a complicated almost unsolvable issue unless the networks are fully synchronized. The market failure of the licensing of non-synchronized TDD bands for 3G in Europe is a well-known case in point [15].
For the 5G roll-out it has been of immense importance for the public networks (PN) to optimize their radio resources in line with the public demand which is currently dominated by downlink services such as Netflix etc. The solution is the use of synchronized TDD network, well regulated by the ECC [16], typically allocating 80% of the time for down-link. However, NPN operators, expected to operate in local areas in bands adjacent to the PN's band, most often do not have the same need for downlink and hence would prefer an alternative (sometimes opposite) frame structure! The problem is, that if the local network is not synchronized with the macro network it will cause cross-link interference and severely degrade the performance of both networks [17] [18].
Another issue is the so called "near-far interference", when e.g. UE:s connected to the public macro network, may suffer from interference from devices connected to the local network, and vice versa. The near far interference may be reduced by allowing the PN users to be connected to base stations located inside the factory [18]. The problems related to the cross-link interference for non-synchronized networks operating in the same geographical area is harder to resolve even though some attempts are being made [19]. Currently it seems that the only available solutions to deploy non-synchronized NPN networks are inside fully isolated buildings or on an isolated frequency.

Business aspects

Business opportunities and analysis of the state of 5G NPN are presented in a literature review paper [21]. An emerging type of business ecosystem is discussed including mobile operators, micro operators and industrial manufacturers. The paper includes a comparison of different main types of network architectures indicating use cases, main features and limitations.

In a deliverable from the 5G Smart project different options for provisioning of 5G NPN service are presented [22]. Three deployment options are considered; a standalone NPN independent of any public network, a public network integrated NPN, and some options "in between" where part of the network functions are hosted in the public network and part are isolated. The analysis include generic stakeholders; the industrial party, a mobile operator or a third party.

Three different business models for local micro 5G operators are presented and compared in [23]. Using a vertical business model the local operator offers end-to-end services in a specific area. With the proposed horizontal business model the micro operator offers hosted connectivity for MNOs. Finally, with an "Oblique" mass-tailored end-to-end services are offered in collaboration with other stakeholders like network vendors, content and internet providers.

3. Methodology

3.1 Data collection

The research, data collection and analysis have been performed in two projects running 2020-2021 and 2021-2022 respectively. Project partners are Swedish manufacturing and mining companies and the Swedish Telecom Authority PTS. Interviews have been performed with the partner industries, some of their customers and also a number of telecom vendors and operators. The interviews and workshops have provided input on market scenarios, use cases, technical requirements and challenges, options for value network configuration and possible roles for different actors, see table 1 below.

Type of actor	Actors within the project teams	Actors outside the project teams
End-user company	Boliden Scania	Outokumpu Stainless SSAB Special Steel Volvo Wheel Loaders
Providers of industrial systems	Epiroc Drills Åkerströms AB	Midroc Automation
Providers of telecom equipment or services	Saab Combitech Tele2	AFRY Ericsson Frequencz Telia U-Blox
Consultants, system integrators		Northstream/Accenture
Government agency	The Swedish Post and Telecom Authority (PTS)	

Table 1. Actors contributing with primary data

Secondary data collection includes literature study of research papers and deliverables of research projects. We have also attended a number of seminars and presentations on 5G business cases, private networks and spectrum allocation.

3.2 Analysis

Analysis of radio network performance, capacity and cost is based on [24]. The analysis of business ecosystems and value networks is based on the ARA (Actors, Resources, and Activities) framework [25] . The ARA framework is applied in order to identify options for distribution of responsibilities and control of resources among actors in the value network. In our analysis the focus will be on actors and activities and the roles different actors can take, this is similar to the analysis in [26].

4. Analysis of network capacity and costs

The present study includes identifying technical, spectrum and market scenarios and carrying out an overall analysis of the consequences of different variants of technology choice and spectrum allocation. This section presents an overall analysis and comparison between some possible network solutions. We want to focus on two issues:

- What network performance is offered with 5G technology compared to 4G systems?
- Can a local private 5G NPN achieve the same performance and cost-effectiveness as an operator-driven local area network using the operator's national spectrum?

We start with a summary of the 5G spectrum allocation in Sweden, these conditions are used as input for the analysis presented in this section.

4.1 Allocation of 5G spectrum – The case of Sweden

Currently spectrum allocation to 5G systems are made in the 700 MHz, 3,5 GHz and 26 GHz bands. In this paper we focus on the 3,5 GHz band.

In 2018 the Swedish Post and Telecom Authority (PTS) decided to grant 5G licenses in the 3.5 GHz band. National block licenses were to be awarded in the frequency range 3400-3720 MHz by selection procedure, and local licenses in the frequency range 3720-3800 MHz. An auction for national licenses for 5G at 2,3 GHz and 3,5 GHz bands was conducted in January 2021. On the 3.5 GHz band, the mobile operators were assigned 100-120 MHz each.

In 2021, PTS carried out an allocation of local licenses. There are existing license holders in the band 3720-3800 MHz, whose licenses are valid until the end of December 2022. Initially, only 40 MHz (3760-3800 MHz) is made available for local licenses. In the longer term, there are reasons to make available the entire 3720-3800 MHz frequency space for future potential uses that need more capacity.

4.2 Overview of different network solutions to analyze

Scenarios using the operators' spectrum bands

Here we assume that a national mobile operator can offer the use of its own spectrum for industrial purposes.

- A 4G reference case.
  Here we consider a LTE system on the frequency bands 2.1 GHz or 2.6 GHz,
  a FDD system with uplink and downlink of 20 MHz each.
- A 5G reference case.
  Here we study a 5G system on the 3.5 GHz band, the bandwidth is 100 MHz, the traffic is distributed between downlink and uplink as 75% and 25% respectively.

Scenarios using local spectrum licenses (or unlicensed cellular bands)

In these cases, we assume that an actor uses local licenses or an unlicensed band.

- A 4G reference case.
  A 4G system that uses unlicensed cellular spectrum band, it refers to an LTE system on the frequency band 1.8 MHz, FDD with uplink and downlink of 5 MHz each.
- A local and completely independent 5G network.
  Here we study a local 5G network that is completely separate from other networks. Thus, there are no problems with coexistence and no need to synchronize the local network with surrounding mobile networks. The 5G network uses the 3.5 GHz band using a bandwidth of 40 or 80 MHz. The traffic is distributed between downlink and uplink as 25% and 75% respectively
- A local 5G network that needs to be synchronized with mobile operator networks.
  Here we study a local 5G network that needs to be synchronized with the surrounding mobile networks. As in the case above, the 3.5 GHz band is used, the traffic is distributed between downlink and uplink as 25% and 75%, and the bandwidth is 40 or 80 MHz

4.3 Assumptions and capacity for different network solutions

Table 2 summarizes the assumptions about frequency bands, bandwidth, spectral efficiency and the distribution of traffic between downlink and uplink (for TDD). The spectral efficiency (bps/Hz) refers to an average value for the whole cell and can be seen as a measure of "how well" a given technology can utilize a given bandwidth.

Fall	Frequency band (GHz)	Bandwidth (MHz)	Spectral efficiency Down/Uplink (bps/Hz)	Traffic distribution Down/Uplink	Cell capacity Down/Uplink (Mbps)
Operator 4G network FDD	2,1 or 2,6	2 * 20	4/2	-	80/40
Operator 5G network TDD	3,5	100	6/3	DDDU	400/75
Local 4G network FDD	1,8	2 * 5	4/2	-	20/10
Local 5G TDD network, No synchronization	3,5	40 - 80	6/3	DUUU	60/90 120/180
Local 5G TDD network, with synchronization	3,5	40 - 80	6/3	DDDU	180/30 360/60

Table 2. Assumptions and parameters for different network solutions

4.4 Comparison between different network solutions

Figures 1 and 2 show the capacity of a base station in uplink and downlink obtained for the different cases. The 5G system offers higher capacity than the two variants of 4G. The difference is due to differences in bandwidth and spectral efficiency. For 5G, it is also possible to distribute traffic between uplink and downlink

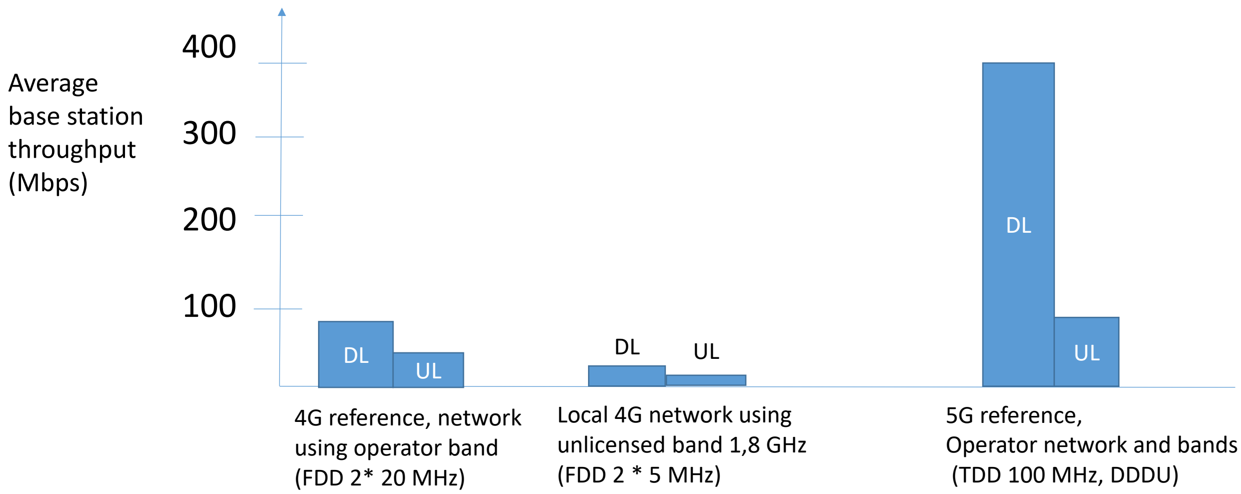

Figure 1. Comparison of capacity of a base station for different cases of 4G and 5G.

If you compare the 5G networks in Figure 2, you see the effect of synchronization and adaptation of the distribution of traffic between uplink and downlink. For a synchronized local 5G network, you have approximately the same capacity as for the operator network, the difference is due to bandwidth. On the other hand, there is a large difference in capacity in the uplink between an “unsynchronized” local 5G network and the other options. With our assumptions, the "non-synchronized" network offers about three times more capacity. This means that if the uplink traffic is the dimensioning factor, the need for synchronization means that you need three times more base stations.

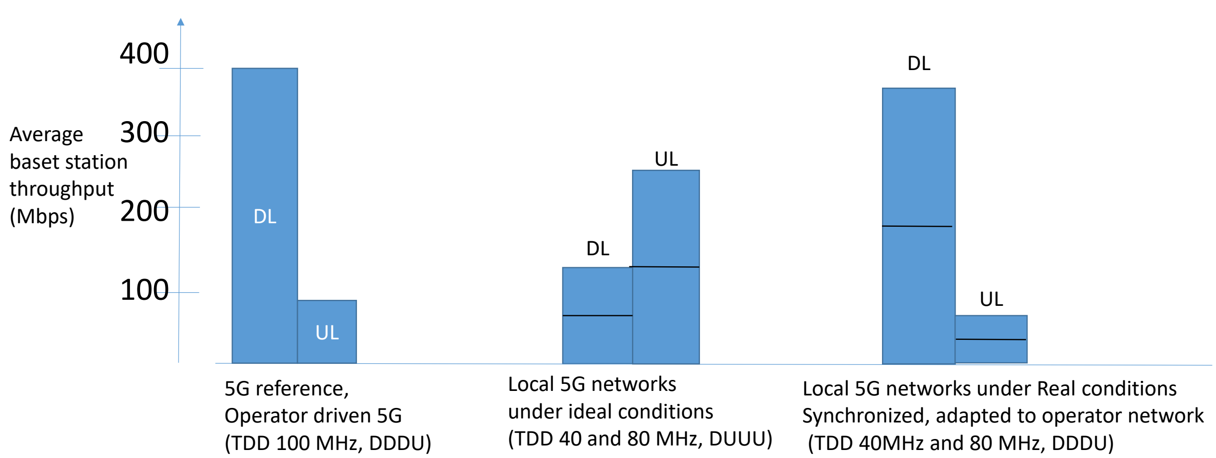

Figure 2. Comparison of capacity of a 5G base station for a mobile operator's network and local networks.

5. Analysis of ecosystem, roles and value networks

5.1 Actors and roles

Analysis of ecosystems, market structure and business models for different scenarios includes identifying business roles, different actors (stakeholders) and how to organize the value chain or value network, ie "who does what". For a local 5G network, we can identify a number of roles, functions and areas of responsibilities:

- To provide spectrum (operator or local spectrum license)
- To own networks and equipment
- To plan and build the network (deployment)
- To operate and maintain the network (maintenance)
- To be responsible for service delivery (service provisioning), this includes ensuring that requirements for availability and performance are maintained.
- To integrate network functions in the company's other IT and/or business systems.

In addition to a mobile operator or the user company itself, a third-party player may be involved. This may be a network provider such as Ericsson and Nokia, a consulting company or a system integrator. Examples in Sweden are Accenture, SAAB Combitech and AFRY, the latter two have offers in the area of private 5G networks. According to information in the spring of 2022, these companies have that number of ongoing "customer cases".

5.2 Distribution of roles and responsibilities

There are many possible ways to organize the value chain and different actors can take different roles:

- A mobile operator or third party operator is responsible for everything.
- The company itself is responsible for everything
- The company owns networks & equipment and has a frequency license while an operator or third party plans, builds and operates the network
- An operator provides spectrum and builds the network while the company operates the network and handles integration with business systems.

Different actors can take the different roles; it can be a mobile operator, the user company or a third party. However, at seminars and company presentations it is often stated that one actor take all roles. From the data we collected it turns out that this is not always true. We can identify a number of different cases, see summary in table 3. Choice of alternatives is affected by a number of different factors, see below for some driving forces and conditions that emerged during the project period.

Activity / responsibility	Different market scenarios and options for distribution of roles and responsibilities					
Provide Spectrum	Mobile operator	User company	User company	Mobile operator	User company	User company
Own network and equipment	Mobile operator	User company	User company	Mobile operator	Third party	User company
Plan and build the network	Mobile operator	Mobile operator	Third party	Mobile operator	Third party	User company
Operate, maintain the network	Mobile operator	Mobile operator	Third party	User company	Third party	User company
Integration with other systems	Mobile operator	Mobile operator	Third party	User company	Third party	User company

Table 3. Examples of distribution of responsibilities and roles

5.3 Identified driving forces

Some factors and driving forces for companies that want to hire an external player:

- The company lacks the competence to plan, build and operate networks and therefore needs an external party who takes responsibility for this
- The company itself has the expertise to plan, build and operate networks, but still wants to outsource it. The motive may be that you want to focus on your core business and /or that you want the external party to take responsibility for availability and performance.
- The company already hires an external party for construction / adaptation / operation of various business systems. This player can then also undertake to take care of a 5G network and / or integration of the 5G network with other systems

Driving forces for companies to build and operate a 5G network themselves:

- Security: You want control over data and equipment, for example by keeping all data and all equipment "in-house"
- Reliability can be increased if you have all the equipment "in-house", there are for example cases where a company sets up its own core network. In this way, data does not have to leave the company's premises or area.
- The company wants to guarantee that its own network meets the own requirements and works as intended.
- Mobile operators may have difficulty offering a customized solution and/or being able to meet the customer company's requirements
- The company wants to reduce the risk of dependence and business lock-in with a certain supplier. This can be a motive for “mixed solutions” in Table 3, for example where the company owns the network but outsources the network operations.

6. Discussion and Conclusions

In this section we will conclude by discussing findings on the three research questions.

RQ1. Is a 5G NPN a cost-efficient way to solve the mobile communication needs?

The NPN needs to be synchronized with the surrounding macro networks and use the same distribution of down-link and up-link traffic. MNO networks are configured to offer higher downlink capacity than up-link. If the user traffic is mostly downlink, both MNO and NPN offer high capacity and suitable solutions. If the user traffic is mostly up-link, e.g., video monitoring, the down link capacity cannot be used, hence we have a non-optimized dimensioning. The NPN cannot change the traffic distribution without introducing interference in the macro networks. An option for the NPN is to reduce the transmit power, this will have an impact on the overall capacity.

RQ2. Is the current allocation of local 5G licenses an efficient way to use these bands?
The answer to RQ1 indicate that end-users may face a situation where most of the base station capacity, i.e. I the down link, cannot be used. This implies the need to deploy a denser and more costly network compared to the case where the down link traffic is larger than the uplink traffic.

When the end-users may not be able use the full offered capacity of the system, you can argue that from a regulatory perspective the current allocation of TDD bands for NPN is not optimal. For example, allocation of FDD bands (2* 20 MHz) would offer a solution with no issues related to synchronization and co-existence.

RQ3. What are the pros and cons of different ways to configure the value network for planning, deployment and operation of 5G NPN?

From a user perspective it can be beneficial to outsource the network planning, deployment and operation to a mobile operator, this can be motivated by limited own competence and/or you want an external actor to take responsibility for the network. External players may also be used if they are already hired for management of other business systems. Motivations for a company to deploy and operate NPN itself include reliability and security concerns where you are in control of both the infrastructure and the data. It may also be that external suppliers cannot fully satisfy the needs and requirements of the user company.

We have also discussed if 5G systems can be used as a platform for digitalization. How important is the use of 5G technology (no matter of it make use of local spectrum or not) for the overall digitalization of industry? Will it play a major role or not? How large share of the industrial need for business support systems and ICT infrastructure can met by local 5G systems?

5G is an important component of digitalization but it is mainly about the connectivity, it is used as replacement or complement for fixed lines, WiFi or point-to-point legacy wireless systems. However, the connectivity is only a share of the overall ICT infrastructure. In many cases, it is a small share where other business support system represents the major part. Another aspects is that the knowledge of mobile systems and 5G currently is quite low within the industry, hence it may not be a good starting point for digitalization of the own ICT infrastructure.

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