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5G in Finland

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The thesis describes about 5G and studies what new it brings and how it is better than the previous telecommunication generation. Firstly, explains when 5G research began presents main user cases and how the new services, xMMB, mMTC and uMTC, will respond to these cases. After that, new concepts such as DyRAN, LSCP, Spectrum toolbox, D2D communication, mmW/cmW and massive MIMO systems are addressed. These all are 5G specific, and they all will provide more flexible systems to bring mobile communications into new levels.

In the end, the thesis analyzes how 5G will be used in Finland when it comes to market, since all of the features will not be useful in the early deployment. The most significant change that 5G brings is in urban environment, where cmW and mmW can be used to improve data rates, capacity and coverage.

In the first years, these smaller nodes will only be focused on common public places, for example. shopping malls, stadiums, and squares. After few years, smaller nodes will start to be deployed and also vehicle-based access nodes will start to appear, even though it might be slow. In the rural areas 5G will only use lower frequencies (below 6 GHz) to give better coverage and to bring its services in use.

MIMO and massive MIMO usage might become more used, but it does not look promising, comparing how little MIMO antennas are currently used in 4G environment.

Keywords	4G, 5G, xMBB, mMTC, uMTC, DyRAN, LSCP, D2D, mmW, cmW, MIMO, GHz

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Insinöörityön tarkoituksena oli perehtyä 5G-tietonsiirtoverkkoon ja sen uusiin tekniikoihin ja siihen, millä tavoin se on parempi vanhempiin sukupolviin verrattuna. 5G-verkon tutkimustyöt alkoivat vuonna 2012 ja jatkuvat vuoden 2020 yli. Sen monet pääkäyttötapaukset jakautuvat kolmeen eri palveluun, jotka ovat xMBB, mMTC ja uMTC. 5G-teknologia tuo uusia konsepteja, joita ei ole ollut aikaisemmissa sukupolvissa. Nämä konseptit ovat DyRAN, LSCP, spetri-työkalupakki, D2D-viestintä, mmW/cmW-taajuudet ja massiiviset MIMO-järjestelmät. Nämä kaikki ovat 5G-kohtaisia toimintoja ja tuovat joustavuutta järjestelmiin tuomalla mobiilikommunikaation uusille tasoille.

Insinöörityössä tutkittiin myös, miten 5G-verkkoa tullaan käyttämään, kun se tulee markkinoille, koska kaikki sen ominaisuudet eivät ole käyttöönoton alussa hyödyllisiä Suomessa. Suurimman muutoksen 5G tuo kaupunkialueille, missä voidaan ottaa käyttöön mmW- ja cmW-taajuudet, jotka parantavat datanopeuksia, kapasiteettia ja kuuluvuutta.

Ensimmäisen vuoden aikana pienet solut keskittyvät vain suosittuihin julkisiin paikkoihin, kuten kauppakeskukset, stadionit, torit ja niin edelleen. Muutaman vuoden jälkeen pienimmät solut alkavat ilmestyä koko kaupunkialueille, ja niitä voidaan käyttää hyväksi ajoneuvoissa, jotka sisältävät mobiilikommunikaatiolaitteita, mutta tämän kasvu voi olla hidasta uusien autojen korkeiden hintojen takia. Tämä myös tarkoittaa sitä, että itseajavat autot tulevat suosioon Suomessa vasta vuosien jälkeen verrattuna muihin Länsi-euroopan maihin. Maaseuduilla 5G tulee käyttämään vain pienimpiä taajuksia (alle 6 GHz), jotta kuuluvuutta voidaan parantaa, ja samalla tulevat käyttöön 5G-kohtaiset tekniikat.

MIMOn ja massiivisen MIMOn käyttö Suomessa voi lisääntyä, kun 5G-verkko tulee. Tämä ei näytä lupaavalta, kun vertaa siihen, kuinka harvinaisia MIMO-antennit ovat tällä hetkellä 4G-verkon käytössä.

Avainsanat	4G, 5G, xMBB, mMTC, uMTC, DyRAN, LSCP, D2D, mmW, cmW, MIMO, GHz

Metropolia

Table of Contents

List of Abbreviations

3GPP	Third Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
5G-PPP	5G Public Private Partnership
BS	Base Station
cmW	centimeter Wave
CSI	Channel State Information
D2D	Device-to-Device
dB	Decibel
DyRAN	Dynamic Radio Access Network
FCC	Federal Communications Commission
FP7	Seventh Framework Programme
GHz	Giga Gertz
ICT	Information and Communications Technologies
IMT	International Mobile Telecommunications
IMT-2020	International Mobile Telecommunications 2020
IMT-A	International Mobile Telecommunications-Advanced
IoT	Internet of Things

ITU	International Telecommunication Union
ITU-R	International Telecommunication Union – Radiocommunication Sector
LSCP	Lean System Control Plane
LTE	Long Term Evolution
LTE-A	Long Term Evolution-Advanced
MHz	Mega Hertz
MIMO	Multiple Input Multiple Output
mMTC	massive Machine-Type Communication
mmW	millimeter Wave
ODFM	Orthogonal Frequency Division Multiplexing
UE	User Equipment
uMTC	ultra-reliable Machine-Type Communication
V2D	Vehicle-to-Device
V2I	Vehicle-to-Infrastructure
V2P	Vehicle-to-Pedestrian
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Anything
xMMB	extreme Mobile BroadBand

1 Introduction

First, this thesis will study already done research on 5G (also known as IMT-2020), and show what new 5G will bring and how. The key points that are addressed in this thesis are listed below:

- **User cases and requirements**, in what situations 5G should support with given requirements.

- **Different services (xMBB, mMTC, uMTC)**, which all are specialized around their requirements and needs.

- **Dynamic Radio Access Network (DyRAN)** and how it makes 5G more flexible within macro coverage area, with different nodes and communications.

- **Lean System Control Plane (LSCP)** will help with more efficient and flexible signaling.

- **Spectrum Toolbox** allows change of frequencies and bandwidths to more suitable ones for different services and will adapt to traffic usage in different time of days.

- **Device-to-Device (D2D)** which will be very useful feature to extend coverage, faster data rates etc.

- **Massive multiple-input multiple-output systems (massive MIMO)** which will help new mmW and cmW frequencies and by giving faster data rates, with less interference.

- **Spectrum**, including new mmW and cmW spectrum bands and how they will improve 5Gs data rates to new heights.

After 5G, the thesis analyzes about 5G, and its usage in Finland. What features and services will be useful, how and how fast 5G will be deployed in urban and ural areas and how it improves data rates and coverage in these areas and lastly problems that 5G brings concerning deployment limitations.

Since population density in Finland is extremely low at ~16 person per km^2. Thus, higher frequencies (5GHz-30GHz) are only going to be used in cities and densely populated areas. The higher the frequency is, the shorter distance it can travel, but higher frequencies bring faster speeds (100-1000 Mbps) that are required in 5G.

I have 2 years of experience in the field of telecommunications, my duties have included installing, disassembly, surveying and executing a variety of documentation and Excel-related information work in this field, in companies such as Dna Oy and Blue Lake Communications Oy, and will use this experience to examine how 5G will happen in Finland.

2 5G Introduction

2.1 Requirements

With increasing mobile usage, 5G requirements are going to have to be future proof and extremely flexible compared to previous generations. Data traffic has increased 100 times from 2010 to present, and by 2020 it is expected to be 250 times larger in western European countries. [1][2]

International Telecommunications Union Radio (ITU-R) has researched recommendations of IMT for 2020 and beyond and compared them to those of IMT-Advanced (4G/4.5G), which are presented in the following table. [3]

	IMT-Advanced	IMT-2020
User Experienced Data Rate [Mbps]	10	100-1000
Reliability [%]	90%	100%
Mobility [km/h]	350	500
Latency [ms]	10	1
Connection Density [#devices/km2]	10 000	100 000
Network Energy Efficiency [bits/Joule]	1x	100x
Area Traffic Capacity [Mbps/m2]	0,1	10
Peak Data Rate [Gbps]	1	20

Table 1. IMT-A and IMT-2020 requirements.

2.2 Global projects

2.2.1 METIS and 5G-PPP

METIS is the first 5G project that was co-funded by European Commission under Seventh Framework Programme (FP7). Research into 5G was started on November 1, 2012 and was finished on April 30, 2015. It resulted in identifying and structuring the 5G key technology components, key point indications, scenarios and test cases. [4]

The European ICT industry and the European Commission signed a commercial agreement to form a 5G Public Private Partnership (5G-PPP) that follows the Seventh Framework Program in December 2013. Its function is to gather telecom operators, industry manufacturers, service providers, small and medium-sized enterprises and researchers to create innovation and to gather feedback from all parties. [5]

METIS-II was started in July 2015 inside the 5G-PPP. Its objective is to develop overall 5G radio access network design and to start standardization for 5G. It also provides ways to integrate and use different 5G technologies and components that are currently developed and to integrate these to LTE-Advanced (LTE-A).

2.2.2 Other 5G projects

China, South-Korea and Japan established their own projects in 2013. They all are researching and contributing into different parts of 5G. It is expected that Korea will have working 5G at 2018 Winter Olympics even though it will be missing many of the new 5G specific features.

2.3 Use cases

5G has to excel previous generations in all levels to make the requirements become possible. It needs to have many different services that cover different areas because one service that fits all is not possible considering all future devices that need to utilize mobile communications for their tasks, for example. hundreds of thousands battery powered sensors that gather data and send them daily.

There are going to be many use cases in different economies with different needs that need to be supported. The 13 most relevant use cases are going to be described in the following sections.

2.3.1 Autonomous Vehicle control

There are a considerable amount of research into autonomous vehicles, and when these vehicles are introduced into the public, there is much 5G can do to make them work. Vehicles need to communicate with every vehicle (V2V), infrastructure (V2I), people (V2D) and sensors to make them safe for everyone. This needs low latency and high reliability communications, but high bandwidth and high data rates are not needed, except for passengers that want to stream videos and other tasks, but these communications are separated and use different services, that are specialized in different types of communications. High mobility and full coverage is also necessary to support fast-moving vehicles and to control them in all locations. [6]-[9]

2.3.2 Emergency communication

One of the most important functions of 5G is device-to-device (D2D) communication. With this in an emergency when base stations become unavailable, D2D becomes extremely important for emergency personnel and to find missing people. Devices can become long relays to available mobile coverage, giving coverage to those outside coverage range. High availability and low energy usage are key requirements in these situations. Availability refers to how many people are in the mobile coverage area, and low energy usage is important in rescue situations to find people with devices after a long time. [6][8]

2.3.3 Factory cell automation

In future factories are going to become more automatized, and to make that possible, 5G needs to be highly reliable with low latency to make it safe to operate. If the factory has thousands of automated machines, they need to be able to communicate with each other. Of course, they could have a fixed connection, but a wireless connection brings more freedom to machine placement and more reliability. [7][8][10]

2.3.4 High-speed train

In high-speed trains, high data rates and relatively low latency are needed to bring entertainment and coverage to passengers. It is estimated that 5G needs to support mobility of 500 km/h with latency at 10 ms. [11][12]

2.3.5 Large outdoor events, shopping malls, stadiums and traffic jams

In these cases, there is a substantial number of users that generate a considerable amount of traffic that can be generated at peaks such as in breaks, after songs, weekends. Base stations need to be able to bear all user caused peak traffic, but also to serve all customers with good data rates. [6] [12]

2.3.6 Massive amount of geographically spread devices

Internet of things (IoT) is going to be big in the future, and it will have many uses. One of these is a large number of devices that collect and send data about what they are measuring. These devices need to be battery powered, meaning very low energy usage is critical. Also, all of the devices might need to be scheduled so that they will not communicate at the same time creating massive interference. Data rates and latency are not issue here, but support for tens of thousands of devices is needed. [6][8]

2.3.7 Media on demand

Downloading 4k movies and other large size data to PCs, televisions or smartphones will need high data speeds that can tolerate data peaks that are usually download focused. The needed download speed is going to be high compared to how many users might be connected simultaneously however, latency does not need to be lowest. [7]

2.3.8 Remote surgery and examination

In future, remote cities might have clinics that do not have doctors, but they are connected remotely, to examine or to perform operations using virtual reality. Recently United Kingdom’s Prime Minister Theresa May signed a deal of £1.3bn to develop and research new innovative products. “Smart bandage” is one of those ideas. It would use Nano-technology sensors in the bandage to tracks the patients’ health and to send it to doctors by using 5G. These kinds of applications vary on requirements, but reliability and latency are the most important requirements for realizing these new products. [7][8][17][18]

2.3.9 Smart cities

Smart city is just what it sounds like: a city where everything is connected to make everyday living easier and safer. People can connect to smart homes and see what is about to spoil or become empty in the fridge. While shopping, you get a map for products that you need. The limits are endless what you could achieve with smart cities. These data sizes are not large, but availability and reliability are most important factors and latency is somewhat important. [6][19]

2.3.10 Virtual and augmented reality

Virtual reality (VR) has started to grow in the past few years, but it is still in the beginning phases. 5G could help by making a VR devices wireless or by having centralized services to make VR headset and other products more compact. These can also be applied to augmented reality, but this would require high data rates for download and upload. Extremely low latency is required, to make this work seamless and to give best user experience. Augmented reality will probably be connected to everything in the near environment, meaning device-to-everything (D2X) is needed. [16, 2.1.1.14]

2.3.11 Conclusions

After examining these use cases it is clear that one service is not enough to support the variety that is needed. The use cases can be used to determine needs for different services and their requirements that are going to be addressed in the next chapter.

2.4 Services

There are currently three different types of services that have been designed for 5G because the one-that-fits all scenario was not good enough, considering all things that 5G needs to achieve, such as all those use cases presented in the previous chapter. These services are Extreme Mobile Broadband (xMMB), Massive Machine-Type Communication (mMTC) and Ultra-Reliable Machine-Type Communication (uMTC). It is possible that more services will be created or changed, but with these three services, 5G can be successful. [16, 2.2]

2.4.1 Extreme Mobile Broadband

xMBB is a better version of current MBB service, with higher data rates, flexible communications, lower latency and more constant experience in the coverage area. 50-100 Mbps is the target speed within coverage to all customers. To be able to do this, a new higher spectrum is needed. With denser network placement, users per cells will decrease, meaning higher data rates. This needs new air interface which could be harmonized Orthogonal frequency-division multiplexing (OFDM) that will also be used for access, D2D and wireless backhauls. MIMO and backwards interoperability benefit from using this new OFDM-based system. It is very likely that all services use different air interface, which gives benefit for their specific requirements. [16, 2.2]

2.4.2 Massive Machine-Type Communication

mMTC is focused on a large number of devices that are cost and energy limited, mainly to collect data in a wide area, such as farms and plantations or in dense smart homes that can be controlled with 5G. It is impossible to predict all use cases which future brings, but having better services will bring new uses without doubt.

3GPP and METIS has made a list of most important requirements for mMTC, which are presented below:

- **10-year device battery life:** Though 10 years would be great, as the first devices placed get older, there will be improved and more efficient devices within years. Thus, it might not be that critical, if the cost can be kept low.

- **300,000 of devices per cell:** This would mean hundreds of devices within a square meter, with current 4G cell coverage depending on path loss. But since these devices do not need high data rates, it might be manageable with lower frequencies. It is clear that this number is too much, but it is future proof.

- **20 dB Coverage enhancement:** 15 dB was set as goal for 3GPP LTE Release 13 for delay-tolerant MTC devices.

- **Low device complexity:** To make mMTC device cost cheaper, they could be designed to only use half-duplex transmission, limiting bandwidth and limiting peak power.

The main features of this service are to have smaller-size traffic with lower energy usage on devices to have longer battery life. Since these devices are spread around, the network coverage might be unavailable, meaning it would be useful if they had device-to-device communication to extend coverage or to create smaller device networks where the “main” device communicates with the base station, and other close devices can use smaller transmission power to communicate with this “main” device. This can help other devices, but will require more from selected main devices. [6] [14] [16, 2.2; 4]

2.4.3 Ultra-reliable Machine-Type Communication

While mMTC has been researched for a few years, the research on uMTC began more recently. uMTC will mainly be used in vehicle communications and in other time-and-reliability-critical applications like factories. Vehicle-to-vehicle (V2V) communication and other vehicle-to-everything (V2X) communications will be needed for safety and control reasons. This means vehicles and devices need to be able to detect other devices even without network coverage. [16, 2.2; 4]

In Figure 1. are examples of how uMTC could work with self-driving vehicles and its surrounding environment. Vehicles communicate with BS where they are controlled and given information, about surroundings. If BS uses two services (xMBB and uMTC) at the same time it can give inside-vehicle high data rate connection and same time using uMTC to control the vehicle. Crosswalks for example could be monitored by sensors, to detect pedestrians that are about to cross. It then communicates information to BS and other vehicles around to make vehicles prepare to stop if needed. Also, if pedestrians have smartphones that support 5G, they could act as sensors to cars if they are on the street, if roadside sensors are not available. In V2V communication, vehicles broadcast vehicle information to whole surroundings, if coverage is not available.

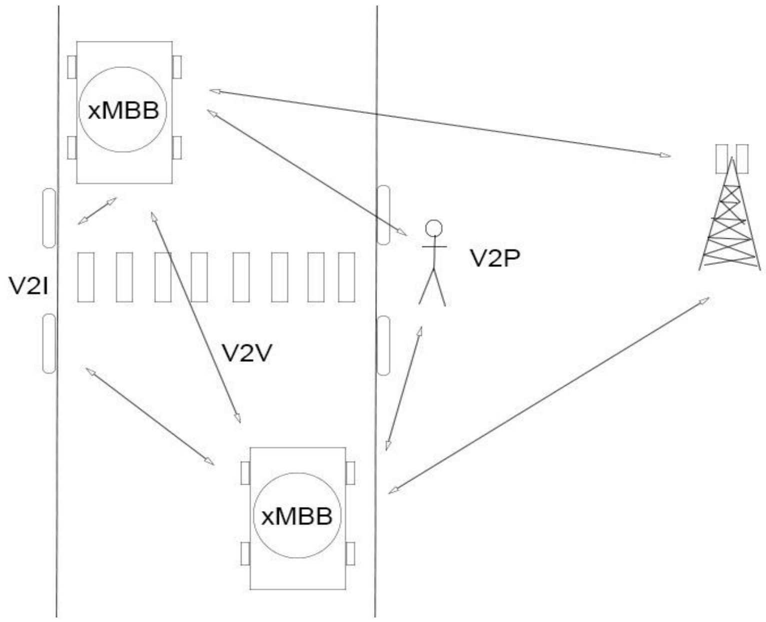

Figure 1. Example use of uMTC in self-diving vehicle environment.

2.5 Dynamic Radio Access Network

The Dynamic RAN (DyRAN) will integrate all other networks, communications and managements within macro-cellular network. These are listed below:

- **Ultra-dense networks (UDN)** is a network only a few meters wide, but this will help increasing the capacity and data rates to 10 Gbps, but since the coverage area is small, these will probably be rare for years from 5G deployment. UDN will only use cmW and mmW frequencies to get the widest bandwidth possible to achieve fastest data rates.

- **Nomadic nodes** are usually vehicle based temporary access nodes for the inside and outside of the vehicle. These are like UDN nodes, but as they move, they are only temporarily available to outside users, and this needs to be controlled dynamically.

- **Moving relay nodes** are also vehicle based, but only relay communications from outside the vehicle to inside, removing all penetration loss.

- **In D2D communication**, DyRAN will control how and when D2D access and backhaul communications are utilized depending on interference levels and available capacity.

- **Beamforming** occurs when antennas beams are controlled dynamically, depending on nomadic nodes and if Signal to Interference plus Noise Ratio (SINR) needs to be increased.

- **Node deactivation and activation** will be key feature, since there will be a considerable number of nodes in 5G, they will not always be used, meaning DyRAN can deactivate different elements such as, nodes, antenna beams and D2D links and devices to save electricity and decrease interference.

These all are dynamically controlled within multi-radio access technology (multi-RAT) areas. [16, 2.2; 6, 7]

2.6 Lean System Control Plane

LSCPs function is to be flexible in control signaling and to support different services, these functions are listed below: [16, 2.2.6]

- **Common system access**, which means first access signal to BS is common in all services, which decreases needed communication.

- **Service-specific signals** are only transmitted when data is being transmitted. In xMBB these signals have channel state information (CSI) to operate at the right frequencies. In mMTC, these are optimized sleep mode and minimum needed signaling and measurement settings. In uMTC to get best latency and reliability continuously.

- **Separating Control- and User-plane** will give different frequencies to be transmitted in xMMB, lower frequencies for larger coverage with C-plane and higher frequencies for higher data rates in U-plane. For mMTC and uMTC, C- and U-plane very likely will need to be combined.

- **Integrate different spectrum and inter-site distances** meaning macro cells will use frequencies bellow cmW (-6 GHz), and smaller nodes will use everything above cmW (6 – 30 GHz) and controlling power levels to decrease overlapping and interference.

- **Energy performance** that common and service-specific signaling decreases the amount of signaling needed and C- and U-plane separation minimized “always on” signaling, which results in lower power consumption and lowers interference.

2.7 Spectrum toolbox

Spectrum toolbox is to make the 5G spectrum usage flexible, because of different services, which use different frequencies, bandwidths and authorization schemes. Also, these need to be changed depending on the time of day to maximize network capabilities and to minimize power consumption and interference. [16, 2.2.8]

2.8 Device-to-Device communication

D2D communication means user devices that communicate directly with other devices, which brings many advantages such as extended coverage, lower latencies, better data rates, increased spectral efficiency, increased capacity per area and lower cost and power usage. Coverage is extended by a device acting as a relay to give coverage (Figure 2), to a device outside of coverage. This could use multi-hop if needed for longer “train” like coverage. Lower latencies, because devices communicate directly with each other, of course with the help of base stations for security reasons. Data rates increase if devices have needed data in cache or could be used as MIMO. Lower signal power is needed when communicating with close users, causing lower power usage and less interference. This can also be applied to V2X. Thus, vehicle based UE will give better coverage. [16, 5]

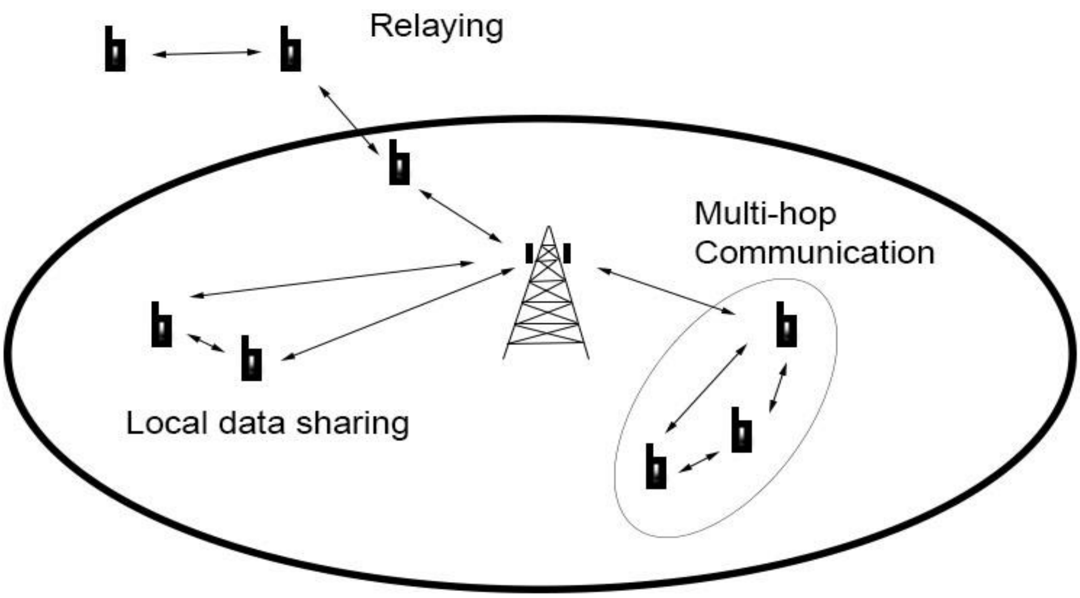

Figure 2. Device-to-Device use cases in cellular network.

Multi-operator D2D communication is a big factor for this to work with all users. Because operators use different parts of the spectrum, they might not permit other operators to use their frequencies and to share user data. These problems can be solved by creating an overlay for multi-operator D2D communications. Because operators do not want to tell their data to other operators, a neutral ground company could be used to run this service for all operators, which would eliminate data sharing between operators. This can also increase security by having all user data at a centralized location. [16, 5]

Another problem is customers and their reaction to this idea. Unless it is forced for all, some people do not want to use this feature, because they do not want their data to go through other people’s phones and they feel insecure. Yet another problem is that the relay user equipment will use power as a result, to give others better power efficiency and other times, roles are reversed. In vehicles power consumption is not an issue since they have bigger batteries and which recharge during driving. These problems are easy to solve by operators, by giving discount on mobile billing, giving faster speeds or unlimited data caps for those who want to use this service since this service helps operators by giving coverage for cheapest price, compared to buying nano- or pico-cells.

2.9 Massive multiple-input multiple-output

Massive MIMO is a system that uses 100+ antennas usually at the base station end, which are individually controllable (Figure 3). MIMO uses transmission technique called *spatial multiplexing* or space-division multiplexing (SDM). This means that different antennas transmit multiple data streams on the same channel. These streams are then combined by a receiver giving multiple times faster data rates depending on how many antennas are used. MIMO antennas can also be focused to the UE to decrease intra-cell (outside the cell) and inter-cell (inside the cell) interference, by using different or same phase shifts to control signal directions to the target. [16, 8]

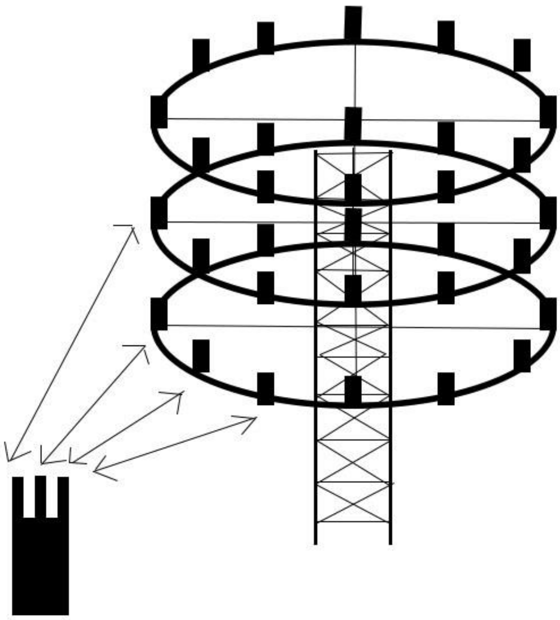

Figure 3. Massive MIMO antenna array and multi antenna user device.

There are a few problems that need to be solved to make this work for 5G. The transmission side needs accurate Channel State Information (CSI), which is acquired by pilot signal communication. This creates linearly increased overhead by the number of transmitter antennas there are. [16, 8]

The second problem is how massive MIMO will work in multi-cell multi-tier networks. This will cause inter-cell interference of both pilot and data signals, which could be solved by common pilot and data channels in multi-cell environments. [16, 8]

2.10 Spectrum

Millimeter wave and centimeter wave

A 3 GHz – 30 GHz frequency band is called cmW, since at that frequency wavelength is cm tall ($\lambda = c / f$) and 30 GHz – 100 GHz frequency band is mmW. In 5G, frequency band within 10 GHz and 60 GHz is needed for data rates that it needs to achieve. The reason why it is below 60 GHz is because at 24 GHz and 60 GHz two atmospheric peaks appear, due to water and oxygen, which causes a 15 dB/km increase at those frequencies. There is a problem using this frequency range, since other devices use it already, like satellite communication, airliner radars, military radars, passive earth exploration, fixed links and radio astronomy, and this needs to be addressed when 5G frequency band is allocated by ITU and these needed frequencies are most likely to be addressed at WRC-19, that is being held in 28 October 2019, where WRTC will review and if necessary, revise the international treaty governing the use of the radio-frequency spectrum, radio regulations and satellite orbits. [16, 12.1]

Currently amplifiers for mmW are expensive to make, because the higher frequency capability and the higher power capability are conflicting according to the Johnson limit. Current mmW circuits use III-V materials, which are a combination of elements from group 3 and group 5 of the periodic table. It is expected that cheaper ways to make high frequency tolerant circuits will come, but currently it would be costly to make all 5G equipment. [16, 12]

Beamforming will be necessary to decrease interference and to keep power consumptions and usages lower. There are digital, analog and hybrid beamforming architectures, which each have their own good points, but it is unsure which will be used or if there will be new types. [16, 12.5]

2.10.1 Other spectrums

Wider spectrum and wider connected bandwidth is needed to achieve current 5G requirements. ITU-R has estimated that frequency range of 1340-1960 MHz will be needed for mobile communications usage by 2020. Nevertheless, this might change or vary between countries and continent, but it is clear that 5G will need more spectrum to fulfill requirements. Also 470-696 MHZ frequency range is likely to be auctioned, which means that if whole range of 200MHz is allocated for 4G and 5G it would be widest continuous range in lower frequencies in 4G. [15] [16, 12]

3 5G in Finland

When the first release of 5G becomes available, its deployment will be slow depending on how you look at it. The first factor is how many phones support 5G frequencies, services and other functions. If these phones are not selling in high quantities, there is no market yet for 5G.

It is likely that first 5G sites will use same frequencies as previous generations, because you can use old antennas for what frequencies they support. Then comes the harder choice, should other antennae and radio receiving units (RRU) for 5G specific frequencies, be added or should old antennae and RRUs be switched to ones that support all generations and frequencies. In the former case, free-standing and small masts will not probably be able to stand the added weight, and in taller ones RRUs need to be placed at a lower height. Most masts have all three operator's antennae and RRUs, meaning at least 9 antennae and 9 RRUs currently, and if all operator also want to add 5G, it will not be possible.

In Figure 4. (a) there is a tubular mast that are most common in urban and suburban areas, and they are around 25-30m high. As you see, there is no room left because this particular mast has the shortest amount of space to install. Thus, 5G would need its own mast or new technology that integrates antennae and RRUs together.

In Figure 4. (b) there is a free-standing mast and has the same problem as the tubular; even though you could add more antennas and RRUs, there comes weight and wind limits.

The only place to add 5G straight is to supported masts (Figure 4. (c)) that are usually same width whole way so that you can easily add more antennae. It can also support more weight because of the steel wire support cables.

Figure 4. (a) Tubular steel mast 25m (b) Free-standing reinforced steel 40m (c) Supported reinforced steel 80m

You can always place more masts, but they are not cheap and need electricity and fiber or wireless broadband link from another mast. Then comes the issue of interference: only 5G used signal can be used so that other signals will not interfere.

Installing 5G on top of rooftops is the easiest option in urban areas when using wireless backhaul; hence only electricity needs to be cabled. The same applies to street-level (e.g. top of lamp posts) placed micro, pico- and nano-cells, but these will most likely only use millimeter waves, i.e. 3-30 GHz range. Thus, they can get the widest bandwidth usage for fastest data rates and not interfere with macro sites that cover the area with older generation signals. This becomes a more widely used design when antennae and RRUs can be integrated or made smaller so that they do not catch the eye or look ugly, which is one of the biggest reasons for not allowing their placement in common public areas. These get power from within the lamp post and use wireless backhaul making installing extremely simple.

But within the first year of 5G deployment, most of the cells are located in high density spots, such as stadiums, shopping malls, markets etc. If antenna and RRU prices decrease and become smaller, then it will probably become more widespread within a millimeter wave-range usage. All macro sites will get the upgrade probably as fast as they can be installed.

Figure 5 Shows how 5G would be deployed within the first year in an urban environment, in this case Helsinki with many busy public places like railway station and Kamppi shopping center. The red circle is macro site, with 2G, 3G, 4G and 5G, and the blue circle is its assumed coverage. Yellow circles are 5G micro coverage areas that only use a 5-30 GHz frequency range to give highest capacity and data speeds. Since the equipment costs a large amount of money they are focused on most common places first. If cars with mobile functions come to the market at that time, they could be used for signaling, but these cars would be rare and rarely stationary.

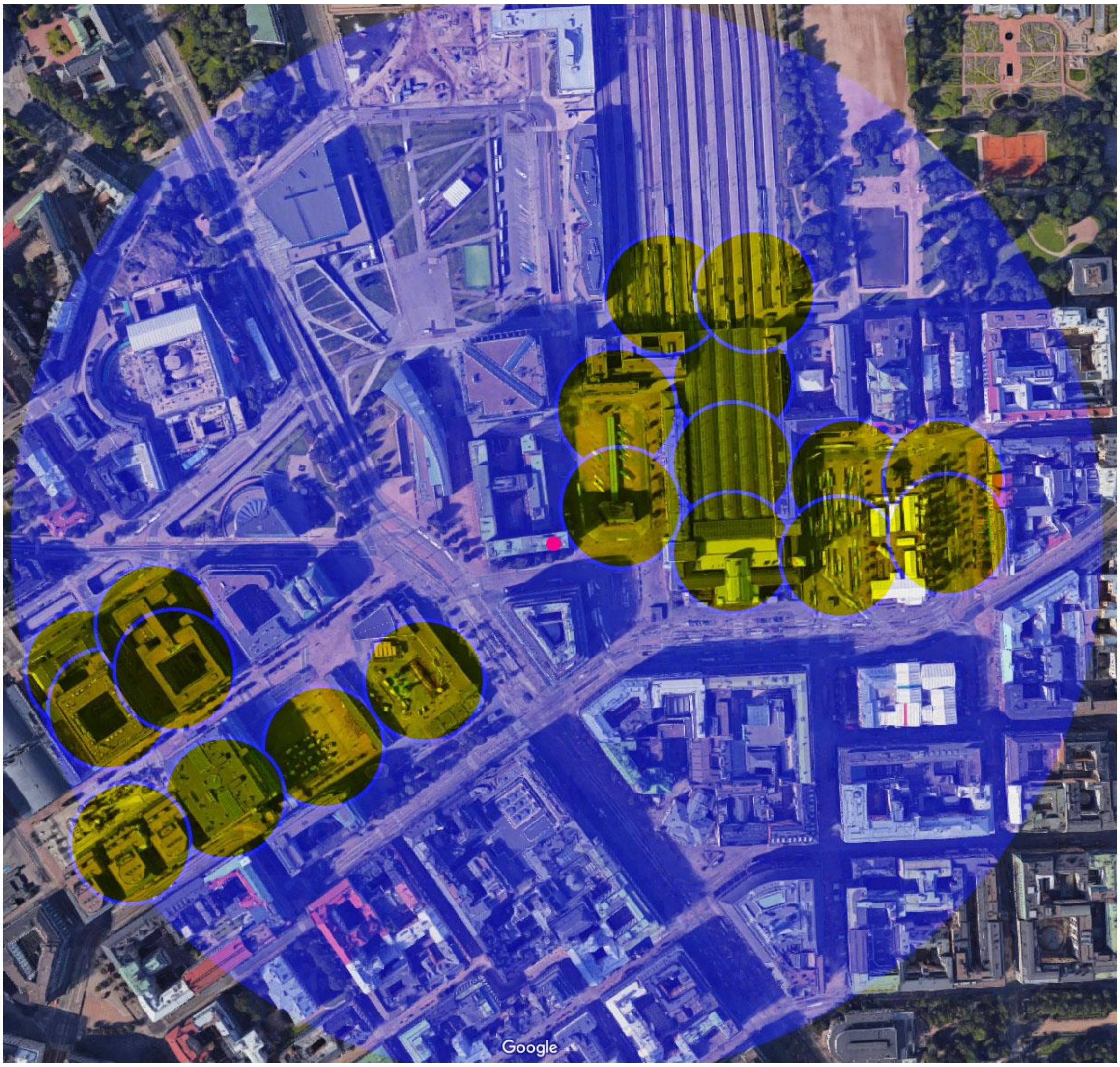

Figure 5. First year of 5G in Helsinki.

In the second year, the urban environment with 5G could look like that in Figure 6. where green circles are 5G micro/nano/pico coverage areas, either from fixed installations or from cars or other UEs. This development might be too fast, but it depends on 5G equipment, car and smartphone manufacturers how fast 5G gets deployed. These also could give coverage to nearby houses and other buildings that usually have worse coverage.

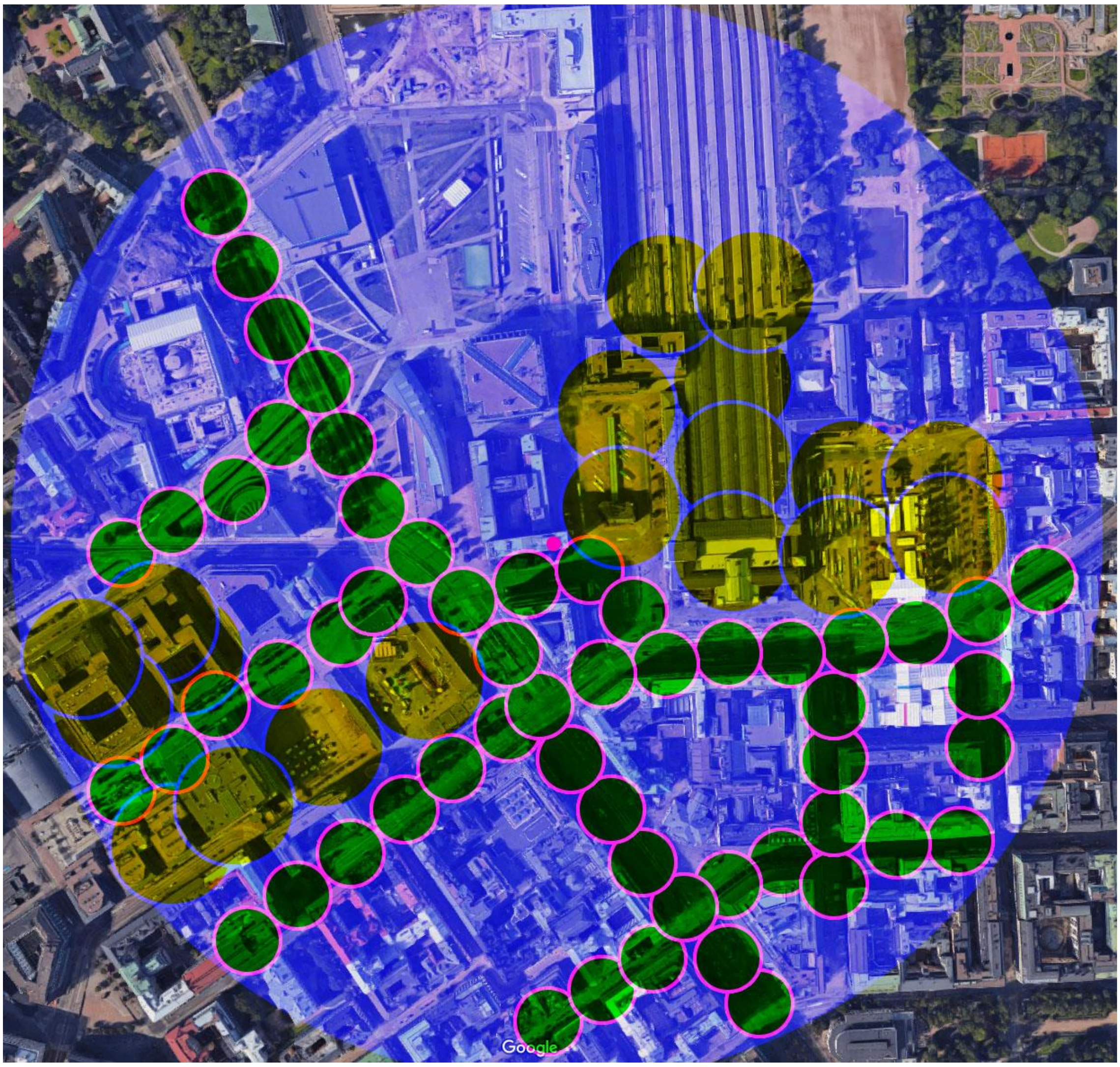

Figure 6. 2+ year of 5G in Helsinki.

Microsites could be designed so that neighbors use different frequencies within a millimeter wave to cause less interference. Because the bandwidth area could be really wide there would not be a problem allocating them smartly. 5G will most likely have systems which enable it to communicate with other sites to automatically change frequencies and power levels to prevent interference.

MIMO and massive MIMO systems in my view are going to be rare, since they need much more space and are expensive. I have only seen a few MIMO sites in Helsinki which means that they are not currently very popular, since Finland is very sparsely populated. In 5G, MIMO systems might become more used, but currently I cannot see it happening, before basic 5G is deployed through Finland.

These are my views on how it could be done, but there could also be other ways. Since I only have experience in installing these mobile communication sites, I cannot say how a real designer would scheme it.

4 Conclusion

5G will be very flexible and dynamic in all parts, which will give it a huge advantage over 4G, by having more services, higher data rates, lower latencies, higher capacities, better coverage, improved efficiency and interference mitigation. D2D and V2X commnications are going to be some of the interesting features of 5G. While 5G is still under research, it is supposed to begin its prototype, optimizations and demos after Q2 2017, in 28 October 2019 WRC-19 will be held where new frequencies like mmW and cmW will be allocated for mobile use and radio regulations will be revised. It is a long way from 2020 when everything will be finalized if they keep the timeplan. This does not mean that the development stops, but when its improvements and uses increase, it may change how we live in this world.

In Finland, 5G deployment will most likely start slowly with UDN and other smaller networks, but macro-sites will most likely be upraged to 5G within a few years in the same way as the majority of Finland got 4G coverage in 2016. 5G deployment will mostlikely focus on urban areas first like how 4G was. Though this means that macro cells and other popular spots like shopping malls will get the upgrade first, but smaller UDN and micro/nano/pico cells will become more popular after few years from beginning of deployment. In ural areas 5G will come after urban areas have been installed. For urab area mmW and cmW will no be useful since the range is short, also MIMO antennas will also not come, because in is not beneficial. Since Finlands average vehicle age is so much older that other bigger european countries, vehicle-based access point will be rarity for many years, unless finnish car taxes are lowered or removed, since new cars prices are higher than in other western europe countries.

5G also brings problems with it too: for example, will 5G share antennae with previous generations or will it get its own antennae, which need new masts? Another problem is D2D communication and how multi-operator communication is handeled and how to make people use it willingly, since some might not want to share downloaded data or be used as coverage extender. These can be solved by having neutral company that controls all D2D communications and operators giving discounts or higher data rates for using D2D features, that benefit operators. And will MIMO become more popular or is it not needed yet.

The first large 5G deployment will most likely be in Korea 2018 winter olympics. This will be when 5G begins its revolution in telecommunications.

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