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Sustainability with 5G

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Abstract

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Abstract:

This thesis aims to answer what kind of roles 5G could play in improving resource management as well as achieve sustainability in general (cost, management, efficiency, and speed). Not just 5G itself, but new technologies that have been built to combat energy challenges to be used alongside 5G will be discussed, as they go hand in hand. Numerous natural resource industries will be given as examples, however the most important one is to combat the challenge of increased power consumption. Energy efficient solutions fall into two major groups: increased usage of renewable energy instead of grid energy (green energy) and efficiency of equipment and network implementations (green technology).

The goal of this thesis is to understand key components of 5G and see where and how efficiency can be achieved. The goal is to also demonstrate how 5G can be used in natural resource industries to gain sustainability and reduce energy consumption.

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List of Abbreviations

5G Fifth generation

AIV Autonomous Intelligent Vehicle

BBU Base Band Unit

CN Core Network

CC Central Cloud

DRAN Distributed Radio Access Network

eMBB Enhanced Mobile broadband

MTC Machine Type Communication

E2E End to End

EE Edge Cloud

ETSI European Telecommunications Standards Institute

EPC Evolved Packet Core

LoRa Low Range

LPWA Low Power Wide Area

LTE Long Term Evolution

MEC Multi Access Edge Computing

eMTC Enhanced Machine Type Communication

mMIMO   Massive Multiple Input Multiple Output

M2M   Machine to Machine

NSA   Non Stand-Alone

NR   New Radio

OPEX Operational Expenditure

QoS   Quality Of Service

RAN Radio Access Network

RA Radio Access

RAP Remote Access Point

SA Stand-Alone

SooGREEN Service-oriented Optimization for Green Mobile Networks

SP   Service Provider

SPSB Shenzhen Power Supply Bureau

SMEAR   Station for Measuring Ecosystem Atmosphere relations

TCO Total Cost Of Ownership

URLLC Ultra Reliable Low Latency Communication

VNF Virtual Network Functions

1 Introduction

During this age of technology, the usage of internet will only increase over time. The total global traffic is expected to grow by the factor of around 4.5 to reach 226EB per month in 2026. This is based on mobile data consumption of about 6 billion people using various devices. (1) This increase raises the question of sustainability. However, the term “sustainability” is vague. Cambridge dictionary defines it as,

“The idea that goods and services should be produced in ways that do not use resources that cannot be replaced and that do not damage the environment” (2)

There is expected to be billions of devices connected to the internet with the emerge of Internet of Things, smart cities etc. There are numerous environmental and energy challenges that come with new technologies like this.

5G or fifth generation is the latest instalment of previous generations of mobile networks such as 1G, 2G, 3G and 4G. 5G will introduce higher speed, throughput, capacity, and lower latency compared to its predecessor. (3)

By the end of 2026 Ericsson forecasted that 3.5 billion 5G subscriptions will be taken into use, which will be about 40 percent of all global mobile subscription at the time. (1)

Therefore, to better understand the basics of mobile networks, their components will be covered in this study. It is important to understand how 5G is different than traditional LTE network architectures and how it can achieve efficiency.

This thesis aims to answer what kind of roles 5G could play in improving resource management as well as achieving sustainability in general (cost, management, efficiency, and speed). Not just 5G itself, but new technologies that have been built to combat energy challenges to be used alongside 5G will be discussed, as they go hand in hand. Numerous natural resource industries will be given as examples, however the most important one is to combat the challenge of increased power consumption. Energy efficient solutions fall into two major groups: increased usage of renewable energy instead of grid energy (green energy) and efficiency of equipment and network implementations (green technology).

The goal of this thesis is to understand key components of 5G and see where and how efficiency can be achieved. The goal is to also demonstrate how 5G can be used in natural resource industries to gain sustainability and reduce energy consumption.

2 Mobile Networks

Traditionally, mobile telecommunication networks consist of 4 major domains:

- The device e.g. a mobile phone.
- The Radio access network (RAN), which uses radio frequencies to provide wireless connectivity for devices to connect.
- The core network (CN), which is responsible for connecting different part of the access network and providing connectivity to the internet.
- The transport network, which connects the RAN and the Core Network.

Thanks to the baseband providing a set of computer-intensive signal processing functions, wireless communication is accomplished. It uses custom electronics that is responsible for the extremely high data processing needs. It is also equipped with sophisticated software in order to provide effective wireless communication.

This includes signal processing for:

- usage of multiple antennas
- auto detection and correction of errors in the wireless transmission
- security
- management of wireless resources in an efficient manner among various devices in the same network

The radio converts digital information into signals. The signals are transmitted wirelessly ensuring that they are in the right frequency bands and have the right power levels. Radiating the electrical signals into radio waves is the job of the antennas.

With 5G the traditional network architectures are changing. For example, to accommodate higher bandwidth the 5G antennas are integrated with the radio. Important parts of the hardware and software are also integrated into the antenna, which leads to higher capacity and efficiency of massive MIMO, beam forming and beam tracking efficiency.

Some features of baseband can be virtualized and placed at the core network sites, instead of the base station. RAN (Radio Access Network) software can also be placed in the same place as CN (Core Network), making management easier as a single solution. (4)

2.1 Radio Access Network (RAN)

Connecting individual devices to parts of the network of the telecommunication system is the job of the RAN. It is achieved through radio connections. It is the key component that connects the end user to the core network. It provides access and enables management across radio sites. For example, a device could be connected to a core (or backbone) wirelessly and travelling to other networks and sending signal is done through the RAN, thus making the communication possible.

Components of RAN include base stations, antennas to cover region, and off course the core network. EPC (evolved packet core) is included at the core in LTE networks.

RAN architectures separates the following two planes into different elements: user plane and control plane. Thus, it enables user data to be exchanged through a software defined networking (SDN) switch and a control-based interface by a RAN controller. This is important as this allows RAN to be more flexible and enables the use of virtual network functions (VNF), e.g. network slicing and MIMO. (5)

A significant amount of energy is consumed in the Radio Access Network, therefore updating the Radio system with intelligent software is beneficial than using legacy equipment. It is achieved by optimizing the capacity not needed during high peaks, meaning the energy can be saved. Studying previous patterns of traffic data, predictions can be made. (6)

For example, an algorithm was trained using real data from radio sites in Portugal using MIMO (Multiple Input Multiple Output) technology. The machine learning was trained to take control when activity at a radio station would be dropped to a certain threshold. The unit would power down and the data would be routed elsewhere to a nearby radio station until the traffic data load would increase again. The results confirmed savings up to 14 percent while having no impact on the users. (7)

Nokia and Telefonica also conducted a study which found that 5G can be up to 90% more energy efficient per traffic unit compared to 4G networks. The study was conducted over the course of three months, also focusing on the RAN power consumption.

The test used various pre-defined traffic load scenarios, measuring the energy consumption per Mbps. The results concluded that 5G RAN is more efficient than its predecessors. This study used Nokia Airscale base stations and Airscale Massive MIMO active antenna solutions. Onsite energy consumption readings in different traffic load scenarios were closely studied. Remote management systems were used to monitor the power consumption.

Various energy saving features were established in order to improve energy efficiency of wireless networks at radio base station and network levels. Some examples are, small cell deployments, 5G power saving features, architectures, protocols. The combination of them could achieve better efficiency. (8)

2.2 Cloud RAN (CRAN)

Typically, the components of a distributed RAN (DRAN) reside at the cell site, and they are divided into two parts: Radio unit (RU) and baseband unit (BBU). CRAN would centralize all the BBU in a shared location, called a BBU hotel, while remaining connected to the radio units at the cell sites, via optical fiber links. This allows BBUs to share the energy consumptions and costs.

All digital baseband computation and cooling processes would be done at certain cluster centres, this enables the reduction of functionalities in each cell sites. Only the radio frequency and analog processes would be handled by the cell sites. This could also allow for better coordination between cells, resulting in better resource and energy utilization.

Aim of CRAN is to provide a more centralized system, reducing the number of BS (Base station) sites. It can achieve this by using smalls cells, which will be connected to the edge cloud, and central system. It essentially means, better coverage, reduction of transmission distance, which could lead to energy efficiency. (9)

Densification of RAN needs to be done in order to scale up the network capacity that is needed for technologies such as mmWave (millimeter wave). This densification would lead to increase energy consumption, cost, etc. While this is unavoidable, centralization and virtualization of components can play a key role in combatting such challenges.

The three components of CRAN are:

- Radio Access (RA): Includes the Remote access Points (RAP), radio, baseband, and optical transport equipment.
- Edge Cloud (EC): performs non real time tasks of telecommunication functions, e.g. data centres
- Central Cloud (CC): includes central servers and switching equipment among others.

There also exists a set of standardization (by ETSI; European Telecommunications Standards Institute) and definitions which assess the energy efficiency (EE) of CRAN. See figure below.

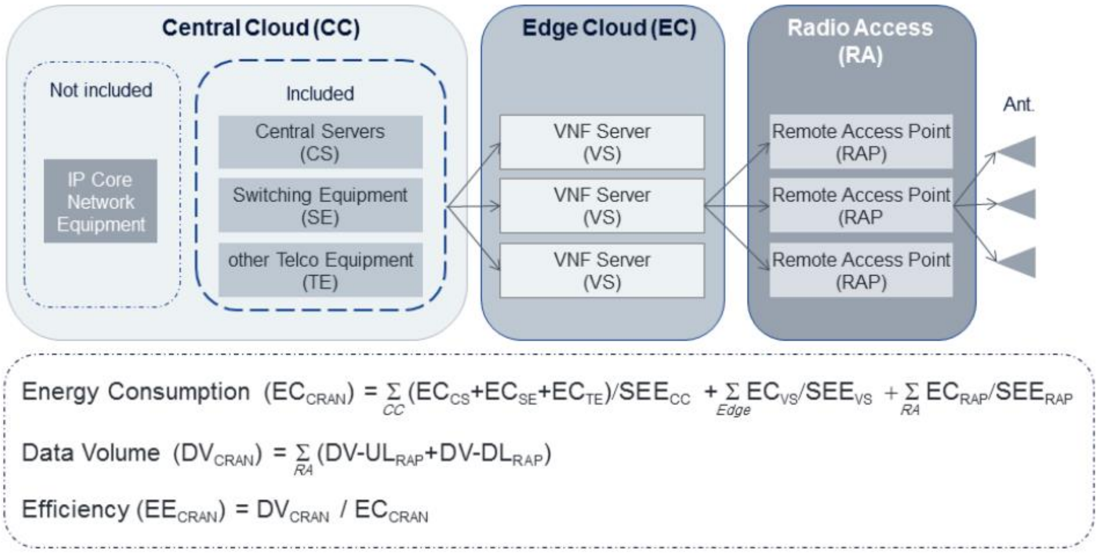

Figure 1: Components of CRAN and formula for energy efficiency. (10)

As shown in figure 1, the radio access site, which consist of the RAPs, does all the real time processing, while forwarding non real time tasks to the edge cloud. The edge cloud is then connected to a central cloud which handles all management tasks.

The data volume can be found by calculating the sum of uplink and downlink data volumes flowing through each RAP.
Energy consumption can be found by summing the three components of CRAN, weighting by its specific site energy efficiency.
Thus, energy efficiency can be measured by dividing Data volume by Energy consumption.

Energy monitoring aspect can be greatly benefited from this technology. Data analytics can provide great insights between telecommunication events (e.g. traffic loads) and the energy consumption correlation. SooGREEN (service-oriented optimization for green mobile networks; an EU Celtic-Plus project) has validated a could-native approach to energy monitoring, which doesn’t require any external device, with micro service workability.

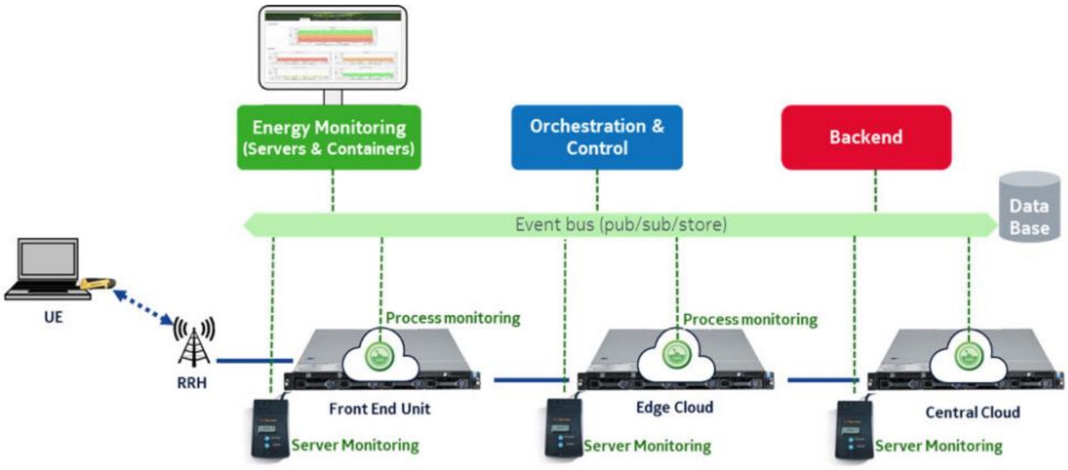

Figure 2: Proposed cloud native energy monitoring solution. (10)

However, due to VNF being shared between services and slices, the end to end energy monitoring is still a challenge. Furthermore, it was proposed that VNFs should be broken down to smaller process, as microservices; this would enable RAN to be even more flexible.

The proposed energy monitoring system needs to be further researched; however, it is still a positive step towards efficiency. (10)

2.3 Relays

Relays are used to help base stations reach the users. Relays are typically stationed outside a BS (Base station) coverage area. They forward information wirelessly from mobile terminals. In simple words, they work as a kind of “middleman” between a device and a base station. Relays can be used not just to increase throughput, system capacity, but they can also be used to increase energy efficiency. Since a relay splits the path of a long signal, it helps reducing path loss, transmission power and interference. (9)

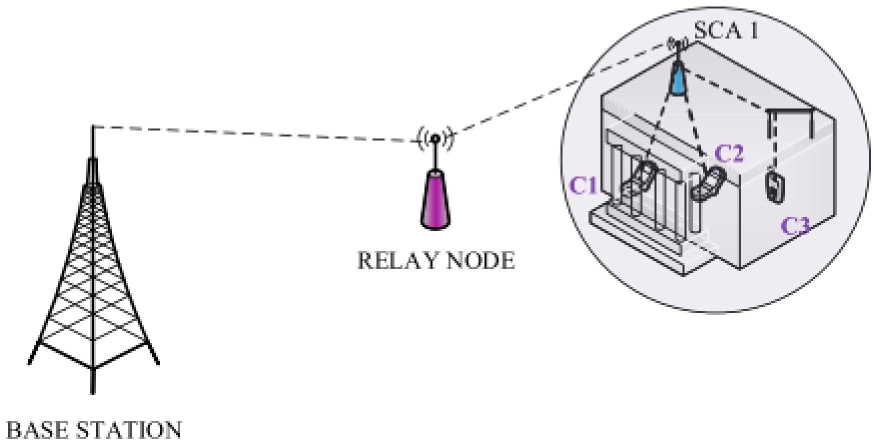

Figure 3: Transmission with a relay. (9)

2.4 The Core Network

The core is the central unit to all cellular communication. In LTE, EPC, the evolved packet core is used. In 5G the core is different, it is called 5G core. For example, dual-mode 5G core uses both EPC and 5G core functionality and combines them to optimize footprint and TCO (total cost of ownership) efficiency. 5G core is designed to handle new functionalities that previous generations cannot. It is built on cloud native, microservices based technology. (11)

However, the dual mode is the most popular one in terms of use case. Because most vendors already have LTE in place, the non-standalone 5G deployment is therefore not as costly as the standalone architecture. (11)

Non-standalone (NSA) generally means operating 5G alongside of LTE technology, complementing and supporting each other. The new 5G NR (New Radio; see chapter 3.1) cells will be in place with EPC (Evolved Packet Core).

Essentially all core technology will be LTE (Long Term Evolution) but the 5G access nodes will act as a slave. (12)

Early adaptations will usually use NSA. It has higher throughput compared to LTE alone and can be used for critical IoT. Data rate is aggregated and its relevant especially for narrowband (<1 GHz, or 3,5 -4,2 Ghz). (12)

Standalone (SA) gives a full 5G E2E (end to end) network experience to the users. It consists of both NR and 5G core. Independent of LTE however, it will provide interoperability to provide continuity between the two networks. For example, LTE will still provide connections to places that are yet to be covered by 5G (12).

Another example are TB4 hybrid base stations. They are a new generation of base station which use Airbus's own product (TAIRA), taking advantage of the LTE advancements to ensure smooth and seamless transition for customers who need the advantages in their mission critical communication. In addition to superior features, it will also allow lower power consumption and OPEX (Operational expenditure) savings. (12) See figures below.

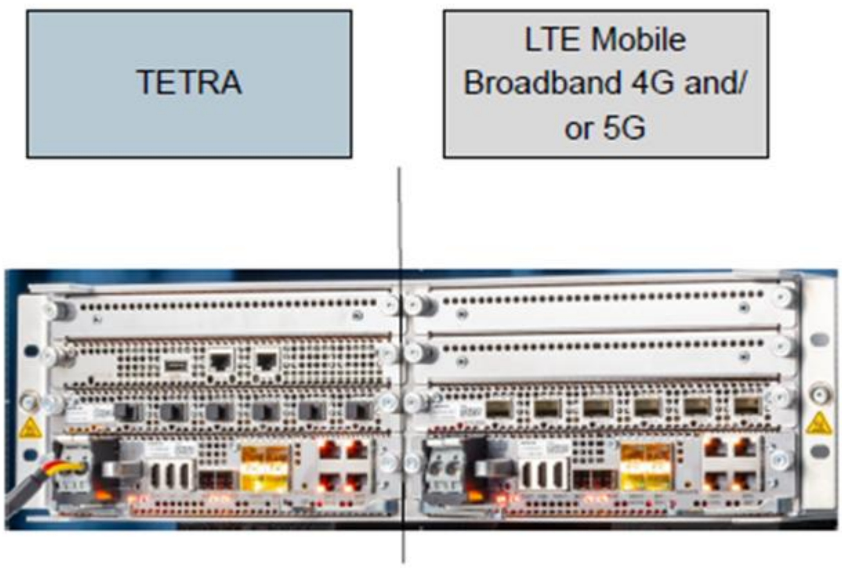

Figure 4: Hybrid Base station. (12)

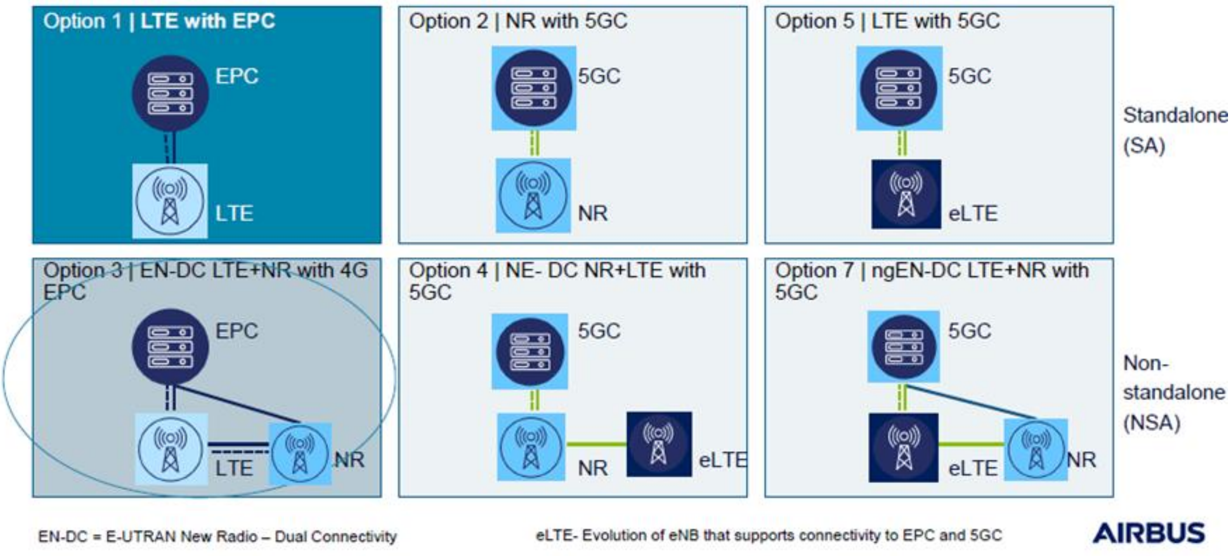

Figure 5: Deployment options of the hybrid base station. (12)

The mobile traffic varies significantly during the time of the day as well as location. However, in traditional LTE the power consumptions at the base stations remain constant even when the base station is at idle state due to the characteristics of the components. The hardware remains active to transmit mandatory signals. (13)

With 5G new radio, the needed support of the sleep states in radio network equipment have been addressed. The more components can be switched off, the more energy will be saved. NR also requires far less when it comes to signalling transmission, allowing deeper and longer periods of sleep when there is no ongoing data transmission, which impacts the overall network energy consumption. (13)

To study the impact of NR on network energy expenditure, Ericsson performed simulations using existing LTE infrastructure and adding NR. It has been performed with hexagonal cells in a super dense situation (such as a city center).

The NR (or extra LTE micro nodes) consisted of addition 1-4 micro cells per macro cells. (13) See figure 3 below.

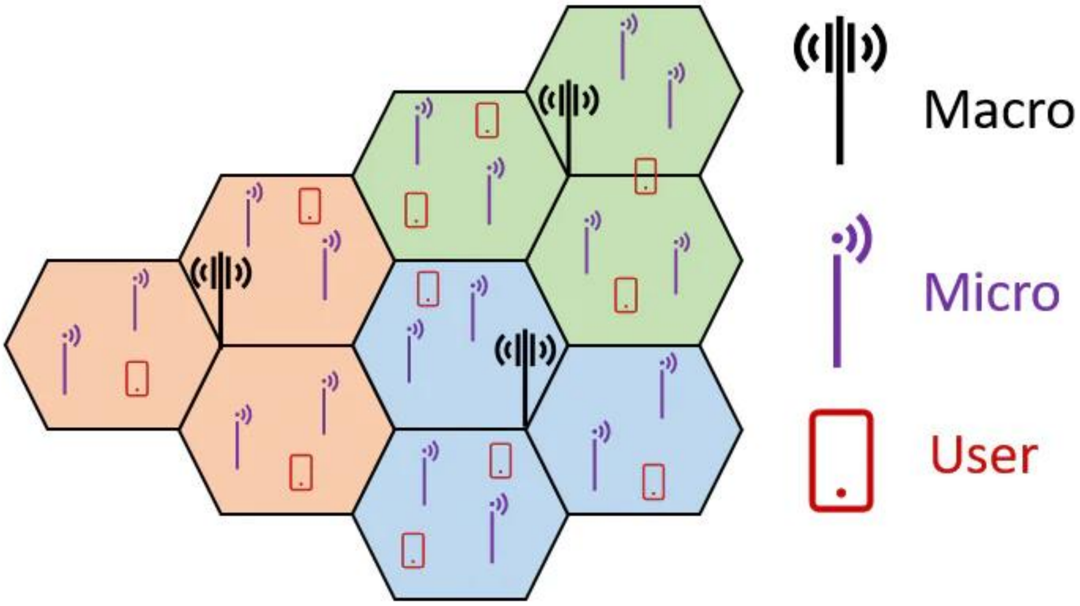

Figure 6: Simulation model. (13)

Macro cells are the most common types of cells. When there is a need for coverage of more than 10 Km, macro cells are used. The base stations of such cells are often mounted to higher locations e.g. hills or rooftops. They are ideal for rural areas or places with small amount of traffic. (14)

In comparison, micro cells provide much less coverage. However, they are often used in urban areas for its capabilities in dealing with high and dense mobile traffic. (14)

There are other types of cells as well, such as nano, femto, small and pico cells. However, only micro and macro cells have been used in this simulation. (14)

Simulation parameters	Macro	Micro
Site type	Hexagonal 3 sector	Single sector
Radio Access Network	LTE	NR/LTE
Number of Antenna Elements	2	64
Frequency [GHz]	0.9	3.5
Bandwidth [MHz]	10	40
BS Transmit Power [W]	40	20
BS antenna height [m]	25	10
Scenarios	Super Dense Urban (SU)	
Propagation	3GPP spatial channel propagation	
ISD [m]	380	
DL FTP traffic [MB]	2	
Indoor ratio [%]	80	
UE antenna height [m]	10	
Traffic load target [Mb/s/km2]	750	

Figure 7: Simulation parameters. (13)

The simulation concluded that a significant amount of energy is saved while using NR deployments. The reason for this is that the added NR micro nodes allow offloading of the traffic between the nodes, enabling single nodes to be able to remain idle for a longer period of time. Although adding more nodes increases a small amount of energy, overall, the energy consumption is reduced as can be seen from the figure below. (13)

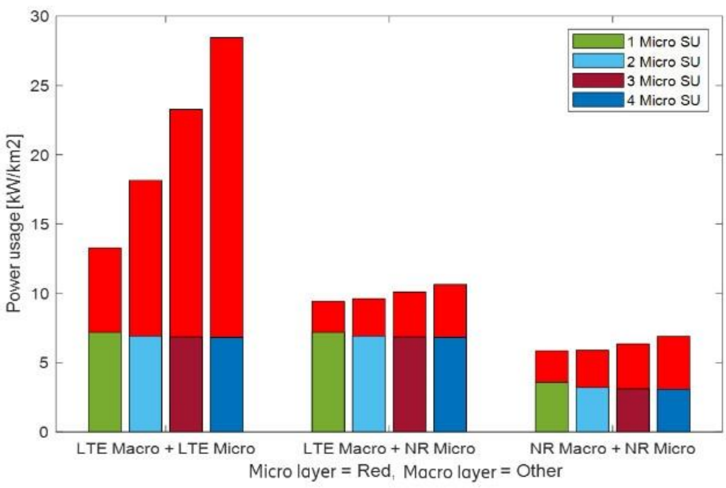

Figure 8: The total daily power consumption from the super dense simulation. (13)

3 Key 5G components

This chapter is dedicated to introducing the key components of 5G and how it differs from LTE network. See figure below.

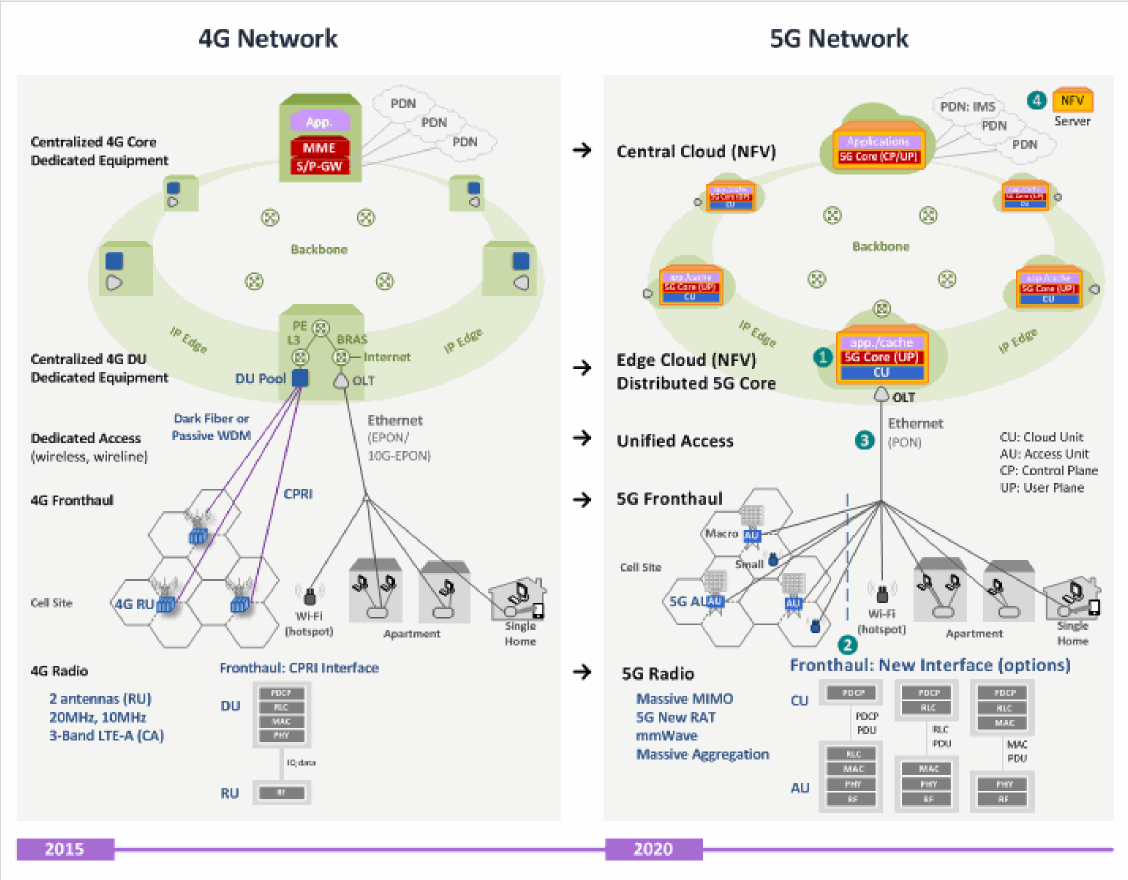

Figure 9: 4G and 5G network comparison. (15)

3.1 New spectrum

In the fifth generation of wireless technology, New Radio is a new type of radio interface and radio access technology. It is used for cellular network. All cellular activities such as voice, is sent via radio waves by converted into digital signals. 5G NR uses two ranges of frequency: Frequency Band 1 (6 Ghz and below) and Frequency band 2 which includes the millimetre wavelength. (16)

The millimeter waves, which essentially means ultra-high frequency radio waves, makes several Gigabits per second download possible. (3)

There are three methods that can be used while building the 5G network, depending on the operator's needs and assets. Low band network has wide coverage but has about 20% more speed than 4G. High band frequencies are ultrafast. However, they have low coverage and are prone to struggle moving against obstacles such as trees or hard objects. Mid band frequencies are a good balance between these two. (17)

Higher frequency is also much wider, thus allows higher bandwidths as well as higher data throughputs rates. The downside is its shorter range; however, it also allows greater frequency re-use. Billions of IoT connected devices in, for example, smart cities, hospitals, vehicles, remote control of devices, factories, can be accommodated through the new spectrum. (17)

3.2 Beamforming & MIMO

Beamforming and MIMO are closely related and sometimes used interchangeably. Beamforming is essentially just a part of MIMO. The way electromagnetic waves work is that a single antenna will be broadcasting a wireless signal in all directions. However, it would be more beneficial if that signal were focused on a specific direction, in order to form a targeted beam of electromagnetic energy. One way to achieve this is to have multiple antennas in close proximity, broadcasting the same signal but at slightly different times, with overlapping waves interference will occur, with constructive and destructive patterns. Constructive means the signal is stronger in those places and destructive means it will be weaker in those areas creating beamforming. (18) See figure below.

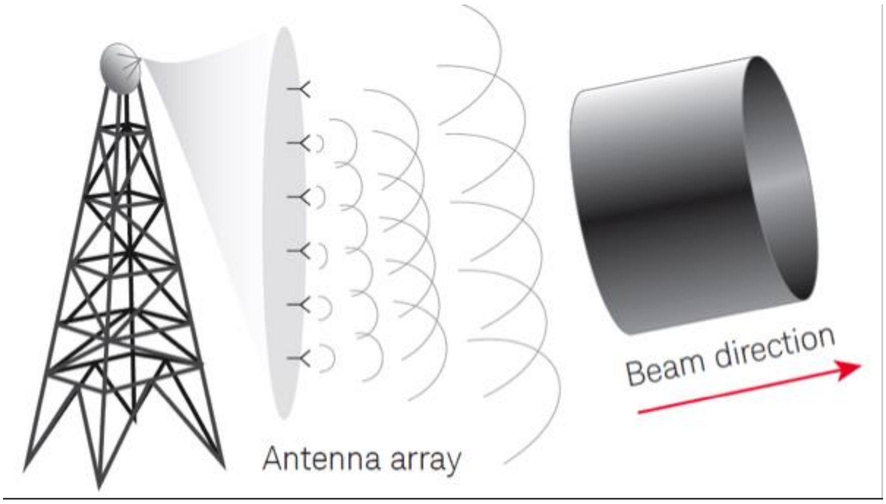

Figure 10: Beamforming. (18)

In simple words, beamforming is about targeting specific receiving devices rather than having the signal spread in a certain surrounding area.

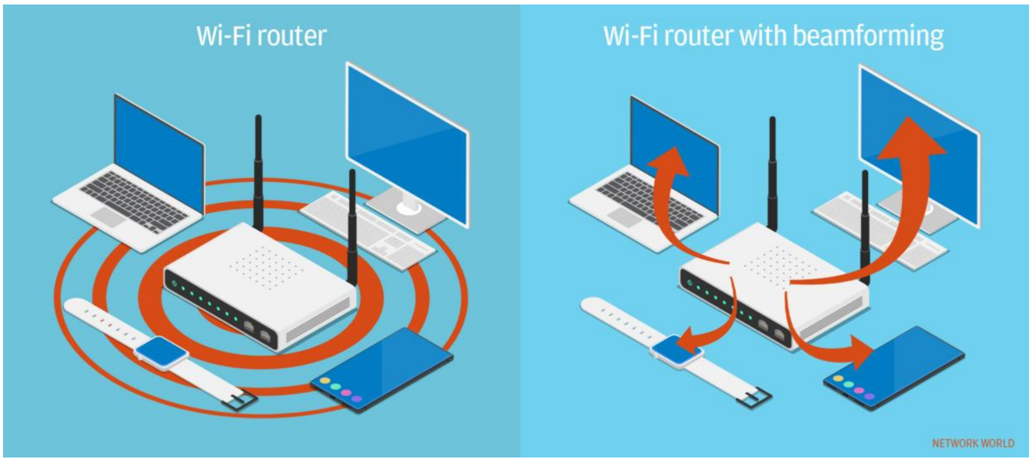

Figure 11: An example of beamforming. (19)

The benefits of this are that signals received in the receiving device can be much better quality, faster with fewer errors without any additional broadcast power. Also, since the signal is not broadcasted where it is not needed, interference can be reduced for devices that are searching for other signals. One downside is that since 5G uses higher frequencies, it is also more susceptible to barriers such as trees and buildings. (19)

MIMO (multiple input, multiple output) has been seen in current wireless technology; however massive MIMO is something exclusive to 5G. (19)

Massive MIMO consist of a significant number of antennas at the base station, thus enabling simultaneous communication between users possible in the same frequency. This further enables high multiplexing, making massive MIMO energy efficiency and spectrum efficient. It has been evaluated that the number of antennas at the base station can reduce the transmit power assuming the channel state information is known.

Several information can be used to improve energy efficiency of MIMO, such as transmission distance, rate and channel state information. This enables a more adaptive MIMO which can switch modes when needed. Furthermore, switching off BS antennas when not needed is also suggested.

Beamforming focuses the radiation patterns, which would increase the range of communication, expecting to increase energy efficiency. The energy could be reduced by the reduction of signal interference between a BS (base station) and a user device. It could be achieved by the use of antenna array with directional transmission. Higher transmission data rates can be achieved, thus enabling more throughput per unit energy.

However, with the increase in antennas it is expected that there would be increase in circuit power consumptions. One study suggests balancing the increased circuit power by using a hybrid model of analog and digital beamforming Radio Frequency (RF) structure. Adding more hardware could also help decreasing the propagation loss and improve efficiency. (9)

3.3 Network slicing

Network slicing is a separate self-contained part of the network. Network slicing offer different QoS (quality of service) to its customers for different use cases. For example, an operator might dedicate a network slice to vehicle-to-vehicle communications. This is useful in terms of mission critical and latency sensitive communication channels due to the use of URLLC (Ultra Reliable Low Latency Communication). (20)

The network is essentially “sliced” into multiple virtual ones. However, they all exist in a single infrastructure. They can be configured according to their needs and specifications. Each slice can then be used for a different purpose, ensuring more efficient use of resources securely and less cross over between them. (21)

A dedicated network can be for one enterprise, or it could be shared by many. For example, one specific slide could have dedicated radio, transport, and other core resources, but another slice might share radio and transport between customers and still provide core network features per customer. (20)

Key benefits of 5G such as enhanced mobile broadband (eMBB), ultra-reliable low-latency communications (uRLLC) and massive machine type communication (mMTC) all have different requirements in terms of bandwidth, mobility, security, latency, reliability. If there were to be a dedicated network for each of these, it would lead to high costs and would be more difficult to manage. Network slicing can be used to solve these problems. (22)

3.4 Edge computing

A specific network architectural model is called Edge which brings the technological resources closer to the end user or the source of the data. That means the data does not need to travel a long distance. The edge is a decentralized extension of cellular networks. The aim of this is to process and store the data near where it is generated, only essentials being transmitted to the central data networks e.g. the cloud. It is a type of hybrid cloud, where the data can be processed faster than by using traditional methods. However, it does not replace traditional cloud computing. Edge computing is beneficial when there is a need for low latency, high reliability, preserve bandwidth, and connectivity, among others.

This is especially useful in IoT (internet of things), where various devices are connected to the internet and transmitting data that need to be processed, for example drones. Edge computing can also enable localization of data for those enterprises that need it for privacy or security reasons. It can also ensure business continuity by enabling backup options when there are disruptions in primary locations of an office. (23) See figure below.

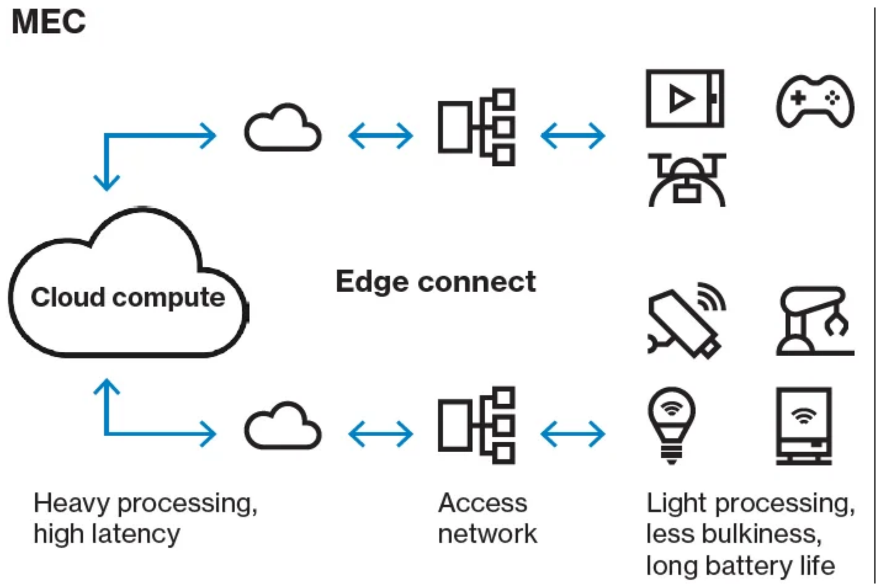

Figure 12: Multi-Access Edge computing (MEC). (23)

Multi-Access Edge Computing (MEC) utilize 5G being its primary connectivity. (23)

4 Industries

4.1 Power grid

China is one of the front runners for the use of 5G when it comes to the energy industry. They have released a few pilots which have shown great potential.

One of them is the 5G powered intelligent inspection conducted by SPSB (Shenzhen Power Supply Bureau).

The use of AI is already prevalent which can lead up to 80 times more efficiency. However, the use of AI with 5G is reaching new height. It is being used in the SPSB for inspection. Manual inspections are often complex and time consuming. It also requires the staff to drive back and forth between substations in the case of power outage between substations. Therefore, the use of intelligent inspection robots with high definition (HD) cameras are being used in substations to monitor and analyse data.

With 4G, wired transmissions were used by most sensors. Configuration was needed by hardware communications facilities, such as gateways, Optical Distribution Frames (ODFs), data communication and auxiliary control devices, and optical cables. This meant high costs.

As of December 2019, these problems were taken care of by upgrading to 5G at Pengcheng Substation.

Now inspection is done by robots with 5G. Results are then transmitted to a central intelligent analysis platform in real time. The analysis platform then detects faults, risks, and creates alarm while using edge computing and AI video recognition to collect data such as meter readings, location, and temperature. The routine inspection efficiency is increased by almost three times.

5G is also being used in the case of differential protection. Huang Fuquan, Deputy General Manager of the Power Dispatch Control Center of SPSB has said that "*Differential protection for a power distribution network can greatly reduce the area affected by power grid faults, eliminate faults at ultra-high speed, and optimize the electric power customer experience, achieving 'zero perception' of power outages."*

The electric input and output currents of a device should be the same, if that is not the case then it is considered faulty. Each electrical device requires protection to stop this from happening. Should it happen, it can be detected. Each device requiring protection is classified as connection nodes by differential protection. There is an automatic controller that is responsible for cutting off supply to any faulty device so other devices cannot be affected, because this could lead to power failure.

How the automatic controller works is that it makes a comparison between the input and output current in a device. Extremely low delay figures are required in this case since electric currents run at the speed of light. Optical fibres were implemented since the delay in 4G networks could reach up to hundreds of milliseconds.

However, it is not a great option since the fibres can be damaged, not to mention the large deployment costs and implementation time. After many tests, in labs as well as outdoor environments, it was concluded that since differential protection requires ultra-low latency of less than 15 ms, 5G networks is ideal choice to replace optical fibres. (24) See figure below.

Figure 13: 5G wireless communication differential protection cabinet.

4.2 Water Management

Water being one of the important natural resources, is very important to manage in an intelligent way. This is especially critical in terms of sustainability. Due to the climate change the effects are unpredictable e.g. draughts. IoT is being used to give customized benefits from unique needs. Benefits of smart water are reduced consumption, waste, reduced leaks, reduced billing and costs. (25)

A more automated, real time collection and analysis of data is needed for smart water management, for example, smart meters. (25)

Identify leaks are an important issue. It is often left to the customer to report the leak in order to get it fixed. It can result in 20% of potable water lost. Pumping and transportation of water is accounted to use 65% of annual energy costs. This figure could potentially be reduced 20% through the use of IoT sensors. (25)

Water demand management is another critical issue. It can be difficult to predict, thus studying patterns and implementing better models could deliver water suited by needs. (25)

Water quality can be monitored through open water or closed water in water mains. Companies may be able to check where contaminations could occur and take steps immediately. A wide range of chemicals and pollutant particulates can be measured.

For example, in Shanghai, China, a smart 5G environmental protection system monitors the water pollution by using satellite remote sensing technology. High resolution remote sensing with image processing technology is used to monitor indicators of water quality such as suspended solid content, water transparency, dissolved organic matter, and cyanobacterial bloom. (26)

All these are possible through IoT sensors, therefore mobile network coverage is crucial. In a smart city, these meters and IoT sensors should be interconnected. Therefore, improvements in networks such as 5G are beneficial. (25)

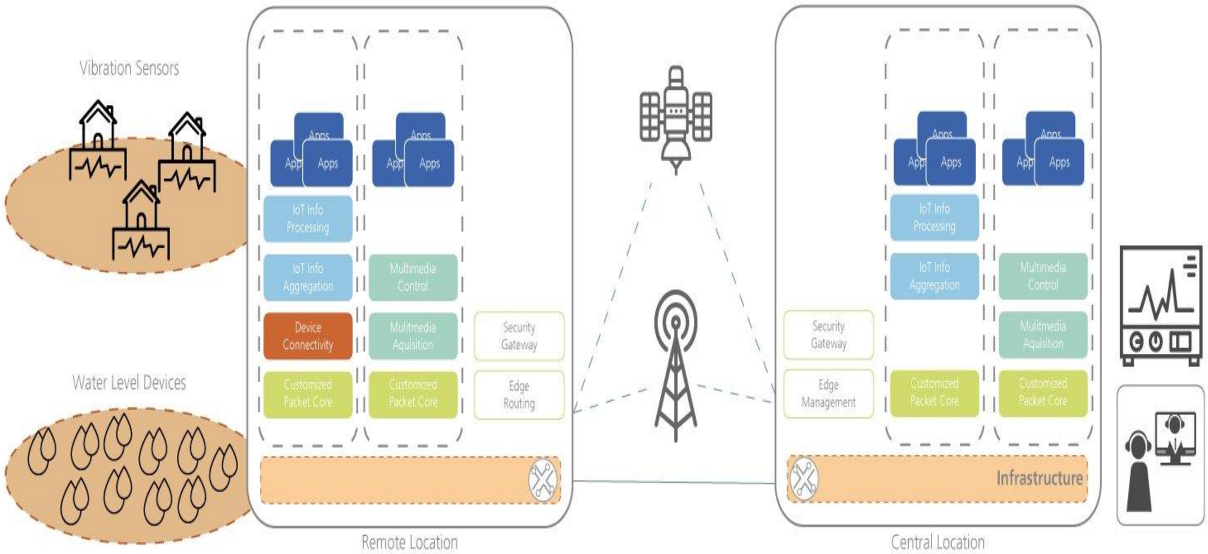

Figure 14: Smart water management system example. (27)

In the figure above, a water management example is shown. Various water sensors (water level and vibration) are in place and real time data is transferred to a central management where they are visualised and configured to make important decisions.

However, in this case 5G is not alone, there are also other contender when it comes to smart water management. Smart meters have been using LPWA (Low Power Wide Area) technologies for some time. Operators are typically choosing from Sigfox, LoRa (Low Range), and eMTC (Enhanced machine type communication).

Sigfox and LoRa operates on unlicensed spectrum, which could lead to interference. However, they are low in cost and has good battery life (about 10 years). Sigfox does not require operators to build their own network. It however may mean that the bandwidth is shared between other devices. It is also one of the higher power consumption choices. They both are ideal choice for uplink heavy use cases, as their downlink capacity is not the best. eMTC or LTE Cat M1, is an ideal choice for controlled applications and situations that need larger data handling as it has higher bandwidth capabilities. (28)

4.3 Air quality

Millions of people die every year due to polluted air. Therefore, maintaining safe air quality is vital. Monitoring air quality has always been a challenge but important to do as it can lead to safer and better life quality. Along the idea of a smart city, monitoring and collecting air related data has been proposed.

Minimizing exposure to poor air would require monitoring air quality in a massive scale. Mass deployment of air sensing devices with edge computing support would need to be implemented.

It would require stable connectivity, high bandwidth, high speed connections, and ultra-low latency for analysis, which all can be achieved through 5G and edge cloud along with AI powered sensors and image processing capabilities.

On top of that, edge clouding with 5G supports various frameworks and connections for smart city implementations. 5G networks with low latency and high bandwidth can transfer the data needed for real time analysis, which is done by an AI algorithm. Edge servers, located with 5G base stations provide close proximity to the sensors and end users. By enabling the low-cost sensors and hyperspectral cameras to send needed data to the servers, battery life and computation power can be conserved while supporting scalable, secure services.

An experiment was conducted by University of Oulu to demonstrate the feasibility in deploying AI algorithms, in calibration and image processing, on a real-world 5G Test Network (5GTN). A comprehensive scalability analytics of system latency, throughput and computation resources on edge servers was conducted. See figure below.

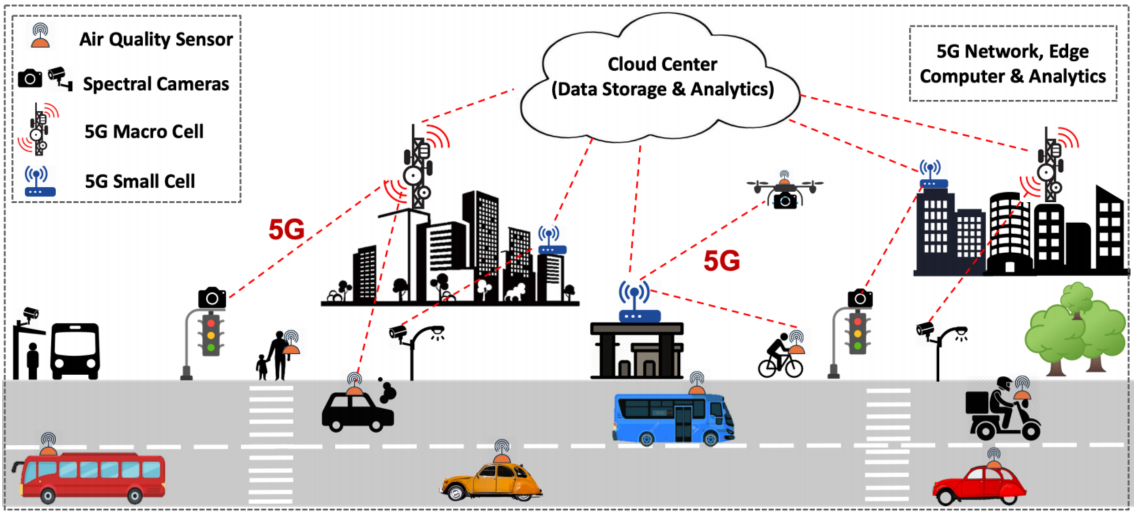

Figure 15: Example of an air quality monitoring system. (29)

The test bed consisted of 5GTN, edge servers, air quality sensors and hyperspectral cameras. It provided a non-standalone 5G and LTE connection, controlled through operator grade EPCs.

The experiment was conducted with air interfaces of two 5G macro cells, several LTE macro cells, and a LoRa network supporting frequencies. The testbed also supported heterogeneous wireless technologies, including IEEE 802.11, Bluetooth LE (Bluetooth Low Energy), LoRa (Long Range), NB-IoT (Narrow Band Internet of Things), and LTE evolutions. See figure below for test results. (29)

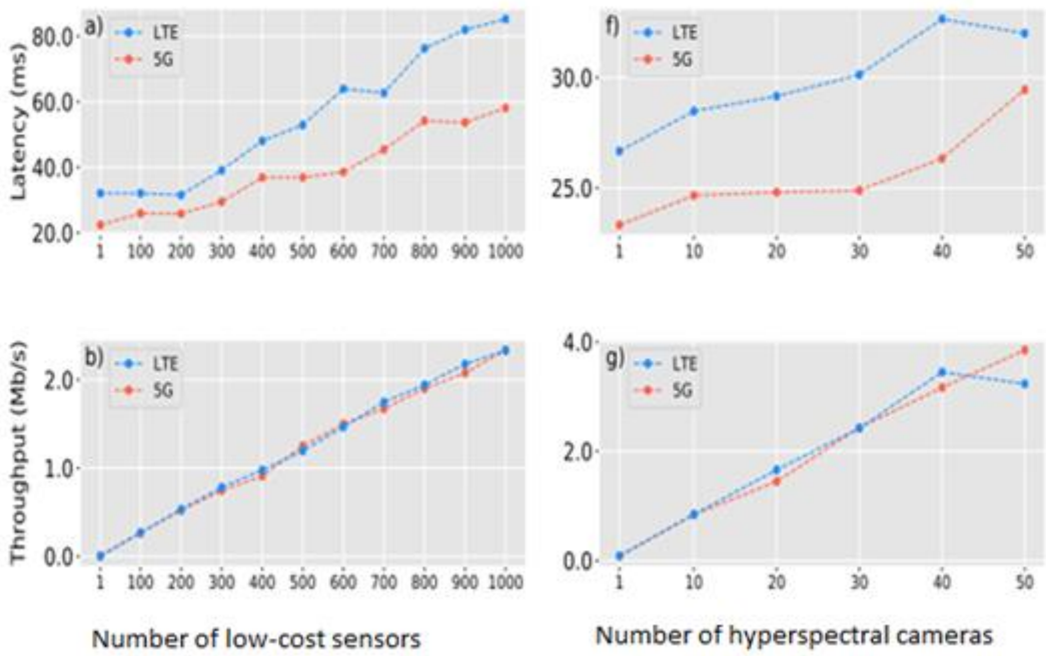

Figure 16: Results from the experiment. (29)

One the left, scalability results for the low-cost sensors are displayed, while on the right the results are for the hyperspectral Specium IQ cameras.

In figure (a), a comparison of 5G and LTE has been conducted, showing that 5G has shown 28% latency improvement.
In (b), a 1.14% difference was found while comparing the throughput of 5G to LTE.
In (f), a comparison is made which finds a 17.6% latency improvement of 5G over LTE.
In (g) a 6.86% percentage difference is found between 5G and LTE connection in terms of throughput.

University of Helsinki has also established a programme by the name of "MegaSense". Since 2017, their goal has been to gather and fuse spatially variable gas and particulate measurements and provide solutions. They use high-end scientific instruments, commercial air quality transmitters, dense low-cost sensor arrays, and consumer wearables utilizing 4G and 5G technologies to collect the data. (30)

GPS and 5G infrastructure are also going to be used for positioning. Placement of mini sensors will be optimized for full coverage and urban mobility patterns will be studied. This project will include low-cost sensors air pollution sensors and high accuracy SMEAR (Station for Measuring Ecosystem Atmosphere relations) stations to monitor over 1200 different pollutant every second. (31)

4.4 Automation

The Oulu automated factory is a prominent example of 5Gs efficiency. In order to match the demand of production and flexibility, automation is needed. To operate more sustainably and safely, industries are using more massive machine type communications (MTC), real time control of machines, robot/human interactions and edge computing with analytic features. 5G played a big part in creating such smart factories as the one in Oulu that Nokia is using to build base stations among other telecommunication devices.

The Oulu factory is powered by Nokia Digital Automation Cloud. It uses a private wireless which provides a safe and secure way for all assets within and outside of the factory. IoT, edge cloud and real time analysis provide full visibility.

Flexibility is key for this factory as new 5G products are designed and ordered to be made. Therefore, rework of the floor plan is constant. Traditionally, all the device and machine communications have been done via Ethernet cables, however the downside of this is having to redo all the cabling once the production changes.

The material flow was handled by Omron LD autonomous Intelligence Vehicle, which would automatically deliver materials from storage to production line. It was connected to a separate Wi-Fi with fixed route. However, during handover it was discovered that the connectivity was poor, and the network coverage was not sufficient along the route. In such cases, the AIV (Autonomous Intelligent Vehicle) needed to be reconnected to Wi-Fi manually, thus providing inefficient material feed to the production as well as tying up staff who could be more useful elsewhere.

To ensure reliable connectivity in automation, Nokia Digital Automation Cloud platform, a private wireless solution was chosen. The AIV settings were adjusted for connectivity, improving automation significantly. The coverage problem was also solved, enabling the AIV to be anywhere on the factory floor without requiring manual reconnecting every time.

The following results were obtained:

- Usability (overall equipment effectiveness): 40% increase
- Efficiency of material feed operation: 30% increase
- System Maintenance work: 98% decrease (32)
-

In cases like this high availability is crucial. High availability refers to an agreed level of a system’s operational time (or uptime); ensuring minimum downtime (which means unavailability of the said system; e.g. for maintenance). The availability can be stated in a percentage system. (33)

Availability %	Downtime per year[note 1]	Downtime per quarter	Downtime per month	Downtime per week	Downtime per day
90% ("one nine")	36.53 days	9.13 days	73.05 hours	16.80 hours	2.40 hours
95% ("one and a half nines")	18.26 days	4.56 days	36.53 hours	8.40 hours	1.20 hours
97%	10.96 days	2.74 days	21.92 hours	5.04 hours	43.20 minutes
98%	7.31 days	43.86 hours	14.61 hours	3.36 hours	28.80 minutes
99% ("two nines")	3.65 days	21.9 hours	7.31 hours	1.68 hours	14.40 minutes
99.5% ("two and a half nines")	1.83 days	10.98 hours	3.65 hours	50.40 minutes	7.20 minutes
99.8%	17.53 hours	4.38 hours	87.66 minutes	20.16 minutes	2.88 minutes
99.9% ("three nines")	8.77 hours	2.19 hours	43.83 minutes	10.08 minutes	1.44 minutes
99.95% ("three and a half nines")	4.38 hours	65.7 minutes	21.92 minutes	5.04 minutes	43.20 seconds
99.99% ("four nines")	52.60 minutes	13.15 minutes	4.38 minutes	1.01 minutes	8.64 seconds
99.995% ("four and a half nines")	26.30 minutes	6.57 minutes	2.19 minutes	30.24 seconds	4.32 seconds
99.999% ("five nines")	5.26 minutes	1.31 minutes	26.30 seconds	6.05 seconds	864.00 milliseconds
99.9999% ("six nines")	31.56 seconds	7.89 seconds	2.63 seconds	604.80 milliseconds	86.40 milliseconds
99.99999% ("seven nines")	3.16 seconds	0.79 seconds	262.98 milliseconds	60.48 milliseconds	8.64 milliseconds
99.999999% ("eight nines")	315.58 milliseconds	78.89 milliseconds	26.30 milliseconds	6.05 milliseconds	864.00 microseconds
99.9999999% ("nine nines")	31.56 milliseconds	7.89 milliseconds	2.63 milliseconds	604.80 microseconds	86.40 microseconds

Figure 17: Percentage calculation of high availability. (33)

In this factory, achieving a full five nine is possible with 5G, which is the same as wired connection with 5 times less cost of ownership. (32)

5 Other sustainable options to support 5G

Deploying 5G is going to take more creativity than previous generations. However, it is necessary because otherwise there will be a negative impact on the environment as well as increase in cost. Due to the nature of 5G, old technologies will need to be replaced. Installations will be costly. Therefore, solutions are needed from telecommunication companies to battle these problems. 5G needs to be supported by greener technology in order to minimize the energy consumption and cost of deployment.

5.1 Reefshark

Keeping small footprint, deployment costs and TCO in mind, Nokia has developed ReefShark chipsets. It is based on 3GPP (The 3rd Generation Partnership Project) 5G New Radio specifications, thus helping it reduce in size, cost and energy consumption at each cell site. It also boosts the intelligence and performance of massive MIMO antennas. The baseband processor boosts throughput capacity up to 84 Gbps while cutting power consumption by up to 64 percent, thus increasing system performance but keeping the operating costs generally low. (34)

5.2 Air-Cooled base stations

Nokia has also introduced water cooled 5G base stations, compared to traditional air cooled stations. This leads to reduction of wasted heat generated by base stations. Water cooling is more effective at trasferring heat than air and does not require noisy fans and reduces power consumption by 30%. It also reduces CO2 emissions by 80%. For example, The Finnish operator Elisa is currently the first one to use such 5G base stations. (35)

5.3 Dedicated software for energy management

Energy Infrastructure Operations (EIO) is a dedicated energy management solution which enables the use of AI and advanced data analytics in order to save energy across the entire network infrastructure, not just on individual sites. It has been in trial across various continents with positive results. SP (Service Provider) can achieve up to 15 percent reduction in energy related Opex, about 15 percent decrease in site visits, and about 30 percent drop in energy related outages. (36)

Operating a radio site is a difficult process. In order to manage it efficiently, a clear picture of their capabilities, capacity and performance is required. Service providers also need to have fast and effective responses to overloads, faults and failures. The information SP uses to make important decisions is not always from real time data from the radio sites. Therefore, a more unified system for management is needed, such as “The Ericsson Smart Connected Site.” It aims to solve such problems by integrating all the site elements to a handy management system. This enables full visibilities which will be helpful in planning, expanding of resources, fault, and energy management. The outcome will be a major reduction in Lifecyle costs, variable costs such as energy through remote control and more precise maintenance. (37)

6 Environmental concerns of 5G

There is no doubt that 5G has numerous benefits and use cases. Vendors have branded 5G to be “greener” and “energy efficient”. Although 5G is more energy efficient than 4G, the data traffic volumes will only go up due to numerous use cases and increased number of users and device. The only thing vendors are trying to achieve is keeping the cost at bay; however, in the long term it is not enough for sustainability.

The latest estimation is that the mobile networks leave energy footprint of about 2-3 % per year.

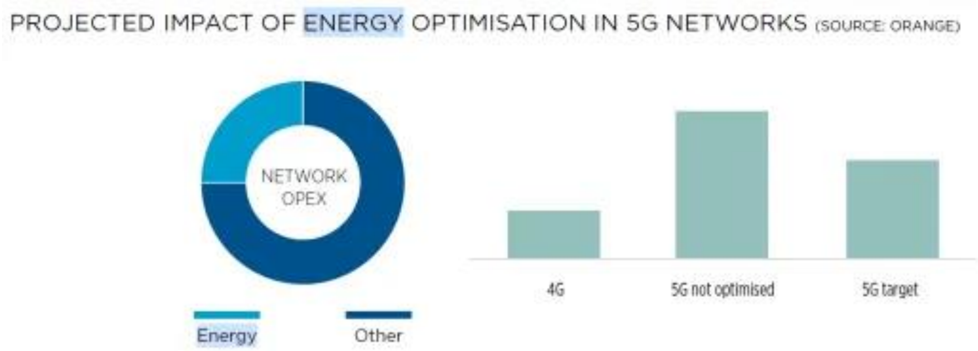

Figure 18: Energy optimization in 5G networks. (38)

The figure demonstrates results by a French telecommunication company. Even with 5G network optimized for energy efficiency, the impact will be higher than 4G.

Some vendors such as Ericsson and Telia believe it is possible to optimize 5G networks without any net increase in energy usage. Huawei, however, estimates that around 2021 the energy consumptions will fall, only to rise again with increased network deployments. It was calculated that the increase will be 5% p.a. throughout 2022 to 2025. This forces companies to look at 5G in another light, as it means that energy usage will be increased by incremental 30%. (38)

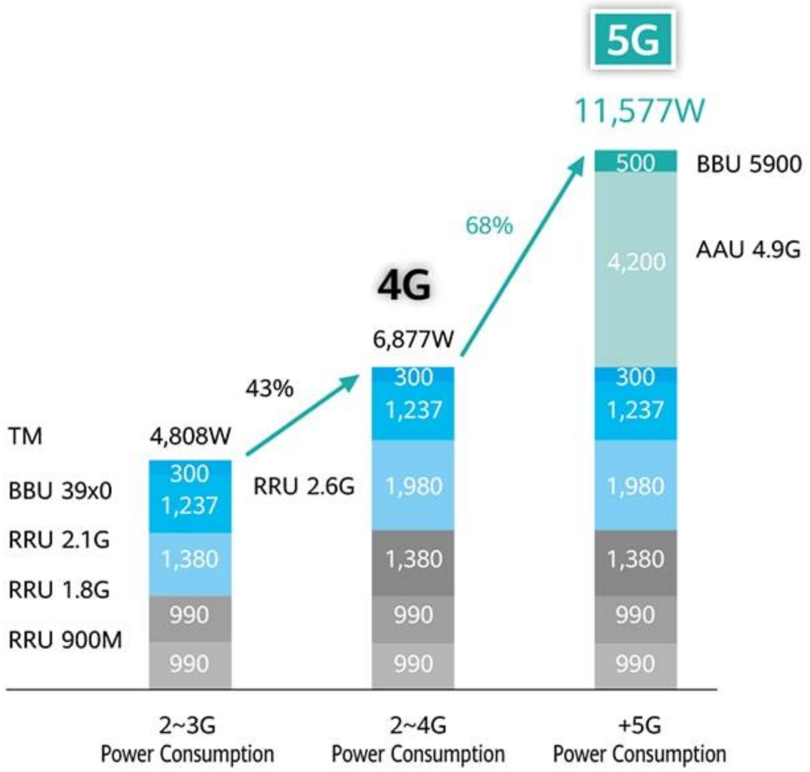

Figure 19: Typical power consumption of a single 5G base station. (39)

Huawei predicts energy consumption of 4G is much more than 5G when comparing consumption per unit data (watt/bit), however, the maximum power consumption of a 64T64R active antenna unit (AAU), is much higher in 5G than

4G. As the figure shows, it could potentially reach anywhere between 1 to 2 kW per BBU (baseband unit). (39)

Various scenarios have evaluated that the usage of green energy in mobile networks could potentially be a sustainable and economically friendly solution in powering heterogeneous networks. (40)

7 Powering mobile networks with green energy

With the surge of mobile traffic, it is prevalent that the industry of mobile networks is a major contributor to the CO2 emission on the environment. Therefore, major telecommunication industry players have introduced the concept of green energy powered off-grid base stations, which also helps to keep OPEX costs low in rural areas. However, these solutions have not been deployed in larger scale as it is more expensive than grid energy. (40) Renewable clean energy is desperately needed in the implementation of smart cities.

By adopting green energy powered base stations, grid energy consumption could be reduced which leads to reducing CO2 emissions. For example, a French mobile network operator called Orange has already deployed numerous green powered base station in Africa, serving over 3 million people. 25 million litres of fuel and 67 kilograms of CO2 have been saved. (41)

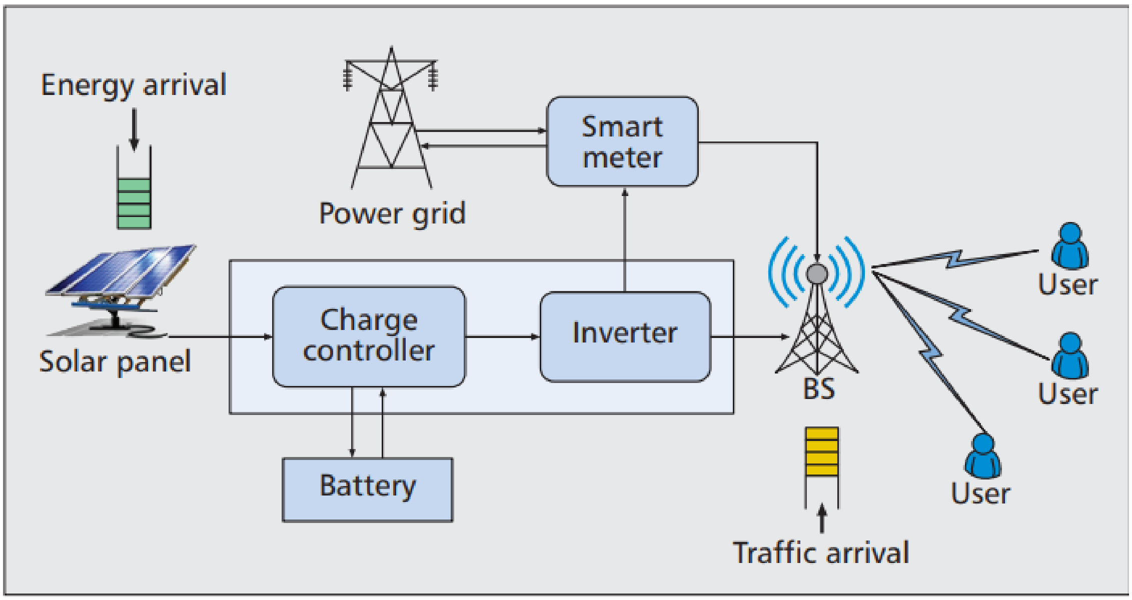

Figure 20: A green powered base station. (40)

Shown in the figure above is a simplified version of a green base station model. In order to utilize green energy, a few energy related components are integrated into the design of the base station. The power generator, in this case solar panels, is connected to a charge controller which regulates the output voltage of the power voltage, which operates on battery and is connected to the DC-AC inverter. The most important part is the smart meter, which is responsible for power transmission between power grid and the green powered base station.

Unfortunately, the green power generation depends highly on the geo locations and weather conditions of the power generators. Meanwhile, the energy consumption of mobile network is also dynamic. Dynamic mobile power consumption could also benefit from the network implementation designs. The implementation should be based on statistical data using prediction models. For example, availability of solar energy can be predicted from statistical data. However, it relies on data of solar energy expected under a clear sky condition, cloud coverage estimation forecasts etc. as demonstrated by the following formula:

$E = Ec(1 – b).$

E = the amount of predicted solar energy

Ec = amount of predicted solar energy

b = the amount of solar energy under a clear sky condition, and the cloud coverage estimation.

The example above illustrates Markov’s stochastic process which is an analytically simple and practically accurate model for solar energy generation. However, just because it is not feasible at the moment, does not mean it cannot be so in the future. For example, Photovoltaic solar panel is expected to be at least 50% cheaper than it is now by 2030 with almost 3 times the increase in number of users. (40)

One other solution could be energy harvesting. Power scavenging from ambient heat, human activity, light, RF, vibration etc. could be a potential alternative. RF is ideal in wireless communication environments. Harvesting energy from the radio signals in air, enables the recycling of energy, avoiding waste. However, it is difficult to predict how much RF signals there could be in real environment. The random nature of this process possesses the risk of power outages. Nevertheless, more research and experimentations are needed in order to make this option viable. (42)

With efficient design and operating 5G with green energy, more sustainability is expected to be achieved.

Conclusion

In many ways 5G is a technology that is still under construction. The potential of this technology is immense and new business opportunities are arising every day. However, with these benefits of 5G, the data consumption rates are rising exponentially. This leads to the question of energy consumption and how sustainable it would be to install all these new upgrades. Big companies such as Nokia and Ericsson are keeping sustainability in mind while developing new solutions and use cases for this technology. In terms of sustainability, saving money, time and efficiency, 5G is unmatched compared to its predecessors, and using 5G is expected to be more beneficial and efficient than 4G.

5G could potentially play a big role in combatting environmental and energy challenges, however it is not enough. New technology must be developed in order to support 5G in the sustainability challenge. Although 5G can be used to save energy, the sheer number of devices cannot be ignored. With new use cases, more devices will be connected, driving up the energy consumption numbers. Some good innovations are being used, such as Nokia’s air-cooled base station. However, more green energy needs to be used as an alternative to grid energy if it were to be sustainable in the long term.

References

1. Ericsson: Mobility Report 2020 November. *Ericsson.* [Online] 3 May 2021. https://www.ericsson.com/4adc87/assets/local/mobility-report/documents/2020/november-2020-ericsson-mobility-report.pdf.

2. Sustainability Definition. *Cambridge.* [Online] https://dictionary.cambridge.org/dictionary/english/sustainability.

3. What is 5G. *DigitalTrend.* [Online] [Cited: 20 November 2020.] https://www.digitaltrends.com/mobile/what-is-5g/ .

4. Ericsson. *5G radio.* [Online] [Cited: 2 May 2021.] https://www.ericsson.com/en/public-policy-and-government-affairs/5-key-facts-about-5g-radio-access-networks.

5. CableFree: RAN. *CableFree.* [Online] 3 May 2021. https://www.cablefree.net/wirelesstechnology/4glte/lte-4g-5g-radio-access-network-ran/.

6. Ericsson: Energy Efficiency in RAN. *Ericsson.com.* [Online] [Cited: 22 November 2020.] https://www.ericsson.com/en/portfolio/networks/ericsson-radio-system/radio-system-solutions/energy-efficiency.

7. Machine Learning & AI. *Ericsson.* [Online] [Cited: 1 May 2021.] https://www.ericsson.com/en/networks/offerings/network-services/augmenting-mimo-energy-management-with-machine-learning-and-ai .

8. 5G networks 90% more energy efficient. *Nokia.* [Online] [Cited: 22 May 2021.] https://www.nokia.com/about-us/news/releases/2020/12/02/nokia-confirms-5g-as-90-percent-more-energy-

efficient/#:~:text=Espoo%2C%20Finland%20%E2%80%93%20A%20new%20study,(RAN)%20in%20Telef%C3%B3nica's%20network..

9. Abrol, Akhshita and Jha, Rakhesh Kumar. *Power optimization in 5G networks: A step towards GrEEn Communication.* [Online] Jammu And Kashmir : s.n., 2016.

10. Masoudi, Meysam, et al. *Green mobile networks for 5G and beyond.* [Online] 2019.

11. 5G core. *Ericsson.* [Online] [Cited: 10 May 2021.] https://www.ericsson.com/en/core-network/5g-core.

12. Sandor Sipor, Product Manager. *TB4 hybrid base station evolution towards 5G.* [Document] Helsinki : Aibus, 2021.

13. Energ consumption with 5G NR. *Ericsson.* [Online] [Cited: 22 May 2021.] https://www.ericsson.com/en/blog/2019/9/energy-consumption-5g-nr.

14. Performance analysis of channel allocation schemes in WiMAX. *Researchgate.* [Online] [Cited: 20 May 2021.] https://www.researchgate.net/publication/268323954_Performance_Analysis_of_Channel_Allocation_Schemes_in_WiMAX#pf56.

15. 5G network analysis. *Netmanias.* [Online] [Cited: 1 May 2021.] https://www.netmanias.com/en/post/blog/8256/5g-c-ran-fronthaul-kt-korea/5g-network-as-envisioned-by-kt-analysis-of-kt-s-5g-network-architecture.

16. 5G NR. *Verizon.* [Online] [Cited: 2 April 2021.] https://www.verizon.com/about/our-company/5g/what-is-5g-nr.

17. What is 5G. *Edition.cnn.com.* [Online] [Cited: 22 November 2020.] https://edition.cnn.com/interactive/2020/03/business/what-is-5g/index.html.

18. Massive MIMO and beamforming. *Rcrwireless.* [Online] https://www.rcrwireless.com/20180912/5g/5g-nr-massive-mimo-and-beamforming-what-does-it-mean-and-how-can-i-measure-it-in-the-field.

19. Beamforming explained. *Network world.* [Online] [Cited: 10 May 2021.] https://www.networkworld.com/article/3445039/beamforming-explained-how-it-makes-wireless-communication-faster.html.

20. Ericsson: Network Slicing. *Ercisson.* [Online] 6 May 2021. https://www.ericsson.com/en/network-slicing?gclid=Cj0KCQjwp86EBhD7ARIsAFkgakgDHQ8bsR62JfjI6nye1m9BXuXtViQD2dwpcVtaJICiMW8ei51_PkcaArNwEALw_wcB&gclsrc=aw.ds.

21. Nokia: 5G connected industry. *Nokia.* [Online] [Cited: 6 May 2021.] https://pf.content.nokia.com/t004f3-private-wireless-manufacturing/ebook-5G-connected-industries.

22. Network slicing. *ZTE.* [Online] [Cited: 5 May 2021.] https://www.zte.com.cn/global/about/magazine/zte-technologies/2018/1/Special-Topic/5G-network-Slicing.html.

23. Verizon: Edge Cloud. *Verzon.* [Online] [Cited: 6 May 2021.] https://www.verizon.com/business/solutions/5g/edge-computing/5g-and-edge-computing/?cmp=knc:ggl:ac:ent:mec:8003162844&utm_term=%2B5g%20%2Bedge&utm_medium=knc&utm_source=ggl&utm_campaign=mec&utm_content=ac:ent:8003162844&utm_term=%2B5g%20%2Bedge&gclsrc=aw..

24. Huawei: 5G and AI encounters power grids. *Huawei.* [Online] [Cited: 3 May 2021.] https://e.huawei.com/en/case-studies/industries/energy/2020/5g-ai-encounter-power-grids.

25. Smart Water management. *GSMA.* [Online] [Cited: 22 May 2021.] https://www.gsma.com/iot/wp-content/uploads/2018/01/miot_smart_water_01_18.pdf.

26. Smart environmental protection with 5G. *Tomorrow city.* [Online] [Cited: 22 May 2021.] https://tomorrow.city/a/5g-smart-environmental-protection-water-at-its-best.

27. Fokus: 5G ready trial platform. *Fokus.* [Online] [Cited: 22 may 2021.] https://www.fokus.fraunhofer.de/f68d069d352478e9.

28. Smart water metering. *m2mserver.* [Online] [Cited: 28 May 2021.] https://m2mserver.com/en/iot-communication-technologies-for-smart-water-metering/.

29. IEEE Xplore. *Intelligent and Scalable Air Quality Monitoring With 5G Edge.* [Online] [Cited: 25 May 2021.] https://ieeexplore.ieee.org/document/9354565.

30. Megasense. *Helsinki.* [Online] https://www2.helsinki.fi/en/researchgroups/sensing-and-analytics-of-air-quality/about-megasense.

31. Air quality monitoring. *Helsinki.* [Online] [Cited: 15 May 2021.] https://www2.helsinki.fi/en/researchgroups/sensing-and-analytics-of-air-quality/topics/air-quality-monitoring.

32. Oulu automated factory. *Nokia.* [Online] [Cited: 2 March 2021.] https://pf.content.nokia.com/t004f3-private-wireless-manufacturing/case-study-Nokia-Oulu-factory.

33. High Availability. *Wikipedia.* [Online] [Cited: 30 May 2021.] https://en.wikipedia.org/wiki/High_availability.

34. Nokia. Reefshark. [Online] 28 October 2020.
https://www.nokia.com/networks/technologies/reefshark/.

35. Air cooled base station. *Nokia.* [Online] [Cited: 19 November 2020.]
https://nokiamob.net/2020/06/07/elisa-will-start-using-nokias-liquid-cooled-5g-base-stations-to-lower-co2-emissions/.

36. Network management. *Ericsson.* [Online] [Cited: 22 November 2020.]
https://www.ericsson.com/en/blog/2020/2/ai-network-management-energy-costs.

37. Site management. *Ericsson.* [Online] [Cited: 22 November 2020.]
https://www.ericsson.com/en/blog/2020/1/bringing-5g-site-management-to-the-intelligent-era.

38. Energy efficiency . *GSMA.* [Online] [Cited: 20 December 2020.]
https://www.gsma.com/futurenetworks/wiki/energy-efficiency-2/.

39. 5G power consumption per base station . *Huawei.* [Online] [Cited: 29 May 2021.] https://www.huawei.com/en/technology-insights/publications/huawei-tech/89/5g-power-green-grid-slashes-costs-emissions-energy-use.

40. Tao Han, Nirwan Ansari. Researchgate. *Researchgate: Powering mobile networks with green energy.* [Online] February 2014. [Cited: 7 May 2021.]

41. —. *Green Mobile Networks: A Networking Perspective.* [E-book] New Jersey : s.n.

42. Energy harvesting technologies. *Researchgate.* [Online] [Cited: 20 may 2020.]
https://www.researchgate.net/publication/4367713_Novel_Energy_Harvesting_Technologies_for_ICT_Applications.

43. Mobile data traffic: June 2020. *Ericsson.* [Online] [Cited: 22 November 2020.] https://www.ericsson.com/en/mobility-report/reports/june-2020/mobile-data-traffic-outlook.

44. 5G SA and NSA. *RedSteelecom: .* [Online] [Cited: 3 May 2021.] https://www.redestelecom.es/siteresources/files/894/48.pdf.

45. NordKapp: Blue Green algae at baltic sea. *NordKapp.* [Online] [Cited: 1 May 2021.] https://nordkapp.fi/insights/5g-harnessed-for-monitoring-of-blue-green-algae-at-the-baltic-sea/.

46. Beamforming explained. *NetworkWorld.* [Online] [Cited: 30 April 2021.] https://www.networkworld.com/article/3445039/beamforming-explained-how-it-makes-wireless-communication-faster.html.