Techno-economic Analysis of 5G Local Area Access in Industrial Machine-to-Machine Communications

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ABSTRACT OF THE
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Billions of connected devices, new application requirements, deployment scenarios and business models are driving the evolution of the next generation 5G networks. 5G will be the key to tap into the business potential for 2020 and beyond. Industrial machine-to-machine (M2M) communications will have highly demanding connectivity requirements. These requirements will be vastly different depending on the specific use case and will require customized connectivity. This thesis builds possible future scenarios and value networks for 5G local area industrial M2M communications beyond 2020 with a 10 years time frame.

The case of Industrial M2M communications is discussed by classifying the future requirements and the business potential, which is discussed using market statistics and forecasts from various sources. By diving into the ongoing research, the promising 5G technology enablers are explored with a possible 5G technical architecture. The theory of the methods used, scenario planning and value network configurations, is explained before formulating the future scenarios and value networks. Interviews with industry experts were organised to find the current situation of industrial internet, market trends and future uncertainties. This forms the basis for future scenarios and identifying most important roles and actors that take part in the value networks.

The resulting four future scenarios indicate how the future of 5G M2M ecosystem will shape up and helps all stakeholders to plan and strategize. The resulting five value networks explore the actors, role distributions and value creation. The value networks are then mapped on to the scenarios, displaying the consistency of the results. These results can help identify the possibilities of value creation, new business models and market changes.

Keywords: 5G, M2M, IoT, Industrial Internet, Scenario Planning, Value Network Configuration

Preface

I am filled with gratitude towards Professor Heikki Hämmäinen and my advisor Alexandr Vesselkov. Heikki always encouraged me to see the bigger picture and discussions with him have helped me build my understanding in the field of techno-economics. Alexandr is a great critic and his advices helped me a lot in the final stages of thesis writing.

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My thanks is also due to my elder brother who has always inspired me and brought out the best in me. Finally I would like to thank my family who have encouraged and supported me at every stage in life.

Otaniemi, 21.11.2016

Jaspreet Singh Walia

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Abbreviations and Acronyms

1G	First Generation
2G	Second Generation
2.5G, 2.75G	Generations between second and third generation
3G	Third Generation
3.5G	Generation between 3rd and 4th generation
3GPP	3rd Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
5GPPP	5G infrastructure Public Private Partnership
6LoWPAN	IPv6 over Low power Wireless Personal Area Networks
AAA	Authentication Authorization and Accounting
APN	Access Point Name
ASP	Application Service Provider
CAGR	Compound Annual Growth Rate
CAN	Controller Area Network
CDMA	Code Division Multiple Access
CoAP	Constrained Application Protocol
CP	Control Plane
C-RAN	Cloud-RAN
Critical MTC	mission-Critical Machine-Type Communication
D2D	Device-to-Device
DA	Device Application
DL	Downlink
DSL	Digital Subscriber Line
DUDe	Downlink and Uplink Decoupling
e2e	end-to-end
E2e QoS	End-to-end Quality of Service
EDGE	Enhanced Data Rates for GSM Evolution
eSIM	Embedded- Subscriber Identity Module
ETSI	European Telecommunications Standards Institute
FDD	Frequency Division Duplex
GA	Gateway Application
GHz	Gigahertz
GSMA	Groupe Speciale Mobile Association
HTTP	Hypertext Transfer Protocol
ICT	Information and Communications Technology
IEEE	Institute of Electrical and Electronics Engineers
IMT-2020	International Mobile Telecommunications for the year 2020
IoT	Internet of Things
IP	Internet Protocol

IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
ITU-T	International Telecommunication Union-Telecommunication standardization sector
LAA	License Assisted Access
LAN	Local Area Network
LOS	Line-of-Sight
LPWA	Low Power Wide Area
LTE	Long Term Evolution
LTE-A	LTE-Advanced
M2M	Machine-to-Machine
M2M SL	M2M service layer
Massive MTC	Massive Machine-Type Communication
METIS	Mobile and wireless communications Enablers for the Twenty-twenty Information Society
MHz	Megahertz
MIMO	Multiple Input Multiple Output
mmWave	Millimeter Wave
MNO	Mobile Network Operator
MTC	Machine-Type Communication
MVNO	Mobile Virtual Network Operators
NA	Network Application
NFC	Near Field Communication
NFV	Network Functions Virtualization
NGMN	Next Generation Mobile Networks
NLOS	Non-Line-of-Sight
PROFIBUS	Process Field Bus
QoS	Quality of Service
RAN	Radio Access Network
RAP	Radio Access Point
RAT	Radio Access Technology
RFID	Radio-frequency Identification
SDN	Software Defined Networking
SIM	Subscriber Identity Module
SL	Service Layer
SMS	Short Messaging Service
SP	Service Provider
TCP	Transmission Control Protocol
TDD	Time Division Duplex
UDN	Ultra Dense Networks
UDP	User Datagram Protocol
UL	Uplink
UMTS	Universal Mobile Telecommunications System
UP	User Plane
USD	US Dollars
VNC	Value Network Configuration
Wi-Fi	Wireless Fidelity
xDSL	All types Digital Subscriber Line

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1 Introduction

Every decade the world sees a new telecommunication generation being adopted. Telecommunication generations have moved from analog 1G (First Generation) to digital 2G giving rise to Short Messaging Service (SMS), to higher data rate 3G giving rise to mobile navigation, location based services and mobile TV, to an even faster, ever evolving, all Internet Protocol (IP) based 4G [1]. The development and adoption of a new generation is not just a tradition but is driven by future needs, a need for more connected devices, higher capacities, higher speeds and newer applications. Thus, the change in the name of a generation refers to a change in the nature of the service, higher peak data rates, new frequency bands, wider frequency bandwidth and higher capacity.

The world is moving towards a more connected society. The idea of the Internet of Things (IoT), as a network of smart devices has been gaining momentum in the industry due to the vast opportunities it can offer. To get an idea of what IoT can become, as an analogy , imagine a crossroad walked by people of different languages, origins, life roles. Each person has his own story and knowledge. If every person could share their useful knowledge and communicate without any barrier, imagine how intelligent and efficient each person could become. Similarly in IoT, every device or thing that is capable of connecting to the internet or be able to be read by sensors, will be connected. IoT is such a network of things/devices that gives a wealth of services that can revolutionize the way we live and work based on seamless interactions between large numbers of heterogeneous devices. A connected car, a lamp post and a wearable device could make crossing roads at corners easier and safer if the lamp post can inform the car driver about the pedestrians walking towards the crossing and vice versa. In industrial context, the industrial processes could reach tremendous level of sophistication and efficiency. For example, logistics, with a fully connected supply chain from raw material to automated manufacturing to final product shipment. All this can be controlled by applications running on local or far away servers, logging and processing data for future enhancements. With more applications and use cases, the possibilities and outcomes are limitless. This puts industrial machines communicating with each other at the forefront of IoT for improving industrial processes.

The vision of industrial Machine-to-Machine (M2M) communications is to enable communication between machines in a flexible and autonomous manner where such connectivity was traditionally provided by non-flexible wired solutions. Cellular M2M is the frontier of revolutionizing the industry, but even with having an upper hand compared over wired solutions, 3GPP (3rd Generation Partnership Project) needs to fulfill many new requirements, like lower latency, flexibility, wider bandwidth etc. to be able to make this vision come true. Continuous research is being conducted to develop new use cases of communication which lead to new requirements in the way these technologies are built. These requirements are fulfilled by enabling technologies also known as technology enablers for the next generation of telecommunication. These technology enablers that make a new generation possible can lead to either evolutionary or revolutionary standards. Evolutionary standards are backward compatible, for example, in pre-3G (2.5G and 2.75G), EDGE (Enhanced Data rates for GSM Evolution) and CDMA (Code Division Multiple Access) are backward compatible with 2G networks but 3G UMTS (Universal Mobile Telecommunications System) does not support EDGE [2]. These changes can also bring about evolutionary and revolutionary changes in the way services are offered and thus bring about changes in the market. The upcoming 5th Generation 3GPP networks, called 5G, is expected to bring about the fourth industrial revolution to the world. 5G will be built on a completely virtualized core that can, with flexibility, fulfill various use cases and orchestrate and manage resources. But the proper description of 5G can be understood by discussing in detail the requirements that it will fulfill, the technology enablers and the architecture that will bring about this change. 5G is still in development and it is pretty unclear how it unfolds and how the market changes, so it is necessary to analyze the uncertainty in the future. This thesis will analyze the future of Industrial M2M and 5G using scenario planning method and build feasible value network configurations. This will provide a good insight from a techno-economic point of view as to what to expect from the future industrial M2M communications in a 5G world.

1.1 Research Question

There is always an uncertainty of success or failure of the market because it is very hard to know the possible future, but with careful investigation this risk can be reduced. There are many directions in which the business can go, thus it is also important to predict how the market will take form. The thesis studies the industrial revolution that will be brought about by 5G in M2M communication, thus the research questions:

- What are the possible future scenarios for 5G local area access in Industrial Machine-to-Machine Communications?

- What are the possible value network configurations for 5G local area access in Industrial Machine-to-Machine Communications?

1.2 Scope of Study

In the thesis the scope is limited to the use cases serving local industrial 5G M2M, also including mobile connectivity for machines moving inside the local area, thus it will include local indoor and on site outdoor area access. The definition of local area is best understood by considering only the industry owned land. The scope includes local area small cells. The corresponding base stations for the small cells on industry premises would most likely be owned by the industry. It will look at some technical aspects of 5G and M2M but on the whole the thesis will focus on a techno-economic view of 5G and M2M.

1.3 Research Method

The thesis includes a research based on interviews and literature survey of academic and industry research publications. Ongoing research in the major organizations is studied, such as ETSI (European Telecommunications Standards Institute), METIS (Mobile and wireless communications Enablers for the Twenty-twenty Information Society), 5GPPP (5G infrastructure Public Private Partnership), 5G Americas, ITU-T (International Telecommunication Union-Telecommunication standardization sector) etc. The interviews conducted with many industry experts helps in getting the industry insight about the current state of industrial connectivity and ongoing research. The knowledge gathered from these sources is used to investigate future trends and uncertainties, major stakeholders and the businesses involved and also are used to explore the options in 5G technical architecture.

Scenario planning method based on trends and uncertainties will be used to construct future scenarios and their analysis will provide us valuable information regarding how the future markets will shape up in a 5G world. This method is described in detail in chapter 3.

Value network configurations are drawn to investigate how roles are distributed between important stakeholders and their analysis will provide crucial qualitative information about who drives the innovation and who collects the most money. This method is described in detail in chapter 4.

1.4 Organization of Thesis

After introducing the topics, research question and methodology in chapter 1, the thesis is structured further into five chapters. Chapter 2 studies the industrial Internet paradigm, future requirements and also what can be expected from 5G. It also discusses the required technology enablers for 5G and M2M. Chapter 3 involves construction of future scenarios based on trends and uncertainties collected through interviews and literature survey. Chapter 4 describes the technical architecture for 5G local area access in Industrial M2M Communications, with technical components and roles upon which the alternate value network configurations are constructed. Chapter 5 discusses the mapping of the value network configurations onto the future scenarios. Chapter 6 discusses the conclusions of the study and describes the future research in this field.

2 Background Information

This chapter describes the industrial Internet of things of today and also builds up the necessary literature required for this thesis. The following sections will contain market trends and future forecasts, key technology enablers for 5G and industrial M2M requirements and finally a proposed 5G architecture that will be used for value network analysis in later chapters.

2.1 Industrial Internet and 5G

IoT promises to revolutionize the way we work, communicate and live, not only human interactions, but also M2M communications. This idea of machines communicating as a network of smart devices has been there in the past but it has gained momentum since 1999 as the term IoT is believed to have first coined then [3, 4].

Microprocessors are found in all manner of things, such as phones, refrigerators, credit cards, biometric passports, cars, cameras, inventory systems, etc. These things have become ubiquitous and with internet connectivity, IoT with heterogeneous devices will soon be ubiquitous as well.

A distinction can be made between consumer IoT and Industrial IoT on the basis of business models. Consumer IoT focuses on individuals by connecting consumer electronic devices and other things within the user environment like homes and cities. This includes all internet connectable ‘thing’ in the user paradigm to make the user’s life easier. For example, connected cars, smart homes, wearables, smart phones, tablets and laptops, all connected to each other on the consumer’s network.

Industrial IoT, also known as Industrial Internet or industrial M2M communications, focuses on integration of machinery and networked sensors and software. It incorporates smart machinery, sensors, applications and data analytics to improve business processes like manufacturing, process automation and monitoring, vehicle fleet tracking, logistics tracking and inventory systems. For example, with industrial M2M, an automated inventory system comprising a device (such as a sensor or meter) to capture an event such as change in the inventory level, which is relayed through a network to an application, running on the device or on a server, which translates the captured event into meaningful information - whether items need to be restocked or not.

2.1.1 State of Industrial Internet

The state of industrial Internet today can be very well understood with an anatomy of the various components of today's M2M ecosystem and the technologies that are being used in the respective components, as follows:

- **Machines in M2M** - The machines that can be attributed an identity and can sense data (such as location, altitude, velocity, acceleration, weight, temperature, illumination, power, humidity, air quality and soil moisture) and are capable of relaying it to other machines on the network or to the servers. This includes all industrial machines those are capable of becoming a node in such network. Machines can have data and application processing capabilities or could just house a sensor to be read by another machine. These can also be scanning devices to scan Radio-frequency Identification (RFID) tags on devices that otherwise don't connect to the internet.

- **Local Area Communication** – There are many short range or local area communication wireless technologies being used, such as Bluetooth, Bluetooth Low Energy, RFID, NFC (Near Field Communication), Wi-Fi (Wireless Fidelity) and Zigbee. There are also wired technologies being used like Ethernet, PROFIBUS (Process Field Bus), CAN (Controller Area Network). 3GPP hasn't been able to enter this space of short-range technologies.

- **Wide Area Communication** – There are many wireless technologies for wide area, such as 3G, 4G and Worldwide Interoperability for Microwave Access (WiMAX). Fixed Machinery could also be connected over wide area using Ethernet or phone lines.

- **Servers** – There are local onsite servers for collecting and processing data as well as cloud based far away servers for further storage and analysis. Local server help in keeping the processing time lower but in some cases where the data generated is big and needs later analysis or the data needs to be shared with other industrial sites and offices then cloud based servers are used.

More information about current state of industrial internet was collected from industry experts about industry processes, automation and limitations of current technologies. Currently industrial internet is dominated by wired technologies like Ethernet, PROFIBUS and CAN, which limit the mobility and flexibility of the processes. There are also some wireless solutions based on Institute of Electrical and Electronics Engineers (IEEE) like Wi-Fi but those suffer from interference because of the sharing of unlicensed spectrum. Unlicensed spectrum inhibits guaranteed access and is also limited by regulatory policies such as listen-before-talk/transmit and limited transmit power [11]. These policies ensure coexistence but not reliability. Further physical layer and medium access mechanism affect end-to-end latency and therefore it is important that the lower layers impart least latency possible. Current wireless technologies can only support limited number of devices to meet latency requirements. Moreover, even though the 3GPP standard Long Term Evolution (LTE) can provide reliability and low latency in a long range it is not suited for short range industry environments as it specifically designed for long range.

Currently there are also some end-to-end proprietary radio solutions serving M2M. With proprietary radio solutions, the customer is dependent on the same operator and must buy all future devices and services from the same operator. This causes operator lock-in. The proprietary solutions lack interoperability and this increases the costs as the customer always has to buy proprietary interfaces and softwares. The ability to provide a Service Level Agreement (SLA) gives 3GPP an advantage over other connectivity solutions. Proprietary solutions do offer end-to-end channel, from device to core, for local area but with the improvements in the 3GPP standards it is expected that 3GPP will be able to offer end-to-end channel. A comparison between the connectivity technologies with respect to performance indicators is shown in table 1.

Table 1: Connectivity Technologies with respect to performance indicators

Connectivity Solution	Current					Future	
Technology/ Performance Indicator	Ethernet	Proprietary (LonWorks, Z-wave, Anaren)	Bluetooth	Wi-Fi	3GPP (3G,4G LTE)	Future Wi-Fi	3GPP (4G LTE NB-IoT, 5G)
Spectrum		Proprietary Unlicensed	2.4 GHz	2.4GHz, 5GHz	400MHz -4GHz	2.4GHz, 5GHz	400MHz-100GHz
Licensing		Unlicensed	Unlicensed	Unlicensed	Licensed	Unlicensed	Licensed
e2e Channel	Yes	Yes	No	No	No	No	Expected
Standard	Yes	No	Yes	Yes	Yes	Yes	Yes
Scalability	Low	Low	Low	Medium	High	High	High
Reliability	High	Medium	Medium	Medium	High	Medium	High
Power	Low	Low	Low	Low	High	Low	Low
Latency	Low	Medium	High	Medium	Medium	Low	Low
Coverage	Medium	Medium	Low	Medium	High	Medium	High
Mobility	No	Low	Low	Low	High	Medium	High
Module costs	Medium	Medium	Low	Low	High	Low	Low

2.1.2 Market forecasts and requirements

It is expected that the M2M value chain can reach projected revenues of 4 billion US Dollars (USD) in hardware, 25 billion in connectivity and 80-120 billion in value added services (connected device platform, device management, device connectivity, device cloud, application development, system integration, analytics and professional services) [6].

Cisco predicts that 14.4 trillion USD of value will be generated worldwide driven by the IoT by 2022 [7]. Out of this 45% will be generated by M2M connections. From a geographical perspective, the United States and Western and eastern Europe will be the leaders in terms of generated value. From an industrial perspective, Manufacturing (27%) and retail (11%) followed by Information services (9%) will lead the way. Cisco also predicts that smart factories will contribute 1.95 trillion USD by 2022.

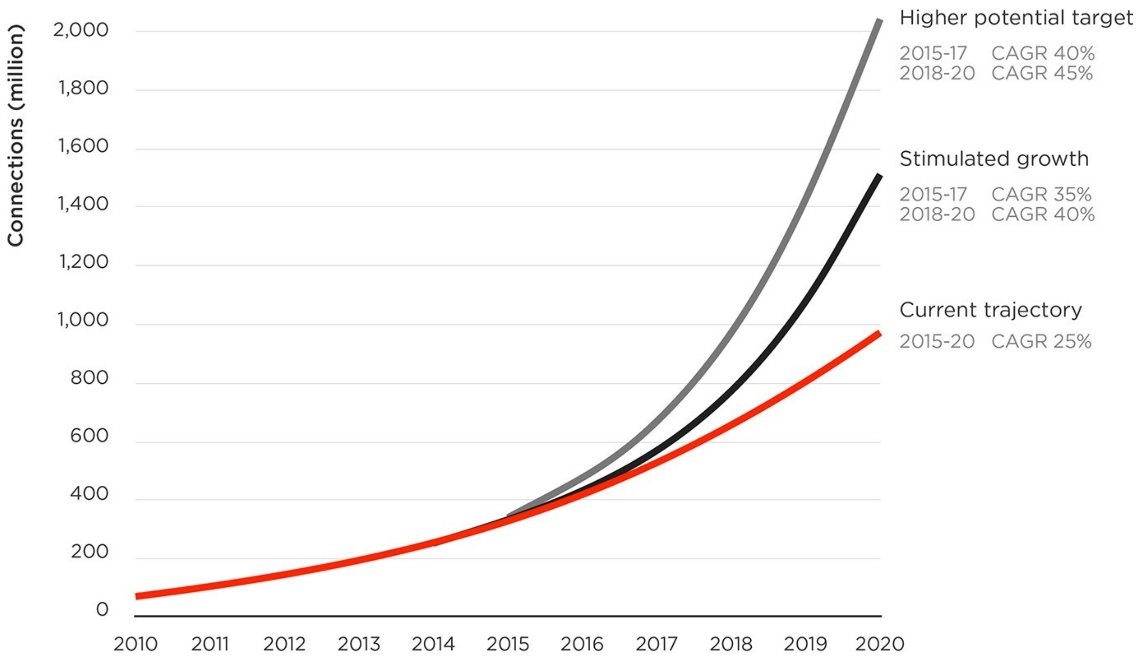

Figure 1: Cellular M2M connections forecast scenarios (Source: GSMA Intelligence ©GSMA Intelligence 2016).

Groupe Speciale Mobile Association Intelligence (GSMA Intelligence) predicts that non-consumer cellular M2M connections excluding consumer electronics like smartphones, tablets, etc. are expected to be 2 billion by 2020 [8]. According to the research by GSMA Intelligence, with the current growth trajectory the number of cellular M2M connection will reach 1 billion by 2020, but with removal of growth inhibitors by industries and governments, the Compound Annual Growth Rate (CAGR) for 2015-2020 could increase from 25% (Current growth trajectory) to 40-

45% (Higher potential target), which would realize the 2 billion figure by 2020. This is shown in figure 1. The future research requirements arise from future forecasts as listed in table 2.

Table 2: Future forecasts and research requirements.

Future Forecasts	**Research Requirements**
10 to 100 times higher number of connected devices	• Reduce signaling overhead by simplifying end-to-end procedures • Flexible network configuration using Network Functions Virtualization(NFV) • Traffic Concentration by using gateways linking local short range capillary networks to cellular networks
1000 times higher mobile data volume per area	• Larger bandwidths at higher frequencies • Densification of networks with small cells that can make use of higher frequency bands such as millimeter wave (mmWave) bands. • Improving performance and spectral efficiency by using massive antenna constellations and multi-node transmission.
10 to 100 times higher data rate	• Usage of higher frequencies • Reducing distance between devices e.g. Ultra-Dense Networks

2.1.3 Technical requirements for 5G and M2M

Within the 3GPP family, the 2G technology is appropriate for low power consumption and low costs but cannot fulfill higher data rates. 3G, has higher costs and lower power efficiency than 2G but is able to fulfill some low end IoT applications for e.g. vehicular communication. 4G technologies, LTE and LTE-A (LTE-Advanced) are able to meet some demanding requirements for M2M applications, although their lower coverage and higher costs are an issue. Also, adapting 4G to M2M applications is a major challenge as it was specifically designed for efficient broadband communications and thus the costs will be higher even with the new narrowband LTE release. Thus 5G could be able to offer lower cost, lower energy, larger number of devices and wider coverage with focus on IoT and M2M and thus shall become a preferred choice over 4G in the future. The future can be seen as a combination of 4G and 5G (3GPP) working together and competing with IEEE standards for local area communication. The 5G standards are tentatively expected to be finalized by October 2020 and a timeline adopted from [9], depicting the various stages is shown in figure 2 .

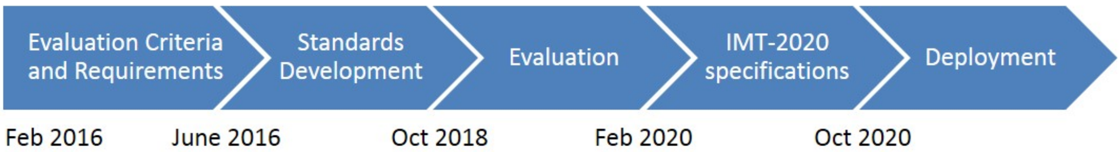

Figure 2: Tentative 5G Timeline.

The main challenge for 5G is to be able to serve and fulfill new requirements. Earlier 3GPP cellular systems were primarily designed more for human and less for machines. The future will have traffic not only between humans but also between machines. There are many technical requirements for M2M that 5G needs to fulfill.

1. **Low latency and high reliability:**
   Latency refers to the time delay between data being generated and the same data being correctly received. For example, the data generated by a sensor and being received by an actuator. Reliability refers to the probability of successful message transmissions with a given latency or within a defined timeframe. Industrial process automation, tactile internet, automated guided vehicles are some use cases that will require very low end-to-end (e2e) latency and high reliability. Such communication use cases that require communication with very high reliability and availability, as well as very low e2e latency are called mission-critical machine type communications.
   From a communication technology perspective, M2M can be divided into

two categories: Massive machine-type communication (Massive MTC) and mission-critical machine-type communication (Critical MTC). Massive MTC requires connectivity for large numbers of low-cost and low-energy devices. Critical MTC requires real-time control and automation of dynamic and mobile processes in for example, industrial process automation and manufacturing, energy distribution, intelligent transport systems. This requires communication with high reliability and availability, as well as low e2e latency (less than 1 millisecond).

In a communication system, delays are generated at various protocol layers and are the cause of e2e latency. These include protocol stack, signal processing, medium access, transmission and propagation delays.The e2e latency requirement may be less than 1 ms in industrial automation [10].

The reliability requirements for mission-critical MTC services may go down to one per billion messages. This means for industrial automation to be reliable, only one message in one billion can be lost or delayed within the given latency [11]. To enable lower latency and higher reliability transmission times need to be reduced with efficient data transmission. This can require redesign of lower protocol layers and better medium access technologies.

2. **Higher data rate and higher data volume:**
   This is a primary requirement for 5G to fulfill and the number of devices and the number of applications that require high data rates are increasing. Primary methods to increase data rates and volume are using higher frequency spectrum, more number of network nodes. Currently the research has been shifting towards promising higher frequency bands which were earlier thought to be unusable. These can work very well in Line-of-Sight (LOS) scenarios in small cells and fit the industrial scenarios of local area communications. The networks are getting denser due to more number of network nodes. In the future the shift to higher frequencies in small cells will support Ultra Dense Networks (UDN) with high data rates and high data volumes. Network slicing to provide dedicated spectrum and resources will also help to achieve higher quality of service with higher data rates and higher volume.

3. **Lower device complexity and lower signaling overhead:**
   There is a need to reduce device complexity in sensor networks as well as in other network devices. This will positively impact the cost of the devices, since silicon costs are virtually absent. 3GPP has been reducing device complexity over the years in its LTE releases 12 and 13. Standardization is further required in 5G to ensure desired system performance.Signaling overhead is an important factor which adds to delays and also system complexity. It can be reduced by designing more efficient protocols and reducing the number of layers.

4. **Identification and control for huge number of devices:**
   Many MTC devices need profile generation and account operation. It is ex-

pected that there will be a large number of MTC devices with embedded-SIM (eSIM). The eSIM is explained in more detail in section 2.3. Thus it will be necessary to be able to regulate access individually based on the profiles. 5G Operators should be able to support customized MTC services. Operators should be able to customize services based on optimal data packet size, optimal routing with dedicated Access Point Name (APN) for MTC services, etc. It is possible there could be specific MTC categories defined by 3GPP. Network slicing is also seen as an alternative to provide customized and dedicated services. There also need to be favorable roaming policies to support innovation in the industries.

5. **Coverage Improvement:**
   Applications such as smart metering, industry automation only work if all devices in the network are online. Thus it is necessary to be able to provide almost 100% coverage including indoor locations for example in basements, or in faraway areas such as a sea harbor. There is a need to achieve this without adding significant costs. Increasing the number of base stations can be a solution but comes at the additional cost such as site acquisition or rental fees, backhaul provisioning, among others. One solution is to deploy small cells in which by reducing the cell size the spectral efficiency is increased by increase in frequency reuse and this also requires lesser transmit power which in turn reduces the power lost during propagation. Indoor small cells can thus be used to improve coverage by offloading traffic from macro cells without big additional costs.

6. **Longer battery life and better energy efficiency:**
   A large number of sensor devices will be battery powered and charging and changing of batteries may not be possible or economically feasible. Also with space constraints it is required to keep devices and batteries smaller. Industries currently run devices with battery life of about 10 years with lower data rates and infrequent data transmissions. In the future these data rates will increase and also applications like industry automation, smart metering, automated vehicles in logistics etc will require more frequent data transmissions which means more power-on time for devices. Also computational processes in the devices can affect their battery lifetime and hence the energy efficiency of the whole industry. The computations can be offloaded to data centers to improve battery lifetime. Energy efficiency needs to be high to have longer lifetime and lower costs.
   Apart from battery lifetime of the devices, another factor that affects energy efficiency is the operator's radio infrastructure. If energy spent by radio infrastructure increases, the operational costs for the operator will increase and this will indirectly show up as an increase in operator bill for industries. For reducing energy consumption in the radio infrastructure, small cells and massive Multiple Input Multiple Output (MIMO) can be used. Small cells reduce the

distance to terminals and thus the energy used for transmission but this needs an economic backhaul solution too. In massive MIMO directive beams are used to focus energy and thus lesser energy is needed but this suffers from wastage of energy in Non-Line-Of-sight (NLOS) scenarios.
The future industrial internet requires a shift in network architecture to include small cells, massive MIMO, traffic dependent power management (on/off periods) of base stations, redesign of lower protocol layers and also dedicated slices of the network that can offer better energy efficiency depending on the requirements posed by various applications.
Further there is also need for changes in the backhaul for example shifting from copper to fiber-optic cables which is actually been happening for some time now.

2.2 M2M architecture

The M2M architecture as proposed by ETSI [12] can be divided into two domains namely a device and gateway domain and a network domain as shown in figure 3.

The Device and Gateway Domain contains the following elements:

- **M2M Device:**
  A device hosts and runs the M2M device Application(s) using M2M Service Capabilities. It may or may not host M2M service layer (M2M SL) capabilities and when it does not contain M2M SL capabilities it is called a legacy device. M2M Devices connect to Network Domain in the following manners:
  - o Direct Connectivity:
    Connecting to the network domain directly via the Accessnetwork. The procedures such as registration, authentication,authorization, management and provisioning are performed by the device or the network operator. In some cases such device can also provide services to legacy device.
  - o Gateway as a Network Proxy:
    Connecting to the Network Domain via an M2M Gateway. M2M Devices connect to the M2M Gateway using the M2M Area Network. The M2M Gateway acts as a proxy for the Network Domain towards the M2M Devices that are connected to it. The procedures such as authentication, authorization, management, and provisioning are proxied. There can be multiple gateways.
- **M2M Area Network:**
  It connects M2M Devices and M2M Gateways. In some literature an aggregator network can replace this entity.Examples of M2M Area Networks include: Wi-Fi IEEE 802.11, Zigbee, Bluetooth, etc.

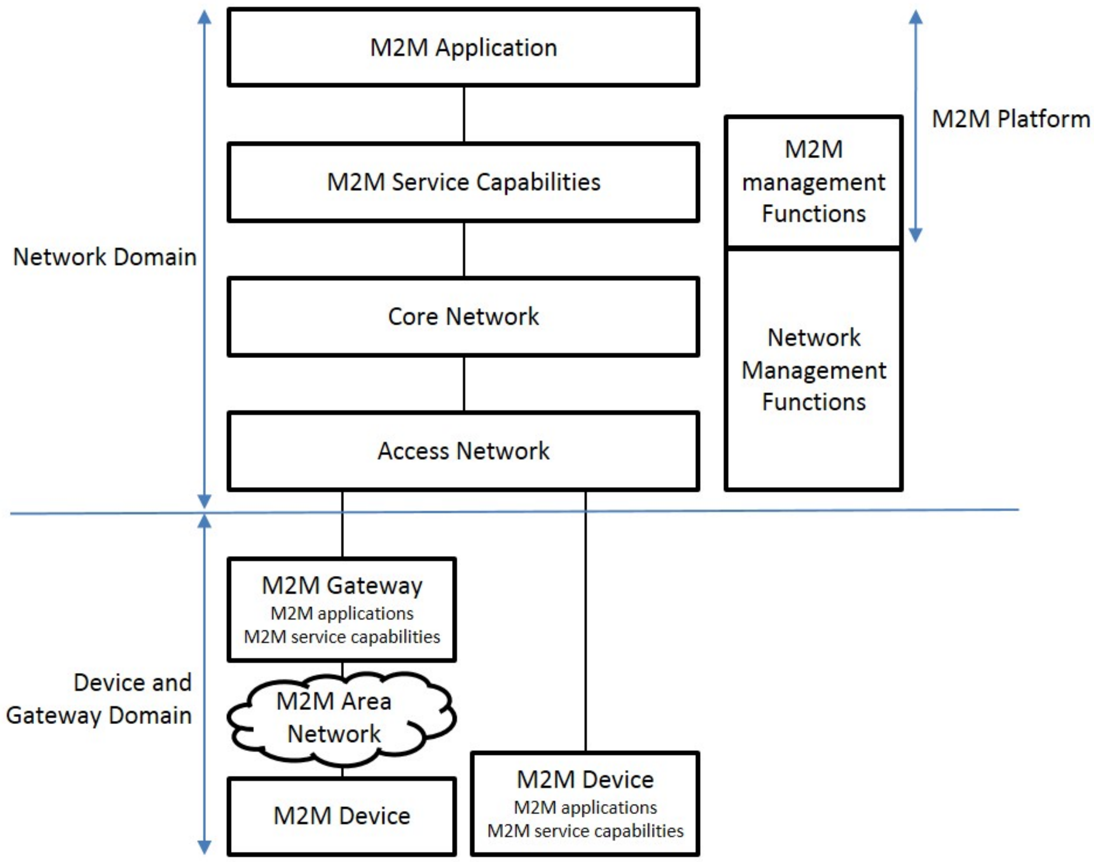

Figure 3: M2M Architecture (Source: ETSI).

- **M2M Gateway:**
  A gateway runs M2M Gateway Application(s) using M2M Service Capabilities. As explained before it acts as a proxy between M2M Devices and the Network Domain. A gateway can provide to service to one or more legacy devices and conversely one legacy device can be using services from more than one gateway.

The Network Domain contains the following elements:

- **Access Network:**
  It allows the Device and Gateway Domain to communicate with the core network. Example: all types of Digital Subscriber Line (xDSL), Hybrid Fibre-Coaxial (HFC), satellite, wireless local area network (W-LAN) and WiMAX.

- **CoreNetwork:**
  It provides IP connectivity, Service and network control functions and connection with other networks.

- **M2M Service Capabilities:**
  It provides M2M functions that are to be shared by different Applications.There

can be three versions of applications namely device application (DA), gateway application (GA) and network application (NA). All these applications use the service capabilities/functions provided by the M2M service layer hosted by the M2M platform.

- **M2M applications:**
  The applications, DA, GA and NA, use M2M Service Capabilities to perform data processing and provide output.

Application/ Data/ Service Layer	HTTP, CoAP
Transport Layer	TCP, UDP
Network Layer	IPv4, IPv6, 6LoWPAN, 3GPP
Link Layer	6LoWPAN, IEEE 802, Bluetooth, NFC, RFID, 3GPP

Figure 4: Protocol Stack for M2M communications (Source: ITU-T).

The Network domain also includes the Network Management functions (to manage the access and core networks) and M2M management functions (to manage M2M service capabilities). ITU-T proposes a similar component based architecture [13] in which it describes a M2M platform that hosts M2M SL capabilities and can be used by one or more application servers. M2M platform is basically a group of technologies used to develop applications, processes and other technologies. M2M platform houses the service layer used by different applications. A protocol stack structure [13] is shown in figure 4.

2.3 5G Technology Enablers

The section describes the most promising enabling technologies that will be a part of 5G radio network architecture.They can be categorized as enablers for Radio Access Technology (RAT), Radio Access Network (RAN) and Core Network as in table 3.

Table 3: 5G Technology Enablers

RAT Enablers	Millimeter Wave Technologies Device to Device Communications Massive MIMO Embedded SIM
RAN Enablers	Downlink and Uplink Decoupling License assisted access Micro-operators
Core Enablers	Software Defined Networking Network Function Virtualization Network Slicing

The enabling technologies are described below:

1. **Millimeter Wave Technologies**
   By 2020 the currently used 700 MHz to 2.6 GHz spectrum bands are going to be saturated with expected thousand fold increase in mobile traffic. Recent studies [14, 15] on mmWave frequencies (30 to 300 GHz) show a viable solution for this future problem.The spectrum beyond 6 GHz had been out of the question

due to its high attenuation but recent research by employing massive MIMO, and steerable antennas shows it can be useful for backhaul, device-to-device and even local area cellular communications.

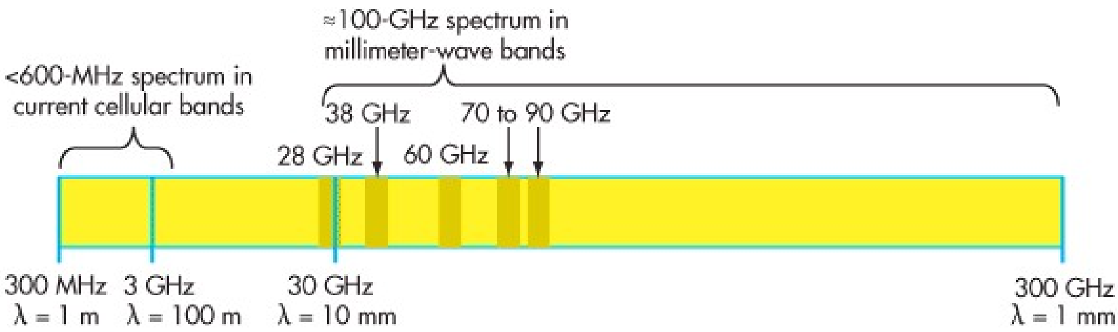

Figure 5: mmWave frequency bands and current cellular bands (Source: Electronic Design).

The mmWave frequency bands and current cellular bands are shown in figure 5 [16]. The mmWave frequencies offer larger bandwidth allocations which means higher data rates and with more spectrum available the overall capacity will be increased. Major challenge to this approach is larger propagation losses in NLOS scenarios due to diffusion of transmission energy by reflections. This problem can be tackled with higher density of antennas and small cells. Studies have shown that high gain steerable antennas with mmWave can be viable for local area communication even in NLOS scenarios [17]. Also massive MIMO is a great alternative for replacing current antenna systems in dense environments. The short range communication offered by mmWaves in case of D2D scenarios allows energy savings which directly improves M2M device lifetime and also saving energy for operators.

2. **Massive MIMO**
   The future of telecommunication is moving towards higher frequencies (mmWave) in 5G. There is immense potential in these unutilized bands but higher frequency means lower wavelength and this means the received power at the receiving antenna will be lower as is evident from the following equation:

Frequency dependent; Wavelength (λ) = Speed of Light / Frequency

$$P_{rx} = \frac{P_{tx}}{4\pi R^2}\frac{\overbrace{\lambda^2}}{4\pi}\underbrace{G_{rx}G_{tx}}$$

Antenna Gain dependent

Here, Prx, received power; Ptx, transmitted power; R, distance between transmitter and receiver; , wavelength; Grx, receiver antenna gain; Gtx, transmitter antenna gain. Thus, higher frequency implies smaller wavelength which implies smaller received power. Higher received power can be obtained with i) increased transmit power Ptx ii) decreased distance R iii) increased antenna gains Grx and Gtx . There is a limit to changing these variables but the antenna gains are easier to increase by increasing the number of antennas which is the basis for massive MIMO.
Massive MIMO employs large number of antennas in an array at each base station thus increasing the gain of the antenna array. Further research shows that using mmWaves (lower wavelength) in small cells (lower distance R) with massive MIMO supporting large number of devices, is a viable solution for utilizing higher frequency spectrum in dense environments. Another characteristic of massive MIMO is the spatial focusing of transmitted energy in a beam. The more number of antennas, the narrower the beamwidth. This allows better energy efficiency as most of the energy transmitted from the antenna array is focused in a very narrow area. An example of beamforming with a simple MATLAB code adapted from [18] is shown in the figure 6. It can be seen that as the number of antenna elements in the array increase, the beam becomes more concentrated in a narrower area.

Research in massive MIMO [19] shows:

- Increase in capacity 10 times
- Increase in energy efficiency 100 times
- Inexpensive design and low power consumption
- Decrease in latency in air interface due to robustness against fading

It is clear the massive MIMO is useful for a more efficient access link where large number of devices are served simultaneously in a small area and also for wireless backhaul link because of spatial focusing characteristic. The need to focus the beam on a small area does come with the disadvantage that the exact location of the device should be known.To tackle this problem, steerable moving nodes can be implemented in moving vehicle nodes, making massive

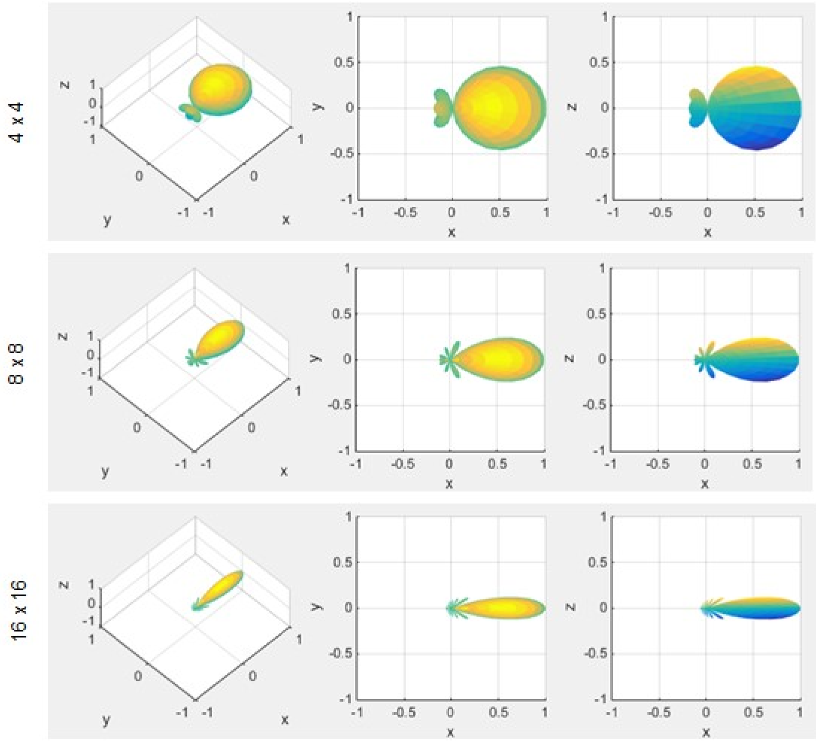

Figure 6: Massive MIMO Beam formation with (Source: Electronic Design).

MIMO feasible.
The antennas involved will be of smaller dimension due to smaller wavelengths which means the size of base stations will be smaller, thus reducing space requirements [20].

3. **Device-to-Device Communications**
Device-to-Device(D2D) communications offer the possibility that two devices can exchange data without the involvement of the BS or with just a partial aid in form of link establishment from the BS. Other technologies like WiFi and Bluetooth technologies, provide D2D capabilities in the unlicensed band but in their case the Quality of Service (QoS) is not controllable as the communications take place in unlicensed band which cannot guarantee reliability and low latency. Mostly WiFi bands are becoming overcrowded as the devices are increasing. With D2D communications assisted by cellular network the QoS is controllable because they use the licensed spectrum. This can lead to enablement of a number of use cases and new applications, for example, device relaying, context-aware services, mobile cloud computing, and offload strategies. There are four different types of D2D communications that can happen using 5G:

    - Device relaying with operator controlled link establishment
    - Direct D2D communication with operator controlled link establishment
    - Device relaying with device controlled link establishment

- Direct D2D communication with device controlled link establishment

Apart from the advantages there are some issues like pricing models as who pays who in these cases is very complex. Also the devices that act as relays will use up their own resources more like battery, storage and processing. Another issue the future research needs to answer is if the devices in a D2D model are using different operators then there is a need to add cross operator D2D capability.

4. **Embedded Subscriber Identification Module**
Embedded Subscriber Identification Module (eSIM) is a specification for the remote provisioning and management of M2M devices. It is not standardised yet and many types of non-interoperable profiles exists but GSMA specifications have included profile interoperability that will simplify the process of connecting M2M devices[23] It allows "over the air" operator subscription and also later changes from one operator to another. Industries using traditional SIM cards face problems of SIM being associated with only one operator and installation and changing of traditional SIM is not flexible and cumbersome, especially in industries where the devices can be hard to reach. There is also possibility to use programmable virtual soft SIM but then most industries face security concerns over the virtual SIM. Thus eSIM offers a more flexible and robust solution for M2M communications. The eSIM and traditional SIM lifecycles in an industry are shown in figure 7.

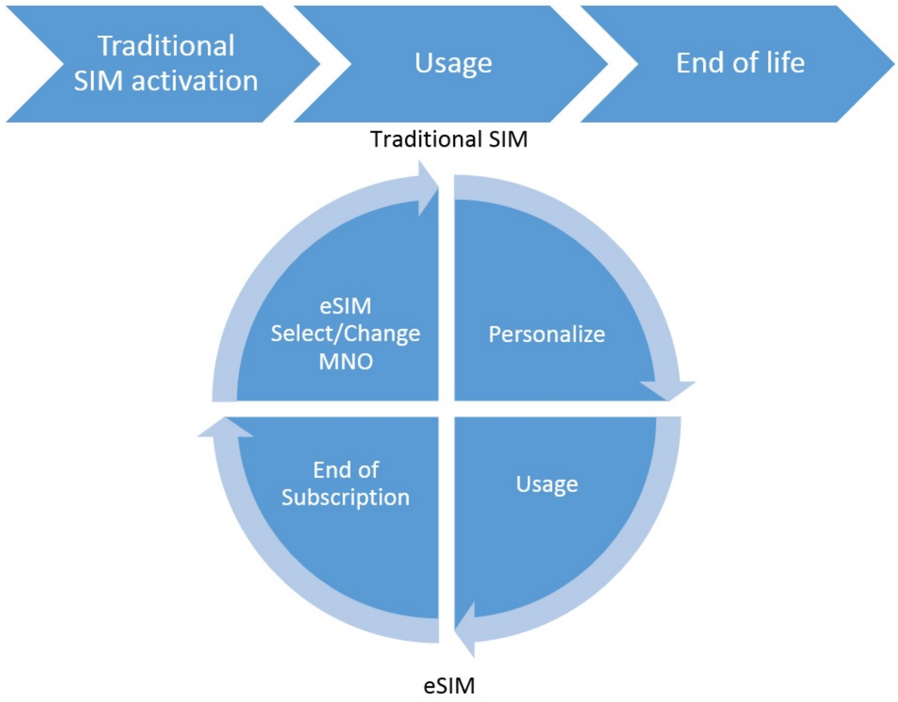

Figure 7: Lifecycles of Traditional SIM and eSIM.

The eSIM will accelerate M2M market and provide possibilities of different business models by reducing costs and efficiency [22]. Businesses will be able to cut operational costs of changing SIMs and switching operators, conduct long term planning without being tied to the same operator and enjoy full lifetime of the device with same eSIM seamlessly. This will also allow operators to reduce logistical costs of traditional SIM and retain security levels.
In 2014 GSMA predicted that at the end of 2020 the M2M eSIM connections could reach 639 million globally with GSMA specification or 479 million using proprietary eSIM solutions [23].

5. **Downlink and Uplink Decoupling**
   Downlink and Uplink Decoupling (DUDe) is an important enabler that will make the future communication more flexible. A device will be able to choose different base station for uplink (UL) and downlink (DL) depending on the transmission power differences between uplink and downlink. Thus, the device will receive downlink traffic from one base station and send uplink traffic to another base station. Recent studies [24, 25, 26] show DUDe to be a future disruptive technology for 5G.

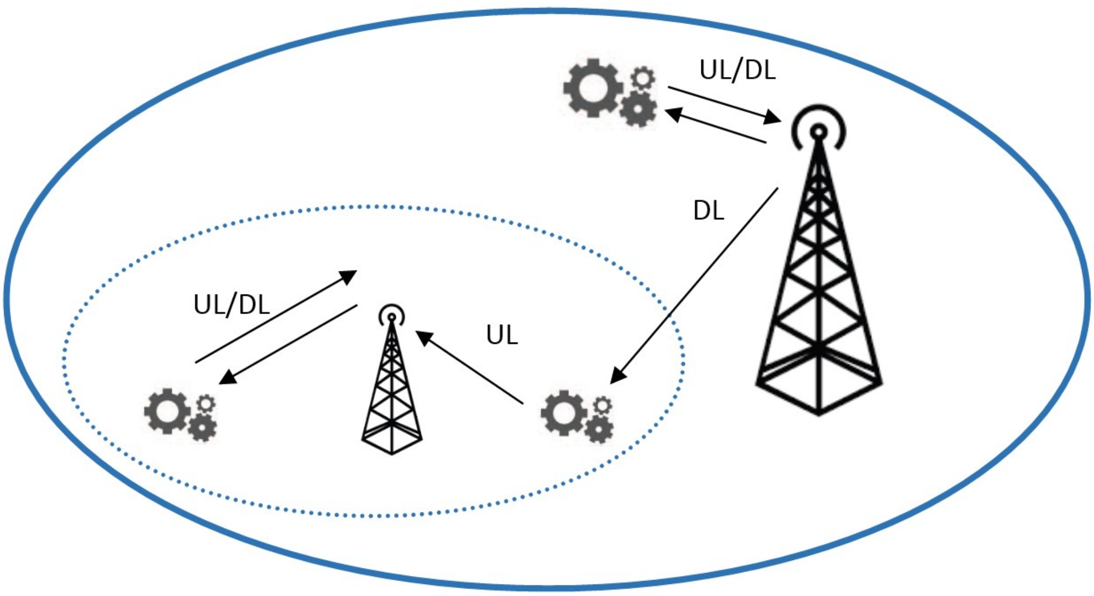

Figure 8: Downlink and Uplink Decoupling (DUDe).

This approach can improve reliability significantly in scenarios with small and macro cells. This is shown in figure 8 , where devices using same BS for UL and DL and also a device using decoupled access.

6. **License assisted access**
   Under License Assisted Access (LAA), licensed carriers will be able to opportunistically use unlicensed carriers to enhance the downlink performance for the user. 3GPP defines LAA as the aggregation of licensed and unlicensed carriers. The licensed spectrum can be used for control related transmission and the data can be sent on both licensed and unlicensed spectrum. This can benefit the increasing demand of spectrum in the future for example non-critical IoT traffic can be transmitted over unlicensed spectrum and be controlled over licensed spectrum. This approach can save the usage of licensed spectrum for control information and critical applications. An example with LAA is shown in the figure 9.

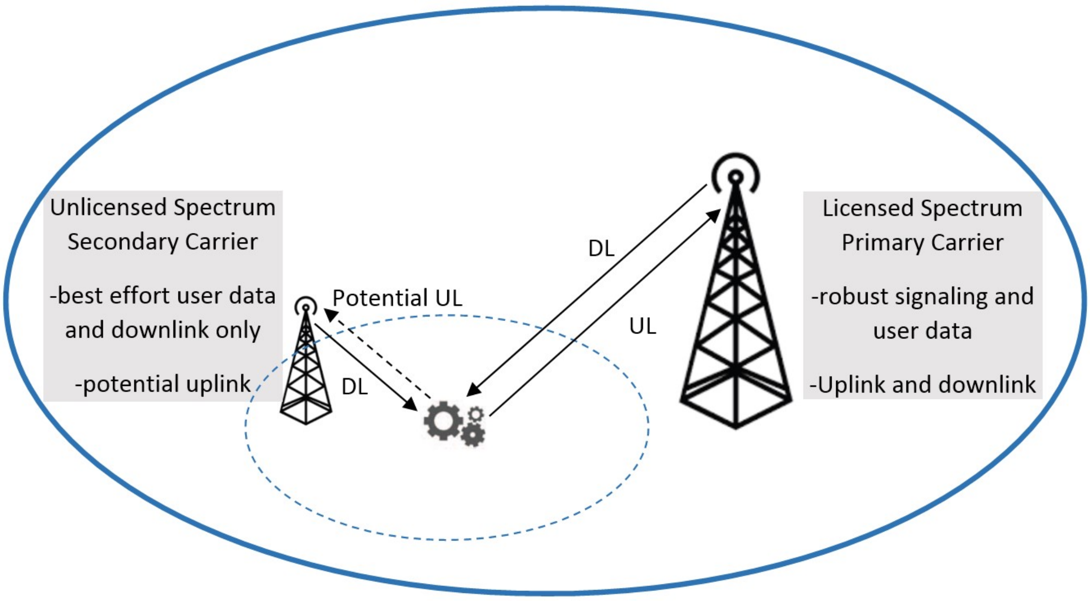

Figure 9: License Assisted Access

7. **Software Defined Networking**
   Software Defined Networking (SDN) is a key enabler for 5G networks. SDN separates the user plane and the control plane. The user plane is responsible for the traffic forwarding between network devices and the control plane is responsible for decision making about the routing of traffic.
   The 5G architecture needs to be flexible to be able to cater to varying requirements such as different deployment environments, different hardware technologies and different features being used in different locations in the network. Depending on the use cases the user plane should be able to meet the specific requirements depending on the connectivity needs, for example, in some use cases the traffic may require small and simple processing which

can be done on low cost hardware or conversely some use case might require higher processing and also expensive hardware. The user plane needs to be cost efficient in such scenarios.
The separation allows the user plane and control plane to be scaled independently. This also means that the planes can be located at different locations. The control plane can be migrated to a central site to make management (authentication, subscriber data, session handling, and policy control) simple and the user plane can be located at many different local user sites to bring it closer to the user as this will reduce the round trip time between the user and the network. This approach makes the most cost-effective deployment possible for each scenario.
Thus with SDN it will be possible to address flexibility and possible future mutli-vendor, multi-tenant 5G scenarios. SDN will be able to provide efficient management for resources and allow co-existence of different services with different QoS requirements [27].

8. **Network Functions Virtualization**
NFVis defined as virtualization of network functions in software that can be run on cloud based servers. NFV technologies will allow to manage many heterogeneous IoT devices with scalability and flexibility in operating and managing network devices. This will lead to decrease in capital and operational expenses.Besides the core network, NFV can be applied to the RAN as well by centralizing the base band processing within RAN [28]. Cloud RAN (C-RAN) will still require specialized hardware in servers to satisfy real time requirements. Another approach can be to be able to switch between virtual functions and real machines to provide low latency for low processing needs by running functions in a Radio Access Point (RAP).
As a comparison with legacy platforms that implement network functions on dedicated hardware, NFV does it by utilizing data centers. NFV can reduce the time-to-market and provide updates in software rather than changing hardware. NFV can also improve energy efficiency as only the required amount of resources will be used.

9. **Network Slicing and Micro-operators**
Flexibility of the network is not just about the software and hardware but also its management. Network Slicing is a concept that allows networks to be logically separated and these logical separations are called slices. Each slice provides customized connectivity. There can be as many slices as supported by the network operator with all slices being run on the same shared architecture. Network Function Virtualization and Software Defined Networking are the main concepts behind network slicing.
Network slices can have different architectures but can share functional components [29]. Network slices should be assigned a set network resources in infrastructure (access, core and cloud). This will improve flexibility and also

expansion as introducing new services will be easier and also open up business opportunities. Network slicing as described by Next Generation Mobile Networks (NGMN) [30] can be seen in the figure 10.

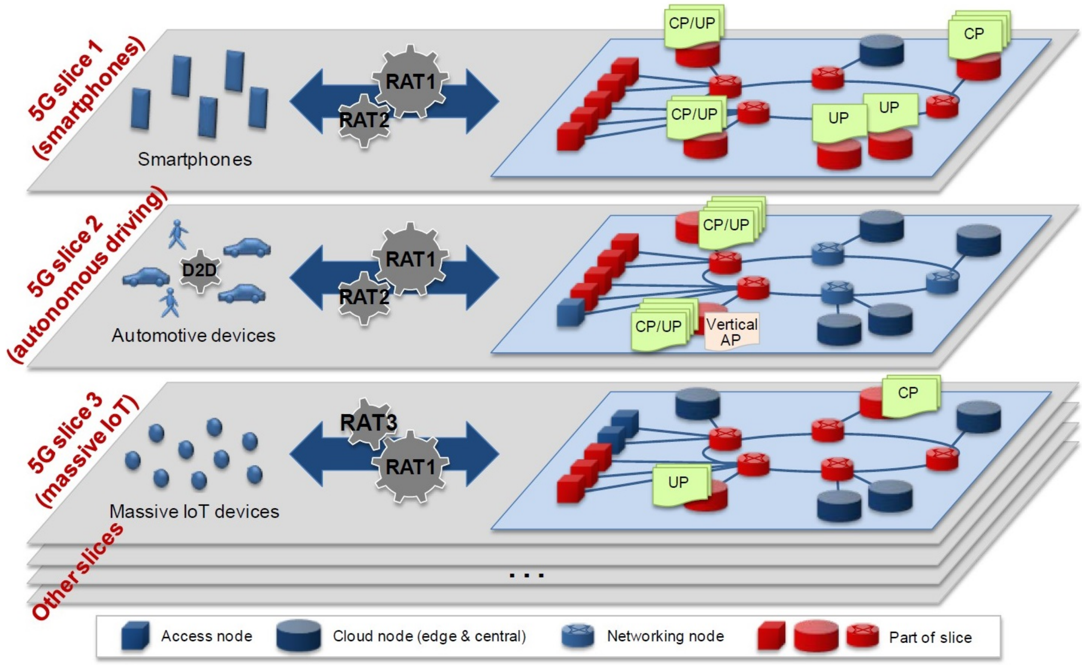

Figure 10: 5G Network Slices (Source: NGMN)

By the concept of network slicing, SDN and NFV, the RAN management functionalities can also be split between the base stations and the cloud, based on the degree of centralization that is required in any specific networking context. This enables coexistence of multiple operators and management functionalities provided by third parties. These third parties can be Mobile Virtual Network Operators (MVNO), Micro-operators or businesses leasing network slices to manage the services themselves. MVNO business models depend on the MNO as they don't own the resources that MNO owns but they manage the resources as a form of sub-licensing of spectrum and base stations. Micro-operators can own radio resources for a particular location and provide local access and management of network devices or simply manage slices bought from MNOs. Network slicing opens up a whole new way of doing business for operators.

10. **Localized Content and traffic**
One of the main goals of METIS is to reduce current E2E latency performance to less than 1ms. Most of the delay comes from the Internet and the core network. Therefore, localized traffic flows, including data traffic offloading, aggregation, caching and local routing can help in reducing latency.
The network operator improves the user experience by providing e.g. authentication and security features while reducing the load on the data transport. In this framework context information and network assistance for D2D discovery are important to enable such direct communication.
In M2M, the use of concentrators acting as local gateways could allow direct communication among sensors located in capillary networks without the need to reach the core network gateway. For M2M the localized traffic flows allow low-power access to the network. The network edge nodes can provide aggregation and information fusion of sensor data reducing the transport load and provide local added information value. Further, the necessary context information for MMC operations can be stored locally.
For delay-sensitive services, e.g. road safety applications, it is necessary to turn-around the traffic flow and perform critical computations close to the user to meet the latency constraints of less than 1ms.
Caching can also be utilized in the network edges, reaching access nodes or even the devices that could act as proxies in case of having the requested content in the cache [31].

2.4 5G Architecture

The 5G architecture will consist of a network that contains 5G devices (mobile phones, wearables, M2M modules and others that are capable of acting as relays/hub), access nodes (capable of the new enabling technologies discussed before), cloud nodes (cloud based servers for running applications and storage of data), multiple RAT and a virtualized core.

The RATs incorporate mmWaves, massive MIMO and license assisted access to utilize more bandwidth. Fast switching between cells and beams is achieved by steerable antennas. Network slicing is expected to be employed in RAN, providing some level of virtualization and processing capabilities to Radio Access Points. Network slices will provide customers to have flexible and configurable services. As shown using double bubbles in figure 11, the RAN, the core network and the servers are part of slicing. SDN is used to separate user plane and control plane. Virtualization of network functions will provide scalability and independence among slices. Depending on the use case the location of servers and other nodes can be moved.

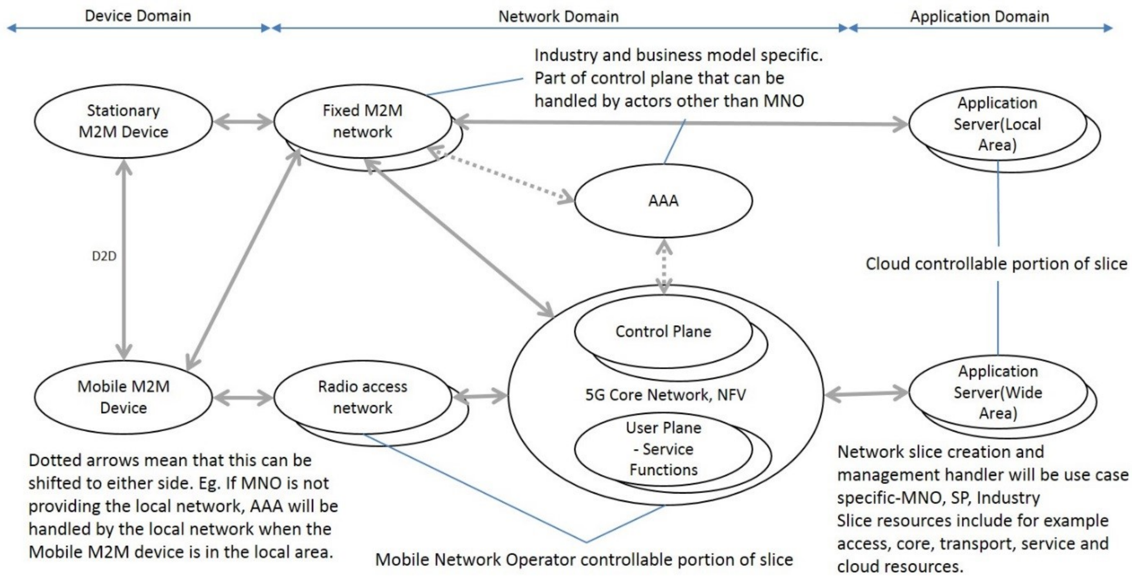

Figure 11: 5G technical architecture for M2M

In the industrial application the low latency requirement is of utmost importance and so it is preferable to keep the deployment of infrastructure local. The network slice could include cloud server locally at the deployment site or it could be located in the operator data center. There can also be a separate cloud service provider or also the cloud could be owned and managed locally. Control plane functions like account operation can be managed by the operator, the customer or a third party. User plane functions can be deployed and configured depending on the use case. Management responsibilities will be shared among customers, operators and service providers. The network slice can be managed by the customer or third parties for example micro-operators. Network slice being managed by the customer will allow the customer to manage network functions and capabilities themselves. Operator controlled network functions will be deployed at a central location in the operator network. Location of core network control plane depends on performance requirements such as latency and reliability but will also depend on how many industries need to be served at the same time and their locations. Thus it is not always possible for operators to move the control plane close to the industries. In such cases the control plane is deployed centrally with some functions controlled locally. For latency and reliability the more the functions are deployed locally the better.

End-to-end quality of service (e2e QoS) should be maintained in the 5G architecture. The QoS has been briefly discussed before in the technology enablers subsection. In the 5G local area access for M2M communications context, the e2e QoS can be defined qualitatively based on the reserved resources, reliability, latency and availability, and thus can be seen as a guarantee of a set level of performance of the network. The MNOs or third parties such as MVNOs, micro-operators and verticals will manage e2e management of network services. They will define network functions and network slices. The network slices will be use case specific and can be configured and scaled according to requirements. The slices will span the device, network and applicaiton domains depending on the deployment of services and industry contracts. Dedicated slices will be able to support e2e QoS requirements, for example, for D2D scenario the device application part of the slice can be configured and for operator assisted D2D communication the processing needs can be moved to the radio access points; for mission-critical communications, the latency can be reduced by dedicated functions in the edge cloud. It is possible that one industry will be using many dedicated slices in parallel and there can also be extra slices for best-effort communication in case of high traffic. Policies such as DUDe, LAA and localized caching, will also improve the availability of resources.

Research in the future networks shows that in contrast to existing cellular systems, sophisticated technologies such as ultra-dense access node deployments, and multi-node coordination will be ubiquitous [32]. Frequency (FDD) and time (TDD) division duplex systems are expected to further coexist, while TDD-only operation is expected to become more widely used in higher frequency bands, but its use will probably be restricted to low-power radio nodes, e.g., for indoor and outdoor small cell applications (including in-band wireless backhaul). Evolved versions of existing communication systems need to be efficiently integrated.

3 Scenario Planning

This chapter discusses the future scenarios for industrial 5G M2M ecosystem. It discusses the scenario planning method, the identified trends and uncertainties that are then used to construct four future scenarios.

3.1 Theoretical Background

Scenario planning is an important tool for constructing a number of possible scenarios by taking into account basic trends and uncertainties. It can be used to minimize errors in decision making that affect the fate of a business ecosystem by finding out how different stakeholders behave in different uncertain futures. This helps big organizations to make flexible long-term plans. When making decisions about the future, we can make errors and biases in our knowledge. As Schoemaker[33] states that contemplating the future requires the knowledge of:

1. Things we know we know.
2. Things we know we don't know.
3. Things we don't know we don't know.

Thus, it is necessary to plan the future broadly by having knowledge of other stakeholders. Apart from identifying basic trends and uncertainties, this helps in developing basic ideas of requirements and gathering relevant data to fill in gaps. Scenario planning originated from strategic planning methods used by military intelligence to simulate war games in 1950s[34]. It has become widely use in the Information and Communications Technology (ICT) industry[35, 36, 37, 38].

There are several different ways in which scenario planning can be performed and the basic idea behind multiple scenarios is depicted in figure 12.

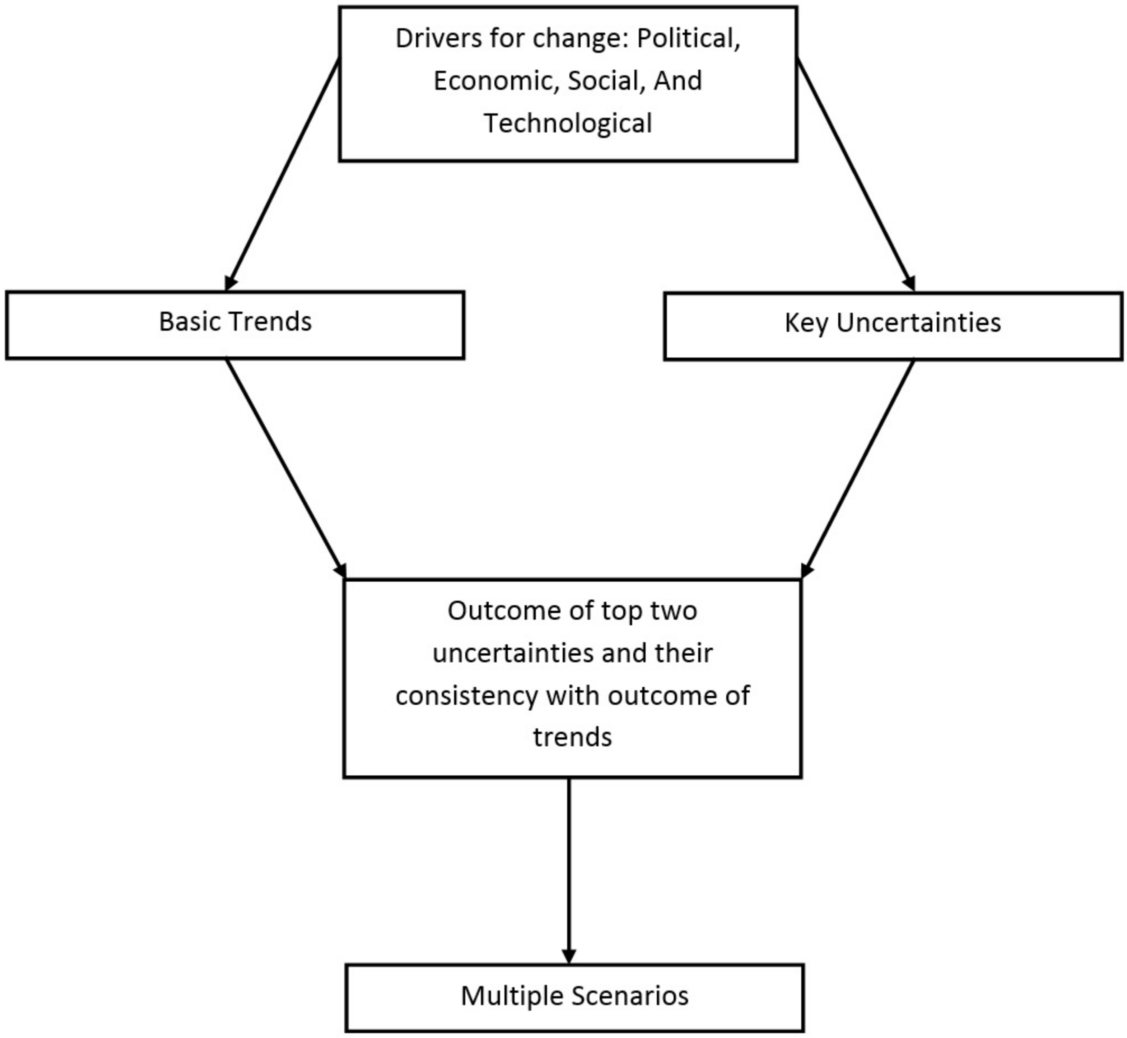

Figure 12: Flow of Scenario Planning

In this thesis the process of scenario planning depicted in the table 4, is inspired from that of Schoemaker[33].

Table 4: Scenario Planning Process

	Scenario Planning Process
1	Define the time frame and scope of analysis.
2	Identify the major stakeholders.
3	Identify basic trends covering political, economic, social and technological domains.
4	Identify key uncertainties covering political, economic, social and technological domains.
5	Construct initial scenario theme based on the most important trends and uncertainties.
6	Select two most important uncertainties and cross their outcomes in a matrix.
7	Check consistency by including other uncertainties and trends into the initial scenario matrix.
8	Check how the stakeholders behave and revise until most consistent scenarios are achieved.

3.2 Scope, Time frame and stakeholders

The focus of the scenario planning is to find out the future scenarios in local industrial 5G M2M communication. The scope is limited to indoor and onsite-outdoor industrial locations for example automated industries like manufacturing, construction, and also partly logistics and agricultural automation machinery in a local scope.

The time frame is defined as 10 years beyond 2020. 5G is expected to be developed by 2020 and it will actually be deployed between 2020-2030.

Major stakeholders are M2M module vendor, M2M service provider (SP), M2M application service provider (ASP), Mobile Network Operator (MNO), Mobile Virtual Network Operator, and Cloud Service Provider. Different firms with different backgrounds can take up different roles and scenario planning can help to find how these stakeholders behave in different scenarios.

3.3 Key Trends

Trends are the factors about which we can be almost sure that they will keep following the trend in future that has been there in the past and present. They are identified from research studies, expert interviews and brainstorming sessions. Expert interviews are very important to identifying trends as research studies can give a lot of information but the experts researching on a topic know more about how the trends carry on into the future when it comes to a long term time scope.The experts included device vendors, network equipment vendors, techno-economic experts, business developers, process automation and logistics experts, researchers and professors from the Aalto University. Many trends encompassing political, social, regulatory, economic and technological fields were collected, studied and discussed, and then the most important ones that were finalized to be used in the scenario construction are listed below:

1. **Increasing number of M2M connections**
   Over the past decade there has been tremendous amount of increase in connected devices. The number of connected devices is expected to grow from 20 billion in 2015 to more than 50 billion in 2020 [39]. In particular cellular M2M connections are expected to increase from 205 million in 2014 to more than 1.3 billion in 2025 with the automotive sector leading the way [40]. This trend is driving industries to become smarter, safer and more efficient and to add value to new business models. GSMA Intelligence predicts that non-consumer cellular M2M connections are expected to be 2 billion by 2020 [8].

2. **Increasing M2M traffic**
   With the advancement in IP based LTE the amount of data generated and exchanged by M2M devices has been increasing with the demand for more data through internet of things and dense networks of sensors. In future with the deployment of 5G the traffic is expected to increase further, as there will be more number of M2M devices with easier deployment and meeting the future industrial internet requirements. Globally, mobile traffic per mobile connection (including M2M and Low Power Wide Area(LPWA)) will increase from 469 megabytes per month in 2015 to 2,625 megabytes per month by 2020 [41].

3. **Digitalization of industries**
   In recent years digitalization has entered vertical industries like automotive, energy, safety, health and sports. The more the use cases are realized and requirements are met, the more new use cases and new requirements arise. Dependence on technology and communication has been increasing among consumers and industries. Role of renewable and fragmented power generation is increasing and thus is increasing the automation involved in the processes.

4. **Role of developing countries is increasing**
The role of developing countries is increasing with more industrial opportunities like manufacturing industries and with the high population the demand for developments in communication will increase considerably more in developing countries. Role of developing countries will increase industrially, economically, technologically and also politically.

5. **Spectrum allocation is moving towards higher frequencies**
Low frequencies provide good propagation characteristics for wide coverage but to support wider bandwidth carriers, larger frequencies are needed which are available at mmWave bands. Telecom operators have already started unloading their traffic in higher frequency unlicensed spectrum earlier used just by WiFi [42]. To accommodate new capabilities of wireless systems there is a need for more licensed spectrum. Various organizations are investigating the new bands for 5G focused in 6 GHz to 100 GHz[43].

6. **Standards moving ahead of proprietary solutions**
Proprietary radio solutions make the industry dependent on the same service provider and vendor and must buy all future devices and services from the same. This causes vendor lock-in. The proprietary solutions also lack interoperability and scalability. This increases the costs as the industries always has to buy proprietary interfaces and software to maintain operability. Standards provide customers the ability to switch between vendors, as they follow the same standard, and be interoperable and scalable in the future. This leads to an important finding that the competition in the future will be between standards.

7. **Voice call priority lowering and data priority rising**
Since the advent of VoIP and 3G the priority has shifted from voice to data. In the following generations 3.5G and 4G, there has been improvement in voice quality but mostly the focus has been to provide higher bandwidths and higher download and upload speeds. Voice remains useful in cases of remote areas with poor network coverage but in urban settings with good network coverage most communication happens over data.

8. **Concerns about wireless radiation is rising**
Results of many studies indicate that wireless radiation has harmful effects on health. One such two-year long study on such effects on rats conducted by National Toxicology Program of America has provided evidence that the rats exposed to cellphone radiation developed cancer whereas the unexposed ones did not [44]. Even though many criticize that these results are very weak but such awareness might affect future usage.

3.4 Key Uncertainties

Uncertainties are those ambiguous factors that shape the direction of outcomes and lead to alternate futures. Uncertainties are identified from expert interviews and brainstorming sessions. Again these encompass political, social, regulatory, economic and technological fields. The collected uncertainties are discussed below:

1. **M2M ecosystem- Integrated or Fragmented (Economy/industry)**
   One of the key uncertainties identified by all experts was that 5G being a new technology, can bring about big changes in the business models, as the M2M ecosystem may develop to be either integrated or fragmented. Here, an integrated ecosystem is such in which all related roles such as, network access, network functions, applications and others service provisioning, are provided by the same company. In this case industries make contract with a single company that takes care of end to end customer experience and billing. This means there are few large players and lesser competition. Such an ecosystem also creates huge economies of scale and barriers to entry of small companies. A fragmented ecosystem is such in which the roles are distributed among many companies and each one has its own value creation method. In this ecosystem, customers purchase different services from different companies and this leads to higher level of competition. It is easier for smaller companies to enter the market and also customers have more options.

2. **Role of shared and unlicensed spectrum- limited or significant (Political/regulatory)**
   Currently the usage of unlicensed spectrum has been on the rise and many operators have been unloading their traffic onto to unlicensed spectrum usually used by WiFi, but also there has been a shift towards regulating and licensing the use of higher frequencies for 5G communications. Thus currently it can be seen that role of unlicensed spectrum has increased but there is nothing for sure if that will still be the case in the future.

3. **New players - modest competition or market disruption (Political/regulatory)**
   As new technologies emerge, so do new use cases and with new use cases there are companies taking up roles they didn't play before and also we see many startups trying to fill the empty spaces. In the end there are always winners and losers but this always causes changes in the market as it brings competition, if there are many players trying to fulfill the same roles or it can bring disruption with one or a few players bringing revolutionary and innovative services and technologies in the market. The first case implies that the customers have a big list of options to choose from and the competitors constantly try to outrun

each other.

4. **Job scenario in a 5G world - minimal impact or significant impact (Social)**
Every revolutionary technological advancement is ought to come with a change in incomes and jobs. Automation has always led to a decrease in manual jobs but with emergence of newer technologies there have been increase in services related jobs and also advent of new businesses. At this point in time the job scenario in a 5G world is very hard to predict as there will be lesser of manual jobs in the industries like manufacturing, construction etc but there will be more technical jobs in programming, research etc and there is also chance of growth in service and marketing sector as the customer base grows.

5. **Local Access technology – IEEE or 3GPP (Technology)**
One big key uncertainty for a new technology is the competition it faces with the existing technologies that have their infrastructure already in place. In the scope of this study the competition can be seen as IEEE vs 3GPP. Although the current communication technologies such as WiFi, Buetooth, NFC etc are doing well when it comes to D2D communication but the ever evolving 4G LTE and the upcoming 5G are going to be key players in D2D as well. The current technologies are not able to fulfill the low latency requirements of critical MTC requirements today but it will be interesting to see how they evolve and compete with the low latencies promised by 5G. This will be a key deciding factor when it comes to adoption of 5G, as emphasized by many industry experts.

6. **Deployment environment - existing trends or new unprepared use cases (Technology)**
Major technology enablers for 5G include higher frequency spectrum (mmWaves) and beamforming using MIMO antennas. This accounts for new infrastructure and as mmWaves have poor transmission characteristics indoors it means it will require more base stations and better handover in micro/pico cells. The environments can vary from urban industries to remote sea harbors or agricultural lands and thus varying use cases and very different deployment environments can arise.

7. **Life cycles – long or short (Technology)**
The employed automation machinery and processes in industries have a fixed budget, contracts, maintenance and life cycle. A change in the infrastructure can happen when their current contracts and life cycle are over. Also, an industry will be less likely to switch to a new infrastructure or changes in the infrastructure if the new technology doesn't promise a life cycle that suits their

budget and their expectation. For example an industry might be having a ten year machinery life cycle and might have a significant amount of years left in the life cycle so it can't be ready to switch. Also if the industry expects to have a 10 year life cycle but the new infrastructure and software used can only promise a 5 year plan, the industry will be reluctant to make a deal.

8. **Automation/safety regulations – progressive or suppressive (Political/regulatory)**
   When the companies are ready to automate the industries and vehicles it's the government and regulatory bodies role to decide what regulations to put in place for companies to abide by. These regulations can put companies in the right to place to facilitate progress or the companies might find themselves in a place where their possibilities are limited and progress is suppressed. Further these regulations can be different in different countries. Progressive regulations will invite and encourage companies while suppressive regulations will suppress their limitations and force them to move their operations elsewhere.

9. **Roaming regulations – same as mobile consumer or specific M2M (Political/regulatory)**
   Roaming regulation will control the extent of operations when it comes to mobile M2M communications. The communications taking place can be stationary to stationary, mobile to mobile, and mobile to stationary M2M device, and vice versa. These cases can involve for example a connected vehicle approaching an industry and switching from the wide area network to the local area network. These can both be provided by the same mobile network operator but as the coverage varies in different environment there might be need of roaming. There will obviously be roaming regulations and deals set up by operators for such use cases but the uncertainty is about if these regulations and deals will be as ubiquitous as consumer mobile phones or will they be specific for M2M use cases and what further development will be needed.

3.5 Scenario Construction and assessment

This section describes the two most important uncertainties based on expert interviews and constructs four future scenarios.

A very broad range of trends and uncertainties were collected by interviewing and discussing with industry experts. The trends and uncertainties were put into four categories that are political, economic, social and technological. Then during the interviews and brainstorming sessions the uncertainties were prioritized, checked for correlation and the two most important uncertainties were selected. Then these two uncertainties were crossed to form the scenario matrix. The two most important uncertainties are:

1. **M2M ecosystem – Integrated or Fragmented**
2. **Local access Technology – IEEE or 3GPP**

The y-axis of the scenario matrix comprises of M2M ecosystem in terms of integration of service and provisioning. On the extremes of the axis are, fully integrated ecosystem and fully fragmented ecosystem. As scenario moves away from fully integrated the roles get more fragmented. A fully integrated ecosystem is one in which network access, network functions, applications and others services are provided by the same company. The customers, in this case industries make contract with a single company to manage all needs from device provisioning to network access to application server to data analytics. This means there are few large players and lesser competition. It is harder for customers to switch between different service providers. In a fully fragmented ecosystem, the network access, network functions, applications and others services are provided by different companies. The customers purchase different service components from different companies. This means there are many different players and higher level of competition. It is easier for a customer in this case to switch between different service providers. It should also be noted that the ecosystem is not defined from the point of view of any one company, but with an overall view of the industry structure. Since, the focus is on 5G, it can also be seen that MNO influence decreases, as the ecosystem becomes more fragmented.

The x-axis of the scenario matrix is defined as communication technology with the extremes as IEEE and 3GPP. The access technology can be either one or a combination of both. These outcomes will depend on how well 5G is able to enter the existing industrial internet market and how well it is able to revolutionize new industrial internet markets. 5G will have a strong position for wide area but the local area competition will also increase between the existing IEEE 802.11 WLAN and 5G. Thus industries will have a lot of factors to decide on and to go either way. The axis will show how the local access will shape in the future.

While describing the scenarios, the terms customer and industry are used interchangeably. The constructed scenario matrix is shown in figure 13.

1. **Industries and Service Providers Dominate:**
   This scenario is constructed out of fragmented ecosystem and IEEE connectivity solutions. This means that 5G connectivity solutions will be lacking behind WiFi connectivity solutions. It can also be noted that D2D communication and other short range communication can also be provided by Bluetooth, Zigbee, NFC etc. The M2M modules will be manufactured by Module vendors and

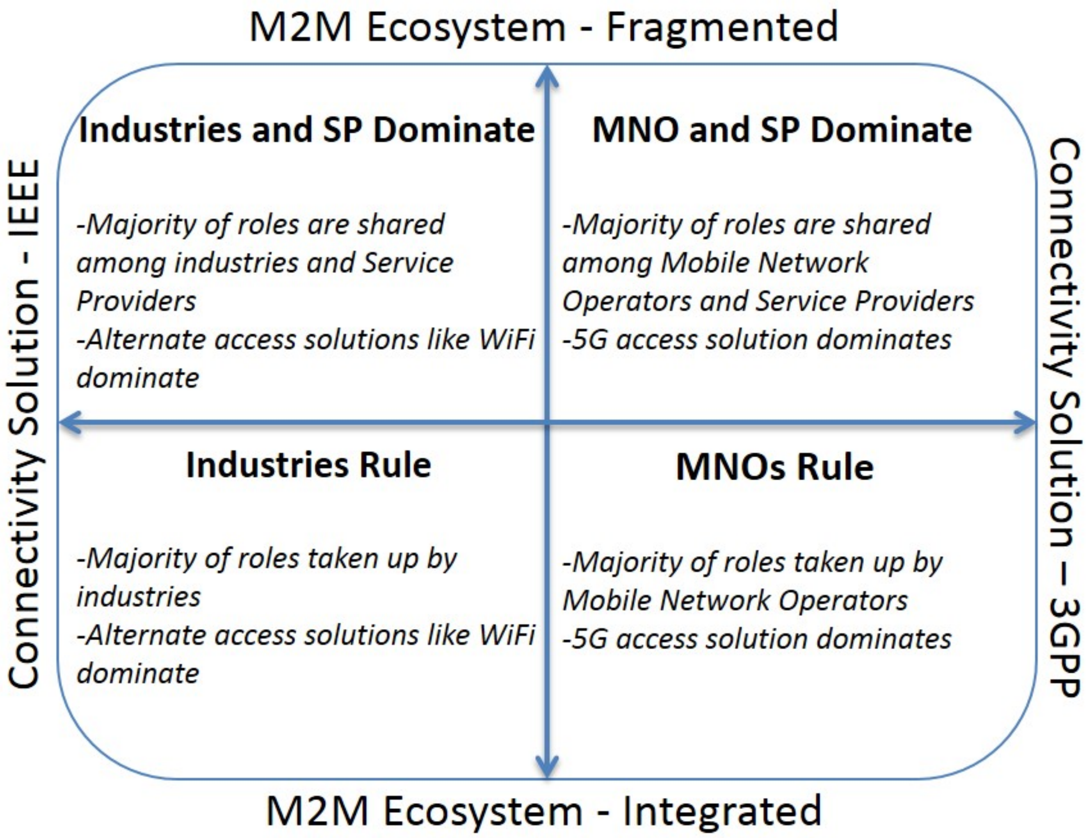

Figure 13: Scenario Matrix.

will be served by M2M service providers who can manage the connectivity solutions. The M2M platform will be provided by M2M service providers. Management functions such as account operation can be performed by the industries/customers themselves or by the service providers. Further the servers could be local and owned by the customers or they can be sold as a service by cloud service providers or M2M service providers. Local servers owned by customers, can increase the capital and operational costs for the industry owners but it can be beneficial if the industry's processes require low latency. In this scenario there will be huge competition in terms of connectivity providers as there is not one single solution and majority of the roles will be shared among the industry owners and the service providers. Thus, the customers will have many options to choose for connectivity and service providers. Also it is possible that the customers have contracts with many different service providers further increasing the competition. This might provide options and lower tariffs to the customers but there can be interoperability issues among different service providers and there can be costs of switching from one provider to another which might not be very high but could cause disruptions in business. This scenario might not give eSIM and network slicing business models a chance to grow. MNOs can be considered to have minimal role or be out of the picture

for local area access in this scenario although wide area coverage might still be provided by MNOs. It does give opportunity for Micro-operator business models to grow but the local access will move along the x-axis away from the extreme. In such a case the micro-operator can employ different access technologies coupled with 5G and the base station on the industry premises will most probably be owned by the industry.
This scenario can occur when:

- it is difficult for industry owners to make a switch to 5G because of their existing contracts and strategy plans.
- switching costs for 5G connectivity are high.
- the needs of industries can be satisfied by existing connectivity solutions or they evolve significantly.

2. **Mobile Network Operators and Service Providers Dominate:**
This scenario is constructed from fragmented ecosystem and 3GPP connectivity solution. This means that 5G solutions will dominate over WiFi for local access. It is expected if the future of local industrial access goes in this direction then 5G will also enter the D2D communication domain and be preferred over Bluetooth, Zigbee, NFC etc. It can also be expected for the alternative D2D connectivity solutions to still be used up to some extent. The M2M modules will still be manufactured by module vendors and provisioned by M2M service providers. The M2M platform will be provided by M2M service providers. The management functions like account operation can be expected to be performed by MNOs or service providers depending upon the business models followed the respective business actors. Servers can be owned locally by the industries or by the MNOs, cloud service providers or M2M service providers depending upon the business model adopted by the industries. Data analytics service provided by the respective actor will play an important part if the industries don't store any data themselves locally. There will be considerable competition among MNOs and customers could enjoy good tariffs. The lack of local servers could mean increase in e2e latency but can be feasible if the latency stays below the maximum allowed by the respective industry processes. This can be beneficial in lowering maintenance costs. This will help eSIM based business models to grow.
This scenario can occur when:

   - it is easy for industry owners to make a switch to 5G because they don't have long commitments towards existing contracts.
   - switching costs for 5G connectivity are low or at least beneficial in the long run.
   - the needs of industries can't be satisfied by existing connectivity solutions.

3. **Industries Rule:**
This scenario is constructed from integrated ecosystem and IEEE connectivity

solution. This means that 5G solutions will be lacking behind Wi-Fi for local access, as industries take over their privately setup local networks. It is also possible for industries to buy network slices from MNO, in this case the local access will shift towards the right on the x-axis. Alternate connectivity solutions for D2D communication will dominate. The M2M modules will still be manufactured by module vendors but will be served and managed by the industries themselves. The industries will buy and manage the M2M platform technologies from M2M service providers, thus only relying on the M2M service providers for initial service provisioning. The industries will be solely responsible for setting up their private network thus giving them full independence over costs and data management. This can be accomplished by big manufacturing business players like ABB, Tesla, Volvo etc. Such big players can even be expected to create and innovate the M2M platform technologies themselves. This scenario removes the switching costs of MNO and service providers, but will require huge initial investments and big maintenance costs by the industry owners. This is also beneficial for ensuring low e2e latency as the server will be owned locally by the industries themselves.
Some smaller players can be expected to rely on service providers for example buying network slicing from MNO or employing micro-operators to setup and manage the network. In any such case the local access and industry structure will clearly shift along the axis away from the extremes.
This scenario can occur when:

- it is easy for industry owners to set up and manage local network given they have the required expertise.
- the industries have huge capital resources to invest.
- the needs of industries can be satisfied by their private solutions.

4. **Mobile Network Operators Rule:**
This scenario is constructed from integrated ecosystem and 3GPP connectivity solution. This means that 5G solutions will be dominant for local access and the MNO will hold the strongest position in creation and acquisition of value. Regarding D2D communication, it is expected that 5G will be the preferred choice, although alternate solutions will coexist and work with 5G while the connection is assisted, relayed or controlled by the MNO. The M2M modules will be manufactured by the module vendors and will be served by the MNO. The M2M platform technologies will be set up by the MNO. The management functions like account operation and data analytics will be performed by MNO. The servers will be owned by MNO or the industry depending on the type of contract and can be deployed local to the customer site. MNOs will compete with each other to provide the best tariff deals to the industries. The MNO will build high switching costs by specialized infrastructure and services. Thus it will be expensive for customers to switch between MNO. If the switching costs get too high then the MNO will be able to raise their prices as they will. MNO will provide customers with the freedom to choose services by paying for the

network slices. This will give customers freedom. The local servers deployed by the MNO will help in keeping low e2e latency and also there will be no maintenance costs for the industries regarding servers. Industries should choose and strike a good deal by choosing the best network slice resources according to their needs, like low tariff, high data rates, high capacity, low latency etc. This scenario will help the eSIM and network slicing business models to grow. This scenario can occur when:

- it is easy for industry owners to make a switch to 5G because they don't have long commitments towards existing contracts .
- switching costs for 5G connectivity are low or at least beneficial in the long run.
- the needs of industries can't be satisfied by existing connectivity solutions.
- Network slices provide enough freedom to customers.

4 Value Network Configurations

4.1 Theoretical Framework

In business, value means the return on a business operation conducted. This return can be in form of money, goods and services or in form of intangible goods such as knowledge, reputation and loyalty. Businesses thrive on value creation. Apart from value creation, businesses also sell or exchange value. Businesses strategize their activities to optimize performance and value creation. Such a set of activities is called a value chain. Porter [45] introduced the value chain concept to represent a set of interconnected activities.

A value chain is a sequential set of activities undertaken by a single firm. Businesses often don't act as individuals but in fact, interact, co-create and exchange value. Thus there is a need to form a system to represent and analyze the combination of several value chains with many businesses involved. In such a network there can exist uncertainty over certain roles that different businesses could perform as they work together to co-create value. This leads a value network analysis approach to allocate roles among businesses. Stabell and Fjeldstad [46] defined three value configuration models based on different value creation logics.

In this thesis the Value Network Configuration (VNC) method based on Casey et al. [47] is employed. According to which, a value network consists of interlinked business 'actors' and 'technical components'. This method describes business 'actors', 'technical components', 'roles', 'technical interfaces' and 'business interfaces'as shown in figure 14.

A technical component is a representation of the technology or collection of technologies into a component to realize the technical functionality. The technical components form a technical architecture. A role is an activity or a set of activities that are to be performed over the technical components for value creation. The actors are linked to the technical components by the roles they perform or in other words the actors take up roles that relate them to the technical components. The technical components are connected by technical interface and the actors take up

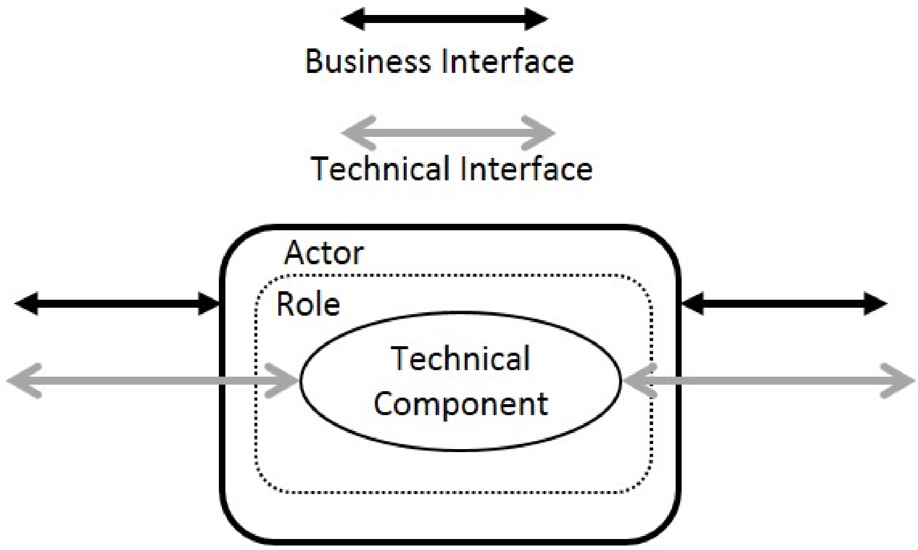

Figure 14: VNC block and interfaces. (Source: Casey et al. 2010)

roles related to technical components they are connected by a business interface. The VNC analysis provides a possibility to study the allocation, distribution and configuration of roles among actors.

4.2 Technical architecture, technical components and roles

The technical components for M2M communications are summarized in the table 5.

Table 5: Technical components for M2M communications and their description.

Technical Component	**Description**
Device (Mobile/ Stationary)	The component that hosts device applications. It connects to the network either directly or via gateway. It may or may not(legacy device) host M2M Service Layer (SL) capabilities.
Network (Access and Core Network)	The component that does not host M2M SL capabilities and that connects device, gateway and network application server with each other. Implements Network Slicing, NFV.
Authentication Authorization and Accounting (AAA)	This component controls access to resources, enforcing policies, auditing usage, and providing billing information for services.
M2M Platform/Slice	The component that hosts M2M SL capabilities and can be used by one or more application servers. The M2M platform is part of network application server.
Application (Device, Server)	Different applications (or the same) that are hosted by the device, gateway and the application server.
Application Server	The component that hosts the server applications.

The 5G technical architecture for M2M communications adapted from figure 11, with the strategically important roles is shown in figure 15. Value creation exists with the roles spread over device, network and application domains.

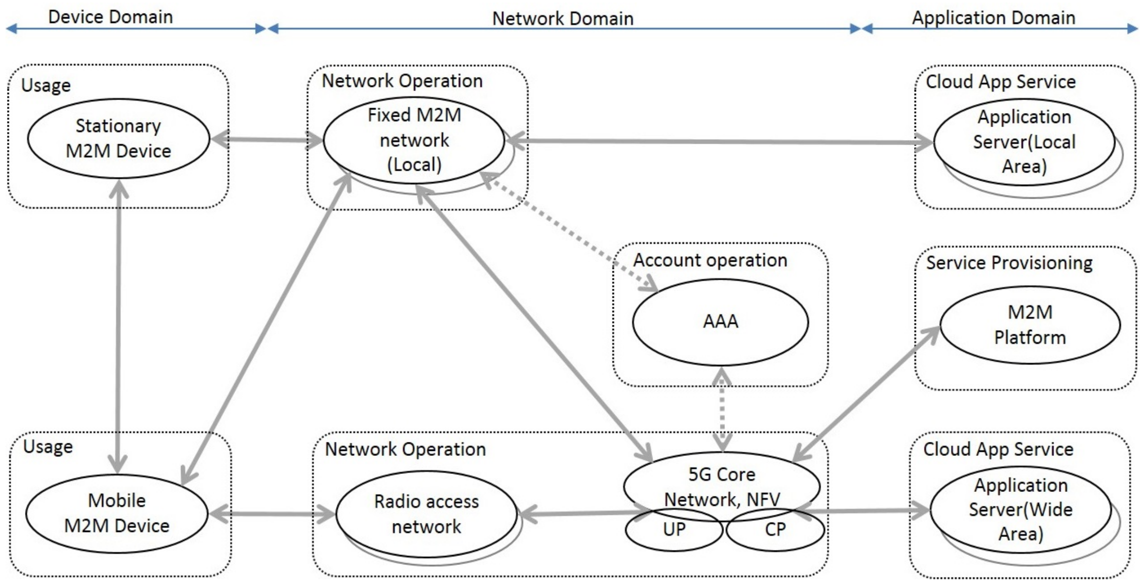

Figure 15: Technical architecture and generic roles

Thorough deconstruction of the functionalities of 5G local area access in Industrial M2M Communications allowed the identification of strategically important roles as summarized in the table 6. Some roles are not included because when designing a value network configuration it is easy to see that some of them are not needed to be included from a communication channel point of view, for example a M2M module vendor is not included in the M2M communication channel and thus is not needed in the VNC analysis. Although not ignoring the fact that it is necessary for initial manufacturing of the module.

Table 6: Business Roles, their descriptions and examples.

Business Role	**Description**	**Business Actor examples**
Service Provisioning	Includes M2M communication module and technologies, setting up M2M network, delivering data to application server and customer/industry.	M2M Service Provider-Eg. Ericsson (after acquiring telenor connexion), KORE Telematics, Oracle, Deutsche Telekom, Digi International etc
Application Service Provisioning	Includes application level functionality.	M2M Application Service Provider-Eg. In 2011, Audi partnered with T-Mobile and RACO Wireless to offer Audi Connect app, etc.
Network Operation	Either, includes operation of radio spectrum, access network and core network	MNO - Eg. Telia, Elisa, Vodafone, AirTel, etc.
	Or, buying of radio connectivity from MNO (It is dependent on MNO for radio infrastructure)	MVNO - Eg. Saunalahti (uses Elisa), ACN mobile (uses Telia), Tele Finland (uses Telia).
	Or, buying network slices from MNO.	Industry or Micro-operator.
Account Operation	Includes providing authentication, authorization, accounting (AAA) services.	Mobile Network Operator, Industry, Micro-operator, M2M SP
Cloud Service Provisioning	Includes data management, analytics, security, application integration to M2M SP.	Cloud Service Provider-Eg. Rackspace, Dimension Data, Qt cloud services etc
M2M module provisioning	The component that hosts the server applications.	M2M module vendor-Eg. 2j antenna, Artesys Ag, ADLINK Technology etc
M2M Platform Management/ Network Slice management	Creation, planning and allocation of resources and management.	MNO, Micro-operator, M2M SP or customer.

4.3 Value network configurations and analysis

The distribution of roles and the related value is dependent on the type of deployment and customer requirements. For example the role of local area access can be provided by different actors and further account operation can be handled by customers or third parties. These business roles can be shared among actors or shifted from one actor to another and this leads to alternate value network configurations. In each configuration there exist some actor that exercises more control over value than others and such actors are supposed to drive that VNC. This leads to following 5 alternate value network configurations.

1. **Micro-operator driven VNC**

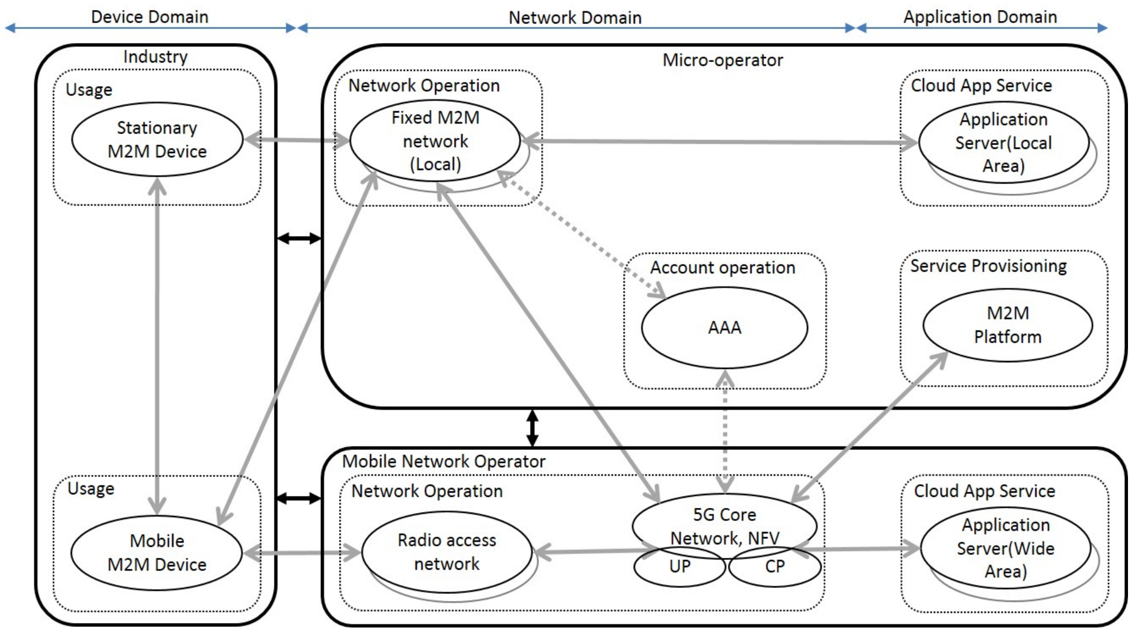

Figure 16: Micro-operator driven VNC

This VNC, shown in figure 16, is formed by the industry, micro-operator and mobile network operator working over device, network and application domain respectively. The industry buys and manages the M2M devices and accumulates the value generated from the industrial processes run on those devices. The industry will be dependent on MNO for wide area communication and micro-operator for local area communication. Micro-operator dominates over the local access and it will have contracts with the industry owners and MNO. Micro-operators can buy network slice from MNO and setup and manage the network for the industry (which will be similar to how MVNO will operate) or it can build the required infrastructure to be fully independent and responsible for the local communication needs that exist on-site. The micro-operator business model gives rise to new actors to enter the industrial internet market. The micro-operator will manage the account operation and also setup the M2M platform thus taking over the role of M2M service providers. The micro-operator will also be responsible for application provisioning as it is responsible for creating the M2M platform. The Micro-operator will own a cloud resource located on-site to support low latency communications for the industry. The devices will be able to use D2D communication independently or under assistance by the micro-operator and since the micro-operator operates locally the assisted D2D will be able to abide by the low latency requirements. Micro-operators could also have LAA policies to utilize the unlicensed spectrum. The customer can enjoy the local operation and management but the customer will still have to make contracts with MNO as well.

2. **MNO driven VNC (A)**

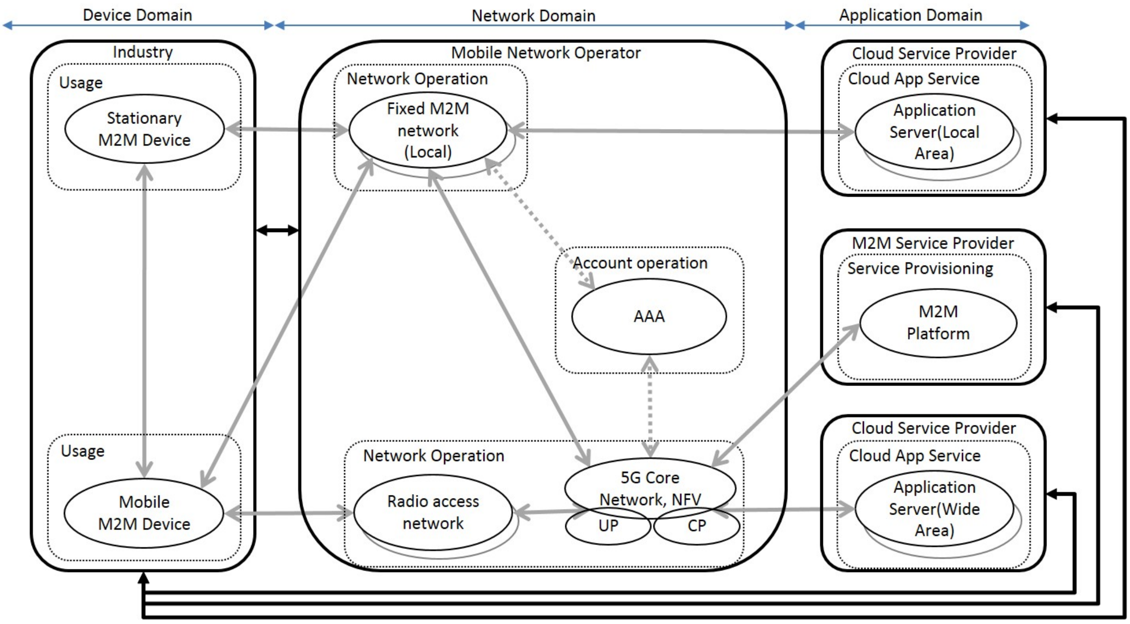

Figure 17: Mobile Network Operator driven VNC

This VNC, shown in figure 17, is formed by the industry working on the device domain, mobile network operator working in the network domain and M2M service provider and cloud service provider working in the application domain. This VNC follows a horizontal industry structure and the dominating communication technology will be 5G. The industry buys and manages the

M2M devices and accumulates the value generated from the processes run on those devices. The industry deals with the MNO, M2M service provider and cloud service provider for different roles. The MNO takes up the role of network operation and is responsible for account operation and management. The industry buys the service of MNO is form of dedicated slices. In such case the core user planes should be located locally to assist low latency and this will hugely impact the density of such customers that the MNO can support. As usual the MNO will also take up wide area communication. The devices on the site will be able to do D2D communication independently or controlled by operator over 5G. The MNO can deploy small cells and also utilize DUDe access to improve availability. The customer will contract the M2M service provider for setting up the M2M platform and the application provisioning. The customer will buy services from cloud service providers to set up a local and a central server for running application and data storage needs. The MNO has a business interface only with the customer and doesn't share revenue with any other actors. The customer needs to make different deals with more than one actor and thus interoperability and availability of actors can cause serious disruption of processes.

3. **MNO driven VNC (B)**

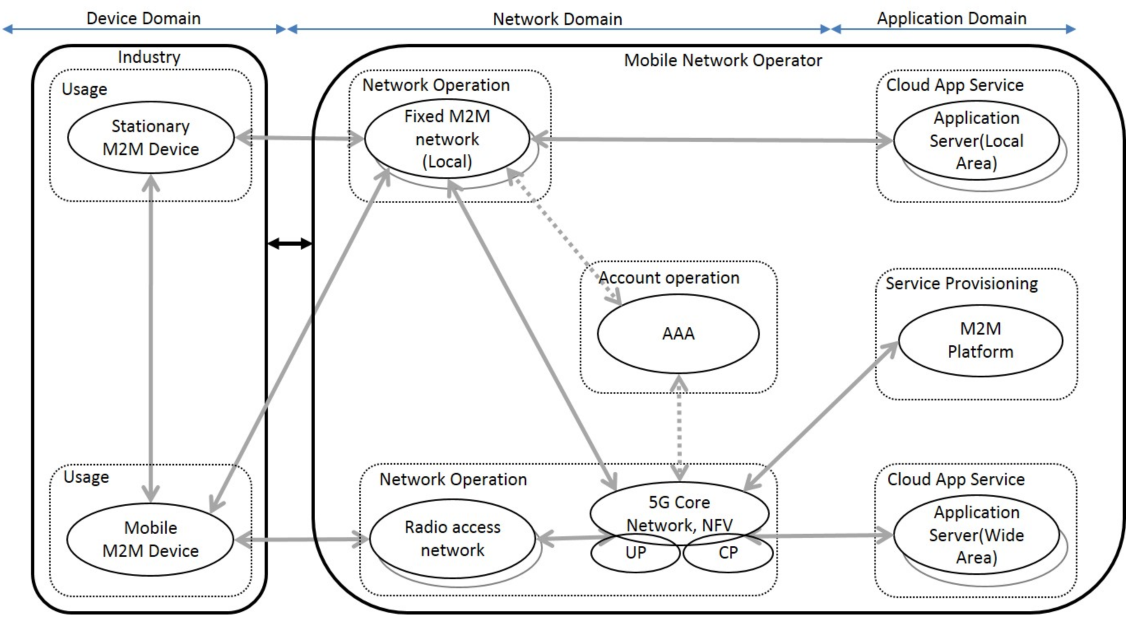

Figure 18: Mobile Network Operator driven VNC

This VNC, shown in figure 18, is formed by the industry working in the device domain and the MNO working in the network and application domain. This VNC follows a vertical industry structure and the dominating technology will be 5G. The industry buys and manages the M2M devices and accumulates the value generated from the processes run on those devices. The industry will make only one contract and that will be with the MNO. The industry will buy the service of MNO in form of dedicated M2M slices. The MNO will be responsible for all the M2M communication needs for the industry in local and wide area. The MNO will set up a local server on the site for low latency communication and also a central server for high processing requiring communications. The MNO will be responsible for setting up the M2M platform and application provisioning. The MNO will not face revenue sharing problems. The industry can be guaranteed better reliability as there will be no interoperability issues.

4. **Industry Driven VNC (A) – Private local network**

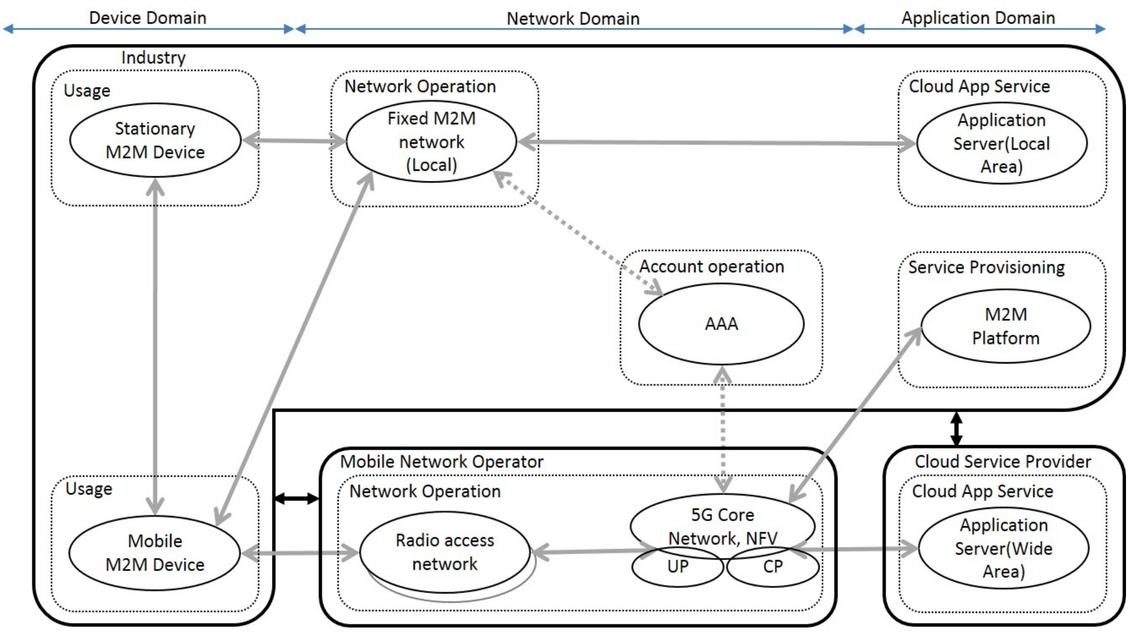

Figure 19: Industry driven VNC

This VNC, shown in figure 19, is formed by the industry working in the device, network and application domain, the MNO working in the network domain and a cloud service provider working in the application domain on for the wide area communication needs. This VNC follows a vertical industry structure and the communication solution will be a privately set up local network by the industry, dominated by WiFi. The industry will have business interfaces with the MNO and the cloud service provider. The industry buys and manages the M2M devices and accumulates the value generated from the processes run on those devices. The industry sets up private local network itself and also manages the account operation that will be managed by the MNO only in case of wide area communication for mobile devices. The Industry is also responsible for provisioning the application itself. The industry will pay for the central cloud server to be used by the MNO. This VNC will be beneficial if the communication requirements of the industry can be met without utilizing 5G. The industry will share the least revenue with others in this VNC.

5. **Industry Driven (B) – MNO slices**

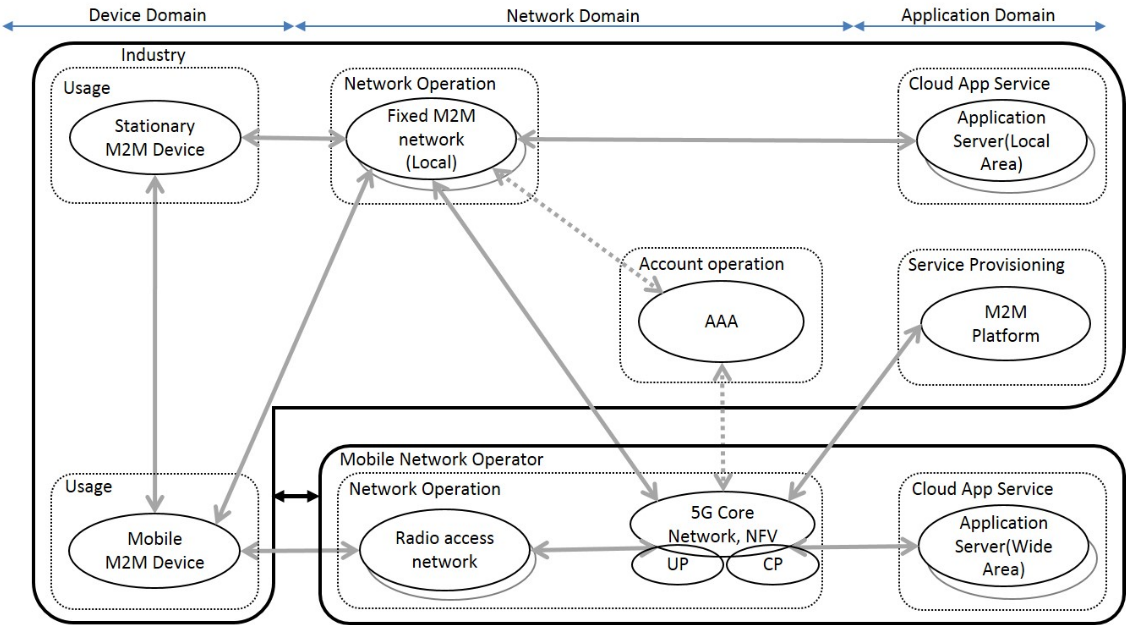

Figure 20: Industry driven VNC

This VNC, shown in figure 20, is formed by the industry working in the device, network and application domains, the MNO working in the network and application domains. This VNC follows a vertical industry structure and the dominating technology will be 5G. The industry will have business interface only with the MNO for the wide area communication for mobile devices going away from the industry site. The Industry buys and manages the M2M devices and accumulates the value generated from the processes run on those devices. The industry will buy dedicated network slices from the MNO and manage the network itself. The industry will provision itself with the application and also manage the local server that will be part of the network slice resources. The industry will have full independency over management of the network and ensure reliability by configuring the slices and be able to manage the network operation locally to ensure low latency. The industry seems to be in the best position in terms of performance and revenue given the industry employs the suitable expertise for network management.

5 Mapping Scenarios and Value Network Configurations

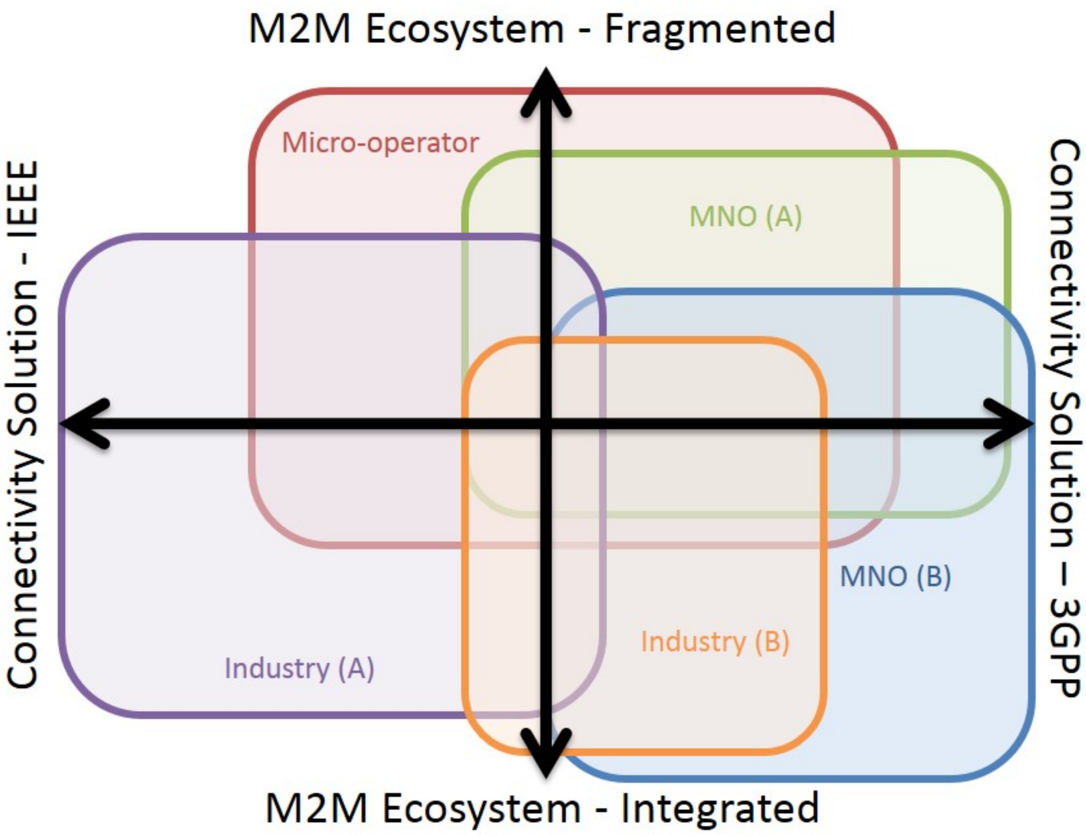

Figure 21: Mapping Scenarios and Value Networks Configurations

The diverse value network configurations vary in the dominating actor, the connectivity solution and the integration of M2M ecosystem. The future uncertainty over the ecosystem and the type of connectivity solution leads to four future scenarios. The value network configurations can be mapped onto the scenario matrix and can move along the two dimensions of the matrix. As the distribution of roles leads to a variety of value network configurations, slight variations along the two dimensions, could make one value network configuration merge into another. It is important to see that these configurations can co-exist and they probably will in the future. Thus, a mapping of the configurations on the scenarios can serve as a good measure to check on the importance of actors and the values they create. Such a mapping of the configurations spanning across the four scenarios is shown in the figure 21.

The VNCs occupy their positions on the scenario matrix according to their role distribution and the area occupied depends on the degree a VNC can vary in both dimensions and does not indicate any absolute values. As the VNC varies along the dimension, the control over the roles and value changes and the driving actor might start to lose maximum control over value creation and also performance of the technical architecture changes. It can be seen, for example - the MNO driven VNC-B constitutes an integrated ecosystem and 5G as the dominating technology. As it moves up along the ecosystem axis, the MNO starts to dissipate roles to other actors and starts to lose the maximum control over value creation. Along the connectivity solution axis, it can only move much so as to keep 5G as the predominant connectivity solution. Moving further along both axis merges it into the other VNCs.

6 Conclusions and Results

6.1 Results

The key findings from the literature research are the market forecast and statistics, the 5G enablers and architecture options that can build the future network. A discussion about e2e QoS is included in the literature survey to emphasize its importance to 5G local area access for industrial M2M communications. It is found that the best QoS can be brought about by locating the processing at the edges.The D2D scenario can be provided by different mechanisms where the devices can communicate independently or with intial authentication and connection setup by the operator. Again this can be improved by bringing the required processing to the access nodes. The industries can buy dedicated slices for guarantee of resources and in case of unexpected circumstances of traffic rise, the MNOs can provide generic slices for meeting the performance requirements by best-effort.

The key results from scenario planning method is that main uncertainties in the future lie in the integration of M2M ecosystem and the connectivity solutions. It is evident that the 3GPP and IEEE solutions will be competing with each other and the industries will have to make a careful decision according their requirements. The other uncertainty about the integration of ecosystem will be caused by the kind of role distribution, and this uncertainty will affect the performance of the M2M 5G ecosystem. These two uncertainties lead to four future scenarios that indicate how the future will shape.

The key results from value network configurations are the different actors that will be in the leading roles and acquire the maximum value. The various VNCs depend on the requirements and costs that the industries are willing to pay for those requirements. The performance requirements are affected by the VNC, for example, in Micro-operator driven VNC a company that has most of its processing needs local, can benefit with the low latencies, whereas a company that requires higher processing needs might need a larger central server provided by the MNO or a third party and having the network controlled by the MNO will also help in handovers for connected vehicles moving in and out of the local network.

The mapping of alternate VNCs on to the possible future scenarios in chapter 5 presents a view of the space spanned by the VNCs in the future directions.

6.2 Assessment of Results

The results are reached through extensive literature research and expert interviews to get industry insight. The experts include professors, researchers, managers and related project heads, in the fields of M2M, 5G, IoT, MNOs, networking and industrial process automation. The results are indicative of the future industrial internet. The results are not from the point of view of one actor but takes into account all the actors. This provides a top-down overview of the future of 5G and M2M communications.

The scenario planning method is consistent with the trends and uncertainties, and provides four possible future scenarios. The architecture employed for the VNC study is based on the strategically important roles for techno-economics and is not an exact representation of the future 5G architecture. The VNCs are formed by extensive research and expert interviews and are found to be consistent with the future scenarios. The mapping of the VNCs and future scenarios indicates this consistency and directional differences in the VNCs. Also the area spanned by the VNCs is not indicative of absolute values but indicative of directional movement along the axes of the scenario matrix.

6.3 Exploitation of Results

The results are useful for all actors who will be interested in being a stakeholder in the future of 5G local area access for M2M communications. As stakeholders, the actors could use the results of the scenario planning method to plan their strategy for the future. The results of value network configurations can be used by the actors to plan their value creation method and fit in the ecosystem. This can also help them to find what and how much influence would the actors have on each other.

6.4 Future Research

The scenario planning method was adopted from Schoemaker's method [33] and the quantifying steps were left out. For future research the scenario planning can be extended to quantifying the scenarios and finding the best results iteratively. The future research is an iterative process and the scenarios should be iterated and adjusted with the changes in the future. The VNCs can also evolve with changes in the future and can expand or squeeze roles depending on entry of new actors, for example, a new entity apart from those already discussed can become responsible for network slice creation and e2e management. Both methods, scenario planning and value network configurations are an iterative process and future research includes iterating and quantifying them with the political, economic, social and technological changes over time.

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A List or Interviewees

- Telecommunication and M2M Expert, Networking Module Vendor
- Corporate Researcher, Process Automation
- Telecommunication Expert, Mobile Operator Business
- Innovation Expert(5G), Mobile equipment vendor
- Professor(Networking,Techno-Economics), Department of Communication and Networking
- Professor(Wireless Communications), Department of Communication and Networking
- Professor(IoT), Department of Information Technology
- Master Researcher, eSIM, M2M, Techno-economics
- Master Researcher, M2M, 5G, Wireless Communications

B Trends and Uncertainties collected from interviews and research publications.

Table B1: Trends.

Trends
Increasing number of M2M connections
Increasing M2M traffic
Digitalization of industries
Role of developing countries is increasing
Spectrum allocation is moving towards higher frequencies
Voice call priority lowering and data priority rising
Concerns about wireless radiation is rising

Table B2: Uncertainties.

Uncertainties
Industry Structure- Vertical or horizontal(Economy/industry)
Role of shared and unlicensed spectrum- limited or significant(Political/regulatory)
New players - modest competition or market disruption(Political/regulatory)
Job scenario in a 5G world - minimal impact or significant impact(Social)
Local Access technology – IEEE or 3GPP (Technology)
Deployment environment - existing trends or new unprepared use cases(Technology)
Life cycles – long or short (Technology)
Automation/safety regulations – progressive or suppressive (Political/regulatory)
Roaming regulations – same as mobile consumer or specific M2M (Political/regulatory)