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M2M on 4G LTE and 5G

Overview of Machine-to-Machine Communications and underlying technologies

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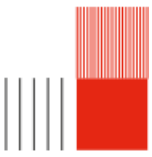

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Chapter 1

Introduction

In a world where the Internet of Things (IoT) is becoming more important, Machine-to-Machine (M2M) communication plays a key role. It allows devices to communicate directly with each other to exchange data and automate processes without human intervention. This type of communication is essential for various applications, such as managing smart cities, Industry 4.0, connected healthcare, and logistics.

To meet the needs of these applications, two mobile network technologies stand out today: LTE-M, an extension of 4G designed for IoT devices, and 5G NR, the new generation of mobile networks. LTE-M is designed to provide extended coverage and low energy consumption, which makes it suitable for IoT devices that need a reliable and energy-e cient connection. On the other hand, 5G o ers signi cant improvements in terms of speed, latency, and connection density, allowing it to meet the higher requirements of real-time and large-scale applications.

This report aims to compare the performance of LTE-M and 5G for M2M communication by examining their advantages, limitations, and main areas of application. By exploring these two technologies, we will show how they enable the creation of more e cient and responsive networks of connected devices, while also identifying the technical challenges and future opportunities for the development of M2M.

Chapter 2

LTE-M

2.1 Introduction to Long Term Evolution for Machines (LTE-M)

In a context of Machine-to-Machine (M2M) communications, we seek to exchange information between connected devices often far from another to achieve speci c tasks and exchange data. The goal is often to create a network of connected devices like sensors and embedded systems to automates process. That's why M2M is a big part of the Internet of Things (IoT).

Considering the requirements of this type of communications, EXALTED [12], a project of the European Union's Seventh Framework Program (FP7) presented LTE-M, a system that extends LTE speci - cations for M2M communications. Machine Type Communication (MTC) also called M2M was indeed in need of solutions for long range communication with a huge number of simultaneous connected devices, making 4G LTE a promising approach. However other needs in terms of adaptable data rates and low power consumption relative to sensors and IoT applications justi ed the necessity of an alternative approach that resulted into the LTE-M. Iterations and revised versions of the project were then integrated in di erent 3rd Generation Partnership Project (3GPP) releases bringing to the table di erent versions of the existing protocol such as LTE-M Cat-0, LTE-M Cat 1.4 MHz and LTE-M Cat 200 Khz for various usage. In this overview of the LTE-M technology we will concentrate on the Cat 1.4 MHz version that operates in the smallest LTE 1.4 MHz band (the most used that was called LTE-M Cat-M1 in the 13th release of 3GPP).

2.2 Physical and MAC Layer of LTE-M Networks

2.2.1 Infrastructure

Since LTE-M was conceived as a Low Power Wide-Area Network (LPWAN) like the Nb-IoT, based on the 4G LTE already existing cellular network, they both coexist on already existing LTE infrastructure with minor modi cations to assure a global functioning network such as M2M gateway performing protocol translation and data aggregation before transmitting messages to the application server via a speci c LTE-M interface [8]. The networks access to LTE-M devices and is performed via eNodeB base stations as shown in Fig. 2.1.

2.2.2 Bandwidth and performances

The radio access network (RAN) termed eUTRAN/eNodeB uses single-carrier frequency division access in uplink (UL) and higher-performance orthogonal frequency-division multiple access in downlink (DL). Thus depending on categories released by 3GPP and use cases the LTE-M network is deployed on di erent bandwidth and achieve di erent performances [8] as shown in Fig. 2.2.

In the case of the LTE-M Cat 1.4 MHz, to solve the adaptable data rate problem an LTE-M device uses a smaller, narrow channel for sending and receiving data and control signals. This channel's width is limited to 1.08 MHz, with a set of six adjacent Resource Blocks (RBs), each 180 kHz wide as illustrates Fig. 2.3. Including guard bands, the total bandwidth adds up to 1.4 MHz, which is the smallest available LTE band. This 1.4 MHz band is used for low-bandwidth applications that need data rates between a few kilobits per second and 1 Mbps, allowing speeds up to 375 kbps for uploading and downloading in

Figure 2.1: LTE/LTE-M Network Architecture [8]

Figure 2.2: LTE-M Network Parameters [8]

half-duplex (HD) mode, and up to 1 Mbps in full-duplex (FD) mode. LTE-M devices use the same cell search and random access methods as traditional LTE devices [4].

Figure 2.3: LTE 1.4 MHz band with 6 Rbs [4]

2.2.3 MAC layer

The communication protocol is articulated around di erent aspects such as ressource management, time sensitive scheduling and error correction. Indeed, by using resource blocks (RBs) with a xed bandwidth, the network can e ectively allocate frequency resources to di erent users. Time-sensitive scheduling is performed thanks to the 1 millisecond transmission time interval (TTI), which is the smallest unit of time in which the eNodeB is capable of scheduling any user for UL or DL transmission, enabling to quickly respond to changing network conditions and user demands. Finally the error correction is performed via an incremental redundancy hybrid automatic repeat request (IR-HARQ) process (shown in Fig. 2.4) enhancing the reliability of data transmissions [4].

A priority system illustrated in Fig. 2.5, is also inherited from the 4G LTE network but networks operators can apply their own discretion to assign the priority levels for their services [4].

Figure 2.4: Incremental redundancy HARQ process [4]

Figure 2.5: 3GPP Proposed LTE-M Priority structure [4]

2.2.4 Coverage and Modulation

Since the LTE-M network is deployed on the already existing 4G LTE Network, a wide area can be easily covered for IoT applications. For example already more than 99% of France population is already covered by the Orange LTE-M network as shown in Fig. 2.6.

Figure 2.6: Coverage of Orange LTE-M Network in France - www.orange-business.com/fr/reseau-LTE-M

Even considering the already large proportion of covered areas, one of the techniques used to enhance the coverage of the network is the low order modulation using quadrature phase-shift keying (QPSK) instead of 16 quadrature amplitude modulation (16 QAM), usually used. However, lower modulation implies lower spectral e ciency (bps/Hz). This results in lower bandwidth but extends the coverage. However the 15th 3GPP release was focusing on low latency and thus introduced a version of LTE-M using a higher-order modulation (64 QAM) [4].

2.3 Power Consumption

Both Nb-IoT and LTE-M supports the Power Saving Mode (PSM) and the extended discontinuous reception (eDRX) that can be used together or individually to conserve battery power and potentially achieve and exceed 10-year battery life (in real application cases we can achieve a battery life greater than 5 years [4]) by sending or receiving data intermittently. In the case of eDRX (illustrated in Fig. 2.7), the device can temporarily turn o the radio receiver for a brief period, which saves power. This feature signi cantly extends the duration that the device can remain inactive and not listening to the network [4].

Figure 2.7: Extended Discontinuous Reception [4]

2.4 Mobility

LTE-M works like 4G LTE and supports seamless switching between cell towers while saving power. It thus supports full mobility.

2.5 Security

Since the project is included in 3GPP releases, it bene ts of every security features provided by 3GPP, such as support for user equipment (UE) identity, con dentiality, entity authentication, and data integrity [4].

2.6 Toward 5G Networks

LTE-M forges a path toward 5G networks since it already proved that it was possible to provided an IoT enhanced network based on already existing cellular networks infrastructure. It is easy to imagine that it will be possible to achieve the same with incomming 5G networks. Thus it is already proven that LTE-M can coexist with 5G New Radio (NR) frequency bands without disrupting existing LTE-M deployments because LTE-M meets 5G's requirements for battery life and message latency within the sub-6 GHz frequency range [4].

Chapter 3

5G New Radio (NR)

3.1 Massive MIMO and Beamforming

Massive MIMO is one of the key factor make the improvements between 4G LTE and 5G NR (New Radio). MIMO stands for Multiple Inputs - Multiple Outputs, and it was used since wi 4 and 3G with multiple antennas on both the receiver and transmitter side, using multipath for increasing spatial multiplexing. In 5G it has been coupled with beamforming in order to further increase the data rates.

Beamforming is a way of spatially modulating the signal (i.e. orienting it in 3D) with constructive and destructive interferences produced by modulating both the phase and amplitude of emmited signals in an array of antennas (see g.). This is roughly equivalent to having a directional antenna, where we can choose the max gain direction without any mechanical part.

5G NR is using a new 24,250 MHz 71,000 MHz frequency range, in part for beamforming, as with $= \frac{c}{f}$, with the wavelength and c, the speed of light, we get that 2 [4:2mm; 12:3mm]. Those smaller wavelengths allow for more compact antennas arrays and hence the technologie can be implemented on smaller devices. However, those higher frequencies comes with a big drawback as their absorption by the atmosphere is higher then for the already used 410 MHz 7,125 MHz band (also used by 5G actually). This is compensated by the gains provided by beamforming [6].

Figure 3.1: Atmospheric gas attenuation versus frequency [10]

Figure 3.2: Massive MIMO antenna array [15]

3.2 Used waveform

For LTE Orthogonnal Frequency Division Multiplexing (OFDM) was used. But for high data rates, high mobility, and power e cient 5G IoT network, this represant sever drawbacks.

For instance, OFDM relies on maintaining strict orthogonality between subcarriers to avoid interference between them. However, in scenarios with high mobility, such as users moving quickly (e.g.,

in vehicles), Doppler shifts cause frequency o sets that disrupt this orthogonality. This leads to Inter-Carrier Interference (ICI), reducing the system's e ciency and increasing error rates. OFDM also use cyclic pre x to counteract multipath interference, helping to mitigate Inter-Symbol Interferences (ISI). However, this spectral e ciency by reserving part of the bandwidth for redundancy instead of useful data. Finaly OFDM inherently has a high PAPR due to the combination of many closely spaced subcarriers. This high PAPR requires power ampli ers to operate linearly over a wide dynamic range, which reduces their power e ciency and makes them less suited for low-power devices.

Hence, to adress those limitations, new waveform where explored such as lter bank multicarrier (FBMC), generalized frequency-division multiplexing (GFDM), CP-OFDM and DFT-S-OFDM (for up-link only) (see: [1]).

3.2.1 CP-OFDM

CP-OFDM was already used in LTE, and is an improvment from OFDM that allows to both simplify signal processing on the receiver side, and reduce the e ect of Inter-Symbol Interferences (ISI). OFDM works be subdivising the bandwidth in smaller orthogonal subcarrier on which the tranfer function of the canal can be consider at. This allow for a reduce symbols rate, and thus it become a ordable to use guard intervals. This comes in handy with the CP part of CP-OFDM. CP mean cyclic pre x in this case. It is a temporal padding of size superior to the impulse response of the canal, done by copying the n-last weights of the symbol signal, at the start of it. This allow for the convolution between the canal impulse response, and the symbol vector (time domain), to be circular. Hence it can be represented in the frequency domain, and by knowing the transfer function of the canal, we can use the single tap equalizer. Moreover it mitigates ISI. As well it was not used in previous standards because of its computational cost.

3.2.2 DFT-S-OFDM

DFT-S-OFDM or Discrete Fourier Transform-Spread-Orthogonal Frequency Division Multiplexing, is used for uplink in 5G NR and LTE technologies. It works similarly as the OFDM, but the symbols are passed in the frequency domain and then those coe cients are mapped to di erent subcarriers (usualy contiguous frequency wise) in order to spread the symbol frequence wise. This help to lower the Peak-to-Average Power Ratio (PAPR), that tends to be high in normal OFDM, as several subcarriers can add up by summing each other in the time domain, and then necessisating more powerfull ampli er with a big dynamical range, whose are costly and less power e cient than less demanding ampli er. Hence the use of this modulation for low power uplink communication, even if it has a lower data rate.

3.3 Power E ciency

According to 3GPP [2], telecommunications account for 2 to 3% of total energy consumption worldwide. Moreover, 5G technologies aimed to enhanced the deployement of massive IoT network. Those IoT devices are embedded by nature, and as such need to be low power / energy e cient. On those application telecommunication can account for a great percentage of total energy consumption, the good question is how mush, and is it suitable for very low power applications ?

Here's how the 3GPP standard evolve in order to create more energy e cient hardware and protocols. Release 15 introduce the addition of a paging indication channel for 5G networks. This is a specialize channel that is used to signal to device if they need to get out of their idle mode. Thus the devices can stay most of the time in a stand by mode, cimsumming less energy. This release also add deferred system information acquisition. Usualy cellular network devices need to wake up to get certain information about the network (frequency bands, cell IDs, and coverage area information, etc), with this addition it can deferre the sending of this message, thus staying in stand by and consumming less power.