Chapter 13. “M2M Communications in 5G”

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1 Introduction

In 2009, the Wireless World Research Forum (WWRF) envisioned a total of 7 Trillion (7,000,000,000,000) of connected devices by 2017 all around the world [WWRF09]. Such expectations led the magazine Forbes to claim in August 2014 that the Internet of Things (IoT) was the most hyped technology, overtaking Big Data (Figure 1).

![Forbes](image)

*Figure 1 IoT: hype or ripe?*

Today, it is possible to assure that the figure envisioned by the WWRF back in 2009 was maybe a bit too optimistic, according to the lower figures brought down to billions or even millions as stated in various market research reports. However, even though the figures may differ by some orders of magnitude, there is a common agreement on the fact the Internet of Things (IoT), or Internet of Everything (IoE), is here to stay, grow, and change the world as we know it. The reality is that, according to Machina Research [MR14], the number of sensor and actuator shipments in 2014 reached 23.64 billion (which mainly includes the dozen sensors found in a typical smart phone), the number of total connected devices was of more than 14.4 billion, and the number of M2M connections were above 4 billion.
Such promising market figures are motivated by the fact that the concept of having all objects interconnected and Internet-connected is very appealing and can foster the creation of innovative applications and business models, and boost societal well-being altogether. The wide range of IoT applications is overwhelmingly wide, including smart grids, smart cities, industries 4.0, smart automotive driving, eHealth, and wearable technology, among many others (Figure 2).

**Smart grids** constitute one of the key markets, and they have received a lot of attention from both academia and industry. The vision is to improve the efficiency of the electric grid so that the energy demands and waste can be reduced by making a smarter use of energy, the dependency on natural resources can be softened, and the distribution of electricity can become more efficient. The use of automated communicating devices monitoring the state of the grid and the instantaneous use of the resources is essential to attain the objective of achieving a truly smart grid. Very much related to smart grids is the concept of automatic smart meter infrastructure (AMI), which may pose a wider view of the application scenario. Besides electricity, the measurement of water or gas consumption can improve the efficiency in which these resources are dispatched and consumed. A smart and automated reading of meters is beneficial for all involved players: consumers can accurately track their consumption and thus learn to be more efficient; on the other side, facilities, besides avoiding the manual reading and reporting of meters, can better dimension the production of resources, thus leading to cost savings.

![Figure 2 Key IoT Verticals](image)

**Smart cities** constitute one of the most appealing applications and markets. Automated parking search, public lights, container levels, notification in case of incident, warning in
case of vandalism of security threat, are some of the example of applications that could make cities more efficient by enabling communications between devices. Indeed, the Smart City concept has triggered the attention of many cities, which are struggling to become the worldwide references in applying technology to their city operations. Barcelona, London, New York, or Sydney are just few examples of emerging technology hubs devoted to the Smart City concept.

The concept of the **Industrial Internet**, as introduced by General Electric (GE) a few years ago, promises improvement of efficiencies in industries, driving down the costs of manufacturing, and creating a revolution in a sector which has an impact in many verticals. According to the numbers presented by GE in Figure 3, improving the efficiency of industrial processes by a factor 1% can lead to huge economic gains and savings, thus becoming a primary application domain for the IoT.

![Industrial Internet: The Power of 1% (benefits over 15 years when scaled up across the economic system)](image)

The **automotive** sector has become a key vertical market for the IoT. Enabling remote monitoring, in-vehicle diagnosis, or car-to-car communication to improve safety on-road emerge as key domains to drive the innovation of the IoT. The European eCall initiative, that targets the installation of SIM cards in each vehicle for automatic notification in case...
of accident, will enable more sophisticated vehicle-based applications in the near future. This is just the beginning.

Today, we also see the advent of **wearable technology**. Bringing technology down to the individual domain, having sensors and actuators interacting with individuals becomes the latest trend in the development of the IoT. Smart clothes, watches, earrings, or glasses, will completely change the world as we know it. **eHealth** raises as a big subdomain of wearable technology. Remote diagnosis and even drug dosing are just two simple examples of applications that can benefit from having automated communications between in- or on-body sensors, actuators located at the patient home, and the centralized servers installed at hospitals.

All in all, the use of automated communications among machines, devices, and people can lead to a smarter and more efficient world. A world which is different from what we now today. However, before this new world becomes a reality, there are still many challenges that need to be faced. Some are related to the new economics triggered by the IoT, or even the societal implications that such hyper-connectivity will impose. However, in this chapter we focus on the technological challenges, many of which are still pertinent because prior technology attempts failed. In particular, the focus will be on the challenges that the definition of the next generation of wireless communications will need to cope with. This is the **5G**.

5G will be the next generation of wireless communications, and its deployment is expected to start by 2020. The Wireless Radio communications Conference (WRC) was held in November 2015, officially starting-off discussions about what 5G will be and what spectrum is needed for it. Over the last 30 years, every new generation of wireless communications has had to deal with the growing need for more data bits and capacity. The evolution from 2G to 4G, passing through 3G, has seen an increase in complexity to satisfy the needs of Mobile Broad Band (MBB) services, requiring more and more data. However, for the first time in history, the arrival of the Internet of Things, dealing with Machine-to-Machine (M2M) communications, also referred to as with the more special 3GPP term Machine-Type Communications (MTC), calls for something different. This new generation of communications has to deal with the coexistence of Human-Type Traffic (HTC), possibly calling for more capacity following the trend of previous evolutions of the various generations, with the emergence of MTC traffic, which is fundamentally different from HTC.

This chapter is devoted to discuss the emerging MTC wireless communications and their role in the definition of 5G. Towards this end, the chapter is organized as follows. In
Section 2, we describe the elements of an IoT application and define the concept of MTC and M2M, highlighting the differences with HTC traffic. In Section 3, we discuss existing technologies to cope with MTC. In Section 4, we set the objectives to be met by 5G in order to cope with the various requirements posed by MTC applications. Towards the conection of these objectives, key enabling technologies are identified and discussed in Section 5. Finally, in Section 6, an outlook and future perspective of MTC in 5G is provided to conclude the chapter.

2 M2M Communications: what is new?

M2M or MTC constitute a fundamental part of any IoT application. Making things simple for the sake of understanding, the elements of an IoT application are (Figure 4):

- **End M2M devices**: electronic platforms consisting of at least some kind of energy source (battery or energy harvester), a microprocessor to execute “smart” instructions, a radio transceiver and antenna to communicate with other devices, and sensors and actuators to interact with the physical world, hence the frequently coined term cyber-physical system (see Figure 5).
- **M2M gateways**: devices in charge of coordinating and concentrating data from a number of end devices in an M2M area network and providing them with connectivity to the Internet.
- **Communications Networks**: backhaul and core networks to connect either the end devices or M2M gateways to the Internet or other external networks. These networks can be either static or virtualized dynamically.
- **M2M Platforms**: hardware/software entities (e.g. data centers, computers, data bases in the cloud, etc.) in charge of providing data storage and (big) data processing capabilities to process the data obtained from the sensors and take some actions (business intelligence).
- **End User devices**: any kind of device which enables the interaction between the cyber-physical system and humans. This could be, for example, a mobile app running on a smartphone or tablet, or a web service browsed from a laptop.
The term M2M or MTC is typically used to refer to any exchange of information between machines into this ecosystem. Note that MTC traffic can travel in the access network from end M2M devices to other end M2M devices or to M2M gateways, from the M2M gateways to the core communication networks, within the communication networks themselves, from these networks to/from M2M platforms, and in data exchanges to/from the end user devices. Essentially, M2M or MTC refer to any communication where at least one of the ends is a machine.

These communications between machines, or between machines and people, MTC, are conceptually different from HTC [LAY15]. This implies that the design of future communication networks has to take these differences into account. Some of the main differences that the specification of 5G will have to deal with are [ZHE14]:

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**Figure 4 Elements of an IoT Application**

**Figure 5 The Internet of Things and Machine-Type Communications**
- **Small Data Transmission**: the data exchanges of MTC are typically small. Think for example of the transmission of a “flag” to indicate whether a light is on or off, or the case of a reading from a smart meter. Few bytes will suffice for that purpose. Compared to HTC traffic, where the payloads are typically very large, MTC deals with small data.

- **Uplink transmissions**: the weight of the uplink of MTC is comparable, or even higher, than downlink. This implies a design shift from traditional HTC communications systems, primarily designed for the downlink. Despite the emergence of interactive applications, still most applications rely on the downlink. The growth of video transmissions and broadcast of multimedia material points at an even higher asynchrony in the data flows for HTC.

- **Energy efficiency**: yes, all communications must be as efficient as possible from the energy point of view to avoid the need for constant battery recharges. However. In MTC, this becomes particularly critical, since in many cases, it will be not feasible to recharge the batteries of all deployed devices due to scalability (size of the network) or reachability. Note that in some cases, the devices will be installed in wide spread areas, and thus it will turn unfeasible to recharge or replace the batteries individually. The energy efficiency needs to be boosted by a factor 10 at least, so that the lifetime of devices can be measured in tens of years.

- **Amount of devices**: it is expected that the amount of devices connected per aggregation point will increase by a factor 1000 with the IoT. Therefore, MTC devices will be deployed in massive networks.

- **Infrequent transmissions**: exploiting “deep” duty cycles will be key to ensure scalability and energy efficiency of MTC applications. Therefore, the infrequent transmission of data is expected from MTC devices. This has a great impact into the design of communication networks, since the systems need to be designed for a huge number of devices, knowing that just a small proportion of them will be active at any given time.

- **Low Mobility**: many MTC applications are characterized by having very low mobility patterns; in many cases, the devices will be completely immobile. This has strong implications in those systems that integrate control signaling to allow mobility and roaming.

- **Heterogeneous requirements**: the wide variety of applications related to the IoT pose diverse, and sometimes counterpoised requirements. For example, some MTC applications will be delay-constrained, while other will be highly delay tolerant. Therefore, the design of communications networks for MTC will have a to deal with a great variety
of different requirements involving capacity, reliability, scalability, delay, Quality of Service (QoS), etc.

The new generation of wireless communications will need to cope with all these requirements of MTC, while ensuring that all HTC services are not jeopardized.

3 Existing Communication Technologies for MTC

As it has been discussed in the previous section, MTC are fundamentally different from HTC. Therefore, new emerging communications systems will need to handle with the coexistence of both types of traffic. However, before starting to define a new technology in 5G to cope with MTC, it is necessary to understand which technologies are available today and how suitable (or not) they are to handle such complex scenario that is being formed today.

Figure 6 shows some of the key available wireless communications technologies used to today to power the IoT.

Before continuing with the discussion, they reader may have noted that there are no wired solutions represented in the figure. A wired solution, understood as a solution where sensors or actuators are physically connected to a gateway that provides connectivity to the backbone network, provides an extremely reliable communication channel, with high rates, low delays, and extremely high security. Information cannot be overheard by a third party unless cables are physically intercepted. However, although wired solutions are cheap to maintain, their deployment might be an important entrance barrier for some IoT applications. The main drawback of wired solutions is the lack of mobility and scalability, as the addition of new devices to an M2M network requires the cabling of the new devices.

Therefore, the IoT will be mainly driven by wireless solutions. Connecting billions of devices through wires does not seem a promising approach. Therefore, even though some applications will still rely on cables, it is expected that the majority of M2M applications running the show of the IoT will be based on wireless technologies.

Looking at Figure 6, it is possible to see how available wireless communication technologies offer different solutions in terms of range and transmission rate. The ones shown in the figure and which will be discussed later on in this chapter are:

- **Visible Light Communications** (high rate, short range).
- **WiFi** (high rate, medium range).
- **Zigbee-like** (low rate, shot single-hop range and long range via multi-hop).
- **Bluetooth Low Energy** (low rate, short range).
- **2G, 3G, 3G+** (medium rate, long range).
- **LTE, LTE-A, and beyond** (high rate, long range).
- **Low Power Wide Area (LPWA)** – (low rate, very long range).

It is important to note that when it comes to selecting the most suitable technology, other performance indicators may become even more relevant than range or rate; note for example the case of eHealth solutions where security and privacy may be the key performance indicators, or automotive applications, where latency and reliability may become the critical parameters to evaluate. An example of business criteria for selecting various technologies for M2M is shown in Figure 7 where availability and reliability are traded for the purpose of selecting the most suitable technology for each IoT application.

In the following sections, each of the technologies shown in Figure 6 are briefly described and their suitability for MTC is quantitatively assessed.
3.1 Visible Light Communication (VLC)

The use of modulated LED (Light Emitting Diode) to transmit data is not a mainstream technology yet, but it has a huge potential to become ubiquitous in the coming years [JOV13]. The reasons are pretty simple:

- It is an extremely secure technology; since the light cannot go through walls, only receivers in line of sight of the transmitter can receive data.
- It has no associated radio emissions, thus avoiding limitations of use in “sensitive” areas such as hospitals, primary schools, or chemical plants, among others.
- It has high bandwidth compared to radio technologies, thus leading to high data transmission rates.

On the counter-side, VLC suffers from not being a mainstream technology, thus not mature enough as compared to other radio solutions. Therefore, its cost is still too high to be widely accepted to deploy billions of devices. Also, the limited range and need for line of sight, while providing strong security, it constitutes a limitation of its usage for certain applications.

3.2 Radio Frequency Identification (RFID)

Many runners all around the world use the technology based on the ISO 18000 Standard to measure the time they need to complete 10k, 21k or marathons. This is probably the most popular usage of RFID in the world. However, this technology is used in a plethora
of other applications, such as proximity access cards, tracking pets or goods for logistics, among many others. By the year 2014, the RFID market was quantified in being close to a 9 billion US dollar market, showing its strength as a tagging technology. Some market research reports claim that the potential of RFID will make it grow up to a 27 billion US dollar by the year 2024.

The relationship between RFID and the IoT is undisputed, and its usage to tag things will play a key role in the future, especially due to its very low cost of deployment. However, the limited data transmission rate and very low coverage limits its applicability to very specific applications, where, by the way, it may see no competition at all in the coming years.

3.3 Wireless Local Area Networks (IEEE 802.11)

The IEEE 802.11 Standard is the most successful commercialized standard for Wireless Local Area Networks WLANs. The WiFi alliance was very successful in maximizing the market penetration of WiFi devices that today can be found almost everywhere. This technology operates in license-free bands, the so-called Industrial, Scientific and Medical (ISM) bands.

The ubiquity of WiFi is becoming undisputed. The number of Access Points (Aps) available in urban cities is growing, and the footprint of WiFi is becoming denser. Today’s data plans to not allow sharing these WiFi APs, but, being the infrastructure already there, it is just a matter of finding the business case to make all these connecting points available to the public.

In addition, the IEEE 802.11 standards family is extremely dynamic, and new amendments are constantly being developed and evolved to increase capacity (e.g., 802.11ac and ad) or to enable new uses cases such as the IoE, home automation, smart grid or wearable consumers (e.g., 802.11ah).

The latter, i.e., the novel IEEE 802.11ah project, is particularly interesting since it can potentially become an accelerator for IoT uptake. The standardization work of the corresponding ah task group had commenced in November 2010 where the prospective technology is generally based on a variation of IEEE 802.11ac standard but down-clocked by a factor of 10. It is currently being developed to enable low-cost long-range (up to 1km) connectivity across massive M2M deployments with high spectral and energy efficiencies. Today, thousands of M2M devices may already be found in dense urban areas, which required providing support for up to 6K machines connecting to a single access point.
Fortunately, IEEE 802.11ah technology does not need to maintain backward compatibility with the other representatives of the IEEE 802.11 family. Operating over different frequencies, 802.11ah could thus afford defining novel compact frame formats, as well as offering more efficient mechanisms to support a large population of devices, advanced channel access schemes, as well as important power saving and throughput enhancements. As the result, 802.11ah is believed to significantly enrich the family of 802.11 protocols, which already receive increasing attention from mobile network operators willing to introduce low-cost connectivity in unlicensed bands.

All these amendments are being already developed with security measures in place, thus making WiFi a very trustful and secure technology. For all these reasons, the cost of WiFi chips is dramatically going down, thus becoming very competitive to become a major driver of the IoT [TOZ12].

On the downside, all IEEE 802.11-based Standards operate in an increasingly crowded license-free ISM band, thus suffering from inter-system interference, suffering from limitations in the transmit power, and suffering from a lack of network planning. The overlapping of access point’s coverage can lead to very low performance in highly dense environments.

3.4 IEEE 802.15.4 (Zigbee-like solutions)

The IEEE 802.15.4 Standard, promoted by the Zigbee Alliance, was originally defined as the most energy efficient solution for short-range communications also operating in ISM bands. Unfortunately, some recent research works have shown that WiFi used in Low Power mode can be more efficient than an IEEE 802.15.4 Network [TOZ11]. WiFi in Low Power mode is nothing else than using smart duty cycling mechanisms to let devices go to sleep whenever they have no data to be transmitted or received. Since energy consumption is the result of power multiplied by time, it has been shown that it is more energy efficient to transmit for short periods of time at high power (also reaching long distances and reducing the complexity of multi-hopping), rather than transmitting for long periods of time at low power.

Further, Zigbee-like solutions suffer from many drawbacks that limit their applications to very specific and delimited applications, such as industrial environments. Zigbee has not followed the market success story of WiFi, and the infrastructure is barely found. In addition, the need for multi-hop transmissions to cover medium and large distances makes its design, implementation, and operation very costly and complex.
3.5 Bluetooth Low Energy (BLE)
Bluetooth also operates in ISM bands. Therefore, it also suffers from the effects of operating in an increasingly crowded band. The last generation of Bluetooth products, based on the specification Bluetooth 4.0 and featuring very low energy consumption have become very popular for the IoT. An example can be seen with the iBeacon technology made popular by Apple, which lets BLE receivers to detect “beacons” transmitted from a base station at close proximity (<10 meters) and retrieve data of interest from the Internet based on the geo-location information. This has a huge potential for delivering personalized services, and this is the reason why a number of companies exploiting the iBeacon technology is emerging. BLE has something on favor; the low cost and extremely high ubiquity it has achieved. Almost all smartphones today are shipped with a BLE transceiver, and thus can communicate via BLE with other devices and access points. In this case, the low transmission rate and short range, play on favor of a technology that is increasingly reaching the IoT market for very specific applications.

3.6 3GPP Solutions
3.6.1 The power of Standardized Cellular Technologies
All the technologies discussed so far in previous sections operate in ISM bands; this means that they are frequency bands free of license which can be used by anyone under certain regulations (transmission power and transmission time). The inter- and intra-system interference thus limits the reliability of communications conducted in these bands. If a Service Level Agreement (SLA) has to be committed and some guarantees of QoS are to be provided, communication in license-bands becomes the only alternative.

3GPP Standards for cellular communications operate in license bands. Mobile Network Operator (MNOs) pay big amounts of money to bid for chunks of frequency bands where they can operate without (legal) interference from other systems. For this reason, they invest in deploying a vast infrastructure which can provide customers with reliable communications. Today, the coverage of standardized cellular systems is enormous, and almost very populated inch in the planet has some kind of cellular coverage.

In addition, these networks can provide mobility and roaming, something that cannot be offered by any other radio system today.

Unfortunately, as it is discussed below, the evolution of standardized cellular systems has followed the increasing demand for higher data rates, and not the specific needs of
MTC described in Section 2 of this chapter. However, from release 12 on of 3GPP, new emerging releases for cellular systems are starting to deal with both HTC and MTC.

3.6.2 From 2G to 4G

Global System for Mobile Communications (GSM) broke into the market in 1990, providing a cellular network infrastructure designed for the transmission of voice calls. This technology showed an extraordinary market penetration and today provides connectivity worldwide. With the irruption of the Internet by the mid-1990s, the transmission of data and the sense of ubiquitous connectivity has become almost a commodity for humans, who demand more and more data transmission capability and some degree of ensured QoS. Unfortunately, GSM was designed for the transmission of voice, and its capability to provide efficient data transmission was very limited. The response of the standard bodies towards this need was the continuous evolution of the cellular technology.

General Packet Radio Service (GPRS) was the first evolution of GSM to provide increased data transmission capabilities, raising the concept of the 2.5 generation of mobile communications (2.5G). Then came the third generation networks (3G), with technologies such as EDGE (Enhanced Data Rates for GSM Evolution), UMTS (Universal Mobile Telecommunications Systems) and CDMA200. High Data Packet Access (HDPA) is called the 3.5G, and still offers increased data transmission capabilities. Even though the data transmission capabilities with 3G and 3.5G are considerably higher than the capability of GSM, the non-top increasing demand for multimedia contents and interactive applications such as social networking, still feeds the need for increased data rates and higher performance. This is the motivation for the fourth generation (4G) of cellular mobile communications, with transmission rates up to 1Gbps are envisioned in the downlink. This is the Long Term Evolution (LTE) – Release 8 - and LTE Advanced – Release 10.

From 2G to 4G, the evolution of cellular networks has been driven by the need for higher transmission rate and increased QoS to meet the increasing demands of humans to use multimedia and interactive applications. However, now is time to evolve and design communication networks so that they can efficiently cope with HTC and MTC. Indeed, the Release 12 of 3GPP already included, for the first time, some improvements towards MTC traffic [3GPP13]. One was, for example, the inclusion of a power saving mode for a newly defined Category-0 of user terminals, with reduced complexity for the sake of lower cost and complexity of MTC devices. Further progress will be achieved in Release 13 bringing more complexity reduction (75% complexity reduction compared to Cat-1 modems), reduced bandwidth, down to 1,4MHz, 10+ years of battery, and 15-20dB coverage extension.
3.6.3 Release 13 and Road to 5G

3GPP Standards continue their evolution to meet the requirements of next generation networks and enable new use cases, new services, and new applications. For this reason, the next releases of 3GPP will continue aiming at improving the capacity of networks for Mobile Broad Band, but also for MTC services.

For the MBB, the next efforts aim at the so-called LTE-Unlicensed. The idea is that LTE can operate also in unlicensed bands via coexistence with WiFi networks, but also via usage of LTE radio in unlicensed bands. While the former option has been progressively integrated into the releases of 3GPP, the concept of LTE-U has been a brand fresh approach for 3GPPP standards to operate in the 5GHz band. The design of Licensed Assisted Access (LAA) will be the key to ensure the right operation of LTE-U. Essentially, this consists in using unlicensed under the control and cooperation of the main cellular network. Critical data would travel through the main site using licensed spectrum, while best effort traffic can be offloaded via the unlicensed links. Other techniques being included in next releases of 3GPP aim at including enhanced LTE carrier aggregation, exploitation of full-dimension MIMO, and downlink multi-user transmission using superposition coding.

As for the IoT, the activities of the 3GPP towards 5G can be divided into two big groups:

1) **Further enhancements of LTE for Machine-Type Communications**, building on the work initiated in the release 12 (which introduced the Category-0 of terminals and new power saving states), reducing the bandwidth channel operation down to 1,4MHz (in contrast with the 20MHz of release 12), enhancing coverage with an increased 15dB budget for extended coverage, simplifying PHY/MAC functions, and further improving power usage.

2) Design of a brand new narrow-band radio optimized for the IoT; the so-called Cellular IoT. This is still in a very early stage, but 3GPP is working towards the definition of a new radio technology that could be accommodated in the channelization of GSM bands. For that reason, the focus is on narrowband systems with a bandwidth below 200KHz, with focus on very low data rate transmissions (below 100bps), with very limited mobility support (to reduce signaling), ensuring very large coverage, an both extremely low cost and power consumption.

Transversal to both HTC and MTC, 3GPP is also working on innovative Device-to-Device communications, enabling the by-pass of the communication through the eNodeB (base stations) to dramatically reduce end-to-end latency.
3.7 Low Power Wide Area Networks (LPWA)

While 3GPP and IEEE do their homework standardizing technologies for MTC, some proprietary solutions have started to gain the market. These are the so-called Low Power Wide Area (LPWA) networks, which offer very large coverage, being able to give service to an entire city with a very little number of connection points, offer extremely low cost, since they have been optimized for MTC and cannot provide services for HTC, offer a SLA to the customer, thus becoming very interesting option for the end users, and what is more important: they are already in the market [XIO15].

Examples of such solutions are those proposed by Neul, Sigfox, and the LoRa Alliance (out of Cycleo/Semtech), each of them offering different business models and technical solutions.

4 Key Objectives for MTC in 5G

Future communication networks must be designed to ensure that the following objectives can be meet to satisfy the new needs posed by emerging MTC services [DAH14]:

1. Reduce latency of wireless communications, enabling end-to-end latencies below 5ms for mission-critical applications where real-time transmissions are required [JOH15][YIL15]. Today’s wireless technology is unable to provide such delay figures, thus blocking some potential applications, which are expected to have a huge impact on economy, industry, and society in various vertical sectors such as automotive, industrial automation, or smart grid, among others.

2. Improve reliability of wireless communications, defined as the probability that a certain amount of data to/from an end user is successfully transmitted to another peer within a predefined time frame, i.e., before a certain deadline expires. The amount of data to be transmitted and the deadline depend on the service characteristics of the underlying use case. In this context, a reliability of at least 99.9999% is targeted within the project, i.e., the probability that a packet is not delivered within the specified deadline must be below $10^{-6}$ (or equivalently, at most one in a million packets does not arrive within the specified deadline, on average). For certain types of applications (e.g., industrial automation), an even higher reliability of up to $10^{-9}$ packet loss rate (outside latency) is sought.

3. Ensure availability of communication networks by extending network coverage, ensuring network access, and providing roaming support to make sure that critical applications are not in outage when needed. An availability of 99.999% is sought
(i.e., less than ~300 seconds of accumulated outage per annum), aiming at equating availability of wireless and wired solutions.

4. **Guarantee interoperability** of heterogeneous communication technologies; in a hyper-connected world with humans, things, and machines connected, it is necessary to make sure that 5G can cope with a great variety of heterogeneous applications, devices, and radio technologies.

5. **Increase** the **number of connected devices** by a factor of up to 100 with respect to currently deployed LTE networks (typically up to 250 simultaneous users per cell); regardless of the particular numbers of the many publicly available market forecasts, there is no doubt that 5G networks will need to cope with an unprecedented number of connected devices [LAY14a].

6. **Boost energy efficiency** by a factor of 10 with respect to currently deployed MTC technology, to significantly reduce energy consumption and operational costs of the network infrastructure, and allow battery-driven devices to operate without the need to recharge or replace batteries frequently, which would constrain the number of potential applications [TIR13].

7. **Secure** communications [GRA15]; many MTC applications will involve personal or confidential data that must not reach the public domain, nor be modified or replayed by unauthorized parties. This becomes a severe challenge when the amount of data to be transmitted is very small and the acceptable securing overhead must be kept to the minimum.

Note that not all specific objectives above are equally relevant to all applications. For example, ultra-low latency is essential for certain future driving applications, whereas energy efficiency is essential for ultra-low power MTC. Furthermore, achieving certain objectives may entail sacrificing others (e.g., very high energy efficiency can usually only be achieved with long sleep modes, which increases latency and has an impact on reliability and availability). All these trade-offs must be well understood in the long run.

**5 Key Enabling Technologies for MTC in 5G**

In order to achieve the objectives defined in the previous sections, many solutions have to be explored at various domains. Considering the particular focus of this chapter towards available wireless communication networks, the following non-comprehensive list of key enabling technologies are identified:

1) In order to ensure scalability of networks, it is necessary to seek for innovative ways of managing the access to shared resources. Looking at the radio access, still today most of wireless technologies are based on ALOHA-based protocols, which suffer from
congestion as the number of users increase. Solutions such as those proposed in [ALO08], based on **DQ technologies** constitute innovative ways of sharing resources that must be further understood. Beyond the radio access, such sharing techniques could be applied to any domain where common resources need to be shared, such as available resources in a cloud.

2) Collisions in the wireless medium must be further exploited to attain useful information. **Advanced coding techniques** from the signal processing domain can be brought to the protocol design domain to turn collisions into useful realizations of data transmissions [PRAT12]. Success Interference Cancellation (**SIC**) techniques constitute a promising technology to be further studied and whose implementation must be better matured [PAO15].

3) Enabling **Device-to-Device** communications, avoiding the two-hop path from devices to infrastructure and from infrastructure to devices, can dramatically reduce the energy of devices, offload main cellular networks, and achieve end-to-end latencies which cannot be attained today [LAY14b]. The use of D2D has started to be integrated into 3GPPPP releases, but still many functionalities need to be further studied and understood to make them viable in future generation networks. Notably, inter-operator D2D functionalities are needed to make D2D a truly scalable solution; i.e. a Siemens sensor on a T-Mobile data plan should be able to communicate directly with an ABB actuator on a Telefonica data plan. The usage of LTE in unlicensed bands (**LTE-U**) is also emerging as an alternative to the D2D facilitated by other radios such as WiFi.

4) **Heterogeneous networks**, combining different cell-sizes and technologies to create a unique and ubiquitous communication infrastructure. As it was pointed in [DOH11], the greatest increases in capacity over the last 35 years have been achieved thanks to making cells smaller. Future 5G networks will be comprised of a gamut of technologies and sites that need to coexist together in harmony.

5) **Network Function Virtualization (**NFV**) and **Software Defined Networks (**SDN**) are promising technologies to make the backhaul and core networks flexible and capable to managing a variable and possibly unexpectedly dynamic network conditions [CON15]. Moving processing power and functions along the network, closer to the edge, can improve the overall QoS perceived by the users, enabling applications which today cannot be realized due to the limitations of an extremely static core network configuration.
6 Summary and Outlook

The definition of 5G must take the emergence of the IoT and its need to coexist with Mobile Broad Band services into account all along the way of the specification process. Involving communication between machines, either M2M or MTC, communication networks need to deal with traffic patterns which are fundamentally different from HTC. These have been discussed in Section 2 of this chapter. Existing wireless communication technologies presented and discussed in Chapter 3 were originally designed for HTC, and thus still further improvements for the future are to be sought. Standardization bodies all around the world are conducting great efforts to standardized new technical solutions that can cope with the particular requirements of MTC. In the meanwhile, some proprietary solutions are already available in the market to cover the needs to today's application. In the long run, it is difficult to ensure that the IoT will become mainstream unless real standards are defined and widely accepted. This was the example of WiFi, and this must be the example for the IoT.

The definition of requirements for the IoT, due to the great variety of possible applications and markets, needs to be agreed with vertical players which are the final end users of the technology. Once these requirements are set, new emerging technology enablers need to be explored to make sure that the necessities are covered, as it has been discussed in Section 5. At the air interface, massive MIMO, disruptive access methods based on something different to ALOHA, such as DQ technologies, exploitation of Successive Interference Cancellation, or Device-to-Device communications have been identified as key enablers, identifying the use of LTE in unlicensed bands (LTE-U) as an emerging area for research. At the architectural level, both Network Function Virtualization (NFV) and Software Defined Networks (SDN) will be core enablers for the core networks of the future.

Global initiatives are working together to make the realization of 5G a reality so that it can efficiently deal with both traffic generated by humans and machines in good harmony.
7 References


