IoT Support

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Abstract This section focuses on the Internet of Things (IoT) context in the 5G framework. First, it introduces the IoT field with a general and incisive definition to clarify its position in the market. Then, it describes the available technologies in details to conclude by spanning many of the increasing potential applications.

1 The 5G Ecosystem for the IoT

When Christianity was "standardized" through the Nicea Council in 325 A.D., all previously defined heathen festivities were absorbed (i.e. same dates used for the "new" celebrations) by the Christian calendar, to ensure its successful assimilation by people. 5G is doing the same, with Internet of Things (IoT) technologies.

The 5G mobile radio network is an ecosystem, made of many interdependent elements: RATs (Radio Access Technologies), Core, Cloud, End Users, their User Equipment (UE), Mobile Network Operators (NMOs), equipment manufacturers, Service Providers, and other. All these elements are currently evolving while 5G is being specified, so that, as in the past, the Fifth Generation of Mobile Radio Networks is a step forward in an evolutionary scenario stemming from the previous 4G. However, one of the key aspects of 5G that come as a profound change with respect to the past, is that the 5G ecosystem is specifically designed to support (also) the IoT evolution.

The Internet of Things is a paradigm that is well known since many years. A formal definition of the IoT can be found in a White Paper of the IEEE Internet Initiative published in 2005 [1]: "Internet of Things envisions a self-configuring, adaptive, complex network that interconnects Things to the Internet through the

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use of standard communication protocols. The interconnected Things have physical or virtual representation in the digital world, sensing/actuation capability, a programmability feature and are uniquely identifiable. The Things offer services, with or without human intervention. The service is made available anywhere, anytime, and for anything taking security into consideration.". The IoT has been conceived and deployed in the past years using communication technologies defined outside the domain of 3GPP: IEEE 802.15.4/Zigbee, Bluetooth, Sigfox, LoRa and others. At the same time, the evolution of 2G, 3G and 4G air interfaces was more oriented towards human-centric applications (with the exception of the recent developments of LTE-M and NB-IoT). This paved the way to the success of the above mentioned non-3GPP communications standards or proprietary solutions for the IoT.

The scenario has now changed. The attention that 3GPP and the main stakeholders of the 5G ecosystem are offering to the IoT, has become huge in the recent years. The 5G network is expected to be "IoT dominated" in terms of number of devices. More interestingly, some stakeholders are starting presenting 5G as the interface between the physical and the digital world, thus emphasizing even more its role as enabler of the IoT. One of the documents delivered by 3GPP within Release 16 in June 2018 [2] starts with a clear mention to the IoT: "5G: the need to support different kinds of UEs (e.g., for the Internet of Things (IoT)), services, and technologies is driving the technology revolution to a high-performance and highly efficient 3GPP system.".

This trend has made more and more clear that 5G has to be considered as a system that will comprise a number of communication technologies, starting from the 5G New Radio (NR) under development at 3GPP, including 3GPP standards like LTE-M and NB-IOT, and the successful non-3GPP solutions that have grown in terms of market shares in the past few years (like e.g. LoRaWAN); according to [2], "... the 5G system shall enable the UE to select, manage, and efficiently provision services over the 3GPP or non-3GPP access.". Like the Christianity did in 325 A.D., Christmas will come on the day of the former heathen feast of the Sun.

While 5G NR is being specified, and 5G networks deployed, the 5G ecosystem will be enriched by additional ingredients. One of the most relevant is the adoption of Artificial Intelligence (AI) technology for the extraction of useful information from the huge amounts of data that IoT networks will generate. AI will be a key ingredient for the concept of "digital twin", intimately connected to the IoT.

2 Not Only 3GPP RATs

In the context of IoT, nowadays manufacturers and stakeholders are looking favorably in the direction of Low Power Wide Area (LPWA) systems. These technologies are devised, as their name suggests, to achieve both longer coverage ranges and low energy consumption. These conditions are highly effective for sensors and actuators networks in IoT, since there is the need of many devices per unit area and no need of a power grid in the vicinity. Maintenance and deployment costs are then reduced. LTE-M, NB-IoT and LoRa can be classified as LPWA technologies, where the first two are bounded to the cellular network and the last one can be deployed as standalone. Note that also the EC-GSM-IoT is a cellular technology for the IoT. However, it leverages on GSM/GPRS frequency bands and it is not expected to keep a relevant portion of the market in the way to 5G. For these reasons it will not be discussed in technical details here.

At the same time, 5G New Radio (NR) and C-V2X are 3GPP RATs that can have a stray impact on specific IoT domains.

2.1 5G New Radio

As foreseen in the previous years, 5G will include deployment scenarios of various type, especially in Enhanced Mobile Broadband (eMBB), Massive Machine Type Communication (mMTC), Ultra-Reliable and Low Latency Communications (URLLC), and Enhanced Vehicle to Everything (eV2X). The IoT context falls within mMTC and partly in URLLC scenarios.

However, 5G NR has scalable configurations to allow more efficient handling of mMTC and URLLC applications. For example, it supports for up-link non-orthogonal multiple access scheme, and, for the scheduling of resources, an up-link transmission scheme without grant is possible. Moreover, the criticality of URLLC links requires additional flexibility in the definition of slots and mini-slots to reduce the end-to-end latency. Therefore, 5G NR is designed to also interface with the always increasing traffic demand coming from IoT devices.

2.2 NB-IoT and LTE-M

An increasing interest in cellular technologies for IoT (or massive MTC) paves the way to the introduction of Narrowband IoT (NB-IoT) and LTE for Machines (LTE-M or LTE CatM1).

NB-IoT is designed for an efficient communication and longer battery life for massively distributed nodes. Its three key elements are the low costs, a large number of connections per cell and an optimal choice for coverage, with very good penetration in indoor environments and underground [3].

Technically, NB-IoT took its first standardization in 3GPP Release 13 and therefore it takes the LTE numerology for synchronization, radio access, resources definition and assignment. Of course, it employs modifications with respect to LTE UEs to allow longer coverage range and low energy consumption. This comes at the expense of lower data rates.

While the other cellular systems for MTC are based on existing radio access technologies, NB-IoT could be considered a "new" radio access technology. In fact, it can either operate in a stand-alone mode or within the guard bands of LTE carriers or within an LTE carrier. Being narrow-band, it supports a nominal system bandwidth of 180 kHz with a channel spacing that can be decreased to 3.75 kHz for the uplink. Thus, it guarantees a higher spectrum flexibility and system capacity with respect to other technologies. Furthermore, it allows energy efficient operation thanks to the possible configuration of three classes of devices based on power levels, by keeping an ultra-low device complexity. NB-IoT becomes then very competitive in the IoT market.

Along with NB-IoT, LTE-M takes the advantages of being a LPWA technology with an LTE base. LTE-M offers a lower coverage range with respect to NB-IoT, but it also proves to reach higher peak data rates, four times the peak rates of NB-IoT. However, LTE-M is mainly dedicated to employ an efficient power consumption and gain from reduced device complexity. Still, its coverage range is extended with respect to the other UE categories of LTE. LTE-M was originally designed as an LTE-based technology competitive with EGPRS in the IoT market. LTE-M is a LPWA technology defined in the Release 13 of 3GPP specifications, specifically as LTE CatM1. LTE-M can co-exist with 2G, 3G and 4G mobile radio networks and benefit from the privacy and security options which are available and previously designed for them. Compared to others like NB-IoT, LTE-M is optimized for higher bandwidth and mobile (in the sense of moving nodes) connections. As a consequence, it reaches up to 1 Mbps of data rate and well supports nodes mobility. One clue advantage of LTE-M included in the standard, is the possible choice for operation in either full-duplex FDD, half duplex FDD or time division duplex (TDD). Its modulation is still OFDMA, following LTE numerology. One other peculiarity of LTE-M is the support of voice over LTE. Furthermore, for what concerns power saving, a longer battery life should last about 10 years for the IoT devices, with reduced modem costs of 20-25% of the current EGPRS modems [10].

For more technical details and comparison between cellular technologies, see Table 1.

Table 1 Comparison among LTE-M and NB-IoT

Technology	LTE-M	NB-IoT
Deployment	In-band LTE	In-band & Guard band LTE, standalone
Bandwidth	1.08 MHz	180 kHz
UL access	SC-FDMA, 15 kHz subcarrier spacing, Turbo code	SC-FDMA, 15 or 3.75 kHz subcarrier spacing, Turbo code
DL access	OFDMA, 15 kHz subcarrier spacing, Turbo code	OFDMA, 15 kHz subcarrier spacing, TBCC
Duplexing	FD & HD (type B), FDD & TDD	HD (type B), FDD
Coverage	155.7 dB	164 dB for standalone
Peak rate	1 Mbps in UL & DL	250 kbps in UL for multi-tone and 250 kbps in DL
Power class	23 or 20 dBm	23 dBm
Power saving	PSM, ext. I-DRX, C-DRX	PSM, ext. I-DRX, C-DRX

2.3 C-V2X

Vehicular networks are also part of the IoT scenario. Vehicles themselves can be nodes of a vehicle sensor network. Transportation might become a mean not only to transmit safety data to other vehicles, but also a mean to increase wireless coverage and move data to different areas. Furthermore, it also fosters use cases for other traffic participants, like cyclists and pedestrians [7].

The novel Cellular Vehicle-to-Everything (C-V2X) standard is based on 4G, and differently from earlier technologies that are based on IEEE 802.11p, can support a wider set of capabilities [9]. The first example are direct communications for V2V, V2I V2Pedestrians. C-V2X operates in the 5.9 GHz frequency band and it is capable of working independently of cellular networks. It is agreed worldwide to have dedicated frequencies not subject to interference and exploit direct low latency links within short distances. Bandwidths can be of 10 or 70 MHz, depending on whether basic or advanced safety services are requested.

Of relevant note is the fact that by operating in the device-to-device mode (as for V2V, V2I, V2P), it is not mandatory for C-V2X to rely on any network infrastructure [6]. C-V2X will allow vehicles to support an interesting set of features, like cooperate, coordinate and share information collected by sensors (comparable to a wireless sensor network for the IoT) in advanced driver assistance systems, as well as connected automated driving. Moreover, the use cases identified by the 5G Infrastructure Association can be subdivided in two architecture types [8]: one with lower tolerance to errors and up to 1 Mb/s of data rate, and the other with a more relaxed tolerance but requesting tens of Mb/s. Both of them require end-to-end latency in terms of few or few tens of ms.

C-V2X must be fully compatible with 5G by design and expanded in Release 15 and Release 16. Thanks to the increased quantity of data available in 5G, vehicles will be able to collect more information. A wide range of business models is then made available, ranging from telematics, infotainment, to real-time mapping, and data analytics.

2.4 LoRa

IoT standards are not bound to 3GPP. Because of the massive number of possible IoT applications, many technologies can operate alongside 5G. For example, the LoRa technology gained its success for its simplicity and efficiency in the WSN context. It is worth of mention because it is highly likely that system based on LoRa will probably have to interface with 5G slices.

LoRaWAN is one of the first technologies defined for LPWAN applications. It specifies a MAC and PHY layer, and we refer to the latter simply as LoRa. Its standardization was initiated by Semtech, an American company, and later by the LoRa Alliance, an organization of companies.

LoRa exploits ISM bands, and it is very robust with respect to the interferers present in the same shared band. LoRa is based on a proprietary modulation based on chirp spread spectrum, with pulses whose frequency increases or decreases linearly over time; information is inserted in these pulses by introducing a discontinuity at different time offsets from the start of a symbol. Bandwidth can be 125, 250 or 500 kHz. Interference is mitigated with the use of forward error correcting codes in combination with frequency hopping spread spectrum. An important parameter for the PHY layer is the Spreading Factor (SF), that is the ratio between the signal bandwidth and the symbol rate. An increase of the SF of one unit, in a range from 6 to 12, corresponds to a doubling of the time on air (duration of a packet transmission) and a decreasing of the receiver sensitivity of roughly three dB.

Then, LoRaWAN introduces three classes of devices with differences in the MAC layer to allow complexity and energy consumption dependent on the application.

3 Application Domains

5G networks will support the IoT through their RATs in a variety of application domains. This section shortly introduces those who are promising to attract more interest of major industry stakeholders.

3.1 Industry 4.0

A term invented in Germany in 2011 to represent the 4-th industrial revolution, Industry 4.0 includes many different application domains; most often, it is used to indicate Smart Manufacturing approaches where wireless communications and cyber-physical technologies are applied to industry plant automation.

3.2 Smart Manufacturing

The application of 5G radio technologies to industry plants might introduce a number of benefits to automation systems, as long as the stringent requirements set in terms of reliability and latency will be met. In particular, making wireless the links between sensors and actuators on robotic machines, will simplify their maintenance and design, and will permit to add monitoring devices on components currently unreachable because of the impossibility to deploy wires. While the due levels of link reliability might be achieved through the application of proper transmission techniques, the requirements on maximum latency might still be a limit; some industrial applications require control loops with maximum delays in the order of tens of microseconds, a level unreachable even by 5G NR. On the other hand, wire replacement is a significant advantage, and for those applications where latency is not an essential requirement, 5G will be an enabler of increased process efficiency. Which RAT will best fit to the user needs is difficult to predict; 5G NR promises to deliver low-latency high reliability services, but at the cost of implementation of a SIM card in UEs. Will the industry managers accept this step?

3.3 Protection of Civil Infrastructures

The adoption of IoT technologies, connecting machines to the Internet, allows industry to implement the so-called "digital twin" paradigm: (physical) factory plants are accompanied by a (virtual) twin, which describes the mechanics of machines and provides an updated status of the running processes. The more sensors are deployed on the plants, measuring physical parameters of all types and transmitting them in real time to the digital twin, the stronger is the ability of algorithms to detect potential future failures and to predict optimally the time for intervention of maintenance operators.

The same concept can be applied for the sake of protection of civil infrastructures, like e.g. bridges, roads, dams. The digital twins of such physical entities might be used to predict and avoid potential collapses, or damages. This would require models able to represent the behavior of the infrastructure. Unfortunately in this case these models are often incomplete or unknown. Under such circumstances, approaches based on AI might be used to overcome the lack of models.

The adoption of the concept of digital twin in civil engineering would requires huge amounts of data generated and transmitted by sensors deployed on and inside infrastructures. On the other hand, requirements on latency and reliability of transmissions might be not stringent, as the AI algorithms would run under a sort of mid-term perspective. So, the most relevant requirement would be on the overall data rate generated by any individual infrastructure (embedding hundreds of IoT nodes); for such application, 5G NR is a must-have technology.

3.4 Smart Agriculture

Tens or hundreds of sensors per hectare will be deployed in agriculture to monitor the health of vineyards, olive trees or other types of cultivations. Most applications under this category do not pose stringent requirements on latency. The traffic density is very low despite the large numbers. The energy efficiency of the RAT used must be extremely high, to ensure long lifetime for devices embedded in terrain or on trees. LoRaWAN seems to be the most efficient technology.

3.5 Smart Cities

While LoRaWAN is currently deployed in many cities for the provision of remote metering services (and other), there is a general thread: as long as the traffic generated by IoT devices in cities will increase significantly, LoRaWAN network might saturate owing to the lack of reserved frequency bands and the long ranges covered by LoRaWAN gateways. This will make room to NB-IOT and/or LTE-M success.

3.6 Automotive Applications

For some years automotive manufacturers have been wondering about whether to rely on ad-hoc networking approaches (like WAVE, based on 802.11p), or wait for 5G deployment. Now, C-V2X promises to enable most of services needed for connected cars. It is most likely that C-V2X will soon become the standard communication system for automotive applications, though advanced services like augmented sensing might require 5G NR interface.

3.7 Unmanned Aerial Vehicles (UAVs)

Soon the volume of space above densely populated areas will be the new frontier for radio technology. Using mobile radio networks to coordinate the flight of UAVs patrolling cities from the sky, has become a clear interest of many stakeholders; the limit is still in regulations, which will evolve as long as safety threads will be faded away through the application of proper technologies on UAVs. However, it is envisioned that the evolution of 5G will include the use of mobile base stations, carried by UAVs. In this case, their control will require highly reliable links (easy to achieve in Line-Of-Sight conditions) and very low latencies, compatible with 5G NR evolution.

4 Expected Trends

Based on the analysis reported above, the 5G ecosystem will optimally serve the various IoT application domains with different RATs. Mobile Network Operators will need to be able to offer services based on a multi-RAT approach comprising non-3GPP solutions. Among the latter ones, which use ISM bands, LoRaWAN is becoming more and more successful; it works mostly on the 868 MHz band, though recent releases of LoRa chipsets operating at 2.4 GHz will make the adoption of this frequency band feasible. In any case, its use for long-range applications in densely populated areas might encounter problems in terms of saturation of the frequency bands. One option to solve this issue might rely on the identification of separate frequency bands specifically for smart city scenarios (as done for other application domains, like e.g. for health).

In any case, what the 5G ecosystem might bring as strong support tool to the IoT world, lies mostly in the cloud computing component, the adoption of AI approaches, the development of digital twin technologies. MNOs will work in that direction. What RAT is used by things, should be transparent to such elements of the ecosystem. Nevertheless, the availability of different RATs, each one being optimal for a different IoT application domain, is an essential aspect of the 5G ecosystem.

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