IoT Evolution: What's Next?

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3GPP supports IoT applications through LTE-M (LTE for machine type of communication) and NB-IoT (Narrow Band-IoT) technologies. These mature technologies are suitable for a wide variety of applications. The future growth of sensor applications will lead to new use cases and scenarios. While many sensors can be supported by existing 3GPP technologies, additional support of satellite-IoT and low power/passive communications will allow for more ubiquitous sensing. This short article considers how 3GPP communications can support sensing applications and some of the technical challenges that should be addressed in future releases of 3GPP specifications.

Overview of 3GPP IoT Communication

The standardization of IoT technologies in 3GPP started in earnest in Release-13 of the LTE specifications when LTE-M and NB-IoT were specified. The original goal of these technologies was to provide a lower complexity device type that was more compatible with the market requirements of machine type communications/IoT than the available LTE device types at the time. Additional requirements were added in terms of coverage, leading to coverage extension of up to 20dB, relative to the coverage of more standard LTE devices. This coverage extension was achieved at the expense of data rate.

A set of massive Machine Type Communications (mMTC) requirements were defined at the start of the 3GPP specification of 5G [1]. These requirements called for a coverage with a maximum coupling loss (MCL) of 164dB, a 10-year battery lifetime for the occasional transmission of small UL packets, a latency for sending an alarm message of less than 10 seconds in poor coverage, and support of one million devices per square kilometre. Studies have shown that both LTE-M and NB-IoT meet these 5G requirements, and these technologies are considered to be the 5G LPWA (Low Power Wide Area-network) technologies for 3GPP. An industry study [2] of LTE-M performance showed that it exceeded the 5G requirements. The key findings of this study are summarized in Table 1. The OFDM-based waveforms for LTE-M and NB-IoT can be multiplexed within the 5G-NR OFDM-based waveform, further cementing the credentials of LTE-M and NB-IoT as 5G technologies.

Going beyond the 5G mMTC requirements, LTE-M supports data rates up to 1Mbps and connected mode mobility, opening up more use cases and support for higher value applications.

The ability of LTE-M and NB-IoT to meet the 5G mMTC requirements in terms of complexity/battery life/coverage/capacity and latency make these technologies suitable for a wide range of sensor applications, whether those sensors are sensing the environment or reporting measurements of utility usage. The stable technology base of LTE-M and NB-IoT allow such sensing applications to be deployed now.

New requirements have led to the need to specify so called NR-Redcap (Reduced Capability New Radio devices), a 5G-native IoT technology. Video cameras and wearables lead to higher data rate requirements than can be satisfied by LTE-M and NB-IoT. Much of the available spectrum for private networks, which are of interest in industrial deployments, is not supported by LTE. Hence, deployments in mmWave bands should be NR-based. There is also a need to deploy IoT devices in a factory environment which may be shared with devices participating in low latency/high reliability communications. This coexistence may be better achieved with NR-based devices that are aware of these low latency/high reliability communications from the outset. These requirements point to the need for a reduced capability NR-based technology. Redcap devices achieve complexity reduction by a variety of simplifications including support for a narrow maximum bandwidth, support for fewer antennas and support for half-duplex communication.

5G requirements	5G target	LTE-M performance
Bandwidth required to serve capacity of 10^6 devices per km^2	50 MHz	70% of a 5MHz system
Data rate at a maximum coupling loss of 164dB	160 bps	UL 363 bps, DL 1200 bps
Message latency at the maximum coupling loss of 164dB	10 seconds	6.7 seconds
Battery life at the maximum coupling loss of 164dB	10 years	10.9 years

TABLE 1. 5G mMTC requirements and LTE-M performance.

While LTE-M/NB-IoT and Redcap are generally useful for sensors and monitoring use cases, URLLC (Ultra Reliable Low Latency Communications) devices support industrial IoT use cases, for example where a robot is controlled with low latency and the communications have to be reliable. While such industrial IoT uses cases are within the scope of the Internet of Things, they are not a focus of this article.

IoT Communication for Sensing

There is a growing need to make better and more efficient use of the planet's available resources, while minimising environmental impact. Sensors will become ever more important in achieving these goals. There are many cases where it is desirable to create a digital twin of the real world where the physical world is sensed and a replica is created in the virtual world. Sensing and digitizing increased amounts of richer information from the physical world will allow the digital twin to make better decisions to feed back to the physical world in a timely manner, optimizing resource usage and minimizing environmental impact. IoT communications technologies will need to evolve to support the growing requirements to sense the physical world.

As an example, new agricultural sensors will allow us to monitor soil condition, livestock health/whereabouts and potentially plant health and productivity. Some of these sensors will be simply based on observing physical properties while other sensors will be more elaborate and based on visualizing the thing that is being sensed. Image-based sensing can either be performed in the cloud, where the image is sent to the cloud and an attribute of that image is derived in the cloud or can be performed on-device. The advent of image sensors with embedded processing technology, such as the Sony IMX500 sensor, allow for the processing to be performed on-device. This on-device processing is preferable from the perspective of reducing the communication burden.

Image-based and sound-based sensing is also applicable in an industrial context. Figure 1 illustrates an industrial IoT use of Sony's SPRESENSE™ low power edge processor, a platform that is useful for fast prototyping, having end-applications in IoT. The figure shows an example where the SPRESENSE module performs edge computing functions on sound inputs from a microphone and image inputs from a camera board. Sound processing can determine whether there are anomalous vibrations. Image processing can observe the status of a legacy analogue meter or detect a gas leak. The sensed results can be sent to monitoring equipment in a control room via an Altair 1250 based LTE-M extension board used in conjunction with the SPRESENSE main board.

Wide Geographic Coverage: Agricultural and environmental monitoring require wide geographic or global coverage. While there is good and growing coverage of LTE-M and NB-IoT, there will likely always be gaps in coverage in sparsely populated or rugged areas. Satellite, or more broadly non-terrestrial networks (NTN), provide a good means of supporting this wider geographic coverage. 3GPP is already addressing NTN support of LTE-M and NB-IoT through the IoT-NTN work item in Release-17 [3]. This work item will address the essential minimum changes that are required to support LTE-M and NB-IoT over NTN networks. This work will support different satellite constellation types, including GEO (Geostationary Earth Orbit) and LEO (Low Earth Orbit). The required changes seem remarkably straightforward. Further evolution in Release-18 should support improved power consumption, data rates, capacity and latency for these IoT-NTN networks.

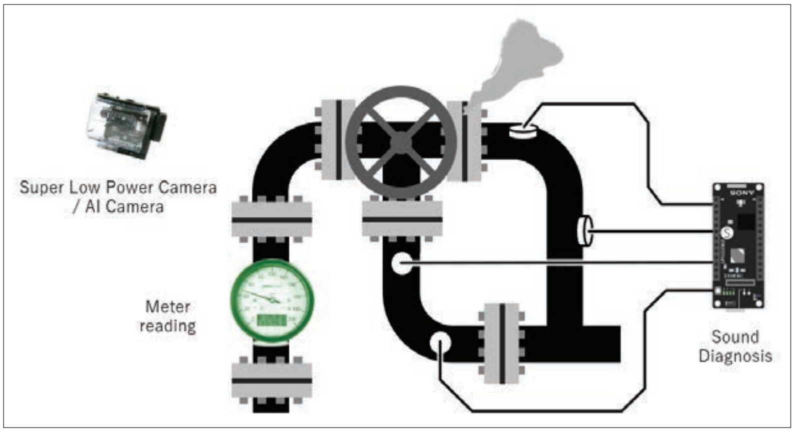

FIGURE 1. Monitoring industrial processes through image and sound-based sensing and communication.

Low Power: Power consumption has always been a key metric for IoT devices. For a utility meter use case, a longer battery lifetime leads to a longer time between maintenance visits to replace batteries in meters. Sensors are being increasingly used in factories to monitor industrial equipment and enable predictive maintenance. If the batteries in these sensors need changing frequently then the maintenance headache merely moves from the maintenance of the monitored machine to the maintenance of the sensor itself. While some sensors in the factory will be mains powered, the wireless sensors should preferably operate either passively or from harvested energy. There is clearly also a need for sensors in geographically remote areas, supporting agriculture or environmental monitoring, to operate without battery changes. When the environmental impact of battery production and disposal is also considered, there is a strong economic and environmental incentive for passive-IoT devices where a stable power source is not provided, such as self-rechargeable IoT devices operating on harvested energy, IoT devices which utilize a backscattering mechanism, and so on.

Technical Challenges

IoT Communications over Satellite: The Release-17 specifications [3] for IoT-NTN will provide the essential minimum functionality that will allow LTE-M and NB-IoT devices to communicate over GEO and LEO satellite links. These specifications will meet pressing market needs but will not be optimized in several regards. The large propagation delay in satellite links means that there is significant dead time during the round-trip time between transmission and reception. Scheduling non-HARQ (Hybrid Automatic-Repeat-reQuest) transmissions during the round-trip time would increase throughput at the expense of performance. The alternative of increasing the HARQ storage in the terminal would not be desirable from a complexity perspective. As an alternative to scheduling during the round-trip time, the terminal could be allowed to sleep. Although sleeping does not improve the device throughput, power consumption is improved.

As the number of IoT-NTN terminals increases, the capacity of the satellite constellations will start to be tested. In Release-17, there is a concern that there will be initial access/PRACH (Physical Random Access Channel) congestion as devices will try to connect following acquisition of satellite ephemeris information, i.e. many devices will simultaneously try to connect to the network following transmission of satellite ephemeris information. The times at which terminals connect to the satellite network should not be bunched around transmissions of system information.

From the above discussion, it is apparent that the Release-17 specifications can be enhanced with a view to improving the throughput, power consumption, latency, coverage and capacity of IoT-NTN. The areas of enhancement to be considered are those covered by the 5G mMTC requirements. It is hence expected that IoT-NTN will be enhanced to strive to achieve the 5G mMTC requirements.

New constellations of satellites will be deployed. In addition to the new satellites better supporting the IoT-NTN link budget due to component improvements, these new constellations may have architectural implications on the IoT-NTN system. Initial deployment of satellites may be sparse until the full constellation is built out. Some constellations of low cost cubesats may always be sparse. In both cases, there is a need to support discontinuous satellite coverage and potentially store and forward functionality. While Release-17 focusses on a bent pipe transparent model of the satellite, newly deployed satellites may support on-board base station functionality and operate in a regenerative mode. Support of regenerative satellites will impact the backhaul network and inter-satellite communication for the purposes of handover and service continuity.

Improving IoT Sustainability: The power consumption of sensors varies. Some sensors will be active for extended periods of time and will need a constant power source. Other sensors will wake up occasionally and can replenish energy reserves between sensing functions. Yet other sensors consume so little power that they can be constantly active while harvesting energy from their surroundings. The power consumption of the communications associated with the sensor should be compatible with the power consumption of the sensor itself. To efficiently support low power sensors, there is hence a need for communicating either passively or with low amounts of replenishable power.

Passive communications can be supported by harvesting energy from the incident RF energy to power a low power receiver and transmitter. The power consumption of the receiver can be reduced by modifying the waveform [4], e.g.

by adopting an on-off keying waveform. The power consumption of the transmitter can be reduced through the use of backscattering communications. A concern with these passive-IoT technologies is the sensitivity and associated coverage. These passive-IoT technologies may find a niche in scenarios where coverage is not a concern. Wireless power transfer may alternatively allow passive-IoT to be operated at longer ranges.

Terminals may be powered from harvested energy, such as solar, wind, vibration etc. These power sources are generally intermittent and provide variable amounts of power. While this power can be stored at the terminal, for example in a battery, the amount of stored energy may be small. 3GPP protocols assume that the terminal can communicate with the network during a connection; running out of energy is an exceptional event that requires user intervention. An IoT device operating on ambient harvested energy will frequently run out of power and the protocol should be tolerant of such events, allowing signalling exchanges to pause during the operation of the protocol. Operation on such harvested energy would allow the terminal to operate for short periods of time at the power levels used for Release-17 devices using existing waveforms.

Conclusion

This short article contains an overview of the 3GPP IoT technologies. LTE-M and NB-IoT meet the 5G requirements in terms of coverage, latency, battery lifetime and capacity. Further work in 3GPP should aim to improve geographic coverage through the support of IoT satellite communications and work toward improving the sustainability of IoT communication.

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