Emerging Communication Technologies Enabling the Internet of Things

White Paper

Abstract:

With the IoT space rapidly growing and spanning into diverse application areas, there are numerous requirements that will be hard for a single technology to address, and while progress is being made, there are still questions on how well these requirements will be met and how fast chipset manufacturers will develop new technologies to support various vertical market's needs. This white paper covers new non-cellular technologies that are being deployed globally today, in addition to emerging cellular standards.

White Paper
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1 Introduction

The Internet of Things (IoT) will impact all industries and ultimately everyone's daily life. Currently, things such as containers, street lights, trash cans, trees and cows are already connected to the Internet. Many new markets are evolving, such as smart homes, connected cars, smart grids and smart healthcare Fig.1; we can only imagine what will be connected in the near future.

Common to all of these markets and related applications is the use of real time data from connected "things", which improves all kinds of processes ultimately saving money. The expectations on reliability, performance, quality of experience and longtime availability are extremely high and connectivity is a critical success factor.

Some applications that require global coverage and/or mobility will use cellular technologies, but the majority of IoT devices will use non-cellular technologies' sharing frequencies in unlicensed bands to communicate with each other and with IoT applications in the cloud.

Before these wireless devices can go on the air, they must be tested against the applicable regulations, standards and operator-specific requirements. The coexistence of multiple technologies operating on unlicensed bands in one device or in areas with high radio usage, such cars or living rooms, is of great importance and therefore requires special attention in the design and validation processes. Accordingly, in order to ensure proper functionality, quality and performance throughout the product's lifetime, it is essential to test the overall communications behavior in all phases of the product life cycle.

Figure 1: The Internet of Things (IoT) Vertical Markets.

2 Technology Overview

The IoT industry incorporates a variety of devices with a wide range of requirements needed to fulfill the many applications Fig.2. For example, with the smart city products, high data rate is not necessarily so critical; therefore, a technology like Long Range (LoRa) with slower data rates and longer battery life is sufficient. However, for the automotive applications, a technology providing a higher achievable data rate and lower latency is required; therefore, 802.11p or traditional cellular technologies is a better technology match.

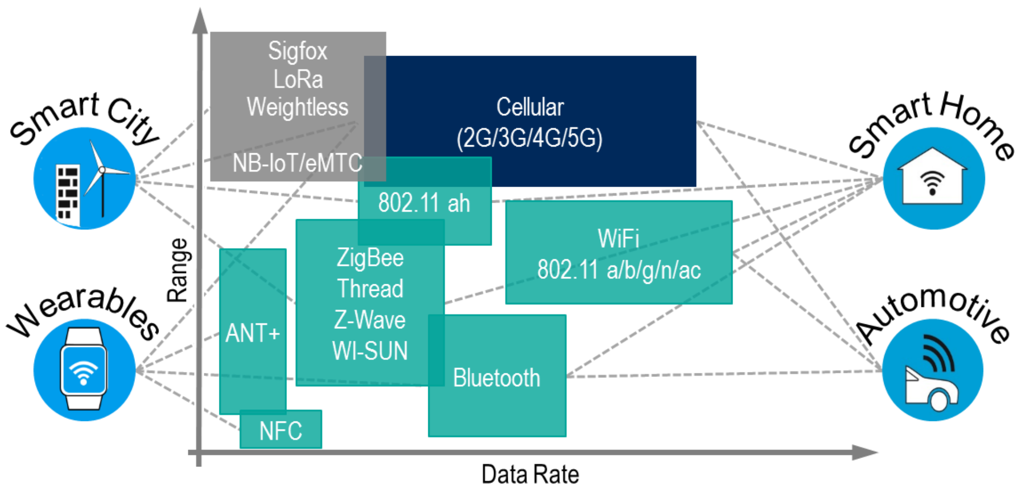


Figure 2: Technology capabilities with respect to data rate and range.

At the present time, there are already billions of devices connected to the Internet by quite, mature wireless technologies like Bluetooth, ZigBee, Z-Wave, WiFi, or cellular technologies of the 2nd and 3rd generation. Due to the growing demand for low cost connectivity, the IoT industry is developing and deploying multiple new technologies that are optimized for this specific need Fig.3. For the devices that fit the Personal Area Network or Local Area Network, traditional technologies like Bluetooth, ZigBee, and WiFi are being enhanced with Bluetooth Low Energy and Bluetooth mesh, Thread, and Wi-Fi 802.11ah. New technologies are being developed for Low Power WAN (LP-WAN), including SIGFOX, LoRa, Weightless, and Ingenu. In the Wide Area Networks (WAN), there are well-known cellular technologies (2G,3G,4G), with new feature enhancements like eMTC and NB-IoT. This section gives a short introduction to the emerging wireless technologies for the IoT market.

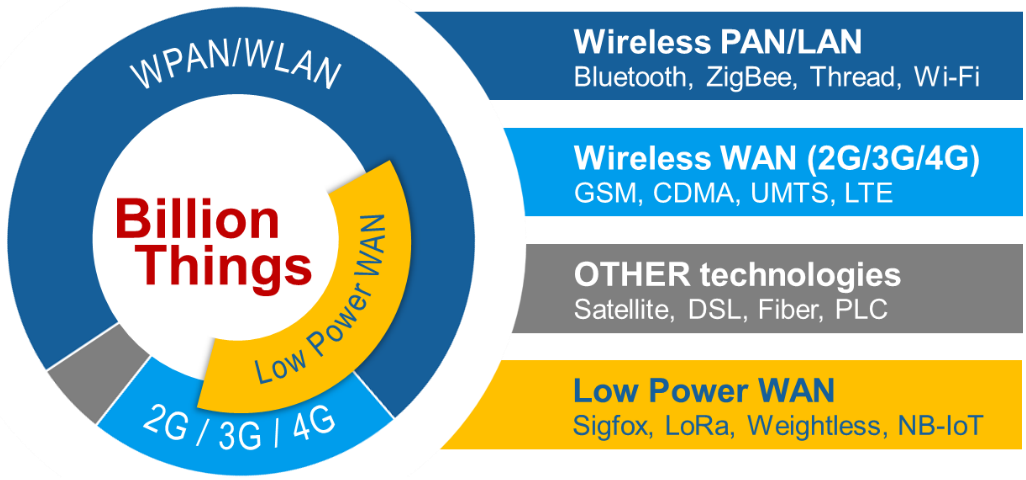


Figure 3: Summary of technologies driving the IoT market.

2.1 Wireless PAN/LAN

2.1.1 Bluetooth

Two of the more widely spread, traditional technologies are Classic Bluetooth and Bluetooth Smart (aka Bluetooth Low Energy). Classic Bluetooth has voice support and uses the unlicensed 2.4GHz ISM band and the Gaussian Frequency Shift Keying (GFSK) modulation scheme with a maximum capacity of 1 Mbps Fig.4. To avoid interference with other devices, frequency hopping is used. There are 79 1 MHz channels in Classic Bluetooth, which hop at a rate of 1600 hops per second. The hopping algorithm excludes channels that have high interference. Bluetooth Smart operates in the same 2.4 GHz ISM band as Classic Bluetooth technology, but uses a different set of channels. Instead of the Classic Bluetooth 79 1-MHz channels, Bluetooth Smart has 40 2-MHz channels, including three fixed advertising channels. One of the big differences between Classic Bluetooth and Smart is that Bluetooth Smart has a 0.01 to 0.5 W power consumption vs 1.0 W for Classic. Bluetooth Smart is most relevant for low power consumption IoT devices, like wearables.

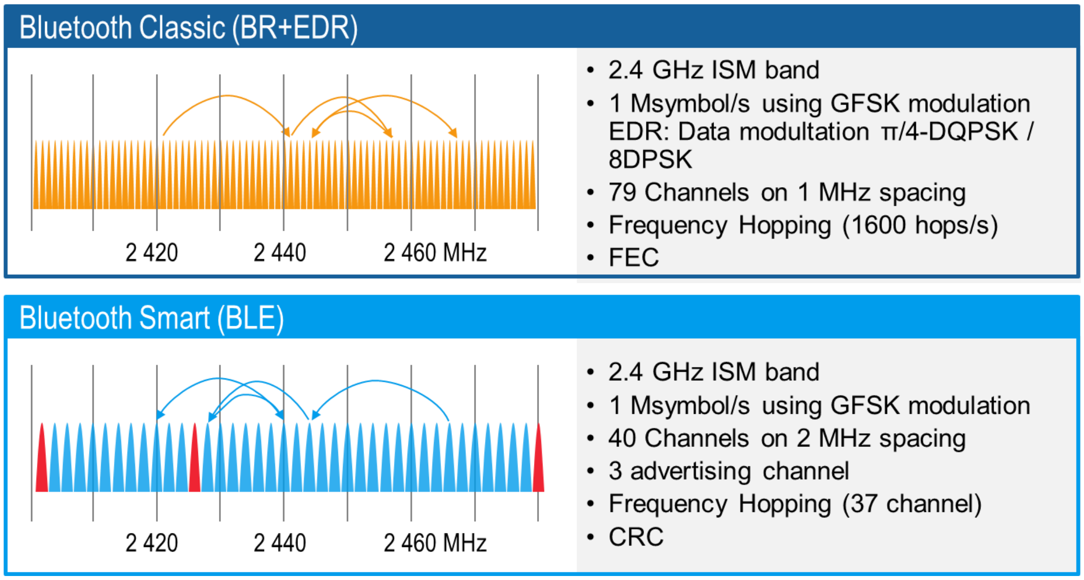


Figure 4: Classic Bluetooth and Bluetooth Smart.

The Bluetooth technology is managed by the Special Interest Group (SIG) which has over 25K members and directs the development of the specifications, manages the Bluetooth qualification program, and protects the trademarks. This group is continually working on improvements to the technology. Some of the enhancements being made include improvements on speed for low latency applications, longer range, as well as extending capabilities of beacons for positioning. Bluetooth SIG has also introduced the ability to build mesh networks and the ability to connect devices directly to the cloud via gateways. With these new features Bluetooth will become applicable for more applications like smart homes and buildings.

2.1.2 WiFi

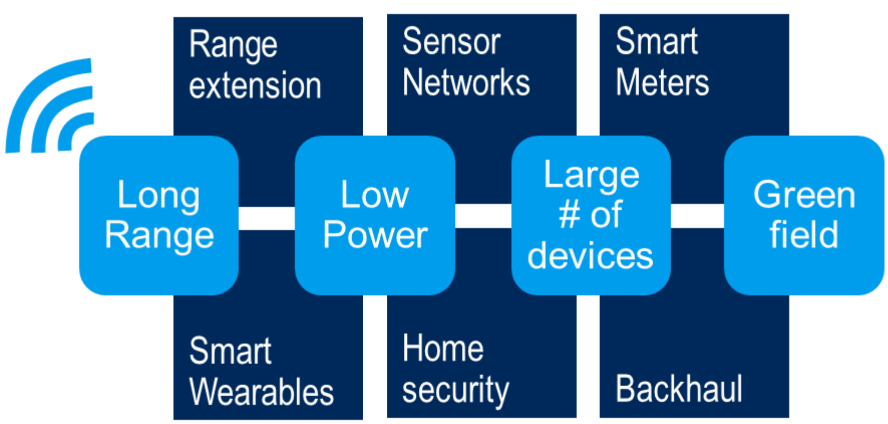


Figure 5: 802.11ah or HaLow use cases.

WiFi is the leading wireless technology for local area networks, with 802.11a/b/g/n/ac widely in use around the world today. The standards body is defining new capabilities to support the demand for long range and low power operations for IoT and M2M communications markets, such as 802.11ah and 802.11af

802.11ah, also known as HaLow, was developed as a lower power WiFi solution and operates in the unlicensed sub 1 GHz range. 802.11ah supports multiple channel bandwidths from 16 MHz channels, for high data throughput, down to 1 MHz, for extended coverage at lower data rate. As compared to Bluetooth Low Energy and ZigBee, HaLow provides longer range (up to 1km) and has higher data throughput (from 100 kbps, up to 40Mbps). HaLow will enable a variety of new power-efficient use cases in the smart home, connected car, digital healthcare, as well as industrial, retail, agriculture, and smart city environments Fig.5.

802.11af is similar to 802.11ah in that it operates in the sub 1 GHz frequency range by utilizing the TV white space bands from 54 to 790 MHz, and can also be used for low power IoT devices. It can support data rates up to 24 Mbps over extremely long ranges (up to several miles) given the lower frequencies available.

802.11ax is still in early stage of development, but it is predicted to have a top speed of several Gbit/s.

2.1.3 LR-WPAN

802.15.4 is one of the more successful standards for low data rate wireless personal area networks (LR-WPANs) and is used as the physical layer for higher layer protocols such as ZigBee, Thread, ISA1000 and WirelessHART Fig.6. 802.15.4 was developed for low-cost, low-speed communications between devices at a limited range (10-30m) and a maximum data rate of 250 kbps. This physical layer technology is ideal for low data rates, low complexity and long battery life applications, such as industrial and commercial sensors and actuator devices.

802.15.4 operates in the unlicensed spectrum depending on the country: 1 channel in the 868MHz band for Europe, 10 channels in the 915MHz ISM band for North America and 16 channels in the 2.4 MHz ISM band worldwide. It defines the channel bandwidth at 5MHz and at the 2.4GHz ISM band, 802.15.4 specifies the use of Direct Sequence Spread Spectrum and uses the Offset Quadrature Phase Shift (O-QPSK) modulation scheme.

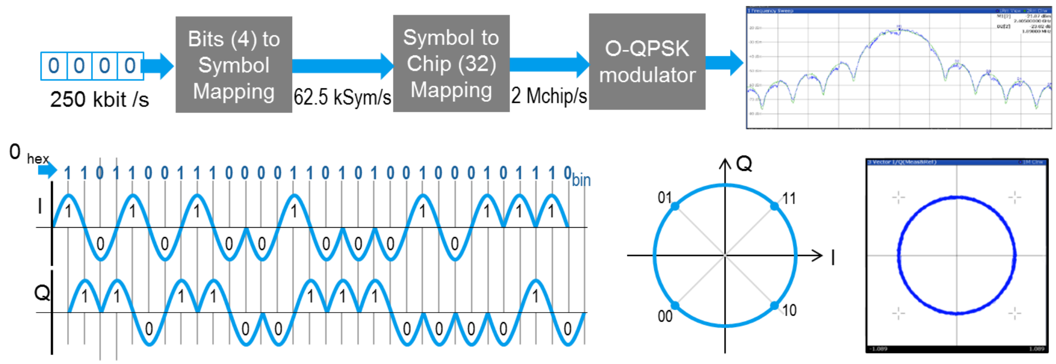


Figure 6: The 802.15.4 standard is used for many different applications.

ZigBee and Thread are the most widely used technologies for LR-WPANs in smart homes and buildings. ZigBee was established in 2002 and has been developed by the ZigBee Alliance, which is an association of companies that work together: The charter of the alliance is to enable reliable, cost-effective, low-power, network monitoring and to control products based on the 802.15.4 physical layer. Several products exist today that utilize the ZigBee technology.

Thread is a networking protocol that defines a flexible, distributed mesh network fabric scalable to hundreds of devices and provisioning for generic IPv6 addressing and interfacing. Thread and ZigBee are known to be collaborating in order to allow the ZigBee application layer to run over Thread networks. The idea is to allow various devices to interact with each other, for example, having a Thread-based thermostat automatically turn on a connected fan.

2.2 LP WAN

Low Power WAN (LP WAN) devices are everywhere and networks to support these devices are being deployed all over the world. They operate in the unlicensed ISM band, using new technologies such as Long Range (LoRa), SIGFOX, Weightless and Ingenu.

The SIGFOX technology is aimed at low cost machine-to-machine application areas, where wide area coverage is required. SIGFOX uses the 915GHz ISM band in the US, with its patented Ultra Narrow Band (UNB) technology. UNB enables very low transmitter power levels to be used while still being able to maintain a robust data connection. SIGFOX messaging has a payload size of just 12 bytes, a maximum throughput of 100bps and uses a narrowband (100Hz) channel. Fig.7 The majority of the SIGFOX traffic is uplink data.

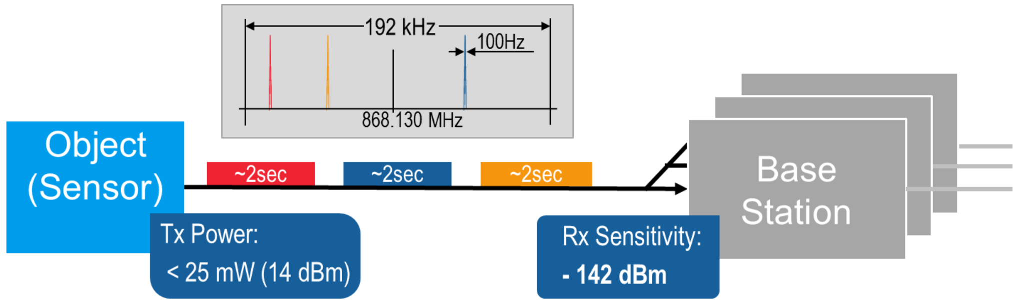


Figure 7: SIGFOX uses ultra-narrow band technology.

With the SIGFOX protocol, the device is only allowed to receive data just after a packet is transmitted, otherwise the device receiver is turned off in order to conserve battery life. There are a number of applications that need this form of low cost wireless communications technology. Example applications include all kinds of low power, low data rate sensor networks.

LoRa is another LP WAN technology being deployed for devices requiring low cost, long range and extended battery life. One of the major advantages of LoRa is the technology's long range capability. A single LoRa gateway or base station is capable of covering an entire city or hundreds of square kilometers, however this highly depends on the environment or obstruction in a given location. As with SIGFOX, LoRa operates in the 915 MHz ISM band in the US and also has a physical layer developed by Semtec. The physical layer uses a proprietary chirp spread spectrum modulation technique where the frequency increases or decreases over a certain amount of time to encode information. LoRa has defined three different classes (A, B, C) Fig.8 of devices in order to address the different requirements needed for various IoT markets. Class A devices consume the least power and are targeted for applications that only require downlink communication from the server, shortly after the end-device has sent an uplink transmission. With Class B devices an additional mechanism was added for the device to receive data at scheduled times. Finally, Class C devices support a nearly continuous open receive window (window is only closed when the device is transmitting), however, this feature increases power consumption.

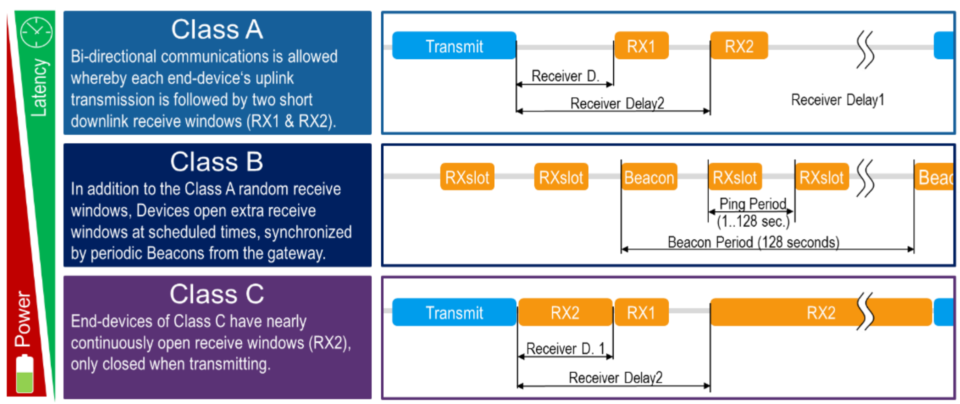
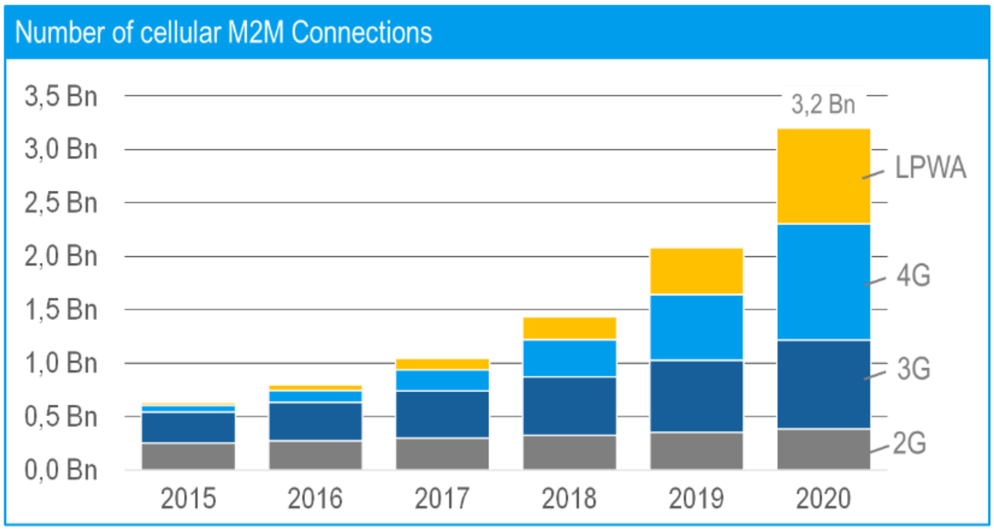


Figure 8: Three different classes of LoRa.

2.3 Wireless WAN (2G/3G/4G)

For many years 3GPP standards bodies have been very successful in developing mobile broadband technologies which provide connectivity to billions of subscribers worldwide. Presently, Machine-to-Machine (M2M) connectivity is still dominated by 2G and 3G cellular technologies and will continue to be for a few more years before LP WAN technologies gain momentum Fig.9. With the introduction of 4G over the past several years, many operators are now looking at cost-effective ways support the M2M devices on their 4G networks.



Source Cisco VNA Mobile 2016

Figure 9: Growth of M2M connections on various technologies.

3GPP has been working on new requirements to support Machine Type Communications (MTC) for LTE Fig.10. The goal for these new 3GPP MTC requirements is to provide cost-effective connectivity to billions of IoT/M2M devices which require very low power consumption and excellent coverage. This work has started a few years ago in 3GPP Release 10 and Release 11 with features such as Network Improvements for Machine Type Communications (NIMTC) and System Improvements for Machine Type Communications (SIMTC). With NIMTC and SIMTC, many new enhancements were added, including reduced network signaling, congestion/overload control mechanisms and improvements for device reachability from the M2M application servers.

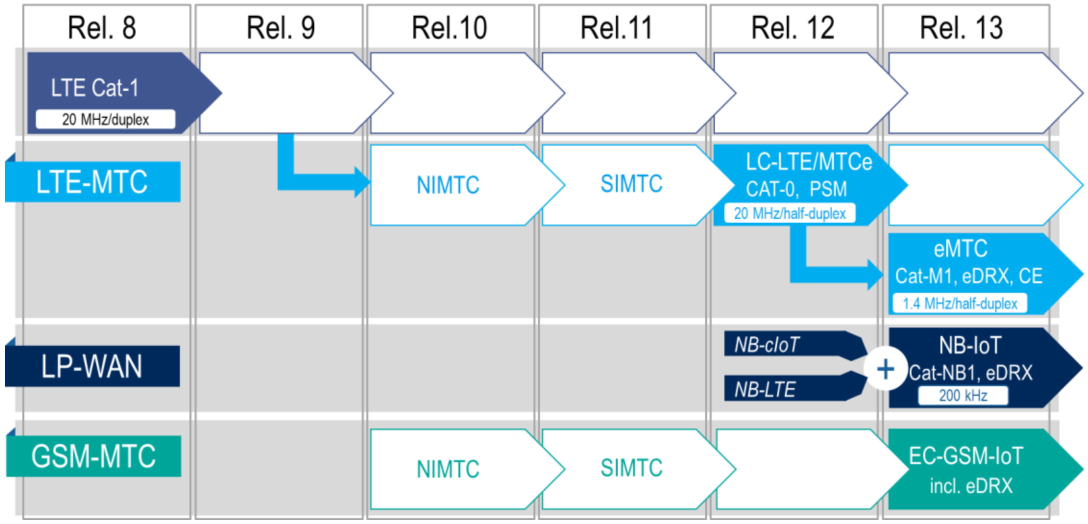


Figure 10: 3GPP schedule for LTE-MTC, LP-WAN and GSM-MTC.

3GPP Release 12 and Release 13 further enhanced the MTC feature set (called enhanced MTC or eMTC) to include new device categories and PHY/MAC changes. Release 12 introduced a low cost CAT-0 device and a battery saving feature called Power Saving Mode (PSM).

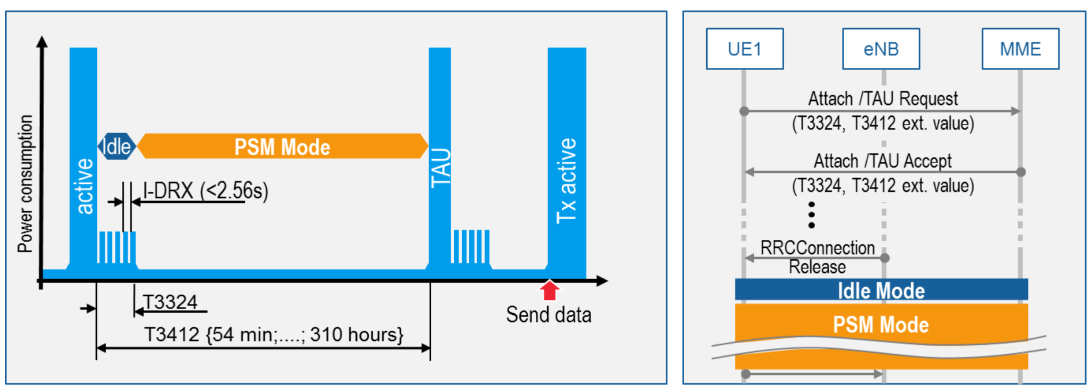


Figure 11: Power Saving Mode (PSM).

With CAT-0 devices, there are a number of changes aimed at reducing the overall cost of the device and improving battery life. The major changes included: rate reduction to 1Mbps in both the uplink and downlink direction, requiring only 1 Rx/Tx antenna (vs diversity antennas) and designing the device to operate in a half-duplex mode. PSM allows the device to more efficiently turn the modem on/off for a device originating or scheduling applications. In other words, the device remains registered with the network, reducing the signaling required for modem wake up Fig.11.

Release 13 standardized a new narrowband radio technology to address the requirements of IoT, called Narrow Band IoT (NB-IoT). The new technology will provide improved coverage, support for a massive number of low data throughput devices, low delay sensitivity, ultra-low device cost, low device power consumption and an optimized network architecture. The Release 13 power saving feature, called extended discontinuous reception (eDRX), extends the sleep cycles for devices with very limited uplink data transmission many minutes to hours, eliminating unnecessary signaling in order to save power Fig.12.

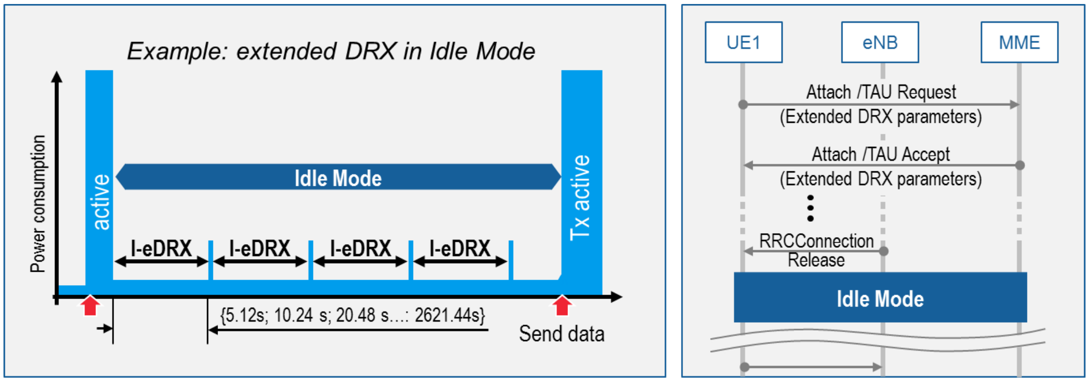


Figure 12: Extended Discontinuous Reception (eDRX).

To improve coverage, new techniques in Release 13 were added that include relaxation of acquisition time requirements and redundant UL/DL transmission by sending the same data in consecutive Transmit Time Intervals. Two new categories of devices were introduced in Release 13 to further target the IoT market – CAT-M1 (eMTC) and CAT-NB1 NB-IoT. The main features of CAT-M1 included a lower power class (20dBm), a reduced channel bandwidth (1.4 MHz/half duplex) and an improved link budget of ~156 dB. CAT-NB1 uses just a 180KHz/half duplex channel bandwidth, limits the DL data rate to just 250kbps, achieves a link budget of ~164dB, improves power efficiency (10 yr battery life) and has a reduced cost.

The NB-IoT technology is being targeted to provide cost-effective connectivity to billions of low-cost IoT devices which require support for low power consumption and excellent coverage for places like basements, tunnels and remote rural locations. One key benefit of NB-IoT, and the main reason why this technology is very desirable for the major cellular network operators today, is that it can be deployed on top of an existing 4G network by software upgrades. NB-IoT can be deployed inside an LTE carrier by allocating a single physical resource block, adjacent to an LTE carrier or even on a re-farmed GSM carrier. Evaluations have shown that a standard deployment can support a density of 200,000 NB-IoT devices within a single LTE cell.

3 Verification and Testing

3.1 Conformance to Standards

Generally, before any wireless device can go on the air, it must be tested against the applicable standards and regulatory requirements. For cellular IoT devices, the compliance requirements defined by the Global Certification Forum (GCF) must be met, which include dedicated tests for 3GPP Machine Type Communications (MTC) features. Mobile operators may also define additional tests which need to be passed for carrier acceptance. Non-cellular IoT devices have to meet certain regulatory requirements defined by various groups like Bluetooth® SIG or the LoRa™ Alliance. In addition, all devices must fulfill requirements defined by international, regional and national regulatory bodies (FCC for the United States and ETSI for Europe) and if designed for global use must fulfill many other regulatory requirements.

For example, any electrical device must satisfy the regulatory electromagnetic compatibility (EMC) requirements. For EMC conformance, radiated and conducted emissions tests as well as radiated and conducted immunity tests need to be performed with a well-defined test setup, under precisely specified test conditions. Usually, special EMC test systems with specialized test receivers are used for these kinds of tests, and are typically performed by certified test labs.

There are also specific requirements for devices operating in ISM bands. For example, all data transmission equipment in Europe operating in the 2.4 GHz ISM band using wide band modulation techniques, i.e. WiFi, Zigbee and Bluetooth, have to meet the technical requirements specified in the European ETSI EN 300 328 standard. The standard essentially describes the technical requirements for two categories of devices: devices using frequency hopping (FHHS) and devices using wide band modulation (e.g. DSSS or OFDM). The standard also defines test conditions and test procedures to verify the defined technical requirements. The long list of requirements includes maximum RF output power of 20 dBm, power spectral density for wideband modulations of less than 10 dBm, a Tx-sequence duration of less than 10 ms, and a spectrum emission mask for unwanted transmitter emissions in the out-of-band.

3.2 Avoiding Interference

Quite a few technologies used for IoT such as Bluetooth, WiFi, Zigbee, and Thread are sharing the unlicensed 2.4 GHz ISM bands and operate in close proximity to certain LTE bands Fig.13. The number of devices and technologies using the unlicensed band is increasing every day. As a consequence, more and more devices will share the same spectrum at the same time.

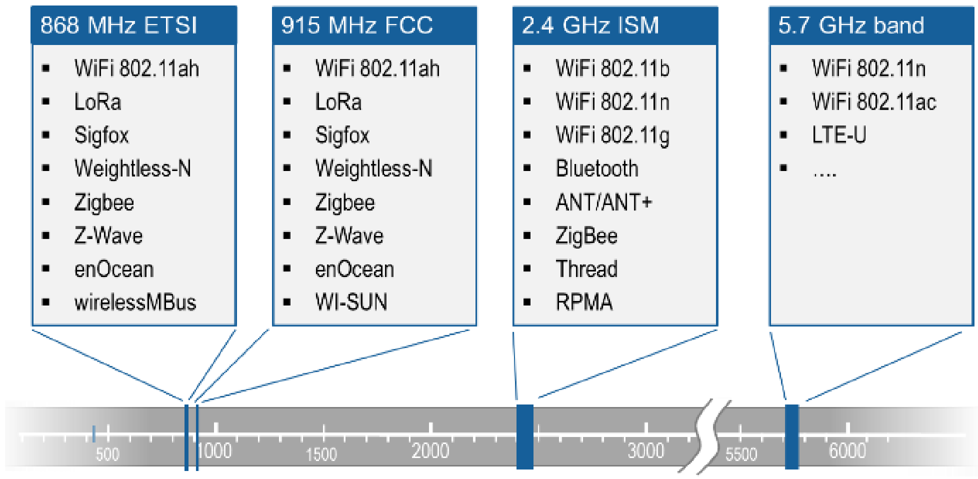


Figure 13: Examples of wireless communications technologies using unlicensed bands.

For example, in a smart home scenario, several of these technologies in different parallel networks could communicate at the same time. Moreover, devices like gateways use multiple radio technologies, thereby making co-existence a significant concern. Even if all the devices meet the regulatory requirements for operation in the unlicensed bands, each device and radio must expect and be able to deal with interference.

From the conceptual point of view, there are two ways to deal with interference issues: interference avoidance and robustness. To avoid interference with other technologies, WiFi uses a "listen before talk" technique with an exponential back-off timer. Bluetooth uses an adaptive frequency hopping scheme where devices belonging to a pico-net hop synchronously among 79 channels, 1600 times per second. The algorithm allows adaptation to the spectrum environment by excluding channels with high interference ("bad channels") from the list of available channels. To improve the robustness, a forward error correction (FEC) mechanism is also used.

In some regions it is important to ensure that WiFi equipment does not interfere with certain radar systems. DFS is a spectrum-sharing mechanism that allows wireless LANs to coexist with radar systems.

3.3 Test Solutions

Testing may seem to be very complicated, time-consuming and costly, especially for players entering the wireless communications arena for the first time Fig.14. As an expert in wireless communications, Rohde & Schwarz will help you understand the critical testing requirements for your IoT device and can provide you with the proper test solutions to validate your device from the early R&D phase all the way through to manufacturing.

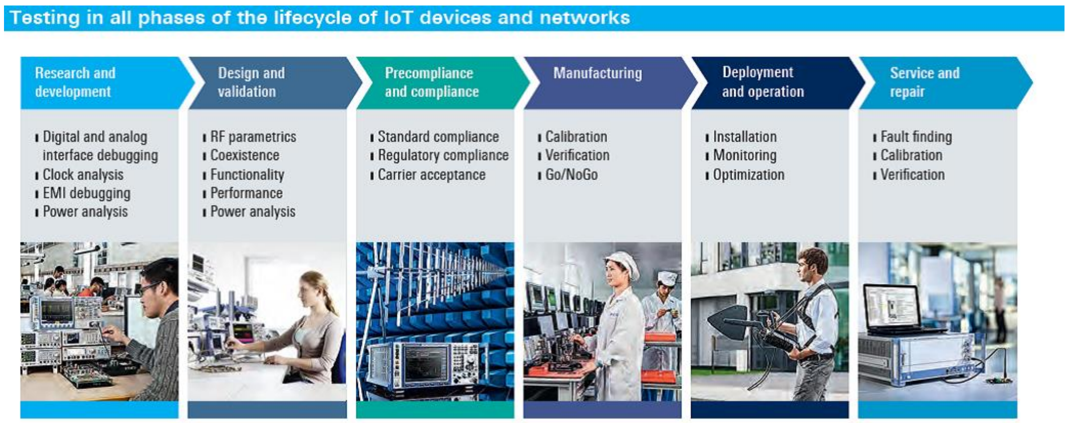


Figure 14: Rohde and Schwarz supports testing throughout the entire product lifecycle.

Test and measurement solutions from Rohde & Schwarz cover all major cellular and non-cellular technologies. Our comprehensive product portfolio offers the right solution for your IoT device – from the first product idea through the full device lifecycle. The following are examples of our many solutions for IoT product development:

Smart debugging of embedded designs.

Troubleshoot your IoT device at the system level through time-correlated analysis of analog components, digital interfaces, protocol-based buses, power supplies and RF signals with a digital oscilloscope.

End-to-end application testing.

Explore the functionality and performance of your IoT device from the end-to-end perspective by analyzing data and signaling traffic, quality of service and battery consumption under realistic network conditions.

Wireless test setups for R&D and manufacturing.

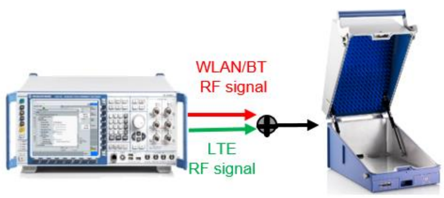
Test the radio interface of various wireless standards over the air with a compact test system consisting of a signal generator, spectrum analyzer and RF shielded box.

Conformance testing.

Test the EMC conformance of your IoT devices operating in the 2.4 GHz and 5 GHz ISM bands such as Bluetooth® and Wi-Fi.

Antenna Performance testing.

Verify proper functionality for IoT device transmitter and receiver within specification by performing TRP/TIP measurements in an Over-the-Air test environment.



Co-Existence testing.

Analyze receiver sensitivity by testing the device under conditions where multiple technologies are communicating at the same time. Eg. WLAN (or BT) and LTE.

4 Summary

The IoT space is growing at a rapid pace and covers many different types of applications. The device requirements for each application vary greatly and it would be challenging for a single technology to address all of these requirements. While there's work going into the 3GPP standards for NB-IoT attempting to address a lot of these requirements, there are still questions on how well each of these requirements will be met and how quickly the chipset manufacturers will develop this new technology. In the meantime, many new non-cellular technologies (WiFi, LoRa, SIGFOX, Ingenu) are presently being deployed globally to address these different IoT vertical markets.

Finally, in order to produce a high quality product which passes all required certifications proper testing must be done throughout the entire lifecycle of the product - from early R&D all the way through the manufacturing of the device.

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