Enabling the Internet of Things
Understanding IoT Technologies
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 fast chipset manufacturers will develop new technologies to support various vertical market's needs and requirements. This white paper is the first in our Enabling IoT Series. It covers the technologies and standards that are being developed and deployed globally for a wide range of applications.

White Paper

9.2018 – 2

ROHDE&SCHWARZ

Table of Contents

1 Introduction

The Internet of Things (IoT) will impact all industries and ultimately everyone's daily life. Currently, items 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; 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. However, IoT applications have a wide variety of requirements depending on their end use. This may include data rates, range, power usage, frequency of communication and more Fig.1.

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.

Figure 1: A diverse range of IoT deployment requirements.

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.

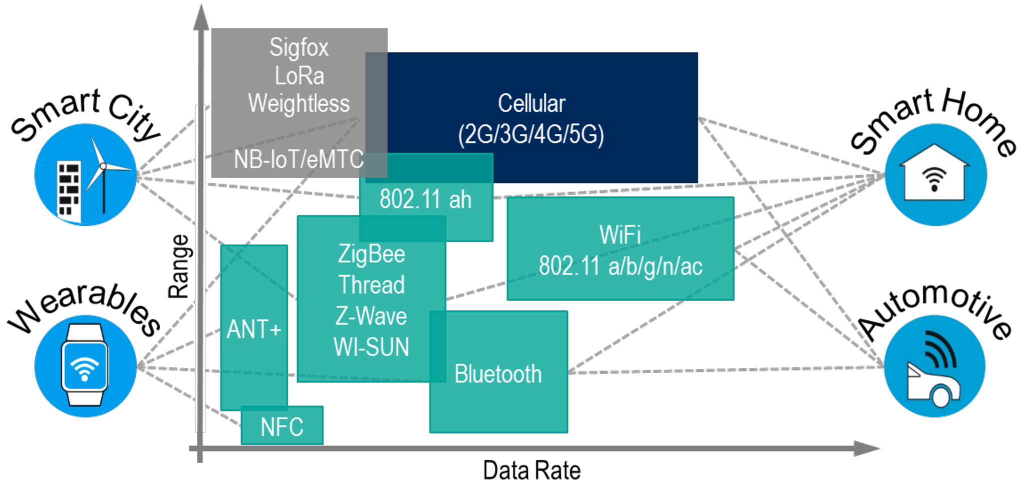


Figure 2: Technology capabilities with respect to data rate and range.

At the present time, there are already billions of devices connected to the Internet by quite, mature wireless technologies like Bluetooth, ZigBee, 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 first paper in our IoT series gives an overview of the emerging wireless technologies for the IoT market.

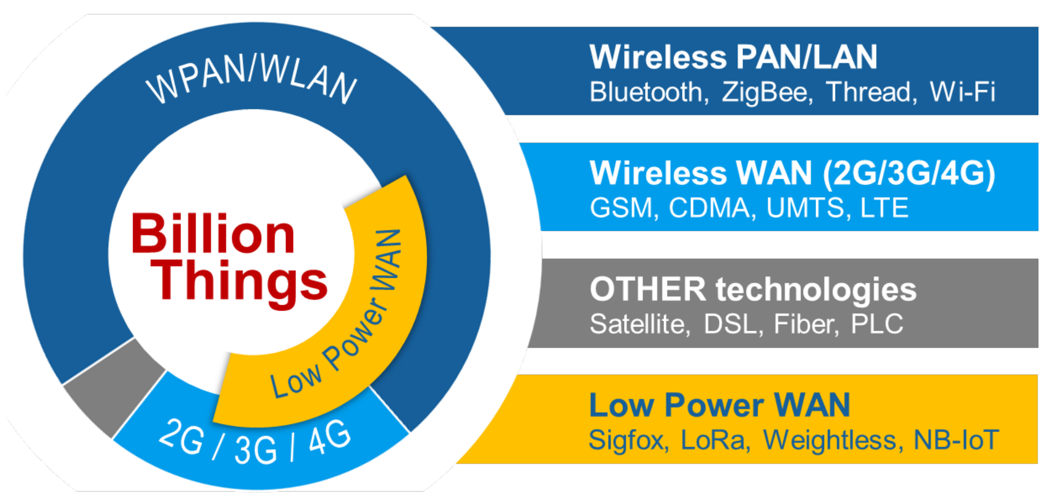


Figure 3: Summary of technologies driving the IoT market.

1 Wireless PAN/LAN

1.1 Bluetooth

Today, Bluetooth may be the most deployed IoT technology, as most smart phones already have Bluetooth capability Fig.4. This gives Bluetooth IoT applications a distinct advantage in that most smart phones could be used collect and send data.

Bluetooth "Classic" has been around a while and had a reputation for being tough to pair, along with short battery life. The new Bluetooth standards – Smart (or Low Energy) and Smart Ready – address these issues and more.

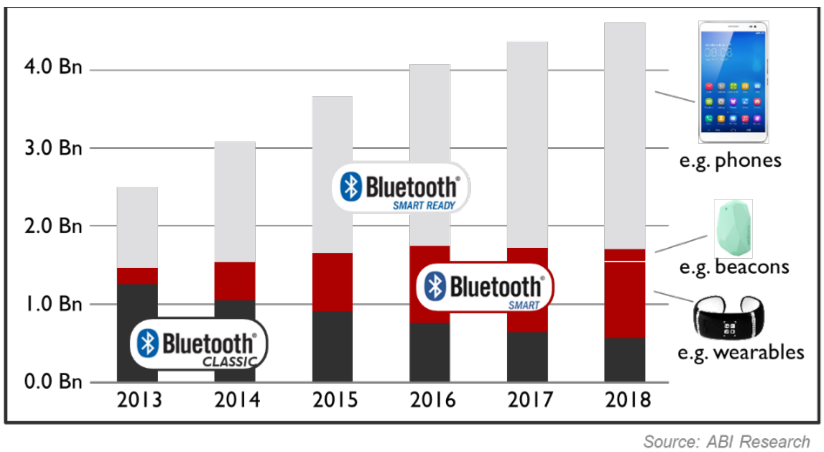


Figure 4: Forecast of Bluetooth shipments.

The new Bluetooth standards (now up to 5.0) split products into two groups: Bluetooth Smart Ready and Bluetooth Smart. Bluetooth Smart Ready devices, such as smartphones, notebooks, and tablets, can receive and share Bluetooth signals. Bluetooth Smart devices are simpler, lower cost peripherals that connect to the Bluetooth Smart Ready products. The power-efficiency of Bluetooth Smart makes it perfect for devices needing to run off a tiny battery for long periods, while the key feature of Bluetooth Smart Ready is its ability to work with any application on a smart phone or tablet.

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.5. 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.

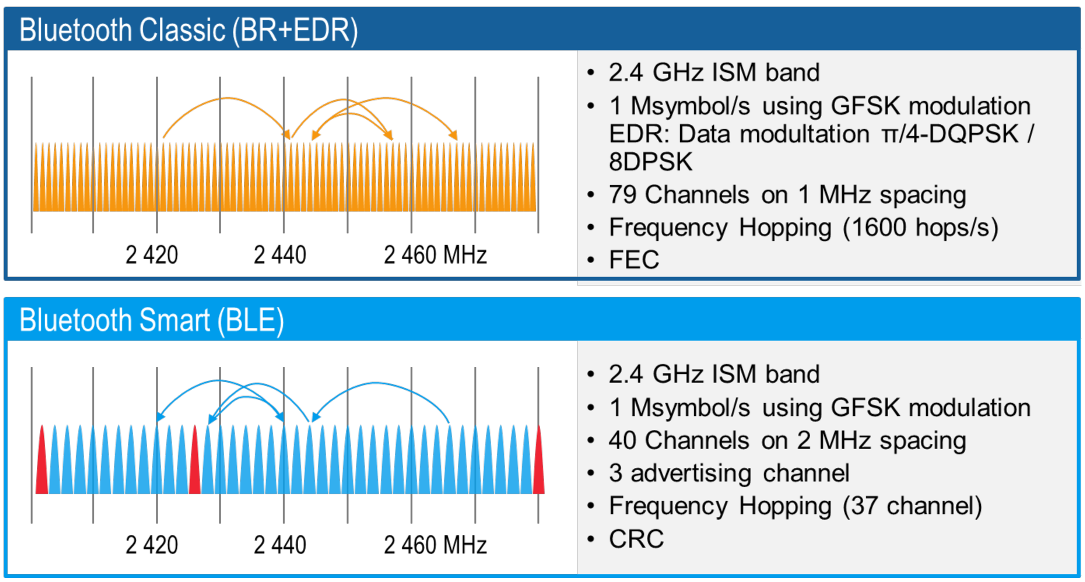


Figure 5: Classic Bluetooth and Bluetooth Smart.

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:

- Mesh - building meshed networks using relay nodes
- Speed - 100% improvement for low latency applications
- Range - 4x range to cover a smart home or office
- Gateway - Connecting devices directly to the cloud
- Direction - Extended capabilities of beacons for positioning

1.2 WiFi

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 Fig.6. These new WiFi technologies are starting to be available, with more on the way in the next few years. Some offer different approaches to WiFi that could enable some entirely new device classes.

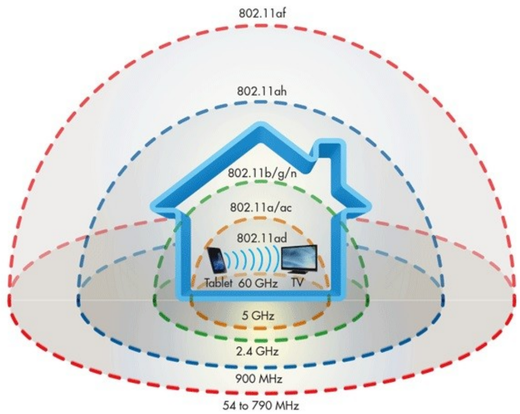


Figure 6: Overview of new and existing WiFi standards.

1.2.1 802.11b/a/g/n/ac Established WiFi Standards

The initial launch of the 802.11 WiFi standard was in 1997, since then, many additional standards have been released. 802.11b became the first to be broadly adopted for consumer devices due to its convenience and low cost. Three years later, a much faster 802.11g mostly replaced the older standards, but maintained compatibility.

In addition to speed improvements, 802.11n introduced the first optional use of the 5GHz band, offering a less cluttered frequency band. 802.11n also introduced the first use of MIMO antennas for higher parallel throughput, where speeds can reach up to 450 Mbit/s, depending on the number of antenna connections.

The newer 802.11ac standard was designed to dramatically increase the speed of data transfers. This is the first standard to offer speeds that can reach 1 Gbit/s and it runs solely on the less cluttered 5 GHz band. Table 1 highlights the capabilities of these established WiFi standards.

	802.11a	802.11b	802.11g	802.11n	802.11ac
Frequency	5 GHz	2.4 GHz	2.4 GHz	2.4/5GHz	5 GHz
Channel bandwidth	20 MHz	20 MHz	20 MHz	20 MHz, 40 MHz	20/40/80/160 MHz,
Spatial streams	1	1	1	4	8
Max. Data rate	54 Mbps	11 Mbps	54 Mbps	600 Mbps	1331 Mbps
System	OFDM	DSSS	OFDM, DSSS	OFDM, OFDMA	MIMO-OFDM,

Table 1: Established 802.11 Standards

1.2.2 802.11ah HaLow

The 802.11ah standard, known as HaLow, was developed as a lower power WiFi solution and is designed to cover a range of up to 1 kilometer. HaLow achieves the greater coverage by transmitting at 900 MHz, a much lower frequency than the existing 2.4 GHz and 5 GHz WiFi technologies. It supports multiple channel bandwidths from 16 MHz channels, for high data throughput, down to 1 MHz, for extended coverage at lower data rate.

At these long ranges, HaLow will only be able to transmit data at speeds between 100 Kbit/s and 40 Mbit/s, making it slower than most existing home networks. However, HaLow will be great for IoT applications that require low power devices that only require the transmission of short bursts of data.

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.7.

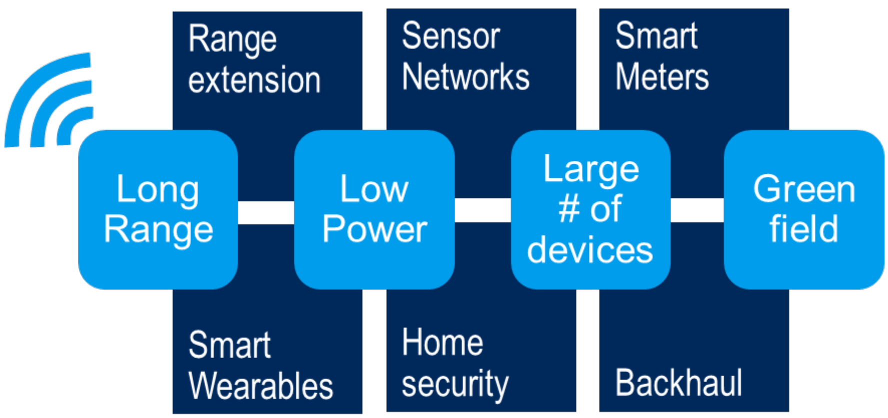


Figure 7: 802.11ah or HaLow use cases.

1.2.3 802.11 af

802.11af is like 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. The 802.11af standard works with TV channels with bandwidths of 6, 7, or 8 MHz. It uses OFDM modulation using BPSK, QPSK, 16QAM, 64QAM, or 256QAM. The maximum data rate at the 6-MHz channel is 24 Mb/s. A typical mobile user station will have a transmit power of 100 mW and the base station or access point will be able to have up to 4 W of power. The range depends on the actual frequency. Several kilometers can be achieved at the higher frequencies. While the lower VHF frequencies offer even longer ranges of up to several miles.

802.11af will be important for IoT applications for business or industrial needs that require long-range communication. Speeds could be acceptable over these distances because of the lack of interference.

1.2.4 802.11ad WiGig

802.11ad, or WiGig, delivers a massive boost in speed by using a very different approach from existing WiFi technologies. It uses a 60 GHz millimeter wave transmission frequency that enables data speeds to almost 7 Gbit/s – more than ten times faster than the highest 802.11n rate. However, it comes with a major trade-off in range, as the frequency requires a direct line of sight between devices and the signal cannot penetrate walls.

This makes 802.11ad suitable for fast data transfers within a single room, but not for a complete home or office network. One of the primary applications may be eliminating the need for HMDI cables to a TV display. Users would be able to wirelessly stream huge 4K movie files from their device to the TV Fig. 8.

802.11ad also supports beamforming, which allows the beam to be steered within the coverage area through modification of the transmission phase of the individual antenna elements, also known as phase array antenna beamforming.

Figure 8: 802.11ad, or WiGig, enables data speeds to almost 7 Gbit/s but requires a direct line of sight between devices.

1.2.5 802.11ax

IEEE 802.11ax is designed to improve overall spectral efficiency, especially in dense deployment scenarios. It is still in a very early stage of development, but is predicted to have a top speed of several Gb/s. It is designed to operate in the already existing 2.4 GHz and 5 GHz spectrums. In addition to utilizing MIMO and MU-MIMO, it uses OFDMA to improve overall spectral efficiency, and higher order 1024 QAM modulation support for increased throughput. It is expected to achieve a 4 × increase in user throughput by using the spectrum more efficiently.

1.2.6 802.11p

IEEE 802.11p is an example of the WiFi technologies being used for an entirely new application. The approved amendment to the IEEE 802.11 standard adds wireless access in vehicular environments (WAVE) to provide a vehicular communication system Fig.9. It defines enhancements to 802.11 standard required to support Intelligent Transportation Systems (ITS) applications. This includes data exchange between high-speed vehicles and between the vehicles and the roadside infrastructure, so called V2X communication, in the licensed ITS band of 5.9 GHz.

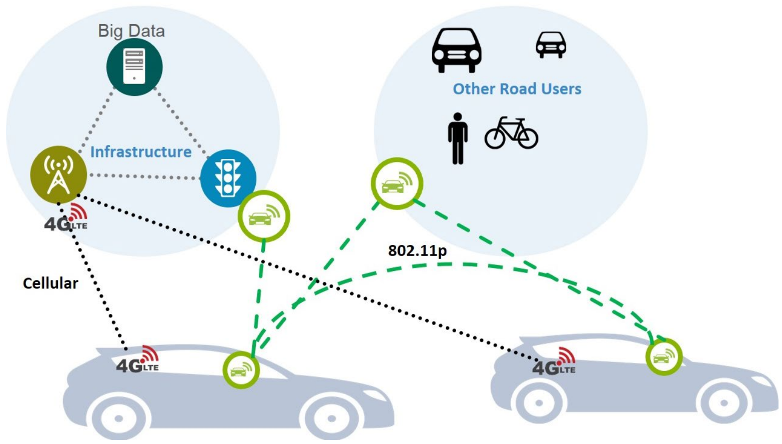


Figure 9: 802.11p offers wireless access in vehicular environments for a new vehicular communication system.

2 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. 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. ZigBee and Thread are the most widely used technologies for LR-WPANs in smart homes and buildings.

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 Fig.10.

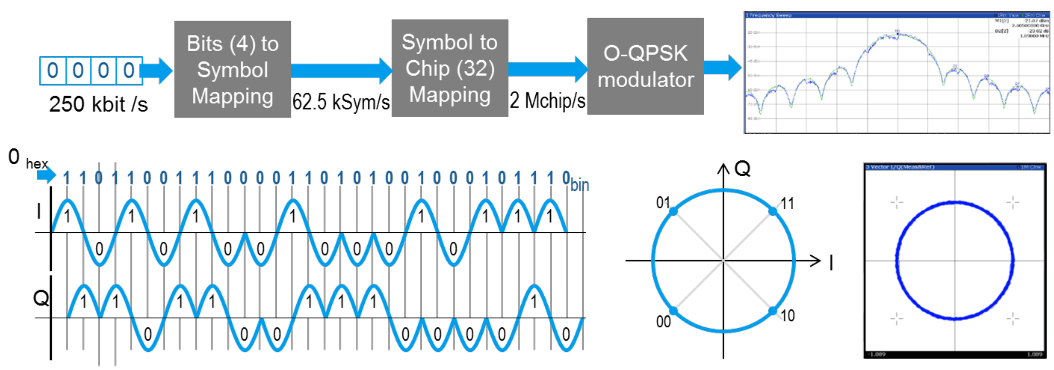


Figure 10: The 802.15.4 standard is used for many different applications.

2.1 ZigBee

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.

In 2016 about 800 million devices were shipped that used the 802.15.4 protocol, with Zigbee solutions accounting for over half of the shipments. Zigbee has become a market leader in home automation in terms of the deployment.

While its range goes anywhere from 10 to 100 meters, a key feature is its mesh networking capabilities Fig.11. Multiple ZigBee devices may interconnect with each other and transfer data. The mesh network allows ZigBee to potentially cover a much broader area than your typical home automation device. This will allow ZigBee to compete with potential competition from next generation Bluetooth and WiFi technologies.

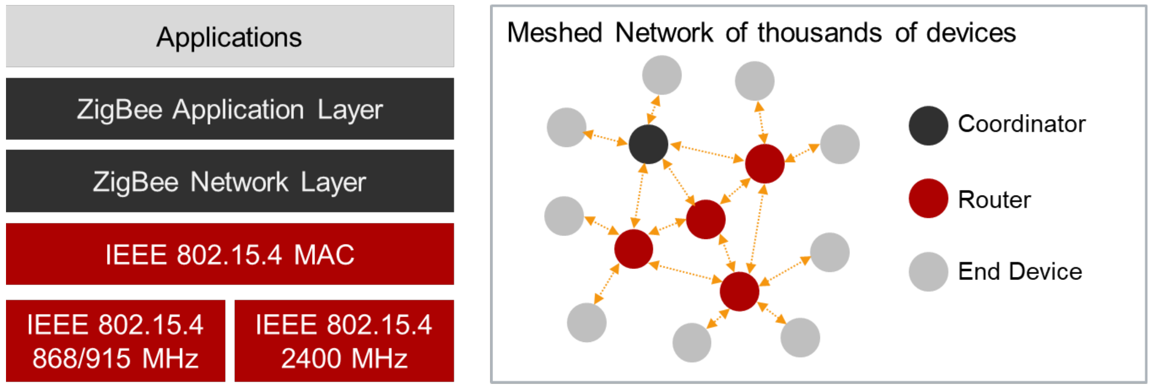


Figure 11: ZigBee offers mesh networking capabilities.

2.2 Thread

Thread's main difference here is that it allows for the functionality of IPv6, which allows IoT devices to have actual IP addresses. This provides the ability for direct internet connection to each one of these sensors or nodes, which may offer a better user interface or user experience.

Thread offers 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.

2.3 WirelessHART and ISA100

There are also a few less known technologies that use the 802.15.4 protocol –WirelessHART and ISA 100. WirelessHART is a proprietary technology that is used in industrial wireless automation areas. ISA100 is also more for industrial processes and controllers, but includes IPv6 functionality.

3 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.

3.1 SIGFOX

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.12. The majority of the SIGFOX traffic is uplink data.

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.

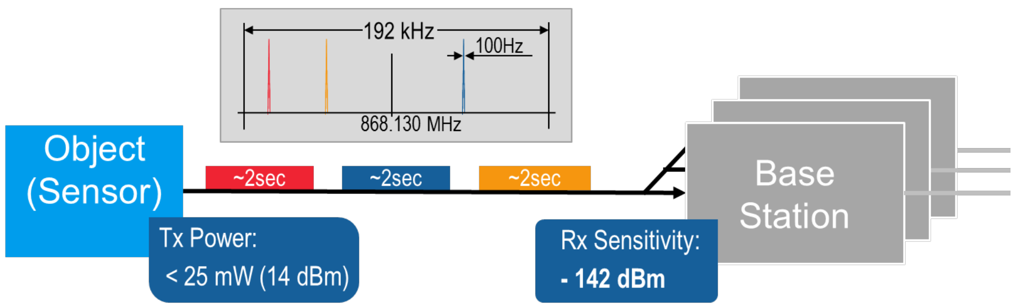


Figure 12: SIGFOX uses ultra-narrow band technology.

3.2 LoRa

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.13 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.

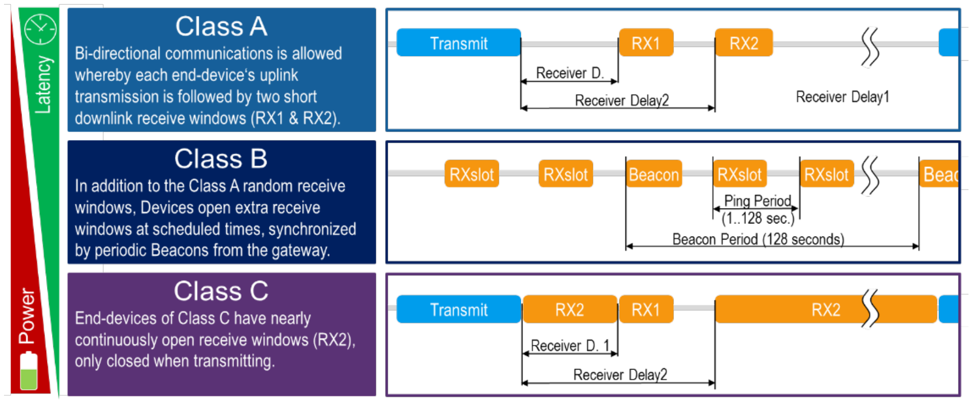
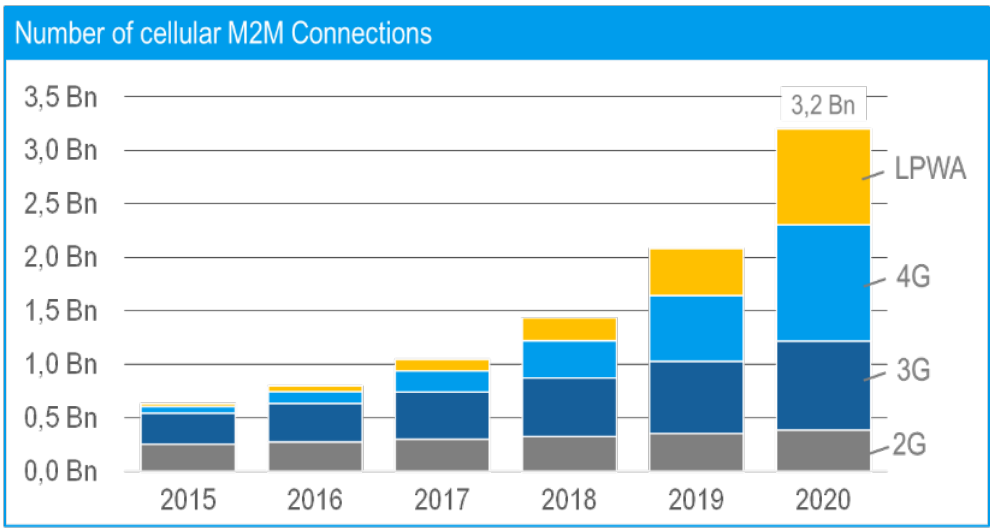


Figure 13: Three different classes of LoRa.

4 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.14. 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 14: Growth of M2M connections on various technologies.

3GPP has been working on new requirements to support Machine Type Communications (MTC) for LTE Fig.15. 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.

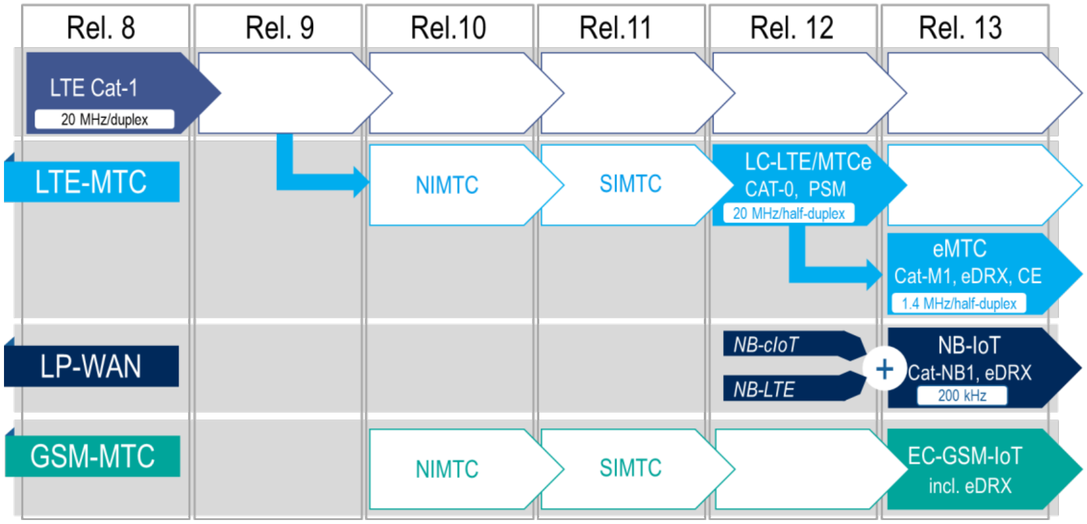


Figure 15: 3GPP schedule for LTE-MTC, LP-WAN and GSM-MTC.

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).

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.16.

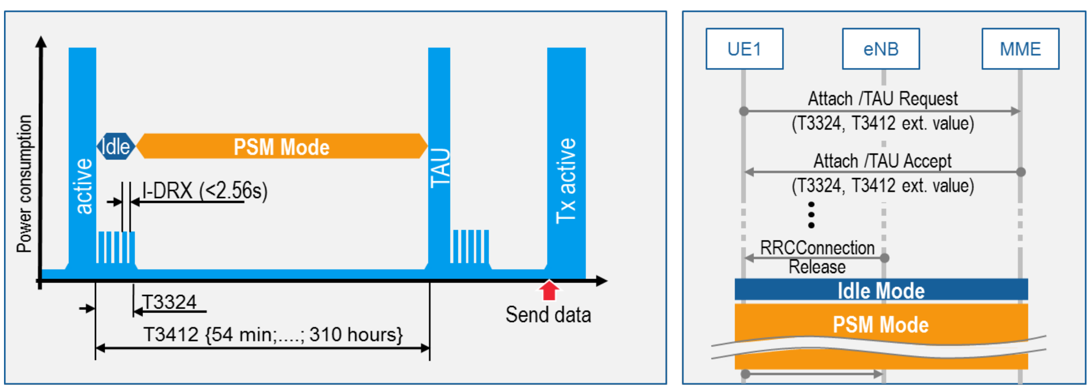


Figure 16: Power Saving Mode (PSM).

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.17.

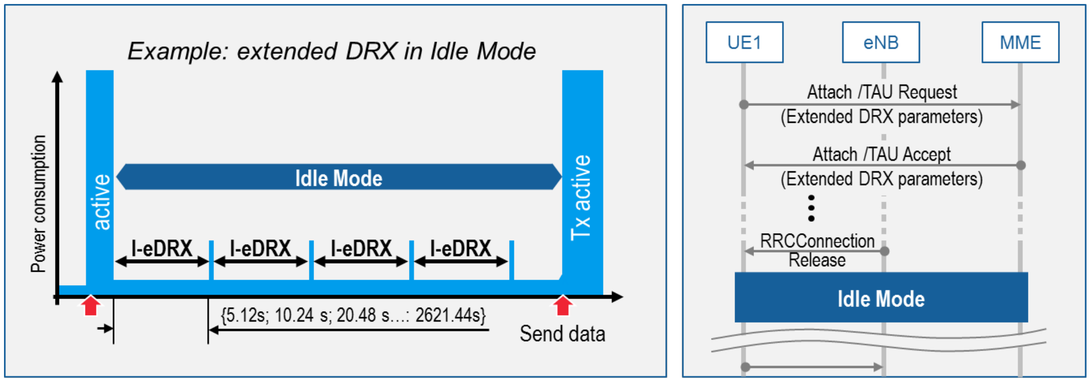


Figure 17: Extended Discontinuous Reception (eDRX).

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. CATNB1 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 NBIoT devices within a single LTE cell.

5 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.18. 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.

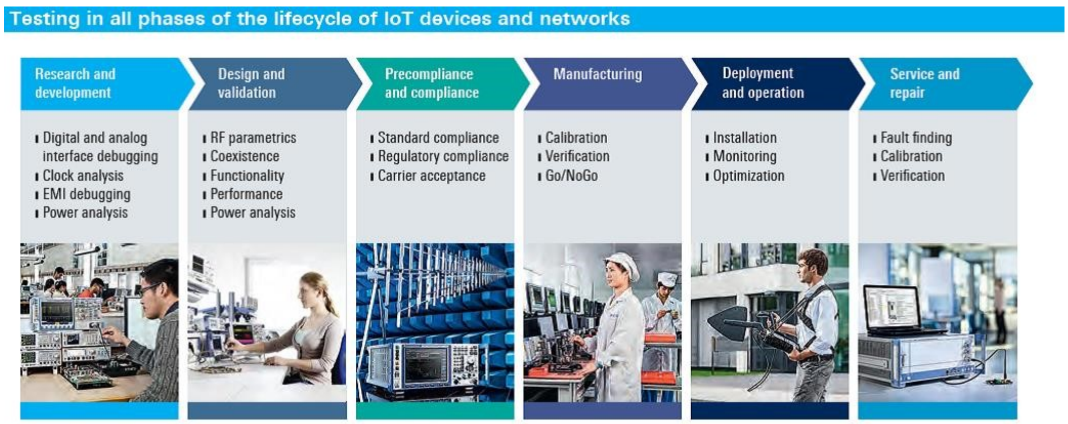


Figure 18: Rohde and Schwarz supports testing throughout the entire product lifecycle.

Test and measurement solutions from Rohde & Schwarz cover all major cellular and noncellular 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.

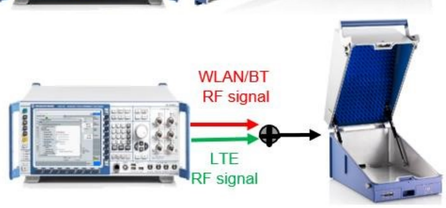
Test the radio interface of various wireless standards over the air with a compact test system consisting of a signal generator, spectrum analyzer and RF shielded box.

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.

6 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 noncellular technologies (Bluetooth, WiFi, LoRa, SIGFOX) are presently being deployed globally to address these different IoT vertical markets.

In the next two papers of this IoT series we discuss all the required certifications to produce a high quality product and finally the proper testing that must be done throughout the entire lifecycle of the product - from early R&D all the way through the manufacturing of the device.

For more information on Rohde & Schwarz please visit https://www.rohde-schwarz.com

Rohde & Schwarz

The Rohde & Schwarz electronics group offers innovative solutions in the following business fields: test and measurement, broadcast and media, secure communications, cybersecurity, radiomonitoring and radiolocation. Founded more than 80 years ago, this independent company has an extensive sales and service network and is present in more than 70 countries.

The electronics group is among the world market leaders in its established business fields. The company is headquartered in Munich, Germany. It also has regional headquarters in Singapore and Columbia, Maryland, USA, to manage its operations in these regions.

Regional contact

Europe, Africa, Middle East
+49 89 4129 12345
customersupport@rohde-schwarz.com

North America
1 888 TEST RSA (1 888 837 87 72)
customer.support@rsa.rohde-schwarz.com

Latin America
+1 410 910 79 88
customersupport.la@rohde-schwarz.com

Asia Pacific
+65 65 13 04 88
customersupport.asia@rohde-schwarz.com

China
+86 800 810 82 28 |+86 400 650 58 96
customersupport.china@rohde-schwarz.com

Sustainable product design

- Environmental compatibility and eco-footprint
- Energy efficiency and low emissions
- Longevity and optimized total cost of ownership

Certified Quality Management ISO 9001

Certified Environmental Management ISO 14001

Rohde & Schwarz GmbH & Co. KG
Mühldorfstraße 15 | 81671 Munich, Germany
Phone + 49 89 4129 - 0 | Fax + 49 89 4129 – 13777

www.rohde-schwarz.com