SINERGIA

Symbiotic Convergence of M2M Wireless Communications and the 5G

Convergencia de las comunicaciones inalámbricas M2M y la 5G

Proyectos RETOS

TEC2015-71303-R

D1.2

State of the Art MAC layers for Wide Area Wireless Communications

Document Properties

Document Number:	D1.2
Document title:	State of the Art MAC layers for Wide Area Wireless Communications
Document Responsible:	Xavier Vilajosana
Document authors:	Xavier Vilajosana, Ferram Adelantado
Security:	Public
Date:	30-12-2016
Status:	Final

Executive Summary

This documents presents the state of the art of Wide Area Wireless technologies, focusing in the details of the MAC layer and Physical layer operation. The aim of the document is to bring a broad knowledge on the different state or the art standards and technologies, focusing also in their level of adoption and standardization status.

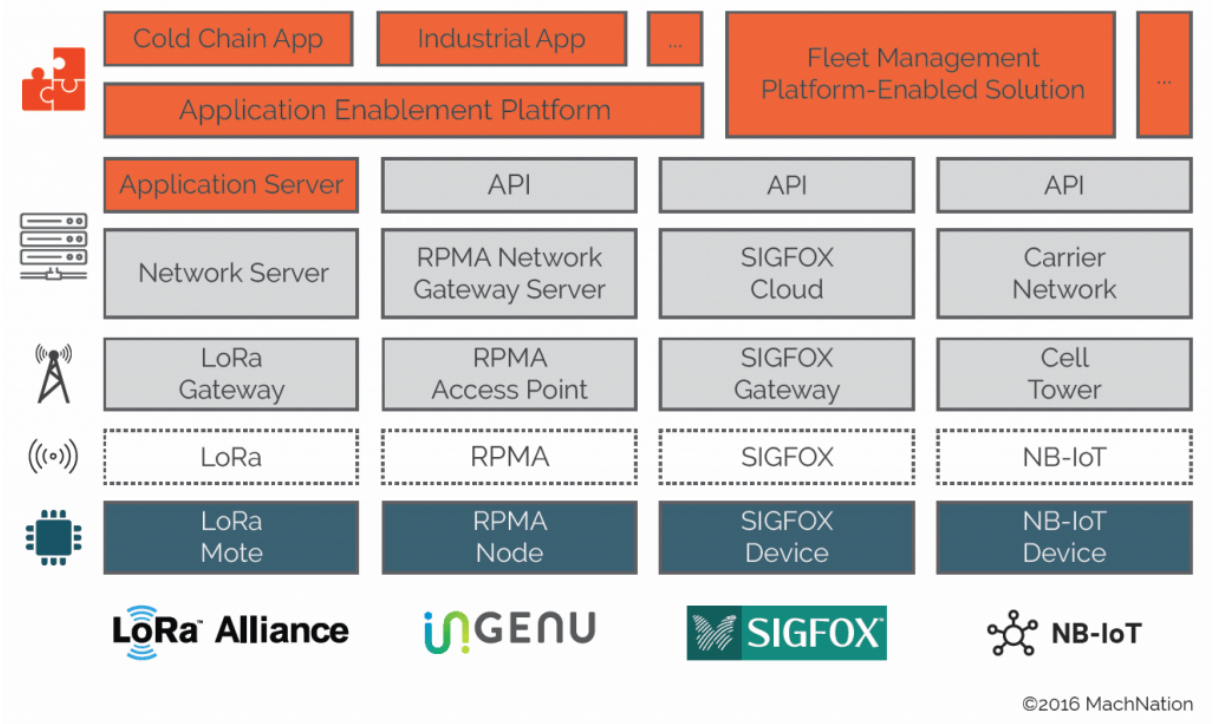
Table of Contents

1. Wide Area Wireless Networks

The Internet of Things (IoT) has fundamentally shifted the nature of connected devices, creating massive opportunities for low-power wide area network (LPWAN) technologies. LPWAN solutions are ideal for devices that need to send smaller amounts of data over long ranges, with particular constraints around power consumption and computational horsepower.

Many of the LPWAN solutions perform well in obstructed environments – like in cities and rugged outdoor environments. There are developments in traditional cellular networks that are improving their suitability for IoT applications – these include the array of low-power, low-bandwidth LTE developments like LTE-MTC, NB-LTE-M, and NB-IoT (now known as CAT-M1 and CAT-M2). These solutions however are largely unavailable at the present time; traditional cellular (2G, 3G, and 4G LTE) is still best suited for higher-bandwidth applications and is not as cost effective as LPWAN for a myriad of IoT use cases.

Given the immediate need for LPWAN in IoT deployments, multiple solutions have emerged offering the right balance of bandwidth, power consumption, and distance range – and at the right cost. Some of these initiatives are coordinated by membership-based standards alliances, while others or facilitated by private companies with proprietary solutions.



2. Low Power Wide Area Networks (LPWAN)

The IoT paradigm has shaken the telecommunications industry and has opened up new business opportunities in the LPWAN market niche. Although LoRaWAN is one of the most adopted technologies, the aforementioned opportunities have resulted in the emergence of a wide range of LPWAN technologies, such as Ingenu, Wieghtless W, N and P, Ingenu (RPMA) or SigFox. The 3rd Generation Partnership Project (3GPP) standardized a set of low cost and low complexity devices targeted to Machine-Type-Communications (MTC) in Release 13 to compete with LPWAN technologies.

2.1 Sigfox

One of the biggest names in the game is the startup company Sigfox. Sigfox has been blanketing large swaths of the planet (notably in Europe) with its proprietary LPWAN solution since 2009, making it one of the older players in IoT LPWAN. The firm completed a $115 million Series D raise in February 2015, bringing its total venture funding to date up to $151 million. Sigofx sets up base station antennas on towers and often works with local mobile network operators (MNOs) to do so. It controls the backhaul communications infrastructure and backend cloud management platform, so any customer that wants to use Sigfox has to leverage its communications infrastructure and cloud platform – and of course pay the associated recurring fees. Radios and modules for endpoints are widely available from manufacturers like Texas Instruments, Atmel, and Telit. The technology is based on ultra-narrow band (UNB) binary phase-shift keying (BPSK) transmitted in the 868 or 902 MHz bands, depending on the region and the regulations – the nature of UNB is that the energy density of noise tends to be spread across spectrum, thus the Sigfox signal in any narrow portion of the spectrum is more likely to be above the noise floor. The flip side is that noise spikes in narrow portions of the spectrum can interfere with a UNB type signal. Sigfox is wellsuited for low-bandwidth (less than 300 bits per second / up to 12 total bytes per payload) and low-frequency (up to 140 messages per day) applications. Sigfox is effective for communications from endpoints to base stations (uploads), but it is not particularly effective from base stations to endpoints (downloads).

2.2 LoRa

The LoRa Alliance is a membership-based alliance dedicated to promoting and developing the LoRaWAN protocol. LoRa is an open alliance in the sense that any organization can purchase LoRa hardware and deploy its own networks without going through (and having to pay fees to) any centralized authority. Like Sigfox, the LoRa alliance is working with MNOs to help deploy its solution and drive adoption. While LoRa is a more open model than Sigfox, there is one closed aspect of the ecosystem: the only vendor that is licensed to manufacturer radio chipsets is Semtech; the alliance has however announced agreements with STMicroelectronics and Microchip, both of which should be shipping radios in the near future. As of now, all module and gateway manufacturers (like MultiTech Systems) source radios from Semtech. LoRa is a chirp-based spread-spectrum technology with a wider bandwidth than Sigfox – that itself looks like noise. Due to the modulation technique and built-in forward error correcting capability, the LoRa signal can transmit data with signal strengths well below the noise floor – LoRa proponents claim that LoRa is the only commercially available technology that can transmit so far below the noise floor.

From a bandwidth perspective, LoRa sits above Sigfox in terms of throughput and is ideal for data transfer rates of between 300 bits per second and 5,000 bits per second. Another important consideration is that LoRa offers effective bidirectional functionality – so it is good for receiving messages from endpoints, but also for sending messages from base stations to endpoints (like for command and control applications). LoRa operates in similar portion of the sub-GHz spectrum to Sigfox.

2.3 Ingenu (RPMA)

Ingenu was founded in 2008 and originally focused on utilities and oil and gas applications; it has however expanded into other IoT applications including urban and agricultural environments. Ingenu has raised $119 million in venture funding to date and is the driving LPWAN solution behind a number of major smart meter and digital oilfield deployments. The firm’s solution is proprietary in the sense that it is the sole developer and manufacturer of the hardware. Its major business model in the past was to sell hardware components to enterprises that built and controlled their own networks; recently however the firm has constructed several public networks, for which it sells radio modules and recurring data subscriptions – many customers for this model are machine-to-machine (M2M) solutions

providers. The proprietary Ingenu solution is based on random phase multiple access (RPMA) technology, which enables higher data throughput rates than Sigfox and LoRa – Ingenu typically transmits at rates in the hundreds of thousands of bits per second, at the cost of higher power consumption than Sigfox and LoRa. Ingenu operates in the 2.4 GHz band, which gives it a shorter range than Sigfox and LoRa, and also encounters more propagation loss from obstructions, like water or packed earth. The Ingenu protocol itself enables precise tracking, while Sigfox and LoRa do not provide similar levels of tracking precision and require a separate global navigation satellite system (GNSS) module for tracking applications. Like LoRa, Ingenu is capable of effective bidirectional transmission; Sigfox and LoRa can typically achieve a greater amount of endpoints per base station.

2.4 Weightless

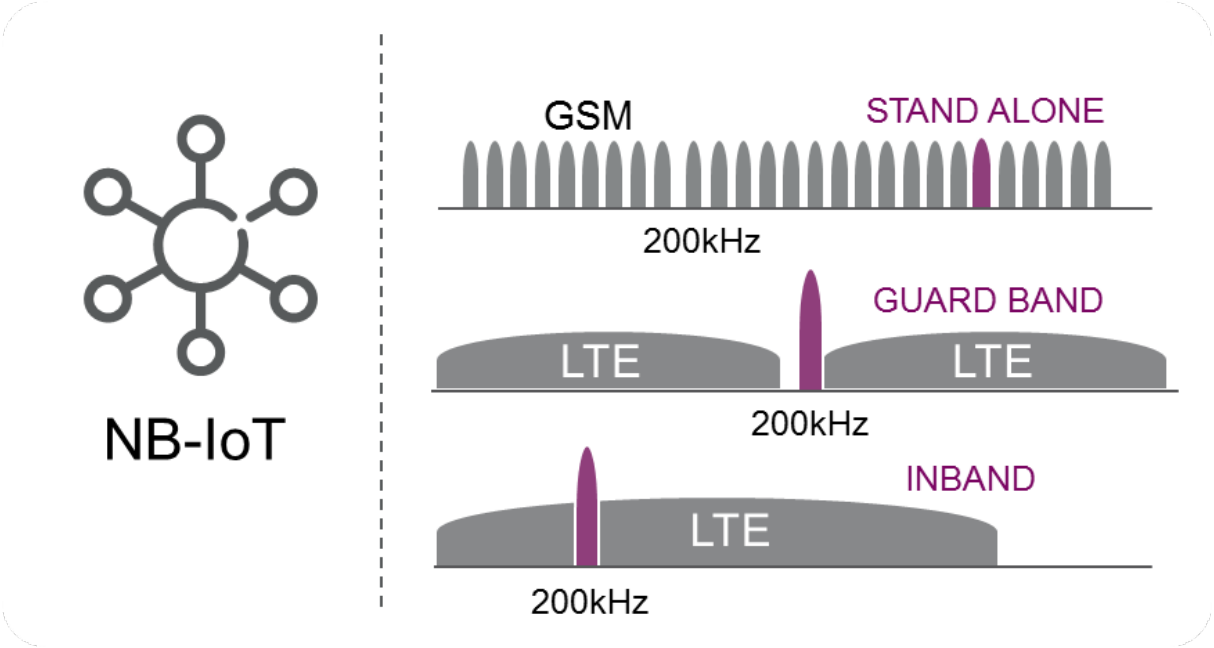
One of the next in line is the Weightless standard, which is developed and maintained by the Weightless Specialty Interest Group (SIG). There are several implementations of the Weightless standard (Weightless-W, -N, and -P) that leverage different underlying technologies and target different bandwidth applications. The company Nwave is one of the major proponents commercializing Weightless technology

The Weightless Special Interest Group has developed a set of three open standards for LPWAN, namely Weightless-W, Weightless-N and Weightless-P. The first standard, Weightless-W, was developed as a bidirectional (uplink/downlink) solution to operate in TV whitespaces (470-790 MHz). Based on narrowband FDMA channels with Time Division Duplex between uplink and downlink, data rates range from 1 kbps to 1 Mbps. The second standard, Weightless-N, was designed to extend the range of Weightless-W and reduce the power consumption at the expense of a reduction of the data rates (from 30 kbps to 100 kbps). Unlike its predecessor, Weightless-N is based on the Ultra Narrow Band (UNB) technology and operates in the UHF 800-900 MHz band to provide only uplink communication. Finally, Weightless-P is proposed as a high performance two-way standard that can operate over the whole range of license-exempt sub-GHz bands. However, terminals have higher cost and higher power consumption.

	SIGFOX	LoRa	clean slate cIoT	NB LTE-M Rel. 13	LTE-M Rel. 12/13	EC-GSM Rel. 13	5G (targets)
Range (outdoor) MCL	<13km 160 dB	<11km 157 dB	<15km 164 dB	<15km 164 dB	<11km 156 dB	<15km 164 dB	<15km 164 dB
Spectrum Bandwidth	Unlicensed 900MHz 100Hz	Unlicensed 900MHz <500kHz	Licensed 7-900MHz 200kHz or dedicated	Licensed 7-900MHz 200kHz or shared	Licensed 7-900MHz 1.4 MHz or shared	Licensed 8-900MHz 2.4 MHz or shared	Licensed 7-900MHz shared
Data rate	<100bps	<10 kbps	<50kbps	<150kbps	<1 Mbps	10kbps	<1 Mbps
Battery life	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years
Availability	Today	Today	2016	2016	2016	2016	beyond 2020

3. Cellular IoT

The 3GPP has addressed the IoT market from a three-fold approach by standardizing the enhanced Machine Type Communications (eMTC), the Narrow Band IoT (NB- IoT) and the EC-GSM-IoT. eMTC is an evolution of the work developed in Release 12 that can reach 1 Mbps in the uplink and downlink, and operates in LTE bands with a 1.08 MHz bandwidth. As for NB-IoT, it is an alternative that achieves lower complexity at the expense of lower data rates (up to 250 kbps in both directions). Finally, EC-GSM-IoT is an evolution of EGPRS to meet IoT needs with data rates ranging from 70 to 240 kbps. Although the different approaches proposed so far by 3GPP have significantly reduced the energy consumption and the complexity of the devices, they have not yet match the low cost and complexity of their non-3GPP counterparts. Therefore, technologies such as LoRaWAN are gaining ground in the IoT market.



As indicated, in the LTE Rel-13, two new features supporting narrowband machine type communications (MTC) are being introduced. The features are called eMTC (enhanced MTC) and Narrowband IoT (NB-IoT). In eMTC, a new UE with reduced radio frequency (RF) bandwidth of 1.4 MHz in downlink and uplink is introduced. In addition, eMTC also introduces coverage enhancement to provide better indoor support. However, eMTC operates in-band as part of the wideband LTE carrier. NB-IoT, however, is a new narrowband IoT system built from existing LTE functionalities. It can be deployed in three different operation modes – (1) stand-alone as a dedicated carrier, (2) in-band within the occupied bandwidth of a wideband LTE carrier, and (3) within the guard-band of an existing LTE carrier. In stand-alone deployment, NB-IoT can occupy one GSM channel (200 kHz) while for in-band and guard-band deployment, it will use one physical resource block (PRB) of LTE (180 kHz). The design targets of NB-IoT include low-cost devices, high coverage (20-dB improvement over GPRS), long device battery life (more than 10 years), and massive capacity (greater than 52K devices per channel per cell). Latency is relaxed although a delay budget of 10 seconds is the target for exception reports. Since NB-IoT is expected to adopt a design based on existing

LTE functionalities, it is possible to reuse the same hardware and also to share spectrum without coexistence issues. In addition, NB-IoT can simply plug into the LTE core network.

This allows all network services such as authentication, security, policy, tracking, and charging to be fully supported.

4. References

Link. Labs, “A Comprehensive Look At Low Power, Wide Area Networks For Internet of Things Engineers and Decision Makers,” White Paper, 2016.

C. Goursaud, , and J. M. Gorce, “Dedicated Networks for IoT: PHY/MAC State of the Art and Challenges,” EAI Endorsed Transactions on Internet of Things, vol. 15, no. 1, October 2015.

X. Xiong, K. Zheng, R. Xu, W. Xiang, and P. Chatzimisios, “Low Power Wide Area Machine-to-Machine Networks: Key Techniques and Prototype,” IEEE Communications Magazine, vol. 53, no. 9, pp. 64–71, 2015.

R. Sanchez-Iborra and M.-D. Cano, “State of the Art in LP-WAN Solutions for Industrial IoT Services,” Sensors, vol. 16, no. 5, p. 708, 2016.

G. Margelis, R. Piechocki, D. Kaleshi, and P. Thomas, “Low Throughput Networks for the IoT: Lessons Learned from Industrial Implementations,” in World Forum on Internet of Things (WF-IoT). IEEE, 2015, pp. 181–186.

N. Sornin, M. Luis, T. Eirich, T. Kramp, and O. Hersent, “LoRa Specification 1.0,” Lora Alliance Standard specification., 2016. [Online]. Available: www.lora-alliance.org

N. Ducrot, D. Ray, A. Saadani, O. Hersent, G. Pop, and G. Remond, “LoRa Device Developer Guide,” Orange, Connected Objects and Partnership. Technical Document., 2016. [Online]. Available: https://partner.orange.com/wp-content/uploads/2016/04/LoRa-Device-Developer-Guide-Orange.pdf

A. Minaburo, A. Pelov, and L. Toutain, LP-WAN Gap Analysis, IETF Std. draft-minaburo-lp-wan-gap-analysis [work-in-progress], February 2016.

Nokia, “LTE evolution for IoT connectivity,” White Paper, 2016.

E. C. Committee and Others, “ERC Recommendation 70-03,” ed. Tromso, October, 5 2016.

F. C. Commission et al., “FCC Part 15–Radio Frequency Devices, Code of Federal

Regulation 47 CFR Ch. 1 (10-1-15 Edition).

W. Giezeman and J. Stokking, “The Things Network,” June 2016. [Online]. Available: www.thethingsnetwork.org

Ratasuk, R.; Mangalvedhe, N.; Ghosh, A., "Overview of LTE enhancements for cellular IoT," PIMRC, Sept. 2015.

Ratasuk, R.; Prasad, A.; Zexian Li; Ghosh, A.; Uusitalo, M., "Recent advancements in M2M communications in 4G networks and evolution towards 5G," ICIN, Feb. 2015.

3GPP TR 36.888, Study on provision of low-cost Machine-Type Communications (MTC) User Equipments (UEs) based on LTE, v.12.0.0, June 2013.

TR 45.820, “Cellular System Support for Ultra Low Complexity and Low Throughput Internet of Things,” V2.1.0, August, 2015.

RP-150492, “Revised WI: Further LTE Physical Layer Enhancements for MTC,” Ericsson, RAN#67, Shanghai, China.

RP-152284, “Revised Work Item: Narrowband IoT (NB-IoT),” Huawei, HiSilicon, RAN#70, Sitges, Spain.

R1-157248, “NB IoT – Capacity evaluation,” Nokia Networks, RAN1#83, Anaheim, USA, 2015.

R1-157246, “Coverage Evaluation for Stand-alone Operation,” Nokia Networks, RAN1#83, Anaheim, USA, 2015.

R1-157249, “Coverage Evaluation for Guard-band Operation,” Nokia Networks, RAN1#83, Anaheim, USA, 2015.

R1-157252, “Coverage Evaluation for In-band Operation,” Nokia Networks, RAN1#83, Anaheim, USA, 2015.