Low Power Wide Area Networks: An Overview

U. Raza, P. Kulkarni and M. Sooriyabandara, "Low Power Wide Area Networks: An Overview"
in *IEEE Communications Surveys & Tutorials*, vol. 19, no. 2, pp. 855-873, second quarter 2017
doi: 10.1109/COMST.2017.2652320

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December 13, 2017

Outline

1. Introduction
2. Design Goals and Techniques
3. Proprietary Technologies
4. Standards
5. Challenges and Open Research Directions
6. Conclusion

Introduction

- Number of connected M2M devices and consumer electronics will surpass the number of human subscribers by 2020 [1]
- IoT industry is expected to generate a revenue of 4.3 trillion dollars by 2024 [2]
- How to provide connectivity for low power devices distributed over large geographical areas?
- LPWA application areas;
  - Smart city
  - Personal IoT
  - Smart grid metering
  - Agriculture
  - Industrial assets monitoring
  - Home automation
  - Logistics
  - Wildfire monitoring
- LPWAN fills the technology gap between;
  - Short range wireless technologies (ZigBee, Bluetooth, Wi-Fi)
    - Very costly to deploy massive/dense # of devices
  - Cellular (2G, 3G, 4G)
    - Optimized for voice and data
    - Complex and expensive
    - High power consumption

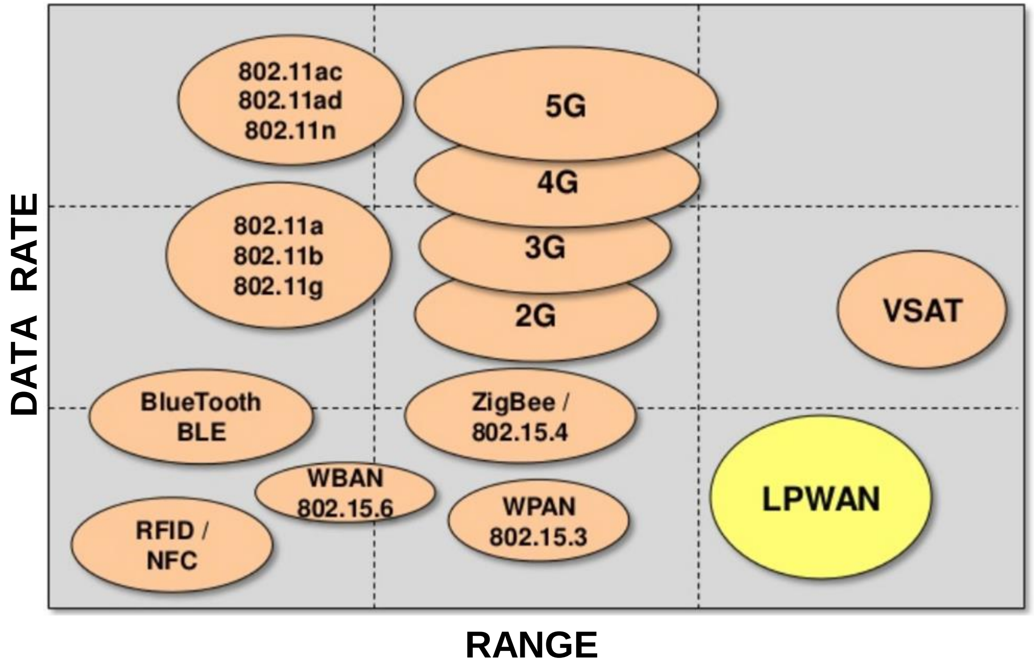

Figure 1: Wireless technologies with respect to range and data rate[1]

1. Image Source: https://www.slideshare.net/PeterREgli/lpwan

Introduction

- Low Power Wide Area (LPWA) networks;
  - + Low power (ten years and beyond)
  - + Long range (a few to tens of kilometers)
  - + Low cost
  - + High scalability
  - - Low data rate (in orders of tens of kilobits per seconds)
  - - High latency (in orders of seconds or minutes)
- LPWAN applicable applications;
  - Delay tolerant
  - Low data rates
  - Low power consumption
- Several competing standards development organizations;
  - ETSI
  - 3GPP
  - IEEE
  - IETF
- Several competing alliances;
  - LoRa™ Alliance
  - Weightless SIG
  - DASH 7 Alliance

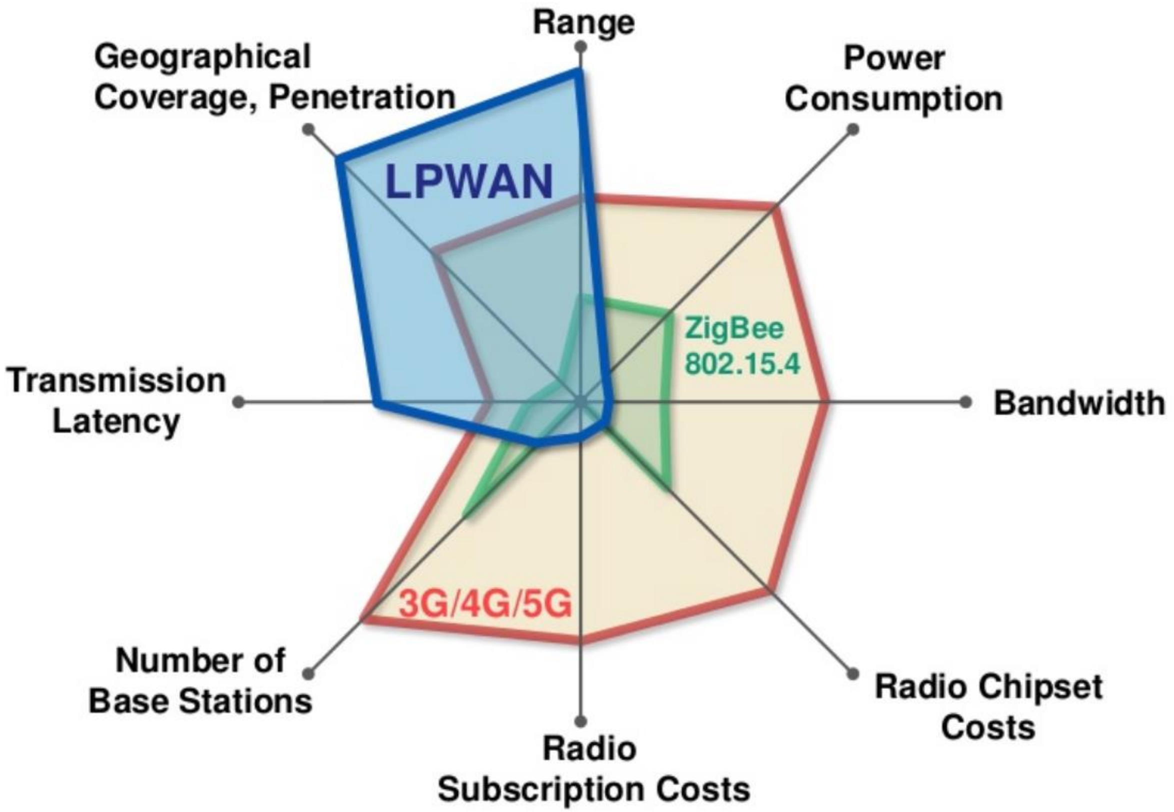

Figure 2: Wireless technologies with respect to various properties[1]

1. Image Source: https://www.slideshare.net/PeterREgli/lpwan

Design Goals and Techniques

- Key objectives of LPWAN technologies; long range + low power + low cost
- Long range
  - Sub-GHz band
    - Lower frequency signals experience less attenuation and multipath fading
  - Special modulation techniques
    - Designed to achieve a link budget of 150 ± 10 dB that enables a range of a few km and tens of km
    - Two classes of main modulation techniques;
      - Narrowband; encoding the signal in low bandwidth (usually less than 25kHz)
        - Reduce noise, decrease data rate
      - Spread spectrum; spread signal over a wider frequency band but with the same power density
        - Resilient to interference, harder to decode
- Low cost
  - Cost of hardware should below $10 and connectivity subscription per unit should low as $1
  - Reduction in hardware complexity
  - Minimum infrastructure
  - Using license-free or already owned licensed bands

Design Goals and Techniques

- Ultra low power operation
  - Simple topology
    - No mesh, direct connection from end devices to base stations
  - Duty cycling
    - End devices to turn off their transceivers when not required
  - Lightweight medium access control
    - Widely used MAC protocols (cellular, WLAN) are too complex. Mostly ALOHA is used
  - Offloading complexity from end devices
    - Simplify the design of end devices, move complexity to base stations and backend system
- Scalability
  - Diversity; channel, time, space, and hardware
  - Densification
  - Adaptive channel selection and data rate
- Quality of service
  - Limited or no QoS

Proprietary Technologies

- Sigfox
    - Patented, proprietary base stations and proprietary network operator
    - Ultra-low power consumption and inexpensive antenna design
    - Maximum uplink throughput of only 100 bps!
    - 140 12-byte uplink and 4 8-bytes downlink messages limit per day!
    - Single message is transmitted multiple times (3 by default) for reliability, no acknowledgments
- LoRa
    - Modulates the signals in Sub-GHz ISM band using a proprietary spread spectrum technique CSS
    - Resilient to interference and noise
    - Multiple spreading factors (between 7-12) to decide the tradeoff between range and data rate
    - Data rate ranges from 300 bps to 37.5 kbps depending on spreading factor
    - The messages transmitted by the end devices are received by all the base stations in the range -> localization
    - LoRaWAN is open standard MAC layer protocol for LoRa physical layer
        - Battery Powered – Class A
        - Low Latency – Class B
        - No Latency – Class C

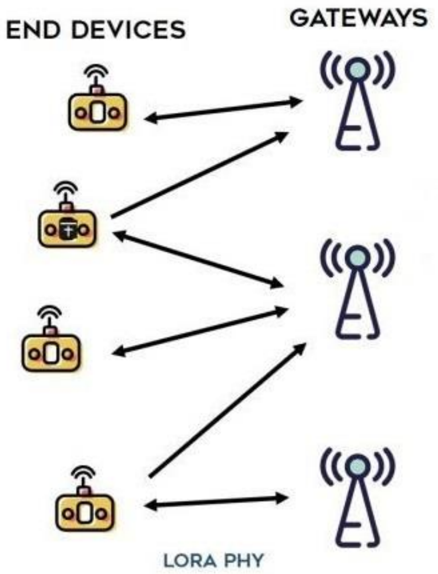

Figure 3: LoRa Topology[1]

1. Image Source: https://i1.wp.com/www.zerynth.com/wp-content/uploads/2017/05/lorawan-architecture.jpg?resize=1024%2C561&ssl=1

Proprietary Technologies

	SigFox	LoRaWAN	Ingenu	Telensa
Modulation	UNB DBPSK(UL), GFSK(DL)	CSS	RPMA-DSSS(UL), CDMA(DL)	UNB 2-FSK
Band	Sub-GHz ISM:EU (868MHz), US(902MHz)	Sub-GHz ISM:EU (433MHz 868MHz), US (915MHz), Asia (430MHz)	ISM 2.4GHz	Sub-GHz bands including ISM:EU (868MHz), US (915MHz), Asia (430MHz)
Data rate	100 bps(UL), 600 bps(DL)	0.3-37.5 kbps (LoRa), 50 kbps (FSK)	78kbps (UL), 19.5 kbps(DL) [39]	62.5 bps(UL), 500 bps(DL)
Range	10 km (URBAN), 50 km (RURAL)	5 km(URBAN), 15 km (RURAL)	15 km (URBAN)	1 km (URBAN)
Num. of channels / orthogonal signals	360 channels	10 in EU, 64+8(UL) and 8(DL) in US plus multiple SFs	40 1MHz channels, up to 1200 signals per channel	multiple channels
Link symmetry	✗	✓	✗	✗
Forward error correction	✗	✓	✓	✓
MAC	unslotted ALOHA	unslotted ALOHA	CDMA-like	?
Topology	star	star of stars	star, tree	star
Adaptive Data Rate	✗	✓	✓	✗
Payload length	12B(UL), 8B(DL)	up to 250B (depends on SF & region)	10KB	?
Handover	end devices do not join a single base station	end devices do not join a single base station	✓	?
Authentication & encryption	encryption not supported	AES 128b	16B hash, AES 256b	?
Over the air updates	✗	✓	✓	✓
SLA support	✗	✗	✗	✗
Localization	✗	✓	✗	✗

Table 1: Technical specifications of proprietary LPWA technologies

Organizations for Standards

Developed Standards

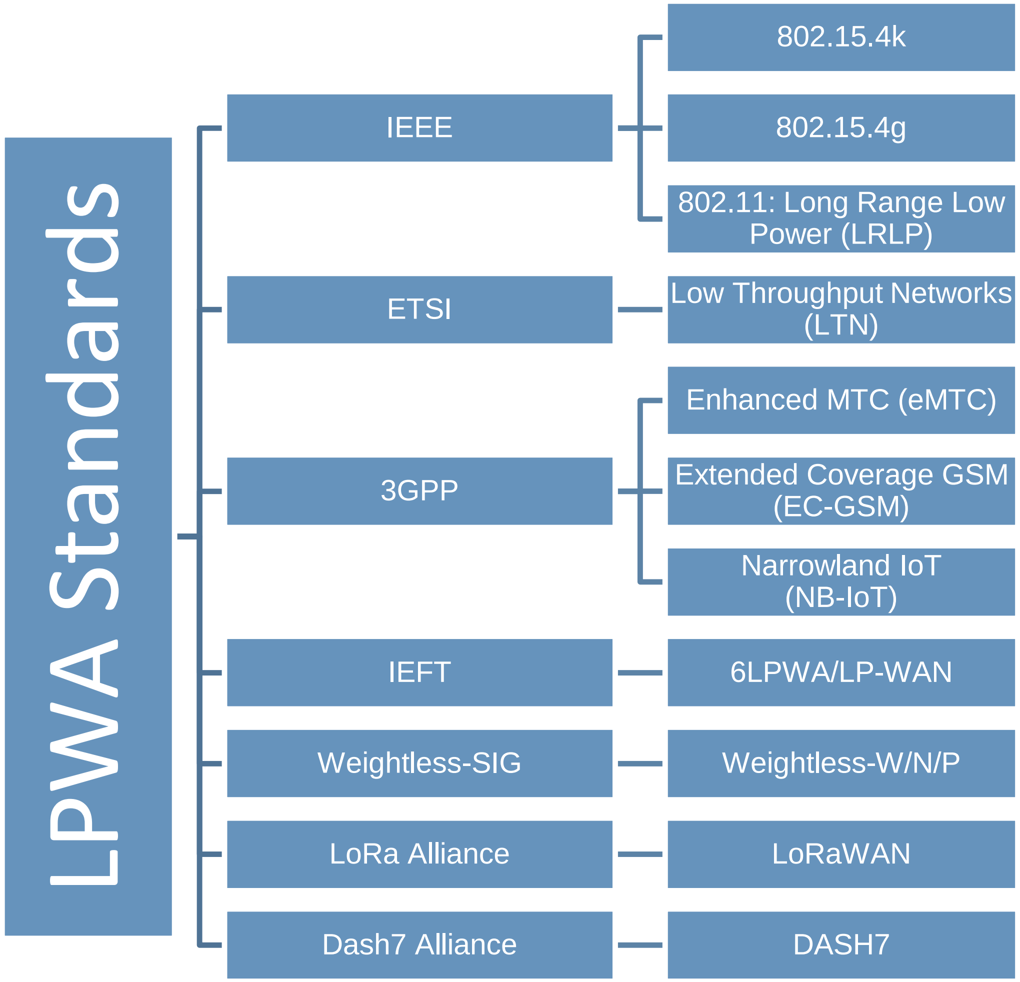

Figure 4: LPWA standards and their developing organizations.

<u>Why Standards:</u>

- Unified end user experience
  - GSM and IS-95 in 2G
- Reduced project risks
- Enable easier and cheaper integrity
- To achieve inter-vendor operability
  - Reducing investment costs
- Enable in-house developments
  - Which is very valuable for IoT environment

Objectives of SDOs and SIGs are diverse.

In the long run, it is expected to enable coexistence of competing Technologies with the adaptation of these standards.

Comparison of Standards

Standard	IEEE		Weightless-SIG			DASH7 Alliance
	802.15.4k	802.15.4g	Weightless-W	Weightless-N	Weightless-P	DASH7
Modulation	DSSS, FSK	MR-(FSK, OFDMA, OQPSK)	16-QAM, BPSK, QPSK, DBPSK	UNB DBPSK	GMSK, offset-QPSK	GFSK
Band	ISM Sub-GHz & 2.4GHz	ISM Sub-GHz & 2.4GHz	TV white spaces 470-790MHz	ISM Sub-GHz EU (868MHz), US (915MHz)	Sub-GHz ISM or licensed	Sub-GHz 433MHz, 868MHz, 915MHz
Data rate	1.5 bps-128 kbps	4.8 kbps-800 kbps	1 kbps-10 Mbps	30 kbps-100 kbps	200 bps-100kbps	9.6,55.6,166.7 kbps
Range	5 km (urban)	up to several kms	5 km (urban)	3 km (urban)	2 km (urban)	0-5 km (urban)
Num. of channels / orthogonal signals	multiple channels. Number depends on channel & modulation		16 or 24 channels(UL)	multiple 200 Hz channels	multiple 12.5 kHz channels	3 different channel types (number depends on type & region)
Forward error correction	✓	✓	✓	✗	✓	✓
MAC	CSMA/CA, CSMA/CA or Aloha with PCA	CSMA/CA	TDMA/FDMA	slotted Aloha	TDMA/FDMA	CSMA/CA
Topology	star	star, mesh, peer-to-peer (depends on upper layers)	star	star	star	tree, star
Payload length	2047B	2047B	>10B	20B	>10B	256B
Authentication & encryption	AES 128b	AES 128b	AES 128b	AES 128b	AES 128/256b	AES 128b

Table 2: Technical specifications of various LPWA standards (?=Not known)

Challenges and Open Research Directions

LPWA striving hard to deliver innovative solutions securing carrier grade performance in case of:

- Scaling networks to massive number of devices
- Interference control and mitigation
- High data rate modulation techniques
- Interoperability between different LPWA technologies
- Localization
- Link optimizations and adaptability
- Testbeds and tools
- Authentication, security & privacy
- Mobility & roaming
- Support for service level agreements
- Co-Existence of LPWA technologies with other wireless networks
- Support for data analytics

Challenges and Open Research Directions

	SIGFOX [9]	LORAWAN [15]	WEIGHTLESS-N [16]	INGENU [90]	3GPP Cellular IoT
Deployment model	Nationwide (multiple countries)	Private or nationwide networks	Private networks	Private or nationwide networks	Nationwide networks
Ease of roaming	Seamless roaming across SIGFOX networks in different countries at no extra charges	Roaming agreements required	Not applicable	?	Operator alliances for cross-border roaming
SLA support	✗	✗	✗	✗	✓
Device availability	✓	✓	Focus is on gateway	✓	✗(Still in standardization phase, devices will emerge later)
Over-the-air updates for devices	✗	possible	✗	possible	likely be made available
Supplier ecosystem	Transceivers and modules from many vendors	Limited choice of vendors for transceivers, several module vendors	Limited choice of vendors	Transceivers and modules from many vendors	Availability likely from all the usual vendors once standard is ratified
Licensing	Technology freely available for chip/device vendors. Network operators pay royalty to SIGFOX (revenue sharing basis)	Technology licensed by device vendors. No royalty to be paid by network operators	Technology freely available for chip/device vendors. No royalty thereafter.	Upfront fee + per application & per device fee / year (No revenue sharing)	Standardized technology. Usual cellular model likely to prevail
Deployment status	Network deployed & running in several countries. Several operators have invested in SIGFOX	Early trials & deployments by some operators. Several operators are members of LoRa™ Alliance	Some trials but no major deployments	Several private deployments in over 5 continents	Early days with some in-house trials with pre-standardized technology by handful of operators
Longevity offered by the solution	Deployments in several countries. Not much insight into transition plan should SNOs find it infeasible to run the network. Transitioning will entail replacement of endpoint/communications module in the endpoints.	Some deployments by cellular operators in a few countries. No insight into transition plan should LoRa network be decommissioned. Transitioning will entail replacement of endpoint/communications module in the endpoints.	No deployments so far so longevity is questionable	Deployments in several countries. Not much insight into transition plan should MNOs find it infeasible to run the network. Transitioning will entail replacement of endpoint/communications module in the endpoints.	Promising as this being a solution designed exclusively for IoT, is less likely to be de-commissioned.

Table 3: Business considerations for various LPWA technologies (?=Not known)

Conclusion

In this paper:

- Low Power Wide Area Network Technologies and Standards surveyed.
- Design criterias and Open Research Areas on this topic briefly described.
- Business considerations are given.
- LPWA applications in different sectors are sampled.

It is observed that:

- Key features of a LPWA technology are;
  - Low power consumption
  - Wide area coverage
  - Inexpensive wireless connectivity
- Each technology driven by different SDOs/SIGs have pros and cons
- There exists several common vulnerabilities in LPWA motivating researchers
- Existing Technologies in MAC & PHY layers does not fulfill LPWA design principles
- Many Technologies with different design principles causing questionmarks about interoperability
- 3GPPs NB-IOT still in draft state, it would provide a main standard for all organizations to follow


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