Low Power Wide Area Networks for the Internet of Things

Framework, Performance Evaluation, and Challenges of LoRaWAN and NB-IoT

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Tutorial Outcomes

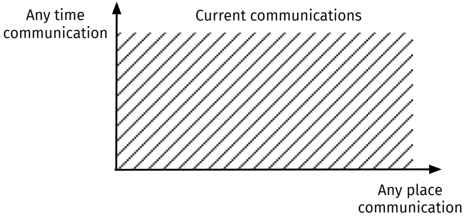
- How do LPWAN complement traditional cellular and short-range wireless technologies?
- What are the fundamental mechanisms that enable to meet the LPWAN requirements?
- What are the major design choices made in the LoRaWAN and NB-IoT specifications?
- How do we evaluate the performance of a LoRaWAN and NB-IoT deployment in terms of coverage and capacity?
- What are the recent research directions for radio resource management in LoRaWAN and NB-IoT?

Feedback and Material

- Feedback form
- Presentation slides are available

Outline

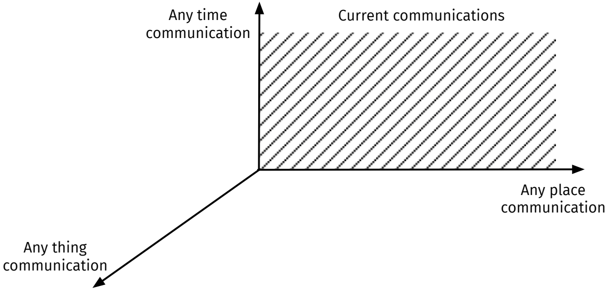
A New Dimension in Communications



Source: The Internet of Things, ITU Internet Reports, 2005

- Current communications brought the ABC (Always Best Connected) paradigm
- The Internet of Things (IoT) explores a new dimension in communications

A New Dimension in Communications



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- Current communications brought the ABC (Always Best Connected) paradigm
- The Internet of Things (IoT) explores a new dimension in communications

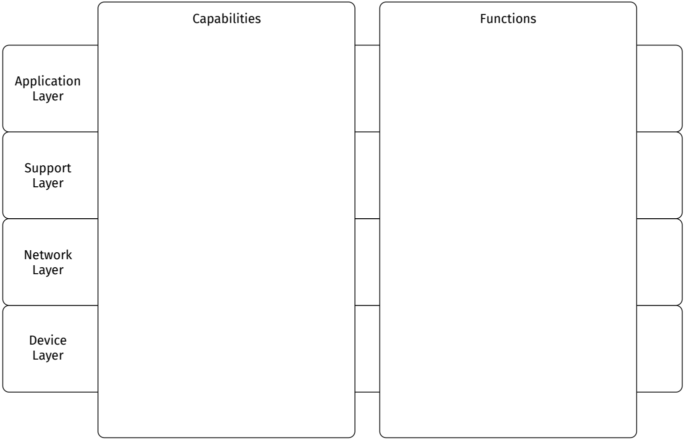
IoT Scenarios

Internet of Things

The Internet of Things (IoT) generally refers to scenarios where network connectivity and computing capability extends to devices, sensors, and everyday items (ISOC IoT Overview, 2015).

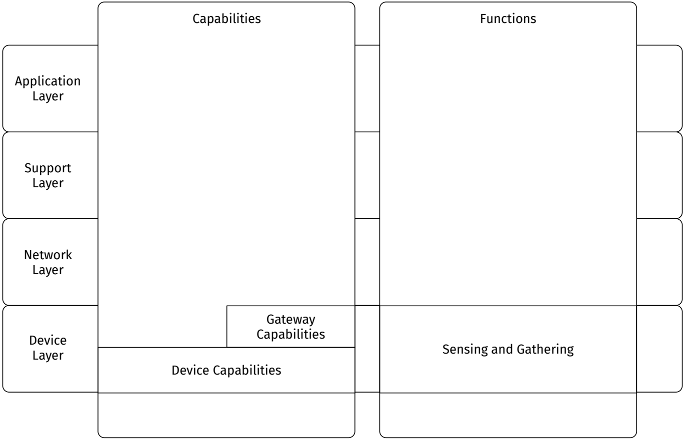
Scenario	Example
Human	Wearables for health monitoring
Home	Heating, security automation
Retail	Self-checkout, inventory optimization
Vehicles	Condition-based maintenance
Cities	Traffic control, environmental monitoring

IoT Reference Model



Source: Overview of the Internet of Things, ITU-T Y.2060, 2012

IoT Reference Model



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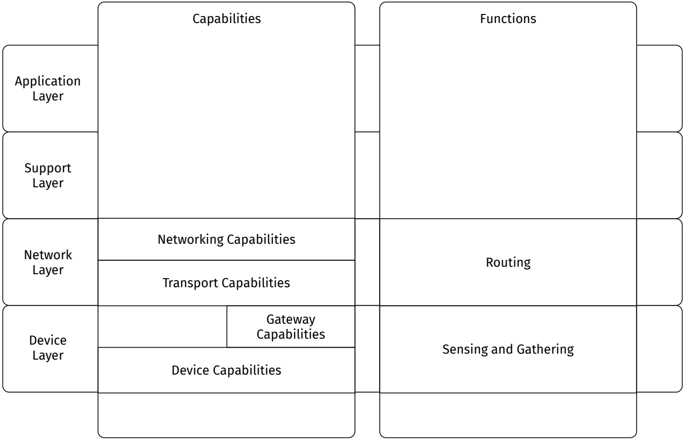

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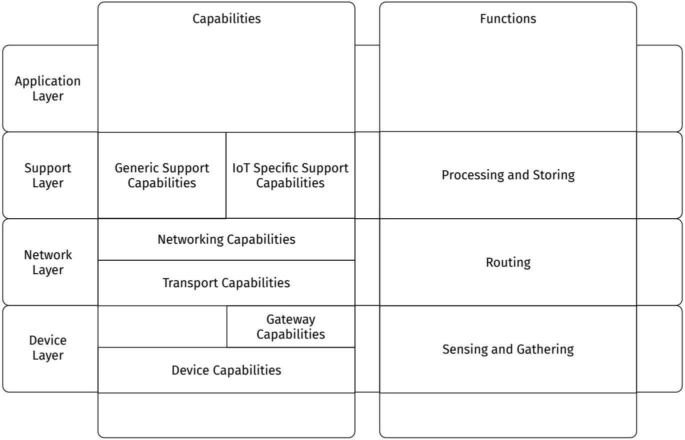

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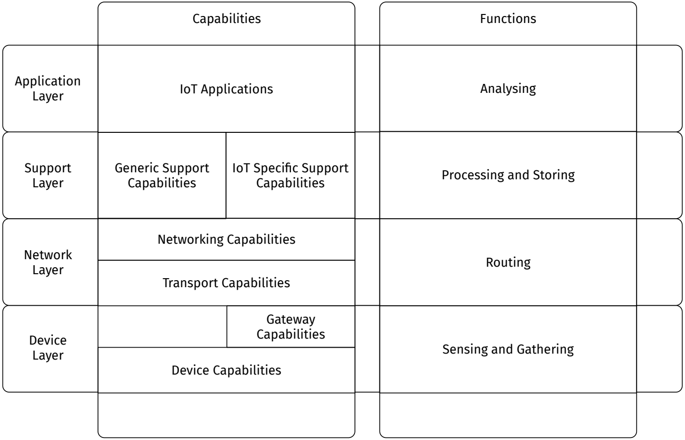

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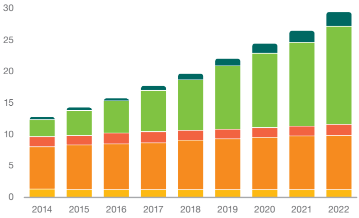
Evolution of IoT Devices

- The largest growth is expected for devices connected to a wide-area network

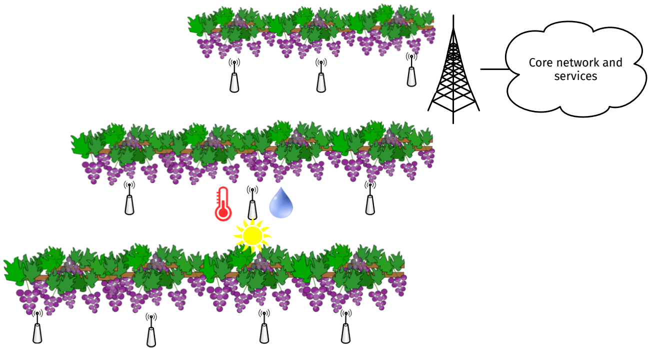
Connected devices (billions)



	2016	2022	CAGR
Wide-area IoT	0.4	2.1	30%
Short-range IoT	5.2	15.5	20%
PC/laptop/tablet	1.6	1.7	0%
Mobile phones	7.3	8.6	3%
Fixed phones	1.4	1.3	0%
	16 billion	29 billion	

Source: Ericsson mobility report, 2017

The Case of IoT for Smart Agriculture



- Periodic sensing of microclimates in vineyards

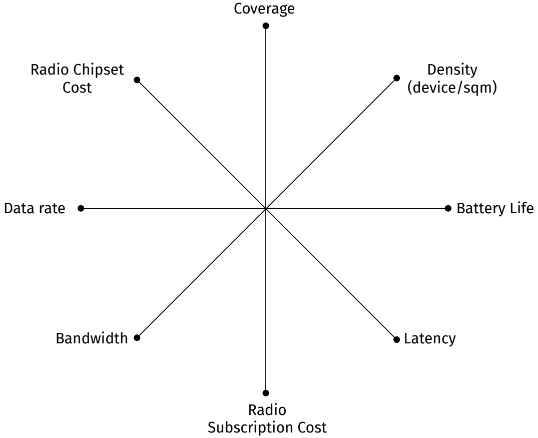
Constraints on the Device and Network Layers

- Difficult physical accessibility and limited access to power sources
  - Wireless communications
  - Autonomy and long battery life operation
- Wide area coverage with a large number of communicating devices
  - Scalable deployment
  - Cost efficient devices
- Very loose bandwidth and latency constraints
  - Adaptive radio and access mechanisms

Challenge

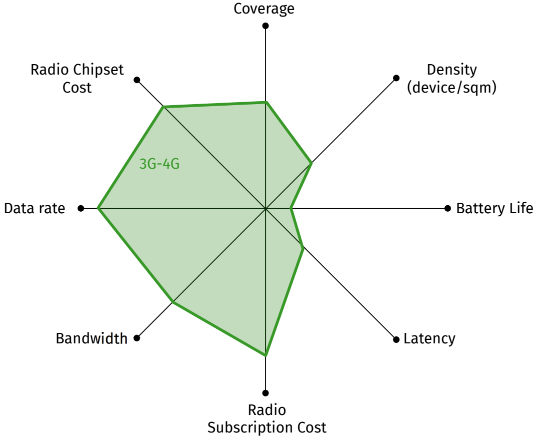
Do existing wireless networking technologies satisfy these constraints?

LPWAN Sweet Spot



Source: Peter R. Egli, Low Power Wide Area Network, 2015

LPWAN Sweet Spot



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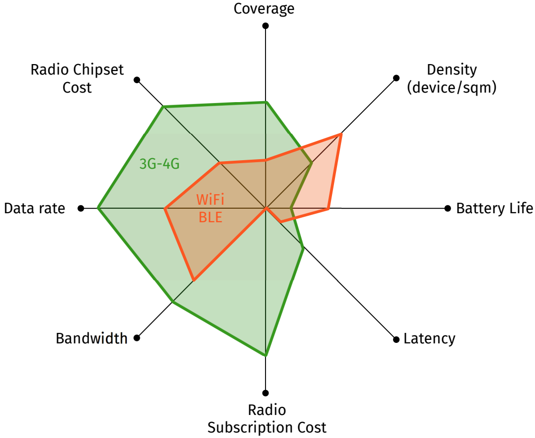

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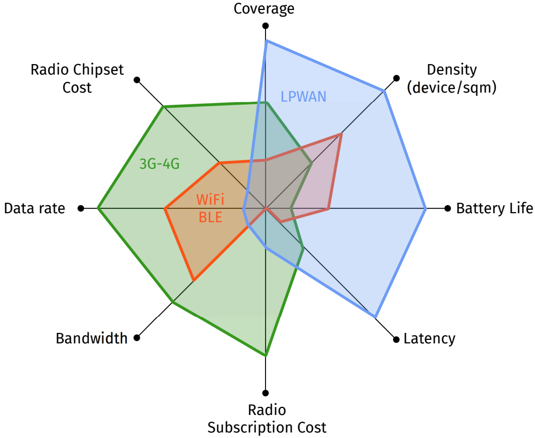

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LPWAN Scenarios

Low Power Wide Area Networks

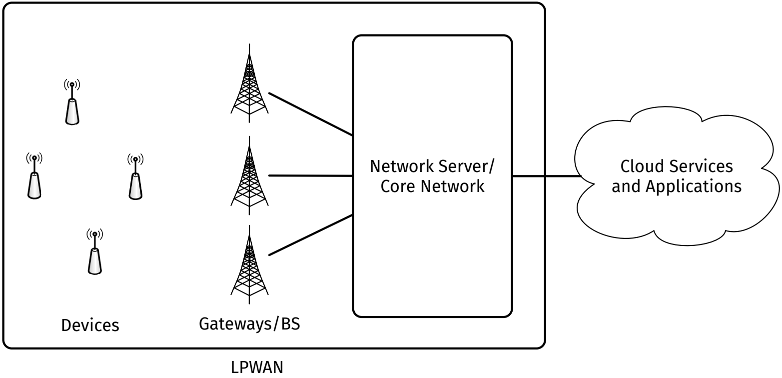
Low power refers to the ability of an IoT device to function for many years on a single battery charge, while at the same time it is able to communicate from locations where shadowing and path loss would limit the usefulness of more traditional cellular technologies (3GPP Low Power Wide Area Technologies, GSMA White Paper, 2016)

- Typical scenarios for LPWAN (Usman Raza *et al.*, Low Power Wide Area Networks: An Overview, IEEE Communications Surveys & Tutorials, 2017)
  - Smart grid
  - Industrial asset monitoring
  - Critical infrastructure monitoring
  - Agriculture

LPWAN Requirements

Indicator	Requirement
Low power consumption	Devices operate for 10 years on a single charge
Low device unit cost	Below $5 per module
Reliability	Completely unattended and resilient operation
Improved coverage	Outdoor and indoor penetration coverage
Security	Secure connectivity and strong authentication
Optimized data transfer	Supports small, intermittent blocks of data
Design complexity	Simplified network topology and deployment
Network scalability	Support of high density of devices

LPWAN Architecture



Common Characteristics of LPWAN Technologies

- Optimised radio modulation
- Star topology
- Frame sizes in the order of tens of bytes
- Frames transmitted a few times per day at ultra-low speeds
- Mostly upstream transmission pattern
- Devices spend most of their time in low-energy deep-sleep mode

LPWAN Technologies

Various technologies are currently candidating for LPWA: LoRaWAN, NB-IoT, Sigfox, Wi-SUN, Ingenu, etc.

Comparison of LPWAN Technologies

Outline

Link Budget

Enhanced Network Capacity

- LoRa employs orthogonal spreading factors which enables multiple spread signals to be transmitted at the same time and on the same channel
- Modulated signals at different spreading factors appear as noise to the target receiver
- The equivalent capacity of a single 125 kHz LoRa channel is:

$$SF12 + SF11 + SF10 + SF9 + SF8 + SF7 + SF6$$
$$= 293 + 537 + 976 + 1757 + 3125 + 5468 + 9375$$
$$= 21531 \text{ b/s} = 21.321 \text{ kb/s}$$

Link Budget

- The link budget is a measure of all the gains and losses from the transmitter, through the propagation channel, to the target receiver
- The link budget of a network wireless link can be expressed as:

$$P_{Rx} = P_{Tx} + G_{System} - L_{System} - L_{Channel} - M$$

where:

P_{Rx} = the expected received power

P_{Tx} = the transmitted power

G_{System} = system gains such as antenna gains

L_{System} = system losses such as feed-line losses

$L_{Channel}$ = losses due to the propagation channel

M = fading margin and protection margin

Capacity of LoRaWAN

- ALOHA with duty cycle

$$\frac{\delta}{\tau} N \exp(-2N\frac{\delta}{\tau})$$

- ALOHA with multiple receivers and perfect packet capture

$$\frac{\delta}{\tau} N \exp(-2N\frac{\delta}{\tau})(1 + \sum_{n=2}^{N} \frac{(2N\frac{\delta}{\tau})^n}{n!}(1 - (1 - \frac{1}{n})^r))$$

- ALOHA with multiple receivers and realistic packet capture

$$\frac{\delta}{\tau} N \exp(-2N\frac{\delta}{\tau})(1 + \sum_{n=2}^{N} \frac{(2N\frac{\delta}{\tau})^n}{n!}(1 - (1 - \frac{K^{n-1}}{n})^r))$$

with

$$K = \frac{1}{2} 10^{-\frac{\Delta}{10\alpha}}$$