

Introduction

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Outline

1. Introduction

1. IoT Devices
2. IoT Applications
3. IoT Wireless Communications

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1. Introduction

1. IoT Devices

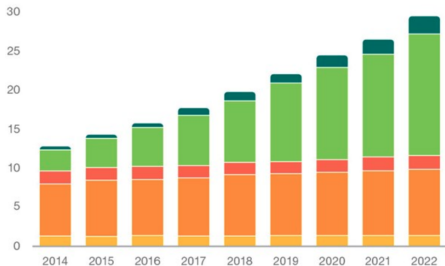
2. IoT Applications

3. IoT Wireless Communications

Massive IoT devices

IoT devices are useless without a good communication capability

Connected devices (billions)



	2016	2022	CAGR
Wide-area IoT	0.4	2.1	30%
Short-range IoT	5.2	16	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	10%



Figure 1. IoT devices perera_mosden_2013.

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Applications diversification

Each application has its own communication requirements

Challenges/Applications	Grids	EHealth	Transport	Cities	Building
Resources constraints	✗	✓	✗	-	✗
Mobility	✗	-	✓	✓	✗
Heterogeneity	-	-	-	✓	✗
Scalability	✓	-	✓	✓	-
QoS constraints	-	-	✓	✓	✓
Data management	-	✗	✓	✓	-
Lack of Standardization	-	-	-	-	✓
Amount of attacks	✗	✗	✓	✓	✓
Safety	-	✓	✓	-	✓

Table 1. Main IoT challenges [kouicem_internet_2018](#)
[venkatesan_design_2017](#)



Figure 2. IoT Applications.

IoT platforms

IoT platforms is a chain of communication process

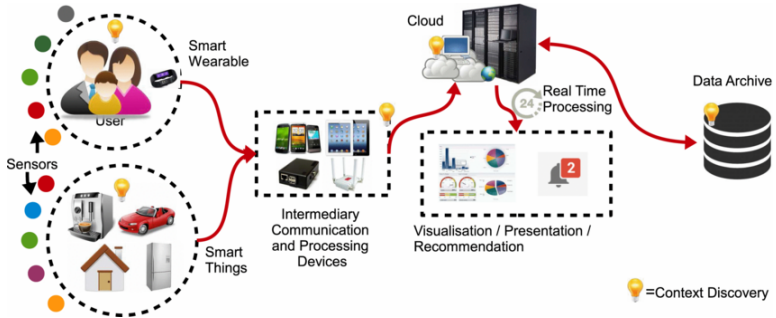


Figure 3. IoT platform.



Figure 4. IoT challenges.

Applications diversification

Requirements

Use Case	Packet rate [pkt/day]	Min success rate [Ps,min]	Payload Size [Byte]
Wearables	10	90	10-20
Smoke Detectors	2	90	
Smart Grid	10	90	
White Goods	3	90	
Waste Management	24	90	
VIP/Pet Tracking	48	90	50
Smart Bicycle	192	90	
Animal Tracking	100	90	
Environmental Monitoring	5	90	
Asset Tracking	100	90	
Smart Parking	60	90	
Alarms/Actuators	5	90	
Home Automation	5	90	
Machinery Control	100	90	
Water/Gas Metering	8	90	100-200
Environmental Data Collection	24	90	
Medical Assisted Living	8	90	
Micro-generation	2	90	
Safety Monitoring	2	90	
Propane Tank Monitoring	2	90	
Stationary Monitoring	4	90	
Urban Lighting	5	90	
Vending Machines Payment	100	90	
Vending Machines General	1	90	1K

Table 2. Application requirements for the use cases of interest **feltrin_lorawan_2018 venkatesan_design_2017 rizzi_evaluation_2017**

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1. LoRa

IoT wireless communication

Wireless communication performance need to be evaluated to match applications requirements

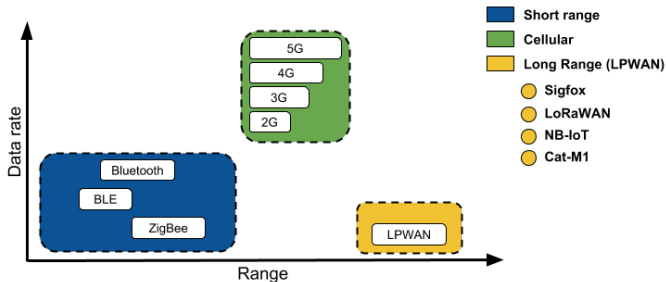


Figure 5. Short range, Cellular and Long range networks.

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1. LoRa

Wireless communication

Exp: LPWAN in a new technology that satisfy IoT applications requirements

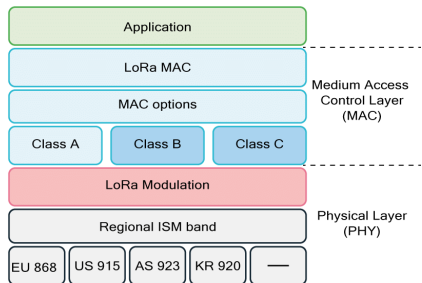


Figure 6. LoRa and LoRaWan stack.

LoRa parameters selection

How to select the optimal configuration

Parameters

- ➡ Bandwidth (BW)
- ➡ Spreading Factor (SF)
- ➡ Coding Rate (CR)
- ➡ Transmission Power (P^{tx})
- ➡ Payload size (PS)
- ➡ Signal Noise Rate (SNR) [-7.5,-20dBm]

Metrics

- ➡ Data Rate (DR)
- ➡ Air Time (AT)
- ➡ PS_{max}
- ➡ Received Signal Strength Indication (RSSI) [-30,-120dBm]

Setting	Values	Rewards	Costs
BW	7.8 ➡ 500kHz	DR	RSSI, Range
SF	2^6 ➡ 2^{12}	RSSI, Range	DR, SNR, PS_{max} , P^{tx}
CR	4/5 ➡ 4/8	SNR	PS_{max} , P^{tx} , AT
P^{tx}	-4 ➡ 20dBm	SNR	P^{tx}
PS	59 ➡ 230B	PS	P^{tx} , AT

Table 3. LoRa parameters selection marco_cattani_experimental_2017

Multi criteria decision making

Layer	Maximize (Reward)	Minimize (Cost)
Application	Sec security	Service Cost (SC)
Network	Range Packet delivery Ratio (PDR) PS DR	Jitter (Jit) Traffic congestion (TC) Round-Trip Delay (RTD) Packet Error Rate (PER) Time Complexity (O_{time}) Space Complexity (O_{space})
Radio	Mobility (Mob) Symbol Rate (SR) Bit Rate (BR) Signal-to-Interference Ratio (SIR) RSSI Signal-to-interference & noise ratio (SINR) SNR	Bit Error Rate (BER) p_{tx} Co-channel Interference (CCI) Duty cycle (DC) Time on Air (ToA) Path loss (PL)

Table 4. Network selection inputs and classification of parameters **bendaoud_network_2019**
chowdhury_survey_2018

Multi criteria decision making

$$ToA_{LoRa} = \frac{2^{SF}}{BW} \left((NP + 4.25) + \left(SW + \max \left(\left\lceil \frac{8PS - 4SF + 28 + 16CRC - 20IH}{4(SF - 2DE)} \right\rceil (CR + 4), 0 \right) \right) \right)$$

$$ToA_{GFSK} = \frac{8}{DR} (NP + SW + PL + 2CRC) \quad (1)$$

$$RS_{[dBm]} = -174 + 10 \log_{10} BW + NF + SNR \quad (2)$$

$$PL_{[B]} = |RSSI| + SNR + P_{TX} + G_{RX} \quad (3)$$

$$SNR_{[dB]} = 20 \cdot \log \left(\frac{S}{N} \right) \quad (4)$$

$$RSSI_{[dBm]} = T_{Xpower} \cdot \frac{Rayleigh_{power}}{PL} \quad (5)$$

$$SINR_{[dBm]} = \quad (6)$$

$$BR_{[bps]} = SF * \frac{4}{\frac{4+CR}{2SF}} \quad (7)$$

$$BER_{[bps]} = \frac{8}{15} \cdot \frac{1}{16} \cdot \sum k = 216 - 1^k \left(\frac{16}{k} \right) e^{20 \cdot SINR \left(\frac{1}{k} - 1 \right)} \quad (8)$$

$$PER_{[pps]} = 1 - (1 - BER)^{n_{bits}} \quad (9)$$

$$(10)$$

Where:

- ➡ NP = 8, if LoRa . 5, if GFSK
- ➡ SW = 8, if LoRa . 3, if GFSK
- ➡ CRC = 0 if downlink packet. 1 if uplink packet
- ➡ IH = 0 if header. 1 if no header present
- ➡ DE = 1 if data rate optimization. 0 if not
- ➡ PS = PHY_Payload bytes
- ➡ SF = 7, 8, 9, 10, 11, 12
- ➡ BW = bandwidth
- ➡ CR = Indicates the Coding Rate

LoRa Frame

Preamble		Sync msg	PHY Header	PHDR-CRC						
Modulation	length	Sync msg	PHY Header	PHDR-CRC	MAC Header					
Modulation	length	Sync msg	PHY Header	PHDR-CRC	MType	RFU	Major			
Modulation	length	Sync msg	PHY Header	PHDR-CRC	MType	RFU	Major	Dev Address		
Modulation	length	Sync msg	PHY Header	PHDR-CRC	MType	RFU	Major	NwkID	NwkAddr	ADR
0	1	2	3	4	5	6	7	8	9	10
PHY Payload								CRC		
MAC Payload								MIC	CRC Type	Polynomial
Frame Header						FPort	Frame Payload	MIC	CRC Type	Polynomial
FCtrl				FCnt	FOpts	FPort	Frame Payload	MIC	CRC Type	Polynomial
ADRACKReq	ACK	FPending /RFU	FOptsLen	FCnt	FOpts	FPort	Frame Payload	MIC	CRC Type	Polynomial
11	12	13	14	15	16	17	18	19	20	21

LoRa Frame

- ➔ **Modulation :**
 - ➔ Lora: 8 Symbols, 0x34 (Sync Word)
 - ➔ FSK: 5 Bytes, 0xC194C1 (Sync Word)
- ➔ **Length :**
- ➔ **Sync msg :**
- ➔ **PHY Header :** It contains:
 - ➔ The Payload length (Bytes)
 - ➔ **The Code rate**
 - ➔ Optional 16bit CRC for payload
- ➔ **Phy Header :** CRC It contains CRC of Physical Layer Header
- ➔ **MType :** is the message type (uplink or a downlink)
 - ➔ whether or not it is a confirmed message (reqst ack)
 - ➔ 000 Join Request
 - ➔ 001 Join Accept
 - ➔ 010 Unconfirmed Data Up
 - ➔ 011 Unconfirmed Data Down
 - ➔ 100 Confirmed Data Up
 - ➔ 101 Confirmed Data Down
 - ➔ 110 RFU
 - ➔ 111 Proprietary
- ➔ **RFU :** Reserved for Future Use
- ➔ **Major :** is the LoRaWAN version; currently, only a value of zero is valid
 - ➔ 00 LoRaWAN R1
 - ➔ 01-11 RFU
- ➔ **NwkID :** the short address of the device (Network ID): 31th to 25th
- ➔ **NwkAddr :** the short address of the device (Network Address): 24th to 0th
- ➔ **ADR :** Network server will change the data rate through appropriate MAC commands
 - ➔ 1 To change the data rate
 - ➔ 0 No change
- ➔ **ADRACKReq :** (Adaptive Data Rate ACK Request): if network doesn't respond in 'ADR-ACK-DELAY' time, end-device switch to next lower data rate.
 - ➔ 1 if (ADR-ACK-CNT) >= (ADR-ACK-Limit)
 - ➔ 0 otherwise
- ➔ **ACK :** (Message Acknowledgement): If end-device is the sender then gateway will send the ACK in next receive window else if gateway is the sender then end-device will send the ACK in next transmission.
 - ➔ 1 if confirmed data message
 - ➔ 0 otherwise
- ➔ **FPending / RFU ↑ :** (Only in downlink), if gateway has more data pending to be send then it asks end-device to open another receive window ASAP
 - ➔ 1 to ask for more receive windows
 - ➔ 0 otherwise
- ➔ **FOptsLen :** is the length of the FOpts field in bytes ā 0000 to 1111
- ➔ **FCnt :** 2 type of frame counters
 - ➔ FCntUp: counter for uplink data frame, MAX-FCNT-GAP
 - ➔ FCntDown: counter for downlink data frame, MAX-FCNT-GAP
- ➔ **FOpts :** is used to piggyback MAC commands on a data message
- ➔ **FPort :** a multiplexing port field
 - ➔ 0 the payload contains only MAC commands
 - ➔ 1 to 223 Application Specific
 - ➔ 224 & 225 RFU
- ➔ **FRMPPayload :** (Frame Payload) Encrypted (AES, 128 key length) Data
- ➔ **MIC :** is a cryptographic message integrity code
 - ➔ computed over the fields MHDR, FHDR, FPort and the encrypted FRMPPayload.
- ➔ **CRC :** (only in uplink),
 - ➔ CCITT $x^{16} + x^{12} + x^5 + 1$
 - ➔ IBM $x^{16} + x^{15} + x^5 + 1$

References