Appendix

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evaluation Nous avons vu en effet plus haut quil a été démontré que la méthode CSMA est plus efficace pour le traitement des faibles trafics, tandis que TDMA est nettement plus appropriée pour supporter les trafics intensesj.

Chirp Spread Spectrum (Proprietary) (CSS) Carrier Frequency (CF) Forward error correction (FEC) Path loss (PL) Link Symmetry (LS) Base Station (BS) CSS Direct Sequence Spread Spectrum (DSSS) Ultra narrow band (UNB) Data Rate (DR) Adaptive Data Rate (ADR) Coding Rate (CR) Bandwidth (BW) Payload size (PS)Signal-to-interference & noise ratio (SINR)

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

0) **Modulation :**
   - Lora: 8 Symbols, 0x34 (Sync Word)
   - FSK: 5 Bytes, 0xC194C1 (Sync Word)
1) **Length :**
2) **Sync msg :**
3) **PHY Header :** It contains:
   - The Payload length (Bytes)
   - **The Code rate**
   - Optional 16bit CRC for payload
4) **Phy Header :** CRC It contains CRC of Physical Layer Header
5) **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
6) **RFU :** Reserved for Future Use
7) **Major :** is the LoRaWAN version; currently, only a value of zero is valid
   - 00 LoRaWAN R1
   - 01-11 RFU
8) **NwkID :** the short address of the device (Network ID): 31th to 25th
9) **NwkAddr :** the short address of the device (Network Address): 24th to 0th
10) **ADR :** Network server will change the data rate through appropriate MAC commands
   - 1 To change the data rate
   - 0 No change
11) **ADRACKReq :** (Adaptive Data Rate ACK Request): if network doesn't respont in 'ADR-ACK-DELAY' time, end-device switch to next lower data rate.
   - 1 if (ADR-ACK-CNT) >= (ADR-ACK-Limit)
   - 0 otherwise
12) **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
13) **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
14) **FOptsLen :** is the length of the FOpts field in bytes ă 0000 to 1111
15) **FCnt :** 2 type of frame counters
   - FCntUp: counter for uplink data frame, MAX-FCNT-GAP
   - FCntDown: counter for downlink data frame, MAX-FCNY-GAP
16) **FOpts :** is used to piggyback MAC commands on a data message
17) **FPort :** a multiplexing port field
   - 0 the payload contains only MAC commands
   - 1 to 223 Application Specific
   - 224 & 225 RFU
18) **FRMPayload :** (Frame Payload) Encrypted (AES, 128 key length) Data
19) **MIC :** is a cryptographic message integrity code
   - computed over the fields MHDR, FHDR, FPort and the encrypted FRMPayload.
20) **CRC :** (only in uplink),
   - CCITT $x^{16} + x^{12} + x^5 + 1$
   - IBM $x^{16} + x^{15} + x^5 + 1$

Characteristics	$CF_{[Hz]}$	6LoWPAN	LoRaWAN	SigFox	NB-IoT	INGENU	TELENSA
Modulation	2.4G	O-QPSK	-	-	QSPSK↓		2-FSK
	915M	BPSK	LoRa	BPSK↑,GFSK↓	QSPSK n-tone↑	RPMA↑, CDMA↓	2-FSK
	868M	BPSK	LoRa/GFSK	BPSK↑,GFSK↓	/4-QPSK 1-tone		2-FSK
$Chwidth_{[KHz]}$			500 - 125		180		
Channels	2.4G	16	-	-	-	40	✗
	915M	10	64+8↑, 8↓	✗	✗	✗	✗
	868M	1	10	360+40	✗	✗	✗
$CF_{[MHz]}$	2.4G	✗	-	-	-	✗	ISM
	915M	902-929	902-928	902	✗	✗	915M
	868M	868-868.6	863-870 and 780	868.18-868.22	✗	✗	868M/430M
$BW_{[Hz]}$	2.4G	5M	-	-	200K	1M	✗
	915M	2M	125K-500K	✗	✗	✗	✗
	868M	600M	125K-250K	0.1K-1.2K	✗	✗	✗
$DR_{[bps]}$	2.4G	250M	-	-	-	78K↑, 19,5K↓	✗
	915M	40M	980-22K	✗	234.7↓, 204.8↑	✗	✗
	868M	20M	LoRa: 0.3K-37.5K	0.1K↑,0.6K↓	✗	✗	62.5↑, 500↓
			FSK: 50K				
$CR_{[dBm]}$	2.4G	-85	-	-	-	✗	✗
	915M	-92	✗	✗	✗	✗	✗
	868M	-92	-137	-137	✗	✗	✗
$ChipR_{[chip/s]}$	2.4G						
	915M						
	868M						
Range	2.4G						
	915M						
	868M	10-100 m	5-15 Km	10-50 Km	1Km	15-? Km	1Km-?
Handover	2.4G	✗	-	-	-	✗	✗
	915M	✗	✗	✗	✗	✗	✗
	868M	✗	Multi BS	Multi BS	✗	✗	✗
msg/day	2.4G	✗	-	-	-	✗	✗
	915M	✗	✗	✗	✗	✗	✗
	868M	✗	Unlimited	140↑,4↓	Unlimited	✗	✗
PL B	2.4G	✗	-	-	-	✗	✗
	915M	✗	✗	✗	✗	✗	✗
	868M	✗	51 - 243	12↑,8↓	1600B	10KB	✗
Coding/Spreading		DSSS	CSS	UNB	✗	DSSS	UNB
Proprietary		✗	✗	✓	✗	✗	✗
Topology		✗	Star, Stars	Star	✗	Star, Tree	Star
ADR		✗	✓	✗	✗	✓	✗
Security		✗	AES 128b	✗	✗	AES 256B	✗
LS		✗	✓	✗	✗	✗	✗
FEC		✗	AES 128b	✗	✗	✓	✗
Battery		1-2 years	<10 years	<10 years	<10 years		
Cost		Free	35e	25e	1020e		
Standar		IETF	LoRa Alliance		3GPP		
Duplex			Half		Half		
Mob support			High,Simple		High,complex		
Mob latency			Low		High (1.6-10s)		
$Tx_{[dBm]}$			+14 - +27		20/23		
Real-Time			Class C		✗		
Scalability			1M↑, 100K↓		55 k		
$Linkbudget_{[dB]}$			157		154		
$Sensitivity_{[dBm]}$			-124 - (-134)		-141		
Multi-hop supporter			✗		✗		
Addressing			Broadcast↑, Unicast↓		Unicast↑, Both↓		
Peak current			32 mA		120300 mA		
Sleep current			1 A		5 A		

Table I. LPWAN Characteristics [1], **lopes_design_2019**, **raza_low_22**, [2]

Characteristics	CF$_{[Hz]}$	**ZigBee**	**LoRaWAN**	**SigFox**	**NB-IoT**	**INGENU**	**TELENSA**
Modulation	2.4G 915M 868M	O-QPSK BPSK BPSK					
Channels	2.4G 915M 868M	16 10 1					
CF$_{[MHz]}$	2.4G 915M 868M	2.4835 902, 928 868, 868.6					
BW$_{[Hz]}$	2.4G 915M 868M						
DR$_{[b/s]}$	2.4G 915M 868M	250 kbps 40 kbps 20 kbps					
CR$_{[dBm]}$	2.4G 915M 868M						
$ChipR_{[chip/s]}$	2.4G 915M 868M	2M 600K 300K					
Handover	2.4G 915M 868M						
msg/day	2.4G 915M 868M						
PL B	2.4G 915M 868M						
Coding							
Proprietary							
Topology							
ADR							
Security							
LS							
FEC							
Range							
Battery							
Cost							
Standar	IEEE 802.15.4						

Table II. LPWAN Characteristics **berder_reseaux_2014**

Standard	**802.15.4k**	**802.15.4g**	**Weightless-W**	**Weightless-N**	**Weightless-P**	**DASH 7 Alliance**
Modulation	DSSS, FSK	MR-[FSK, OFDMA, OQPSK]	16-QAM, BPSK, QPSK, DBPSK	UNB DBPSK	GMSK, offset-QPSK	GFSK
BW	ISM S UB -GH Z, 2.4GHz	ISM S UB -GH Z, 2.4GHz	TV white spaces 470-790MHz	ISM S UB -GH Z EU (868MHz), US (915MHz)	S UB -GH Z ISM or licensed	UB -GH Z 433MHz, 868MHz, 915MHz
DR	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)
MAC	CSMA/CA, CSMA/CA or A LOHA with PCA	CSMA/CA	TDMA/FDMA	slotted A LOHA	TDMA/FDMA	CSMA/CA
Topology	star	tar, mesh, peer-to-peer	star	star	star	tree, star
PL	2047B	2047B	>10B	20B	>10B	256B
Security	AES 128b	AES 128b	AES 128b	AES 128b	AES 128/256b	AES 128b
Forward error correction	✓	✓	✓	✗	✓	✓

Table III. **raza_low_22**

Phy protocol	**IEEE 802.15.4**	**BLE**	**EPCglobal**	**Z-Wave**	**LTE-M**	**ZigBee**
Standard		IEEE 802.15.1				IEEE 802.15.4, ZigBee Alliance
BW(MHz)	868/915/2400	2400	860-960	868/908/2400	700-900	
MAC	TDMA, CSMA/CA	TDMA	ALOHA	CSMA/CA	OFDMA	
DR (bps)	20/40/250 K	1024K	varies 5-640K	40K	1G (up), 500M (down)	
Throughput				9.6, 40, 200kbps		
Scalability	65K nodes	5917 slaves	-	232 nodes	-	
Range	10-20m	10-100m				
Addressing	8|16bit	16bit				

Table IV. IoT cloud platforms and their characteristics **al-fuqaha_internet_24**

	802.15.4	**802.15.4e**	**802.15.4g**	**802.15.4f**
CF	2.4Ghz (DSSS + oQPSK) 868Mhz (DSSS + BPSK) 915Mhz (DSSS + BPSK)	2.4Ghz (DSSS + oQPSK, CSS+DQPSK) 868Mhz (DSSS + BPSK) 915Mhz (DSSS + BPSK)	2.4Ghz (DSSS + oQPSK, CSS+DQPSK) 868Mhz (DSSS + BPSK) 915Mhz (DSSS + BPSK)	2.4Ghz (DSSS + oQPSK,CSS+DQPSK) 868Mhz (DSSS + BPSK) 915Mhz (DSSS + BPSK) 3∼10Ghz (BPM+BPSK)
DR	Upto 250kbps	Upto 800kbps	Up to 800kbps	
Differences	-	Time sync and channel hopping	Phy Enhancements	Mac and Phy Enhancements
PL	127 bytes	N/A	Up to 2047 bytes	N/A
Range	1 75+ m	1 75+ m	Upto 1km	N/A
Goals	General Low-power Sensing/Actuating	Industrial segments	Smart utilities	Active RFID
Products	Many	Few	Connode (6LoWPAN)	LeanTegra PowerMote

Table V. IEEE 802.15.4 standards **sarwar_iot_2015**

Feature	**Wi-Fi**	**802.11p**	**UMTS**	**LTE**	**LTE-A**
Channel MHz	20	10	5	1.4, 3, 5, 10, 15, 20	<100
Frequency band(s) GHz	2.4 , 5.2	5.86-5.92	0.7-2.6	0.7-2.69	0.45-4.99
BR Mb/s	6-54	327	2	<300	<1000
Range km	<0.1	<1	<10	<30	<30
Capacity	Medium	Medium	✗	✓	✓
Coverage	Intermittent	Intermittent	Ubiquitous	Ubiquitous	Ubiquitous
Mobility support km/h	✗	Medium	✓	<350	<350
QoS support	EDCA Enhanced Distributed Channel Access	EDCA Enhanced Distributed Channel Access	QoS classes and bearer selection	QCI and bearer selection	QCI and bearer selection
Broadcast/multicast support	Native broadcast	Native broadcast	Through MBMS	Through eMBMS	Through eMBMS
V2I support	✓	✓	✓	✓	✓
V2V support	Native (ad hoc)	Native (ad hoc)	✗	✗	Through D2D
Market penetration	✓	✗	✓	✓	✓
DR	<640 kbps	250 kbps	106424 kbps	✓	✓

Table VI. An example table.

Spreading Factor (SF)/BW	**125kHz**					**250kHz**				**500kHz**			
-	**varsier_capacity_2017**		[3]	[4]									
-	Sensitivity	BR	Rx wind	SINR	PS	Sensitivity	BR	Rx wind	SINR	Sensitivity	BR	Rx wind	SINR
-	[dBm]	[kb/s]	[ms]	[dB]	Byte	[dBm]	[kb/s]	[ms]	[dB]	[dBm]	[kb/s]	[ms]	[dB]
6	-118				242+13	-115				-111			
7	-123	5.468	5.1	-7.5	242+13	-120				-116			
8	-126	3.125	10.2	-10	242+13	-123				-119			
9	-129	1.757	20.5	-12.5	115+13	-125				-122			
10	-132	0.976	41.0	-15	51+13	-128				-125			
11	-133	0.537	81.9	-17.5	51+13	-130				-128			
12	-136	0.293	163.8	-20	51+13	-133				-130			

Table VII. Receiver sensitivity [dBm]

DR	**Modulation**			PS	**BR**
	SF	**BW [kHz]**	**CR**	Byte	x kbit/s
0	12	125	4/6	51+13	0.25
1	11	125	4/6	51+13	0.44
2	10	125	4/5	51+13	0.98
3	9	125	4/5	115+13	1.76
4	8	125	4/5	242+13	3.125
5	7	125	4/5	242+13	5.47
6	7	125	4/5	242+13	11
7		125	4/5	242+13	50

Table VIII. oioioi

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Others

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