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A Study of LoRa Low Power and Wide Area Network Technology

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***Abstract*—$LoRa^{TM}$ is low power wide area wireless network (LPWAN) protocol for Internet of Things (IoTs) applications. LPWAN has been enabling technology of large scale wireless sensor networks (WSNs). Effective cost, long range and energy efficiency of LPWANs make them most suitable candidates for smart city applications. These technologies offer novel communication paradigm to address discrete IoT's applications. LoRa is a recently proposed LPWAN technology based on spread spectrum technique with a wider band. LoRa uses the entire channel bandwidth to broadcast a signal which makes it resistant to channel noise, long term relative frequency, doppler effects and fading. This paper focuses on the emerging transmission technologies dedicated to IoT networks. Characteristics of LoRa are based on three basic parameters: Code Rate (CR), Spreading Factor (SF) and Bandwidth (BW). This paper provides in depth analysis of the impact of these three parameters on the data rate and time on air.**

Keywords*—*Wireless sensor Networks, $LoRa^{TM}$, LPWAN, Smart cities, Internet of things.

I. Introduction

The evolving field of WSNs has an extensive range of potential applications in industry, science, transportation, civil infrastructure and security etc. WSNs comprised sensing (measuring), computation, and communication into a single tiny device called sensor node [1] [2]. WSNs typically consist of a large number of heterogeneous sensor devices that contain processing capability, sensor(s) and/or actuator(s), a power source (batteries and eventually some energy harvesting modules), multiple types of memory and a radio frequency (RF) based transceiver. This large number of sensors are densely deployed over a large field and inter-networked together. They monitor physical or environmental conditions that generate sensor readings and deliver them to a sink node in order to be further processed [2].

Wireless network industry is gradually changing their interest towards LPWAN. LPWAN technologies (SigFox, LoRa, Weightless-W etc) successfully propose wide area connectivity from a few to tens of kilometers for low data rate, low power and low throughput applications [3]. Their market is anticipated to be huge. Nearly a quarter of overall thirty billion IoT/M2M devices are assumed to be connected through the internet using LPWAN [4]. Smart cities are considered as the biggest potential customers of LPWAN, which includes smart metering, smart grids, smart parking, optimized driving and walking routes, energy radiation measurements, measurements of nuclear power station radiation, weather adaptive street lighting, smart waste management, structural health monitoring, air pollution monitoring, water leakages monitoring, forest fire detection and so forth, as also shown through Figure 1.

In a wireless sensor network composed of many spatially scattered wireless nodes, communication is constrained by various impairments such as the wireless propagation effects, network interference, and thermal noise. The effects of signals propagation in the wireless environment include the attenuation of radiated signals with distance (also known as path loss), the blocking of signals caused by large obstacles (also called shadowing), and the reception of multiple copies of the same transmitted signal (also called multipath fading) [5]. The network interference is due to accumulation of unwanted signals radiated by other transmitters from inside or outside of the network, which undesirably affects signal reception at receiver nodes in the network. The thermal noise is introduced by the receiver electronics and is usually modeled as additive white Gaussian noise (AWGN).

Due to the scarcity of radio spectrum, it is not completely possible for large wireless networks to communicate without interference. Probably other radio devices will make transmission using the same radio frequency band at the same time. Consequently, at the receiver, many undesired signals from interfering transmitters will add to the desired transmitter's signal. This phenomenon is called interference, and it causes a performance degradation of communication networks [6] [7]. This paper gives a short description of Bluetooth, ZigBee and Wi-Fi, and the brief description of LoRa as LPWAN technologies.

Rest of article is organized as follows. Section II defines some of the existing potential candidates for LPWAN technologies. Section III describes some key features of LoRa technology. Conclusive remarks are drawn at the end in Sections IV.

II. Low Power Wireless Technologies

Several low power wireless technologies can be utilized for WSNs. Choice of a particular technology for a particular application can be made by examining required data rates, power consumption and range [8]. Some of these major communication technologies, which utilizes licensed free ISM bands, have been discussed and compared further in this

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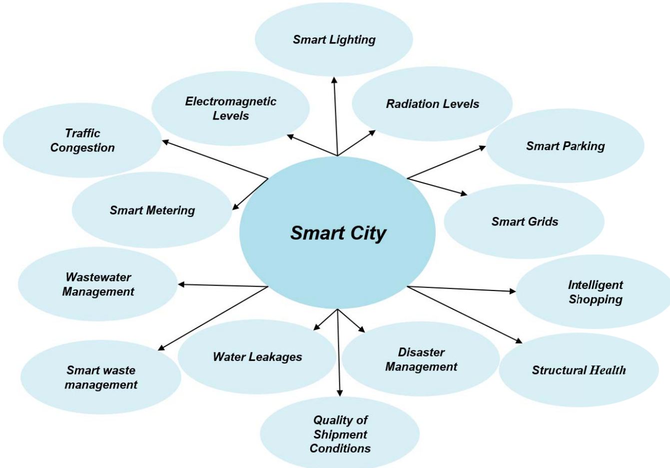

Fig. 1. Smart city applications

TABLE I. COMPARISON OF COMMUNICATION PROTOCOLS.

	Bluetooth	ZigBee	Wi-Fi
Max. end-devices	255 (2 Billion in BLE)	more than 64000	Depends on number of IP addresses
Peak Current Consumption	30 mA	30 mA	100 mA
Range	10 m	10 to 100 m	100 m
Data Rate	1 Mbps	up to 250 kbps	11 Mbps and 54 Mbps
Relative Cost	Low	Low	Medium
Topology	Star	Star and Mesh	Star and Point-to-point
Transmission Technique	FHSS (Frequency Hopping Spread Spectrum)	DSSS (Direct Spread Spectrum Sequence)	OFDM (Orthogonal Frequency Division Multiplexing)

section. Also, comparison of some basic features related to these technologies are highlighted in Table I.

A. Bluetooth

Bluetooth is a wireless personal area network (WPAN) technology based on IEEE standard 802.15.1. It was launched in 1994 by Ericsson. It utilizes licensed free 2.4 GHz frequency band with up to 1MHz channel frequency band. Bluetooth adopts frequency hopping spread spectrum (FHSS) transmission technique and offers maximum data rate up to 1Mb/s. Conventional Bluetooth can connect eight nodes to each other with seven slave nodes and one master node. Bluetooth based networks can be deployed in a point-to-point master-slave manner. The power consumption of any type of communication network strongly depends on the distance between transmitter and receiver nodes, the preferred power to be retained by the signal and most importantly type of data being exchanged. Bluetooth based networks are able to exchange more or less all types of data like multimedia or text etc. [9].

Another extension of Bluetooth was proposed as Bluetooth 4.0 also known as Bluetooth Low Energy (BLE) after the Bluetooth 1.0, 2.0 and 3.0. It was designed as alternative low power solution to classic Bluetooth. Bluetooth and BLE are used for different purposes. Conventional Bluetooth can handle almost all the variety of data, but it consumes more power and cost. BLE is used for low data rate applications, and can therefore, have longer battery life time. Like classic Bluetooth, BLE also utilizes licensed free ISM band and offers 40 different channels. Three among these are labeled as advertising channels and are used establish a connection. The remaining 37 channels are labeled as data channels and as name suggest are used to exchanged data after the connection established between sender and receiver [9].

B. ZigBee

The IEEE standard 802.15.4 commonly known as ZigBee is most popular choice in Low Rate Wireless Personal Area Networks (LR-WPAN) and WSNs. IEEE standard 802.15.4 has only defined the characteristics of physical (PHY) layer and Medium Access Control (MAC) layer. These characteristics have been adopted by ZigBee. ZigBee has defined the specifications for network layer and application layer. In wireless networks, MAC layer allows efficient access of wireless physical medium, wireless node associations, data frame validation and security services. Based on the application requirements, ZigBee based networks can be centralized and/or decentralized [10].

ZigBee based wireless network can adapt star topology and/or peer-to-peer topology. Star topology offers both contention-based and contention-free wireless medium access to its member nodes. In peer-to-peer topology, nodes can communicate with other nodes within their radio range. Decentralized or peer-to-peer topology based wireless network supports contention-based un-slotted carrier sense multiple access with collision avoidance CSMA/CA wireless MAC protocol. In CSMA/CA protocol nodes compete with each other to access the shared wireless medium. More than 64000 nodes can be connected in zigBee where each one needs only to allocate a role. ZigBee uses direct spread spectrum sequence (DSSS) transmission technique and offers up to 250 kbps of data rate in 2.4 GHz frequency band [11] [12]. Spreading techniques are applied to increase the signal bandwidth (BW). DSSS phase shifts a sine wave pseudo-randomly with ”chips”. These continuous strings or chips are called pseudo-noise (PN) code symbols or PN-sequence. This phenomenon helps to increase the signal power, decrease the interference effects on received signal, allows sharing of spectrum among multiple users and provides resistance against intended or unintended signal jamming. PN-sequence remains known at transmitter and receiver. ZigBee is low power and low cost system which makes it well suited for WSNs [13]

C. Wi-Fi

Although, Bluetooth and ZigBee are low power and low complexity wireless sensor technologies, but they have some limitations, such as low data rate, short range, and less penetration across obstacles. With the advancement in the fields of wireless and system on chip (SoC) technologies, a number of Wi-Fi based wireless sensor SoCs have been developed for low power wireless sensor applications [14]. Wi-Fi is a wireless local area network (LAN) technology based on IEEE standard 802.11. In literature though, IEEE standard 802.11 and Wi-Fi is used interchangeably, and we will also follow the same convention in this paper. IEEE standard 802.11 provides set of specifications for media access control (MAC) and physical layer (PHY) for implementing wireless WLAN in the frequency band of 900 MHz, 2.4GHz, 3.6GHz, 5GHz and 60 GHz [15]. 2.4 GHz frequency operation band is most common in many extensions of IEEE standard 802.11, with 14 distinct channels. Wi-Fi based WSNs could be network-centered or data-centered networks and consists of a large

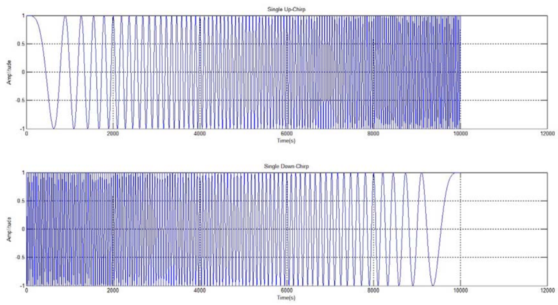

Fig. 2. Up-chirp and down-chirp waveform

number of low power nodes distributed over the large area. Wi-Fi offers data rate of 11Mbps to 54Mbps (250 Mbps: Wi-Fi Direct) with 100 m transmission range. The number of nodes in the network depends on the number of IP addresses.

Orthogonal Frequency Division Multiplexing (OFDM) is the variant of Multi-Carrier Modulation and is employed in several IEEE Wireless Local Area Network (WLAN) standards like IEEE 802.11a and IEEE 802.11g. IEEE standards 802.11n and 802.11ac also utilize OFDM modulation technique but coupled with a multiple input multiple output (MIMO) [16].

D. SigFox

It supports narrowband (or ultra narrowband) technology with standard radio transmission method called binary phase-shift keying (BPSK) (going up). Which allows the receiver to only listen in a very small part of the spectrum that mitigates the noise impact. It requires an inexpensive endpoint radio and a more sophisticated base station to manage the network. These transmissions use unlicensed frequency bands [15]. Section II defines some of the existing potential candidates for LPWAN technologies.

III. LoRo TECHNOLOGY

LPWAN is the rapidly growing area of the communication industry. Amongst the recently introduced low power and long range technologies, the semiconductor manufacturer Semtech has introduced extensive utilization of advanced spread spectrum technologies with their Long-Range $LoRa^{TM}$ product line. In comparison with legacy modulation techniques, the spread spectrum modulation technique implied in LoRa assures an increased link budget as well as better immunity to network interferences. LoRa utilizes wider band usually of 125 kHz or more to broadcast the signal. LoRa allows the usage of scaleable BW of $125kHz, 250kHz$ or $500kHz$ [17]. Usage of a wider band makes LoRa resistant to channel noise, long term relative frequency, doppler effects and fading. But, spreading a narrowband signal over wider band makes less efficient use of spectrum until the end devices utilize orthogonal sequences and/or different channels which result higher overall system capacity.

The transmitter generates chirp signals by varying their frequency over time and keeping phase between adjacent symbols constant. The transmitted signal is noise alike signal which is resistant to multipath fading and doppler shifts, robust

TABLE II. CODE RATES IN $LoRa^{TM}$

CR value	1	2	3	4
no. of redundant bits	1	2	3	4
Coding rate	4/5	2/3	4/7	1/2

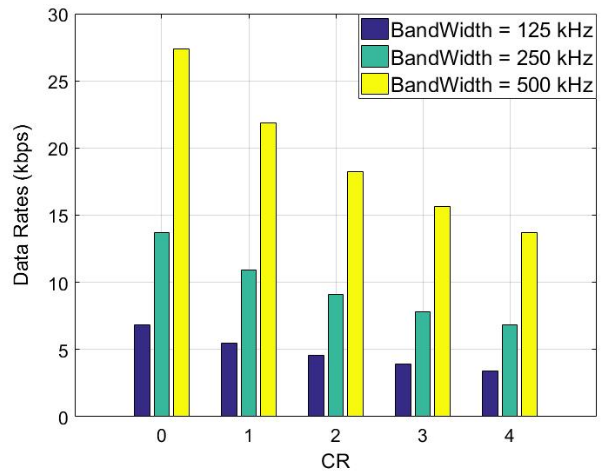

Fig. 3. Data Rates offered in LoRa with different code rate and bandwidth values, $(SF = 7)$.

to interferences and jamming attacks and difficult to decode by an eavesdropper. Receiver can decodes even a severely attenuated signal $19.5\ dBs$ below the noise level [18]. Chirp spread spectrum (CSS) is a subcategory of DSSS, and it allows to send one bit per each chirp. It takes much larger BW for transmission than actually required for the considered data rate. A single chirp waveform can be defined as:

$$c(t) = \begin{cases} exp(j\phi(t)), & -\frac{T}{2} \leq t \leq \frac{T}{2} \\ 0, & otherwise \end{cases} \tag{1}$$

where $\phi(t)$ is the phase of chirp waveform. Examples of up-chirp and a down-chirp waveform are shown in Figure 2.

Apparently, characteristics of LoRa modulation depends on following three parameters:

Code rate (CR)

Forward error correction (FEC) techniques are used in Lora to further increase the receiver sensitivity. Code rate defines the amount of FEC. LoRa offers CR values between 0 to 4, where CR = 0 means no FEC. LoRa uses code rates of $4/5, 2/3, 4/7$ and $1/2$, also shown in Table II. Which means, if the code rate is denoted as k=n, where k represent useful information, and encoder generates n number of output bits, then $n - k$ will be the redundant bits. The redundancy allows the receiver to detect and often to correct errors in the message, but it also decreases the effective data rate. Data rates corresponds to each CR value in LoRa are shown in Figure 3, over three bandwidths. As the CR value increases, the effective data rate decreases in each bandwidth spectrum.

Spreading factor (SF)

LORa employs multiple orthogonal spreading factors (between 7 to 12). SF provides a tradeoff between data rate

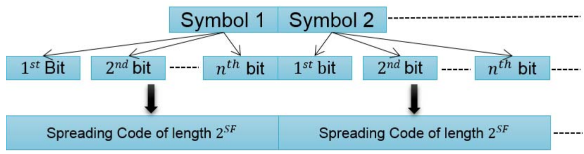

Fig. 4. Spreading in LoRa

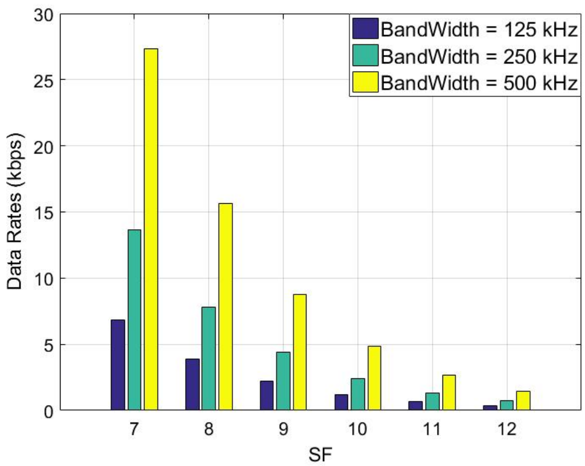

Fig. 5. Data Rates offered in LoRa with different spreading factor and bandwidth values, $(CR = 0)$.

TABLE III. SPREADING FACTORS AND CORRESPONDING CHIP LENGTH IN $LoRa^{TM}$

Spreading Factor (SF)	**Chip Length 2^{SF}**
7	128
8	256
9	512
10	1024
11	2048
12	4096

and range. Choice of higher spreading factor can increase the range but decreases the data rate and vice versa. Each symbol is spread by a spreading code of length 2^{SF} chips. At the transmitter, the spreading code is subdivided into codes of length $2^{SF}/SF$. Then each bit of symbol is spread using the subcode also shown in Figure 4. So, it takes 2^{SF} chips for spreading of one symbol $(SFbits \times 2^{SF} = SF)$, as shown in Table III. This spreading code is also known at the receiver. The substitution of one symbol for multiple chips of information means that the spreading factor has a direct influence on the effective data rate [19]. The relation between the data rate and the choice of SF is shown in Figure 5, over three bandwidths.

At the receiver, spreading code is multiplied by the received bits to regenerate the input data. Spreading mechanism can also see in Figure 4.

Bandwidth (BW)

LoRa provides three scaleable BW settings of $125kHz, 250kHz$ and $500kHz$ also shown in Figure 6. Transmitter sends the spreaded data at a chip rate equal

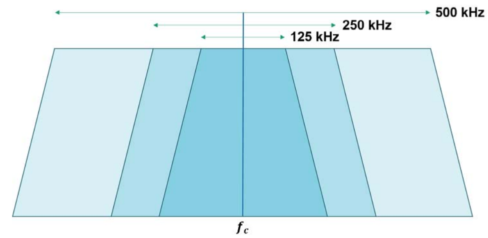

Fig. 6. The LoRa Bandwidth Corresponds to the Double Sided Transmit Spectrum Bandwidth

to the system bandwidth in chips per-second-per-Hertz. So a LoRa bandwidth of 125 kHz corresponds to a chip rate of 125 kcps.

A. Packet Structure

Figure 7 shows packet structure used by LoRa. LoRa offers maximum packet size of 256 bytes. The LoRa packet is composed as follows [20]:

- Preamble field: is used for the synchronization purposes. The receiver synchronized with the incoming data flow.
- Header field: depends on the choice of two available operation modes. In default explicit operational mode, the number of bytes in the header field specifies forward error correction (FEC) code rate, payload length and presence of CRC in the frame. The second implicit operational mode specifies that coding rate and payload in a frame are fixed. In this mode, frame doesn't contains this field, which gives reduction in transmission time. Header field also contains 2 byte CRC field which allows the receiver to discard packets with invalid header. Header field along with its CRC field are 4 bytes long and are encoded with $1/2$ coding rate, while coding rate for the rest of the frame specifies in PHY header. The first byte of header field specifies the payload length.
- Payload field: Maximum payload varies from 2 to 255 bytes. This field further contains following fields:
  - MAC header: defines the frame type (data or acknowledgment), protocol version and its direction (uplink or downlink).
  - MAC payload: contains actual data.
  - MIC: is used as the digital signature of the payload.
- CRC: is optional and comprises cyclic redundancy check (CRC) bytes for error protection for payload (2 bytes).

B. Time on Air

For LoRa, the actual time on the air for a packet can be defined as:

$$T_{packet} = T_{preamble} + T_{payload} \tag{2}$$

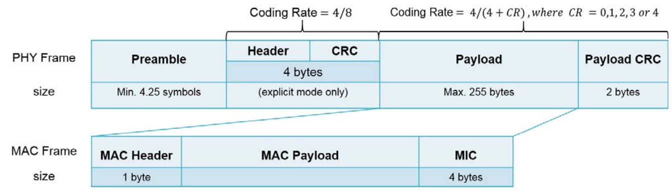

Fig. 7. $LoRa^{TM}$ packet structure

where $T_{preamble}$ is preamble duration and $T_{payload}$ is payload duration. $T_{preamble}$ can b defined as:

$$T_{preamble} = (n_{preamble} + 4.25)T_s \tag{3}$$

where $n_{preamble}$ is the preamble length and T_s denotes time of 1 symbol and

$$T_s = 1/R_s \tag{4}$$

with SF as spreading factor, R_s is symbol rate which is

$$R_s = BW/2^{SF} \tag{5}$$

The payload time is:

$$T_{payload} = PLSymb \times T_s \tag{6}$$

$PLSymb = 8 + max(ceil(\frac{8PL-4SF+28+16CRC-20H}{4(SF-2DE)})(CR + 4), 0)$

with the following explanations:

- PL : number of payload bytes.
- H : 0 when the header is enabled and 1 when there is no header.
- DE : 1 for enabled low data rate optimization and 0 for vice versa.
- CR : code rate.

So total time on the air taken by LoRa devices can be defined by using Equations 2, 3 and 6.

$$T_{packet} = T_s(n_{preamble} + PLSymb + 4.25) \tag{7}$$

From the above calculation, one can say that spreading factor has a direct influence on the time on air of the LoRa packet. Figure 8 shows time on air for a LoRa frame with different payload sizes and SF values. Time on air increases with the increase in payload size and SF values. Although higher spreading values highly influence the time on air of a LoRa packet, but time on air also varied with the change in code rate value. This variation is shown in Figure 9.

Same as SF and CR, the third parameter of LoRa modulation bandwidth, also influence the time on air of a packet. Higher the bandwidth means lower the time on air. This is shown in Figure 10, with different payload values and $CR = 0$, $SF = 7$.

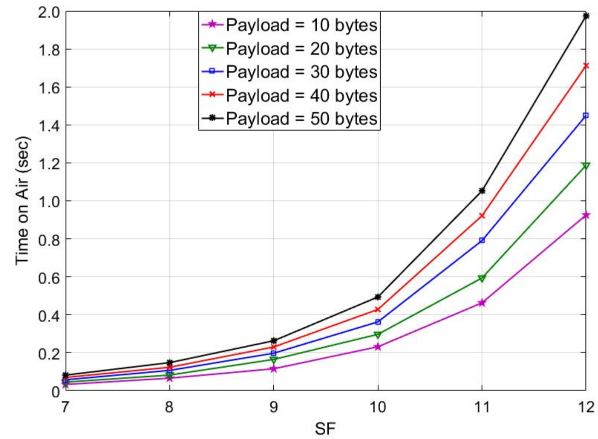

Fig. 8. $LoRa^{TM}$ packet time on air with $BW = 125\ kHz$ and $CR = 0$

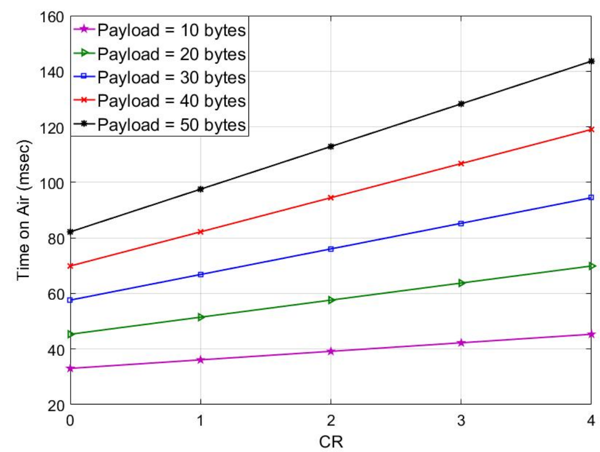

Fig. 9. $LoRa^{TM}$ packet time on air with $BW = 125\ kHz$ and $SF = 7$

IV. CONCLUSION

Various LPWAN technologies are currently contending to gain an edge over the competition and provide the massive connectivity that will be required by the world in which everyday objects are expected to be connected through wireless network in order to communicate with each other. This paper focused on one of the most prominent LPWAN technology: $LoRa^{TM}$.

In this work, we have analyzed the performance of LoRa, based on its three basic parameters: code rate, spreading factor and bandwidth. Lora offers five code rates for forward error correction which permits the recovery of bits of information due to corruption by interference. Similarly higher spreading factor provides longer range. The spreading codes correspond to each SF are considered as orthogonal. This means that multiple frames can be exchanged in the network at the same time, using one the six different $(SF = 7, 8, 9, 10, 12)$. An increase in CR and SF values decreases the effective data rate and causes increase in time on air of LoRa packet. Choice of bandwidth also influences on data rate and time on air of a packet.

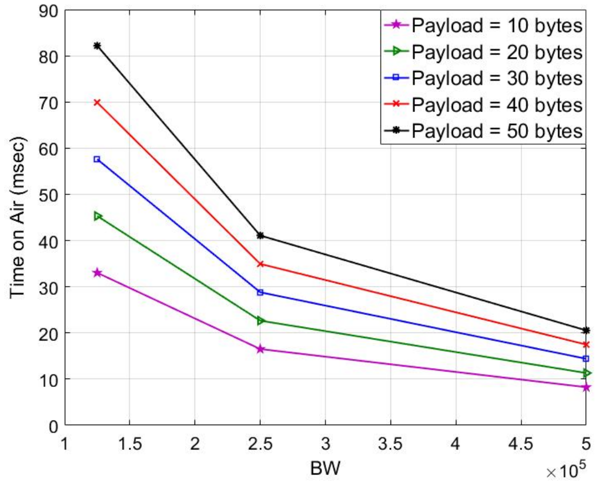

Fig. 10. $LoRa^{TM}$ packet time on air with $CR = 0$ and $SF = 7$

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REFERENCES

[1] Akyildiz, I.F., Su, W.J., Sankarasubramaniam Y., and E. Cayirci, E. (2002). A survey on sensor networks. IEEE Communications Magazine, pp. 102114

[2] Shen, C., Srisathapornphat, C., and Jaikaeo, C. (2001). Sensor Information Networking Architecture and Applications. IEEE Pers. Commun., pp. 52?59.

[3] Nokia.: Lte evolution for iot connectivity. Nokia white paper, http://resources.alcatel-lucent.com/asset/200178 (2016).

[4] J. Petajajarvi, K. Mikhaylov, A. Roivainen, T. Hanninen and M. Pettissalo. On the coverage of LPWANs: range evaluation and channel attenuation model for LoRa technology. 14th International Conference on ITS Telecommunications (ITST), Copenhagen, 2015, pp. 55-59. doi: 10.1109/ITST.2015.7377400

[5] U. Raza, P. Kulkarni, and M. Sooriyabandara.: Low power wide area networks: An overview. IEEE Communications Surveys Tutorials, 1–1 (2017).

[6] Moe Z. Win, Pedro C. Pinto and Lawrence A. Shepp. 2009. A Mathematical Theory of Network Interference and Its Applications. Proceedings of the IEEE. vol.97, no.2. pp.205-230. doi= 10.1109/JPROC.2008.2008764

[7] ITU. Tech. Rep https://www.itu.int/net/wsis/tunis/newsroom/stats/The-Internet-of-Things-2005.pdf (2005)

[8] J. S. Lee, C. C. Chuang, and C. C. Shen.: Applications of short-range wireless technologies to industrial automation: A zigbee approach. Fifth Advanced International Conference on Telecommunications, 15–20 (2009).

[9] M. O. A. Kalaa, W. Balid, N. Bitar, and H. H. Refai.: Evaluating bluetooth low energy in realistic wireless environments. pages 1–6 (2016).

[10] U. Noreen, A. Bounceur, L. Clavier, and R. Kacimi.: Performance evaluation of IEEE 802.15.4 phy with impulsive network interference in cupcarbon simulator. International Symposium on Networks, Computers and Communications (ISNCC), 1–6 (2016).

[11] IEEE draft standard for local and metropolitan area networks - part 15.4: Wireless medium access control (mac) and physical layer (phy) specifications for low rate wireless personal area networks (wpans) amendment - physical layer (phy) specifications for low energy, critical infrastructure monitoring networks (lecim). 1–133 (2013).

[12] IEEE standard for local and metropolitan area networks, part 15.4: Low-rate wireless personal area networks (lr-wpans). IEEE Std 802.15.4-2011 (Revision of IEEE Std. 802.15.4-2006), 1–314 (2011).

[13] Hui Li and Dan Yu.: Comparison of ad hoc and centralized multihop routing. 2:791–795 (2002).

[14] Zhao Xiaohui Lei Yuan, Xiong construction. Wi-Fi based wireless sensor network design and research. 18:192–197 (2009).

[15] L. Kleinrock and F. Tobagi. Packet switching in radio channels: Part I - carrier sense multiple-access modes and their throughput-delay characteristics. IEEE Transactions on Communications, 23(12), 1400–1416 (1975).

[16] U. Noreen and S. Baig. Modified incremental bit allocation algorithm for powerline communication in smart grids. In 2013 1st International Conference on Communications, Signal Processing, and their Applications (ICCSPA), 1–6 (2013).

[17] B. Reynders, W. Meert, and S. Pollin. Range and coexistence analysis of long range unlicensed communication. In 2016 23rd International Conference on Telecommunications (ICT), 1–6 (2016).

[18] Semtech. http://www.semtech.com/.

[19] LoRa Alliance. Lora alliance, https://www.lora-alliance.org/what-is-lora/technology.

[20] Semtech, http://www.semtech.com/wireless-rf/lora/LoRa-FAQs.pdf: