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# Performance Evaluation for LoRa Transceiver

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## ABSTRACT

The LoRa (Long Range) defines the physical layer modulation technique that offers a longer range communication link than other challenging technologies, while LoRaWAN is the communication protocol for the network defined by data link (MAC) protocol and its system architecture. LoRaWAN is designed to optimize a Long Range Low Power Wide Area Network (LPWAN) for battery lifetime, capacity, range, and cost. Its concerns on the necessities of the web of things, as a bi-directional communication, mobility and localization services securely and efficiently. In mainly the unlicensed frequencies, it uses direct sequence modulation held in reserve for Industrial, Scientific, and Medical (ISM), for example in Europe (868 MHz) and the United States ranged from (902 MHz to 928 MHz). Network operators can deploy networks without the costly load of frequency licensing. The LoRa modulation is established on the integration of Chirp Spread Spectrum (CSS) which keeps the low power features as Frequency Shift Keying (FSK) modulation and enlarges the link range with Forward error correction (FEC) used for controlling errors in transmission channels. Both of them are essential for modulation. Having different chirp rates is a dominant feature that gives LoRa the ability to demodulate various orthogonal and simultaneous signals at the similar range of frequency. LoRa Transceiver model is implemented using Matlab - Simulink with fundamental components to demonstrate how reliable elaborate modulation schemes can be built. The paper consists of ..... sections in addition to references. A brief summary about the contents of sections is presented as follow: Section I provides a brief introduction about LPWAN. Section II presents LoRaWAN architecture. Section III describes how LoRaWAN works. Section IV presents implementation of LoRaWAN. Section V presents Challenges and Obstacles. Section VI presents Market Status. Section VII presents LoRaWAN simulation. Section VIII presents the results. Section IX presents the comparison. Section X presents the conclusion and future work. Finally, a list of references used as background of the paper is presented at the end of the proposal.

**Keywords:** *LoRa Transceiver, Long-range wireless, Low power transmission, Physical layer modulation, Wide area*

*networks.*

## 1. INTRODUCTION

LPWAN networks characterize a relatively new communication model, in which traditional cellular and short-range wireless technologies are complemented by addressing different requests in applications. The underlying technologies propose wide-area connectivity for low power consumption and suitability for low data rate devices with low cost, which is a unique set of features. The market for LPWA networks is also expected to be of a substantial size resulting in the connection of about 30 billion devices to the internet.

LPWAN networks create different balances from traditional technologies, for example, short-range wireless networks (Zig-Bee, Bluetooth), wireless local area networks (Wi-Fi), cellular networks (Global System for Mobile Communications (GSM), Long-Term Evolution (LTE), etc.).

### 1.1 LPWAN vs. other technologies (pros and cons):

The range of non-cellular wireless technologies is restricted to a few hundred meters. So, these technologies are not ideal to connect low powered devices spread over a large area. Low power devices are required in many applications for smart cities, logistic service, and personal health. Therefore, the devices cannot be randomly deployed or relocated anywhere. The cost of deployment is also an issue. These technologies have limited communication coverage areas and higher power usage.



Mass adoption of 2nd generation (2G) and 3rd generation (3G) technologies in cellular networks resulted due to their wide area coverage. Traditional cellular technologies do not achieve energy efficiency to offer extended battery life. The complexity and cost of cellular devices are high due to their ability to cooperate with complex waveforms and they can be increased by optimizing voice, high-speed data services, and text [1].

## 1.2 LPWAN applications:

LPWA technologies are favorable for low-power, low-cost, low throughput devices, and allow devices to extend and transfer over wide areas. Internet-of-Things (IoT) and Machine-to-Machine (M2M) devices associated with LPWA technologies can sense and interact with their environment immediately. LPWAN technologies can achieve long range and at low power operation data rate and low latency



Fig. 1. Applications of LPWA technologies across different sectors [1].

As shown in Figure 1, LPWAN technologies are considered for delay tolerant applications, do not require high data rates, and need low power and cost. LPWAN does not support many industrial IoT, vehicle to vehicle (V2V), and vehicle to infrastructure (V2I) applications. Due to their strict performance requirements, which cannot be ensured with a low cost and low power solution, they require ultra-low latency and ultra-high reliability. This technology can support the requirements of applications for smart cities, smart metering, home automation, and environmental monitoring, etc. This technology can support applications which exchange a small amount of data.

These applications can be classified as follow:

1. Commercial facilities / Buildings / Warehouses:  
Remote monitoring and control of equipment, operating optimization, employee administration.
2. Homes / Schools / Hospitals / Senior facilities  
Senior citizen and child monitoring smart meters (electricity, gas, water)

## 3. Mountains / Rivers / Oceans

Disaster countermeasures for landslides, flooding, earthquakes, etc.

## 4. Public Infrastructure

Management prediction and maintenance of infrastructure, street lighting.

## 5. Cars / Trucks / Buses

Freight and palette management, smart parking, logistics, fleet operation management, optimization.

## 6. Fields / Rice paddies / Ranches

Water quality, soil management, livestock tracking.

## 2. LoRaWAN ARCHITECTURE

LoRa is the physical layer or the wireless modulation used to create the long range communication link. Applying FSK modulation in various wireless systems as the physical layer because it is a very effective modulation for consuming low power [7]. LoRa relies on CSS modulation shown in Figure 2, which sustains the similar low power features as FSK modulation but significantly increases the range of communication. Each LoRa symbol is composed of 2-SF chirps, where SF represents the corresponding spreading factor. The use of six orthogonal SFs in the range of 7 to 12, which provide different data rates, results in high spectral efficiency and high network capacity. CSS has many applications in military and space communication for a long time due to the long communication distances that can be attained with strong interference, but the use of LoRa is the first commercially viable implementation [2].

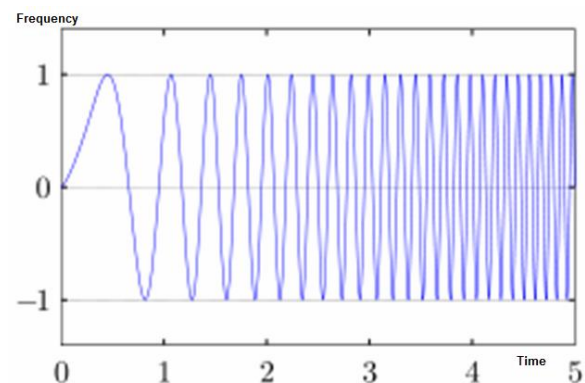


Fig. 2. A linear frequency modulated upchirp in the time domain

Currently, LoRa Alliance is standardizing LoRaWAN (the MAC layer protocol for LoRa Technology), to make sure that the different networks are interoperable. The optimization of LoRaWAN protocol for low cost, battery-operated sensors contains various classes of nodes. Defining dissimilar classes of nodes basically helps to optimize the balance between network latency and battery lifetime.

- Bi-directional communication is permitted by end devices of class A whereby each end device's uplink transmission is followed by two small downlinks receive windows. The scheduling of transmission slot by the end device is dependent on its private communication requests. After the end device has sent an uplink transmission, class A operation is the lowest power end-device system for applications that only need downlink communications from the server in a small period. Automatically, downlink communication from the server is queued until the subsequently scheduled uplink.
- At scheduled periods, Class B devices can open additional receive windows. The end device receives a time synchronized beacon from the gateway to open its own receive window at the scheduled period. When the end device is listening, the server can recognize.
- Class C have nearly continuously open receive windows at its end devices that are only closed when transmitting.

With various protocols, the network can be used in different architectures (Mesh, Star, point to point, etcetera). However, to extend the operable range and take advantage of the increased link budget and also the range capability of LoRa, a star architecture can be used to optimize the network capacity, extend the battery lifetime, and simplify the installation.

LoRa allows sensors to expand their communication range more than 100 km for favorable environment, 15 km for semi-rural area and more than 2 km for dense urban environment with rates from 300 bit/s to 100 Kbit/s [1]. Such a low data rate results in a good sensitivity, which permits for long-range communication of multiple kilometers. In practice, the reasonable operable distance will be shorter due to increased packet-loss ratio for the low data rates while distance increases, this will lead to new hidden challenges.

To this end, LoRa technology solutions can target multiple application domains, such as Internet-of-Things (IoT), machine-to-machine (M2M), device-to-device (D2D), Automated Meter Reading (AMR), wireless alarm, security systems, industrial monitoring and controlling, and long-range irrigation systems.

Lora is significant due to its long-range capability; a single gateway or base station can cover whole cities or hundreds of square kilometers. Range highly relies on the environment or impediments at a given site, but Lora and LoRaWAN have a higher link budget than any other standardized communication technology. The link budget is the main factor in defining the range in a certain environment and typically given in decibels (dB). Entire countries can easily be covered with a minimal amount of

infrastructure. LoRa is a wireless technology mainly used in M2M and IoT. Table I summarizes the LoRa wireless technology key features such as range, standard, modulation scheme, capacity, power consumption and physical layer [3].

LoRaWAN is an LPWAN established and maintained by the Lora Alliance. While the Lora physical layer allows the long-range communication link, it defines the communication protocol and system architecture for the network. The protocol and network architecture determine the battery lifetime of a node, the network capacity, the quality of service, the security, and the applications served by the network.

Secure bi-directional communication, mobility and localization services are the LoRaWAN key necessities of IoT. The description of LoRaWAN gives seamless interoperability within smart Things and gives back the freedom to the user, developer, and businesses without the necessity of complex local installations allowing for the roll-out of the Internet of Things.

Table 1 : Key Features of Lora wireless Technology

Specification/ Characteristic	LoRa Support
Range	In intensely urban ranged from 2 to 5 Km and in rural areas is 15 Km
Frequency band	Industrial, Scientific and Medical band (868 MHz and 915 MHz)
Standard	IEEE 802.15.4g
Modulation	Spread spectrum (SS) modulation type is applied. Along determined time the frequency raises or frequency reduction is used to cipher data information to be sent. It provides 30dB enhancement over FSK.
Capacity	Be careful of a lot of nodes by LoRa gateway.
Power Consumption	Extended time of battery
LoRa Physical layer	Be careful of frequency, power, modulation, signaling among nodes and gateway

The LoRa protocol was established by IoT industry leaders including IBM, Actility, Semtech and Microchip. It is now transferred to the LoRa Alliance. The LoRaWAN architecture includes three main components:

- The end nodes with the low data-rate applications, which are sensing and governing the world connected to one or more gateways.

- The signals which directed to a network server are collected by gateways.
- The responsibility of network server is for authenticating end nodes and discussing the end-to-end coding that is part of the LoRaWAN specification.

As shown in Figure 3, LoRaWAN network architecture is represented in a star-of-stars topology. Gateways are a transparent bridge depending messages among end-devices and a central network server. Network servers are connected by gateways through standard IP connections while end-devices are linked to one or many gateways using single-hop wireless communication [4].

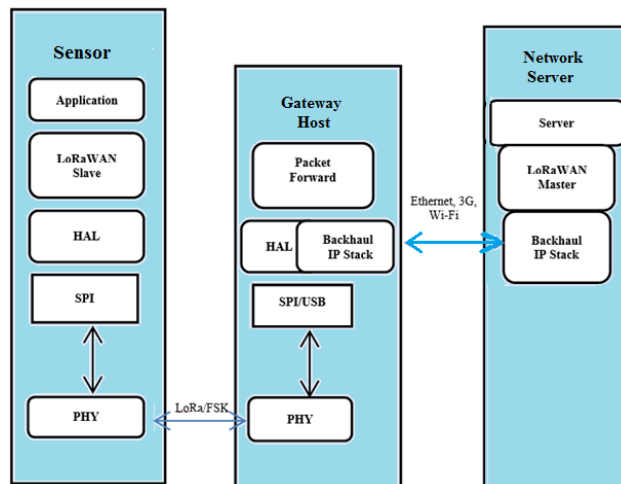


Fig. 3. End devices layers and connection between end devices and gateway

A single LoRaWAN Gateway is comparatively cheap and covers more than 10 Km in range. For example, The Thing Network covered the city of Amsterdam using 10 gateways at the cost of 1200 dollars with the advantage of LoRaWAN's long range.

Security is a big concern in LoRaWAN in such a way that it can be used to build a national network and assist critical building infrastructure of IoT. The Lora Alliance has attempted to increase the security of LoRaWAN by adding three different layers of security:

- 1- Confirming security on network level using unique network key.
- 2- Approving end-to-end security on application level using unique Application key.
- 3- Fixed key of the device.

LoRa based LPWAN looks more promising and is more general although there are other variations for LPWAN like Sigfox [5].

Gateways are a transparent bridge transferring messages among end-devices and a central network server. LoRa gateways (also named LoRa concentrators) are multi-channel, multi-modem transceivers. Because of the

physical properties of LoRa, its gateways can demodulate on multiple channels and multiple signals on the same channel simultaneously. The gateways use different radio frequency components than the end-point to allow high capacity and clearly to enable the gateways to serve like a transparent bridge transferring messages among end-devices and a central network server in the backend. All end-point communication is commonly bidirectional. In addition, it provides operation such as multicast enabling, software upgrade, over the air or other mass delivery messages to decrease the on-air communication time. Different gateways relying on the installation location and the preferred capacity

Data rates of LoRaWAN ranged between 0.3kbps to 11kbps and data rate of one Gaussian Frequency Shift Keying (GFSK) for Europe is 50kbps. The minimum data rate in North America is 0.9kbps. However, the physical specifications are capable of more options. By using different frequency channels and data rates, the communication can spread among end-devices and gateways. The channel and data rate chosen is a trade-off between communication range and message payload.

The LoRaWAN network server is managing the data rate and Radio Frequency output for each end-device separately using an adaptive data rate algorithm to maximize both battery life of the end-devices and full network capacity. Under the local radio conditions, this unique optimization relies on advanced link information such as Signal Noise Ratio (SNR), Received Signal Strength Indication (RSSI), and channels to confirm optimal performance. This type of link information is usually used such that instant synchronization dynamically adapts the spreading factor and coding rate to the actual link budget. A connectivity comparison to existing wireless technologies is illustrated in Figure 2. The end-device changes channel in a pseudo-random fashion every 19 transmissions to mitigate the possible interferences. The frequency range result can make the system more resistant to interference.

LoRa long-range star network architecture mimics existing cellular architecture and has a link budget 5-10dB more than cellular systems. This permits use of existing elevated cellular base stations to be equipped with LoRa gateways. To allow the small end nodes to communicate through a public or a private network, this system of end nodes communicating via a gateway infrastructure to a centralized network authority is intentionally corresponding to present cellular networks and results in a new type of network for M2M communication. LoRa is ideal for battery-powered sensors and controllers, because LoRa transceivers are capable of bidirectional communication in ranges equal to or more than current LTE technology, but at 1/100<sup>th</sup> the power consumption.



### LoRa network elements

**Endpoints:** The elements of LoRa network are usually remotely positioned where the sensing or the controlling is assumed [6].

**LoRa gateway:** The gateway sends the communications onto the backhaul system after accepting them from the LoRa endpoints and this LoRa network portion can be Ethernet, cellular or any other telecommunications link wired or wireless. Using standard IP connections, the gateways are linked to the network server. By this way, the data uses a standard protocol, but can be connected to public or private telecommunications network. LoRa gateways may often be co-located with a cellular base station which prove the similarity of a LoRa network to that of a cellular one. Gateways can use spare capacity on the backhaul network.

**Server:** The LoRa network server manages the network, it acts to delete duplicate packets, schedules acknowledgment, and adapts data rates. Considering the way in which it can be deployed and connected, makes it very simple to deploy a LoRa network.

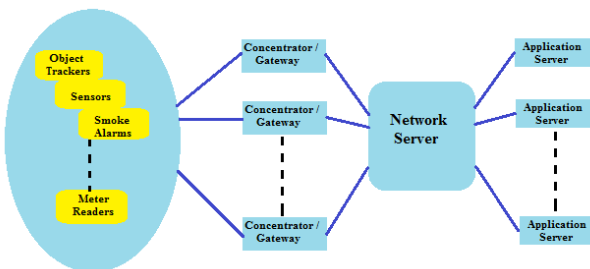


Fig. 4. Structure of LoRaWAN

**Remote computer:** LoRa network is a transparent in which a remote computer can then control the actions of the endpoints or collect data from them.

## 3. HOW IT WORKS

LoRaWAN is connected in a star network topology where all sensors have LoRa chips to transmit messages to gateways and not to other sensors. Therefore, gateways can pass along the messages with cellular, satellite, Ethernet, or Wi-Fi to a network server. The duplicate messages that are sent by multiple gateways will be eliminated by the network server. Messages are sent from the server via the gateway to the sensors to update firmware and approve received messages.

### 3.1 LoRaWAN Protocols

By the LoRa Alliance, LoRaWAN is a protocol specification built on top of the LoRa technology. To enable low power, wide area communication between

remote sensors and gateways linked to the network, LoRaWAN uses unlicensed radio spectrum in ISM bands.

### 3.2 Where does LPWAN Fit?

All the expected applications and volumes for IoT cannot be served by one technology. Wi-Fi and Bluetooth Low Energy (BTLE) technologies are widely adopted standards and the applications related to communicating personal devices are served. Cellular technology is a great fit for applications in which high data throughput and a power source are required.

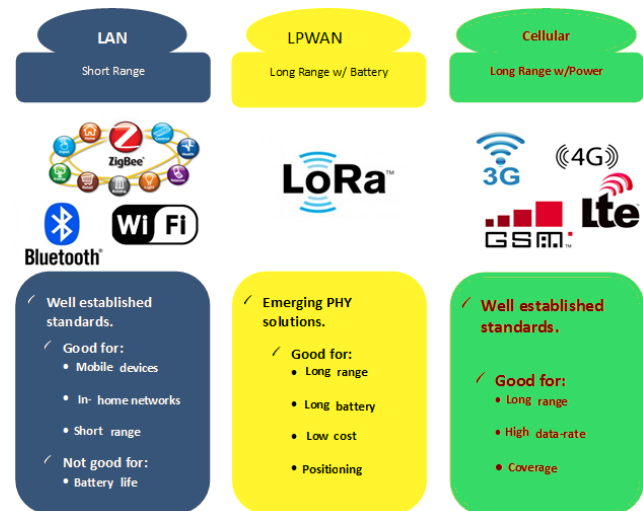


Fig. 5. Wireless segments tradeoff

LPWAN presents long battery lifetime and is designed for sensors and applications that require to transmit small amounts of data a few times for every hour over long distances from varying locations [7]. The following table II describe the key features for LoRaWAN protocol.

## 4. IMPLEMENTATION OVERVIEW

The LoRa Alliance details the protocol as:

- LoRaWAN is an implementation for a server-side of several access protocols designed to decrease collisions with a huge number of endpoints.
- Customer logic is constructed into the network server, making LoRa operate in a centralized network architecture.
- Gateways within the same network require synchronization.
- Allowing passive geolocation of things, without requiring any GPS which is embedded into objects.
- Antenna diversity can be deployed since all gateways listen to the same uplink channels. The distributed antenna model and geolocation enabled gateways helps

network locating nodes position, even when they are mobile.

Table 2: Lora Technology and LoraWAN Protocol Key Features [3]

Geolocation	GPS-free, low power tracking applications are allowed.
Low cost	Reduction of costs by three ways: infrastructure investment, operating expenses and end-node sensors.
Standardized	Enhanced speeds adoption of global interoperability and roll out of LoRaWAN-based networks and Internet of Things applications.
Low power	Designed for low power consumption to extend battery lifetime up to 20 years.
Long range	Single base station provides deep penetration in dense urban/indoor regions, connects rural areas up to 48.3 kilometers away.
Secure	End-to-end AES128 encryption is embedded.
High capacity	Millions of messages are supported per base station, ideal for public network operators serving many customers.

Table 3: LoraWAN device classes

Class name	Intended usage
A (all)	<b>Battery powered sensors</b> , or actuators with no latency constraint. Most energy efficient communication class. Must be supported by all devices.
B (beacon)	<b>Battery powered actuators</b> , an energy efficient communication class for latency controlled downlink based on slotted communication synchronized with a network beacon.
C (continuous)	<b>Mains powered actuators</b> , the devices which are able to listen continuously with no delay for down link communication.

- Extending the communication between end-devices and gateways on diverse frequency channels and data rates. The trade-off data rate is chosen between communication range and message period.
- Increasing capacity of gateway using different data rates do not interfere and creates group of “virtual” channels.
- The data rate and RF output for each end-device individually are managed using the LoRaWAN network server by means of the Adaptive Data Rate (ADR) scheme which updated every 24 hours.

- LoRa is bidirectional, allowing sensors to transmit and receive (i.e., communicate through uplink and downlink directions, respectively).
- Different types and categories of sensors (Classes A, B, and C) are offered, which is further considered as an added value services to the industry as summarized in Table III and Figure 6.
- In general, all communication is bi-directional. However, the major traffic estimates the uplink communication from an end-device to the network server.

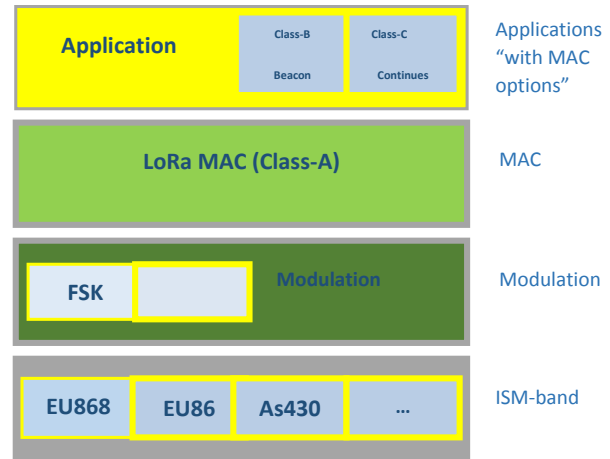


Fig. 6. Basic LoRaWAN in class A and optional features in class B and C

- The end-device select the channel in a pseudo-random way for every transmission. The consequential frequency diversity further makes the system more influence to interferences.

LoRa is well suited for sending small amounts of data, and is ideal for low power applications using battery-operated sensors communicating over long range links. Over the range of the network, because of synchronization and hops, a mesh network can spread but comes at the cost of decreased network capacity, synchronization overhead, and decreased battery lifetime. However, a star architecture can be used to improve the network capacity, battery lifetime, and installation ease by the increased link budget and range capability of LoRa. Using a wide bandwidth to send a low rate signal and a modulation format that does not tolerate any activity in the used bandwidth becomes a significant issue for capacity especially in a long-range network. In addition, the network will be very vulnerable to interference. However, it all depends on the application. For example, if a sensor sends a small amount of data every hour, LoRa is a better solution.

Using Few base stations, and care of thousands of nodes as in mesh network can cover entire cities or countries, therefore, IoT with least infrastructure investment is high concern, ensuring better opportunities for customers. If

cellular networks are ineffective, while Wi-Fi, ZigBee or Bluetooth features of networking are not enough, a LoRa solution can be initiated to fit the requirements. The gap between current LAN and WAN/Cellular technologies is neglected using LoRa.

LoRa allows minimizing energy consumption at the end-to-end links as well as at the end-points by optimizing bandwidth and power resulting in the nodes experiencing a longer battery life.

Chirp modulation helps LoRa wireless link to achieve sensitivity up to -137 dBm and up to 157 dB of link budget (as claimed by LoRa Alliance). The trade-off in the range of Kbps is the achievable data rate. This defines the applicability of the technology to IoT, M2M and home automation applications. It is not currently suited for video streaming.

Further field and designated sites experimental work needs to be initiated to fully understand the protocol and confirm its specifications and capabilities. A significant amount of development work is required to build a LoRa system or network. LoRa is an emerging solution when compared to well-established standards, e.g., Wi-Fi, ZigBee, Bluetooth, Cellular, etcetera. Like most new networking technologies, LoRa has not yet settled into a standard protocol that everyone agrees upon. To list some

intended data alteration because after changing the data, the unauthorized intruder can produce the same CRC of the source node. The aggregation result must be confirmed before accepting it as data aggregation result for such enormous long-range network is used for critical decision making. A large amount of resources are consumed using data privacy and integrity protection processes (i.e., limited power) of LoRa nodes, it is an essential to devise and deploy a light-weight integrity technique, which can attain data privacy and integrity security for such type of networks.

- At the downlink level, to keep messages short with lowest effect on any duty-cycle limitations of the ISM bands used, no data integrity check is done.
- To change from Class A to B, the decision comes from the application layer of the end-device. If the network side controls the switching from class A to Class B, the customer application uses one of the end devices Class A uplink to send back a downlink to the application layer, and the application layer identifies this demand on the end-device, the LoRaWAN level does not manage the described process.
- The network server is informed by a mobile end device of its position periodically to update the route of downlink. Optimally, for more efficiency, it is better if the application discovers that the node is moving by analyzing the beacon content. To avoid systematic uplink collisions, the end-device must apply a random latency between the beacon reception and the uplink transmission.

Messages can be unicast when the messages are sent to a single end-device or multicast when the messages are sent to multiple end-devices. For multicast group, all devices must share the same multicast address with associated encryption keys. The methods remotely setup are not identified by the LoRaWAN Class B specification.

### 3.3 Network Setup

To collect measurements of signal strength when we have one gateway and one end-device have been used. The gateway consists of a Beagle bone Black controlling an iC880A concentrator module from IMST and acts as a host for the concentrator, which forwards any traffic from LoRa network onto a wired Ethernet connection in the case of uplink messages, and vice versa for downlink messages. To modulate the symbol stream, and handle up to eight links simultaneously, the iC880A board uses a Semtech SX1301 baseband processor.

An Arduino based solution is used for end nodes. The setup consists of an Arduino Uno, paired with a LoRaWAN module from Labellum. Both of them linked through a multi-protocol shield from the same company.

Table 4: LoraWAN device classes

Class name	Intended usage
A (all)	<b>Battery powered sensors</b> , or actuators with no latency constraint. Most energy efficient communication class. Must be supported by all devices.
B (beacon)	<b>Battery powered actuators</b> , an energy efficient communication class for latency controlled downlink based on slotted communication synchronized with a network beacon.
C (continuous)	<b>Mains powered actuators</b> , the devices which are able to listen continuously with no delay for down link communication.

examples:

- The transmission of multicast messages from a network server to many end-devices is not defined by the candidate specification for the LoRa Alliance protocol.
- Keeping consistency and correctness of messages using Cyclic Redundancy Check (CRC) in LoRa uplink which supports data integrity, to confirm that the received data in transit is not changed either by an intentional illegitimate access or by noise. CRC for the most cases can handle unintentional process; on the other hand, it is incapable to cope with the





The RN2483 board from Microchip is the basis of the LoRaWAN module. For the sole purpose of sending uplink messages, this end-device has been programmed as a Class A device. The network back-end consists of a server hosted by Semtech for testing purpose, where both transmission content and metadata can be downloaded. Any device can extract parameters such as RSS, SNR, SF and Bandwidth (BW) of the signal [2].

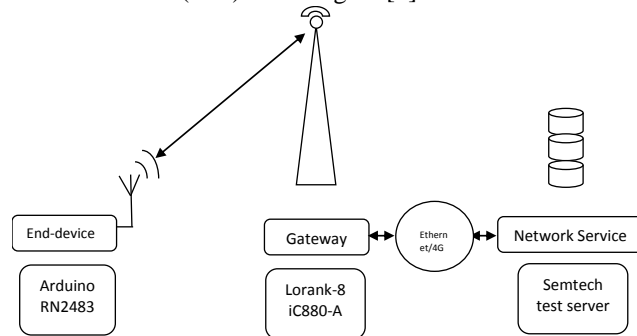


Fig. 7. Network map of implemented LoRaWAN setup.

### 3.4 Gathering RSS measurements

Both gateway and end-device are located within an office area to collect indoor measurements. The office area has a typical open layout with a partition type design and used for testing. Several measurement sequences are collected at different distances by interchanging the location of the end-device. Multiple measurements series are gathered to test and confirm the long distance path loss model at certain distances. The measurement data is then used to calculate the model parameters, which will be used to control the distance between gateway and end-devices in the simulation. The RSS are presented as integers in dbm scale in measurements [2].

To address the different requirements reflected in the wide range of applications, LoRaWAN has various different classes of end-point devices.

**Class A - Bi-directional end-devices:**

Bi-directional communication is allowed for end-devices of Class A whereby two short downlinks receive windows follows each end-device's uplink transmission. The end-device schedules the transmission slot which is established on its own communication requirements with a small difference based on a random time basis (ALOHA protocol). After the end-device has sent an uplink transmission, this Class A operation is the lowest power end-device system for applications that only need downlink communication from the server. At any other time, downlink communications from the server will have to delay until the next scheduled uplink.

**Class B - Bi-directional end-devices with scheduled slots:**

Class B devices open extra receive windows at scheduled times. In addition to Class A. random accept windows in

a time synchronized Beacon from the gateway in order for the end-device to open its receive window at the scheduled time. When the end-device is listening, this agrees the server to know.

**Class C - Bi-directional end-devices with highest receive slots:**

End-devices of Class C have close transmit windows, nearly continuously opened when receiving.

Table 5: Market Status

	Europe	North America	China	Korea	Japan	India
Frequency band	867-869MHz	908-928MHz	470-510MHz	920-925MHz	920-925MHz	865-867MHz
Channels	10	64+8+8				
Channel BW up	125/250 KHz	125/250KHz				
Channel BW dn	125KHz	500KHz				
TX power up	+14dBm	+20dBm-typ(+30dbm is allowed)				
TX power dn	+14dBm	+27dBm				
SF up	7-12	7-10				
Data rate	250bps-50kbps	980bps-21.9kbps				
Link budget up	155db	154db				
Link budget dn	155dB	157db				

In definition by technical committee

## 5. CHALLENGES AND OBSTACLES

**New technologies for data connectivity:**

Without using 3G or Wi-Fi, new data network technologies permit for things to join to the internet. LoRaWAN is one of these technologies which is suitable for the IoT with low battery, long range, and low bandwidth. Imagine a network that can be used without cumbersome Wi-Fi passwords, mobile subscriptions, and zero setup costs [8].

**Low costs:**

Covering a whole city can be done with a small investment because the cost of the equipment is low and the impact is very high. For example, Amsterdam city was covered by only 10 gateways with each one costing 1200 dollars [8].

**Crowd sourced:**

To construct such a network, it has to base on large telecom corporations because the costs are not expensive. Instead, without any form of subscription, it can crowd source the network and make it public. Our goal is to enable a network by the users for the users [8].

LoRaWAN has capacity and interference challenges

1. When a gateway is transmitting, all gateway receive channels are disabled, thereby making it half-duplex only.

2. Testing shows LoRaWAN's MAC efficiency is only in the 18-22% range.

LoRaWAN has significant security and privacy risks

1. Public key handshaking cannot be executed safely via LoRaWAN due to networking limitations.
2. All encryption is handled using static keys, such as SIM cards.
3. LoRaWAN beacon mode is easily detected.

LoRaWAN does not support multi-hop

1. LoRaWAN does not support multi-hop networking.
2. LoRaWAN does not support mesh networking.
3. LoRaWAN does not support P2P networking.

## 6. MARKET STATUS

LoRaWAN design differs slightly from region to region relied on regulatory requests and the different regional band allocations. For Europe and North America the LoRaWAN plan are distinct, but the technical committee is still describing other areas. As a contributor member and sharing in the technical committee, linking the LoRa Alliance can have important benefits to companies for the Asia market as targeting solutions [7].

**LoRaWAN for Europe**

For Europe, LoRaWAN specifies 10 channels, one high data rate LoRaWAN channel at 11kbps, another for FSK channel at 50kbps and eight channels for multi data rate range from 250 to 5.5 kbps. With the exception of the G3 band that permits +27dBm, the maximum output power allowed by European Telecommunications Standards Institute (ETSI) is +14dBm. With no maximum transmission, there are duty cycle limitations under ETSI.

Table 6: Features

Feature	LoraWan	Narrow-band	Lte cat-1 2016(rel12)	Lte cat-M 2018(rel13)	NB-Lte 2019(rel13+)
<b>Modulation</b>	UNB/GFSK/BPSK	Ofdma	Ofdma	Ofdma	Ofdma
<b>Rx bandwidth</b>	500-125KHz	100Hz	20MHz	20-1.4MHz	200KHz
<b>Data rate</b>	290bps-50kbps	100bit/sec 12/8bytes max	10bit/sec	200kbps-1Mbps	20K bit/sec
<b>Max.#Msgs/day</b>	Unlimited		Unlimited	Unlimited	Unlimited
<b>Max output power</b>	20dbm	20dbm	23-46dbm	23/30dbm	20dbm
<b>Link budget</b>	154db	151db	130db+	146db	150db
<b>Battery life time - 2000mah</b>	105 months	90 months		18 months	
<b>Power efficiency</b>	Very high	Very high	Low	Medium	> Medium
<b>Interference immunity</b>	Very high	low	Medium	Medium	Low
<b>Coexistence</b>	Yes	No	Yes	Yes	No
<b>Security</b>	Yes	No	Yes	yes	Yes
<b>Mobility/ localization</b>	Yes	Limited mobility no loc	Mobility	Mobility	Limited mobility no loc

**LoRaWAN for North America**

For North America, the ISM band is from 902-928MHz. LoRaWAN specifies 64 and 125kHz uplink channels (902.3 to 914.9) MHz in 200kHz increases. In 1.6MHz, there are an extra eight 500KHz uplink channels increases (903 to 914.9) MHz. Starting from (923.3 to 927.5) MHz, there are eight downlink channels, 500kHz wide. In North America (902-928) MHz, the maximum output power is +30dBm band, but for most devices +20dBm is enough. There are no duty cycle limitations under Federal Communications Commission (FCC), but there is 400msec maximum time per channel.

**LoRaWAN Hybrid mode for North America**

The frequency hopping requirements for FCC require more than 50 channels to be used equally in the ISM band. To get advantage of the offered spectrum and permit maximum output power, LoRaWAN is defined with more than 50 channels.

Under a hybrid mode of operation, LoRaWAN modulation qualifies as a digital modulation technique so it is not observing all the frequency requirements stated by FCC, in which the maximum output power is restricted to +21dBm and only a subset of 8-channels out of the 64-uplink channels is used.

At the same time on the similar carrier from the FCC, a hybrid system uses both digital modulation and frequency hopping techniques. When the frequency hopping function is turned off, a hybrid system must submit with the power density standard of 8 dBm in any 3 kHz band. When the hopping function is turned on, the transmission also must observe with a 0.4 sec per channel maximum time. For this type of hybrid system, there is no requirements to observe with the 500 kHz minimum bandwidth normally associated with a Distributed Transmission System (DTS); and, there is no minimum number of hopping channels associated with this type of hybrid system.

In the IoT sector comparing LPWAN selections, there is a lot of activity, both from a technical comparison and from a business model view. There is a robust business case to support immediate deployment. So, LPWAN networks are being deployed now, and the installation cost of the network in unlicensed bands requires much less capital than even a 3G-software upgrade. To compare different LPWAN technologies, there are a number of questions that should be answered: [8]

- Flexibility needed to target a broad range of applications.
- Technical features, range, capacity, bi-directional communication, and interference robustness.
- Cost of network installation, end-node, and battery.
- Solutions suppliers' ecosystem needed for flexible business models
- End-products availability.

- Strength of the ecosystem to confirm quality and permanency of the solution.

The state of LoRa and LoRaWAN in other regions

There are strategies for nationwide deployment, local applications, and trials in some other countries.

LoRaWAN in the US:

There are two markets in the US to test the LoRaWAN IoT networks (Philadelphia and San Francisco). They have been designated for trials in IoT applications such as asset tracking, utility metering, and environmental monitoring.

However, Senet presents the first public LPWAN for IoT applications, using LoRaWAN in North America with coverage in more than 100 US cities.

LoRaWAN in Oceania:

On 20<sup>th</sup> September 2014, Semtech is deploying a LoRaWAN -based network in New Zealand, promising to cover half the population.

Focus on Asia-Pacific:

Several creativities are being deployed in Asia on top of Australia and New Zealand and Semtech and others are commonly present at events in the region.

To deploy a LPWAN network using the LoRaWAN protocol in its current fiscal year Telecom Asia covered the plans of Japanese operator SoftBank.

In India, Tata Communications promised at the end of 2015 that it would deploy a LoRaWAN network, which had been tried in Mumbai, Delhi and Bangalore. And on July 12th, Semtech released a statement saying that the national deployment of a LoRaWAN IoT network in South Korea by local telecom provider SK Telecom covered 99 percent of the population.

## 7. LORAWAN SIMULATION

This section discusses the design methodology and overviews the block sets in blocks include. [9]

### 7.1 Block Sets

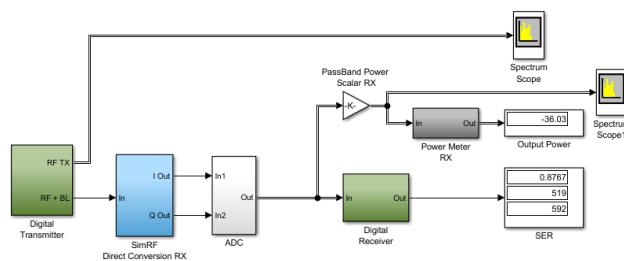


Fig. 8. The proposed simulation model.

Figure 8 shows a general view of the blocks used for the simulation model of Lora Transceiver using Matlab Simulink for the following fundamental components.

Digital Transmitter:

Figure 9 shows the digital transmitter including two 8-PSK modulated waveforms, a target waveform, and an interfering waveform. For pass band-waveform power measurement and spectrum visualization, the waveforms are scaled by  $1/\sqrt{2}$  and spaced in frequency.

Table 7: Values of low noise amplifier used in this simulation.

LNA power gain	18 db
LNA noise figure	3 db
LNA impedance	50 ohm

RF-Blockset:

Figure 10 shows the RF Block set consisting of amplifiers, mixers, S-parameter blocks, and other blocks for designing architectures for wireless transmitters and receivers in communications and radar systems. It permits to simulate RF amplifiers to guess gain, noise, even-order, and odd-order intermodulation distortion. Mixers are used to guess image rejection, reciprocal mixing, local oscillator phase offsets, and DC conversion. Also, the paper simulates frequency-dependent impedance unequal between linear and nonlinear components in the time and frequency domains.

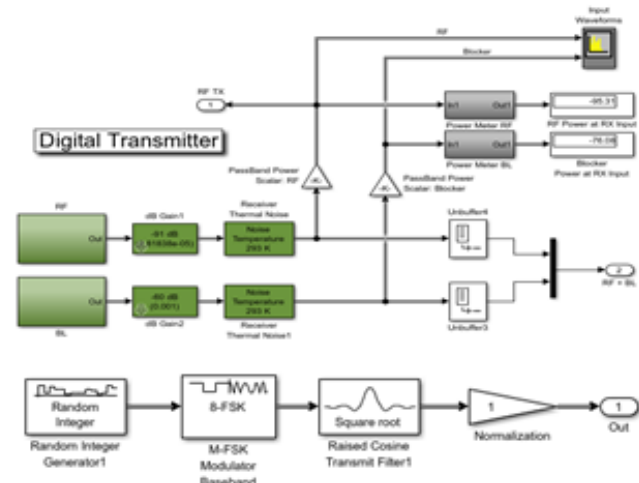


Fig. 9. RF block

To confirm performance and automatically set up a multicarrier simulation, the RF Budget Analyzer application permits to generate transceiver models and measurement exam benches.

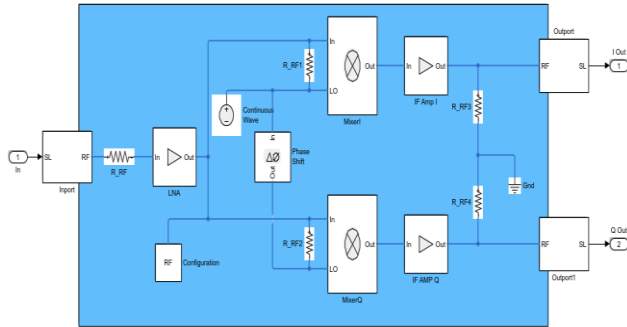


Fig. 10. RF-block set

A frequency conversion phase and two gain phases are included in the direct-conversion RF receiver. Each of the blocks capture RF impairments related to this design and each of the nonlinear blocks is specified in figure 10.

#### RF-Blockset basic components

The in port block imports Simulink signals into the RF Blockset. Complex-valued input signals  $I_k(t) + j \cdot Q_k(t)$  are the modulations at the frequencies  $\{f_k\}$  stated in the Carrier frequencies parameter of the block. The Source type parameter defines the Simulink signal as either current, voltage, or power source. The Continuous wave block models a constant modulation on a carrier in the RF Blockset.

The Resistor block models a resistor within the RF Block set model input and output resistance of the RF system in addition to the isolation between the LO and RF ports of the mixers. The Amplifier block is used to model a linear or nonlinear amplifier, with or without noise. Specifying the amplifier gain using a data source also specifies input data visualization and modeling.

Low-noise amplifier (LNA) is an electronic amplifier that enlarges a very low-power signal without considerably degrading its signal-to-noise ratio. An amplifier increases the power of both the signal and the noise present at its input. LNAs are designed to decrease extra noise. The LNA non-linearity is specified by IP3 and the nonlinearity of the IF amplifiers are specified by both IP2 and IP3 parameter.

The Configuration block is used to set the model settings for a circuit envelope simulation. To distinguish each topologically distinct RF Blockset subsystem, the block parameters describe a set of simulation frequencies, solver attributes, and thermal noise. To model a thermal noise floor in the RF Blockset environment; the temperature parameter in the configuration block defines a noise temperature of 290.0 K, each configuration block specifies the parameters of the linked RF Blockset subsystem.

The Mixer block performs signal frequency translation and nonlinear amplification. For a given RF input signal and an LO input signal, the mixer multiplies the signals at the input ports, this mixing converts the frequency of RF

signal to  $\omega_{RF} + \omega_{LO}$  and  $\omega_{RF} - \omega_{LO}$ . The frequencies must be included in the simulation frequencies of the configuration block calculations for the mixer to achieve this operation correctly.

The mixer block performs amplification after mixing the RF and LO signals. The mixer scales the signals by the coefficient  $a_1$  to model linear amplification. Nonlinear amplification is implemented by a Voltage Controlled Voltage Source (VCVS) defined with a polynomial which includes saturation automatically and yields extra intermodulation frequencies.

The mixer nonlinearity is specified as a scalar. It is specified by 2nd order intercept point (IP2) parameter. The default value of this parameter is 90 deg. The phase shift is applied to all nonzero simulation frequencies. For zero (DC) frequency, the shift is constantly zero. The Outpost block outputs carrier modulation signals in the RF Block set into Simulink. RF Block set current and voltage signals consist of in-phase ( $I_k$ ) and quadrature ( $Q_k$ ) components at each frequency  $f_k$  specified in the Configuration block.

#### ADC Block

The ADC is modeled using an ideal sampler and an 8-bit quantizer which takes into account the full-scale range of the ADC and the dynamic range. Next, the ADC properly models the system quantization noise floor and has a direct impact on the receiver performance. The ADC block outputs digital values representing the analog input signal [9].

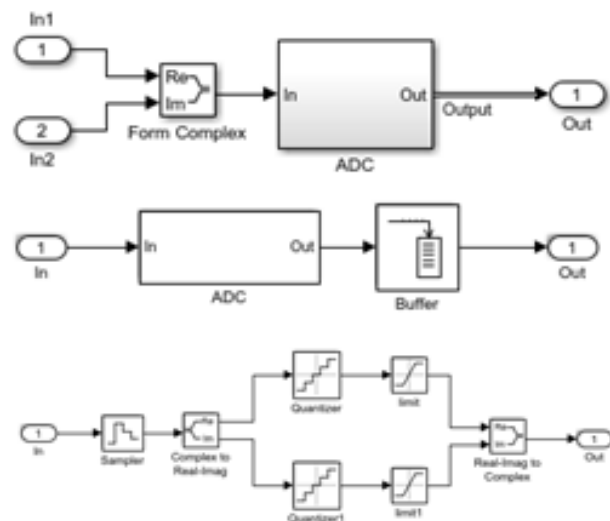


Fig.11. ADC Block set

#### Quantizer

The Quantizer block passes its input signal over a stair-step function and many neighboring points on the input axis are mapped to one point on the output axis to quantize a smooth signal into a stair-step output. The

output is calculated using the round-to-nearest method, which yields an output that is symmetric about zero.

### Sampler

The sampler block holds its input for the specified sample period. The block accepts one input and generates one output. Each signal can be in scalar or vector form. If the input is a vector, the block holds all elements of the vector for the same sample period.

### Limit

Saturation creates a default saturation nonlinearity estimator object for estimating Hammerstein-Wiener models.

### DC Offset Cancellation

The DC Blocker block removes the DC component of the input signal. To visualize the DC offset outcome associated with RF-LO isolation the manual switch in the design allows the user to switch the offset correction subsystem in and out.

### Digital receiver

As shown in Figure 12, a coordinated filter applied to the received waveform implements an AGC function and demodulate the waveform for symbol-error-rate calculation [9].

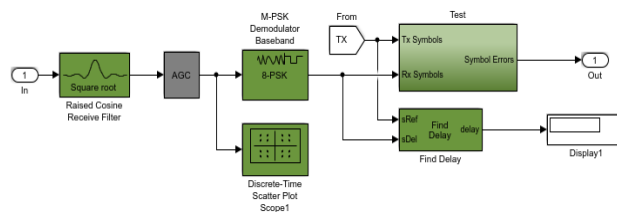


Fig. 12. Digital receiver.

The automatic gain controller (AGC):

Block adaptively adjusts its gain to achieve a constant signal level at the output.

The Discrete-Time Scatter:

Plot Scope block displays scatter plots of a modulated signal, to reveal the modulation characteristics, such as pulse shaping or channel distortions of the signal.

M-FSK Demodulator Baseband:

Using the M-ary frequency shift keying method, the M-FSK Demodulator Baseband block demodulates the signal. A baseband of the modulated signal is the input. The input and output for this block are discrete-time signals. This block receives a scalar value or column vector input signal of type single or double.

The M-ary number parameter (M), is the number of frequencies in the modulated signal.

## 8. RESULTS

As shown in Figure 13, the wave inputs, which are composed of the radio frequency (RF) and blocker, the blue wave is blocker, and the yellow wave is radio frequency. Resolution Bandwidth is 23.46kHz and it takes time 960  $\mu$ sec and the waveform at transmitter is the same.

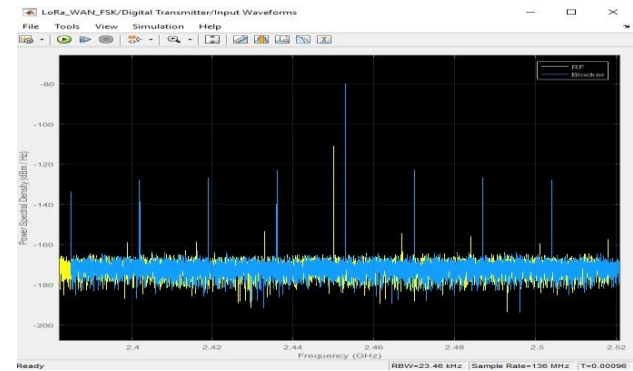


Fig.13. RF + BL signal.

Figure 14 and Figure 15 show that the receiver signal is like a transmitter signal with a slight difference. This is normal due to a noise which occurs when the signal is sent, ADC has a direct influence on the receiver performance. Resolution Bandwidth at transmitter is 23.43kHz. Resolution Bandwidth at receiver is 23.44kHz. It take time 960  $\mu$ sec. The error rate calculation equal 0.8767.

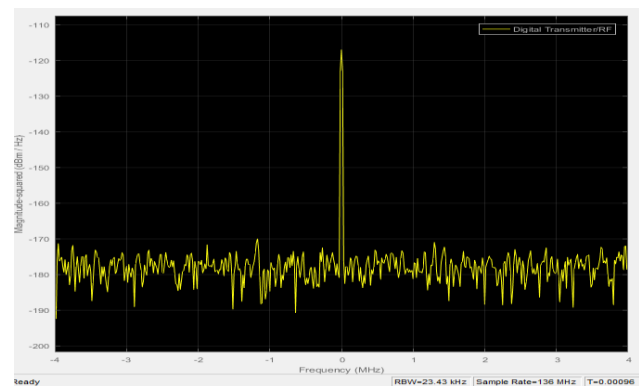


Fig. 14. Transmitted signal.



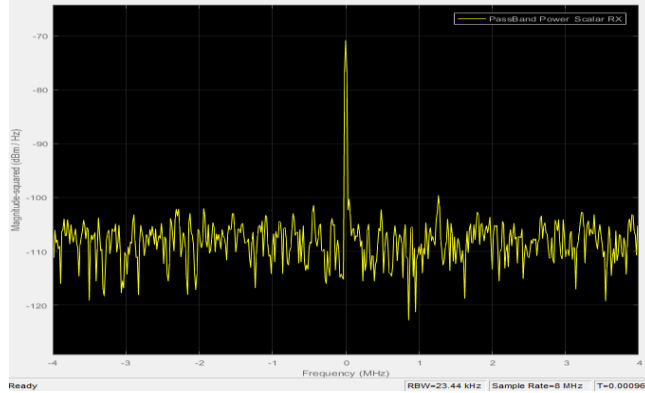


Fig. 15. Received signal.

Figure 16 represents a constellation chart of the input signals and the relationship between Quadrature Amplitude on y-axis and In-phase Amplitude on x-axis.

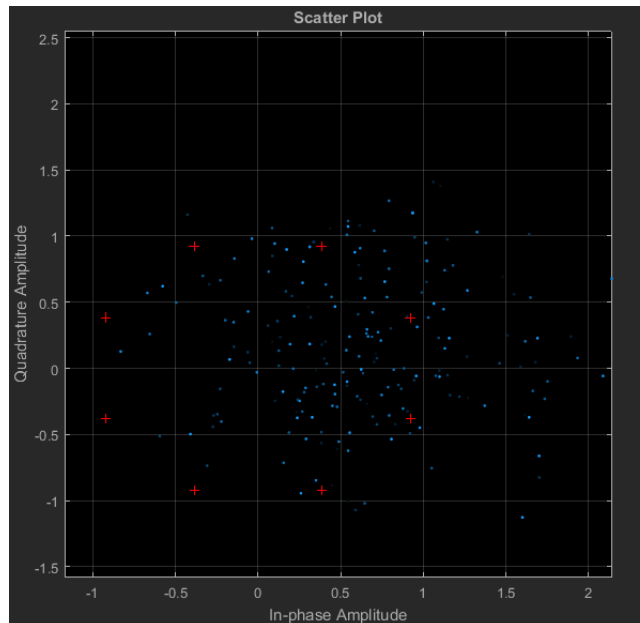


Fig. 16. Discrete time-scatter

Figure 17 shows the Discrete time-scatter relation between Quadrature Amplitude and trajectory on y-axis and In-phase Amplitude on x-axis

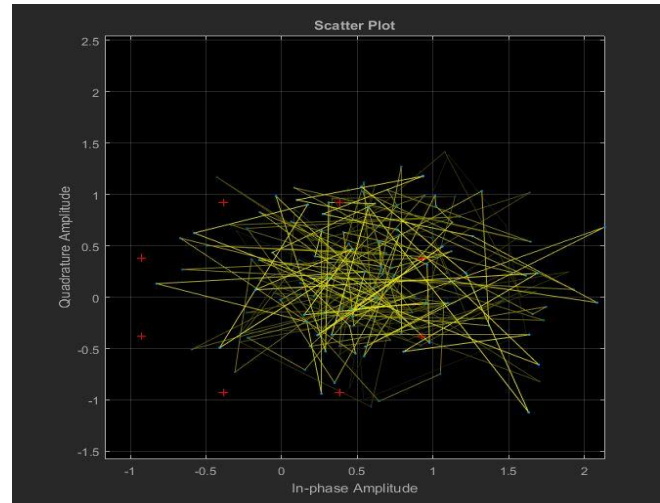


Fig. 17. Discrete time-scatter.

## 9. COMPARISON

### 9.1 LoraWAN vs. LoraWAN Standard

In this section, we will compare the simulation of LoRaWAN with the standard of LoRaWAN. We will compare power and bandwidth because frequency band depends on the different regions, range is fixed and packet size is defined by the user [11].

Table 8: LoraWAN vs. LTE CAT M [10].

Name of Standard	LoRaWAN	Weightless		
		-W	-N	-P
Frequency Band	433/868/780/915 MHz ISM	TV whitespace(400-800 MHz)	Sub-GHz ISM	Sub-GHz ISM
Channel Width	EU: 8x125kHz, US: 64x125kHz/8x125kHz Modulation: Chirp Spread Spectrum	5MHz	Ultra narrow band (200Hz)	12.5 kHz
Range	2-5k (urban), 15k (rural)	5km (urban)	3km (urban)	2km (urban)
End Node Transmit Power	EU: <+14dBm US: <+27dBm	17 dBm	17 dBm	17 dBm
Packet Size	Defined by User	10 byte min.	Up to 20 bytes	10 byte min
Uplink Data Rate	EU: 300 bps to 50 kbps US: 900-100kbps	1 kbps to 10 Mbps	100bps	200 bps to 100 kbps
Downlink Data Rate	EU: 300 bps to 50 kbps US: 900-100kbps	same	No downlink	same
Devices per Access Point	Uplink: >1M Downlink: <100k	Unlimited	Unlimited	Unlimited
Topology	Star on Star	Star	Star	Star
End node roaming allowed	Yes	Yes	Yes	Yes
Governing Body	LoRa Alliance	Weightless SIG		
Status	Spec released June 2015 in deployment	Limited deployment awaiting spectrum availability	Deployment beginning	Standard in development. Scheduled release 4Q 2015

### End node transmit power:

Power in the standard of LoRaWAN in Europe is less than +14dBm. Power in our simulation of LoRaWAN is +14dBm.

### Bandwidth:

As we mentioned previously Bandwidth= 23.44 kHz. In standard of LoRaWAN channel width= 8 x 125kHz. So, Bandwidth is less than the channel width. Which shows us that the signal can be transmitted from channel width.

## 9.2 LoRaWAN vs other networks

Various wireless communication technologies designed at low power have been proposed and installed. Their fall within two types:

1. Local area networks which have low power with lower than 1000-m range. It contains IEEE 802.15.4, IEEE 802.15.4g, Bluetooth/LE, etc., which are valid directly in short-range personal area networks.
2. Wide area networks which have low power with greater than 1000-m range. These are low-power cellular networks, with each "cell" covering thousands of end-devices. It includes LoRaWAN, LTE Cat M, Sigfox, DASH7, etc. [11]. The differences between LoRaWAN and LTE Cat M are related to network topology and coverage, communication performance, industry standards, and security.

LoRa Alliance™ provides certification for vendor interoperability for LoRaWAN. LoRaWAN is used in low power devices with rare data transmissions and typically placed out in a star topology with gateways depending messages between end-devices and a central network server.

LTE Cat M is expected to be used for low power and infrequent data transmission devices and a mobile technology description by the 3GPP standards body. It can operate in the GSM spectrum or use an unused resource block within a LTE carrier's guard-band.

Table 9: Security element of LoRaWAN and LTE CAT M

Security Elements	Network	
	LoRaWAN	LTE Cat M
Authentication Chain of Trust across the platform for mutual authentication and applications	Not Specified	Challenge/response authentication using pre-shared secret
Key Exchange and Distribution	Static key exchange; no rotation	
Key Generation and Storage	Not specified	
Data Transmission	AES, CMAC and pre-shared secret	LTE data transmission encryption: AES
Network Access Control	Authentication via pre-shared secret	Challenge/response authentication using pre-shared secret
Network Topology and Coverage		

Topology: LoRaWAN and LTE Cat M networks are connected via a tower or star-based topology and Commonly used in cellular networks, a star topology uses gateways (cellular towers).

### Coverage:

LoRaWAN: 2-5k (urban), 15k (rural)

LTE CAT M : 2.5- 5km

### Communication Performance:

Communication performance of a technology have large effect on the usable period and network functionality. LoRaWAN and LTE Cat M are designed for low bandwidth and infrequent communication. They can drive down device costs and extend battery life. Table X shows a comparison of LoRaWAN versus LTE CAT M.

### Bandwidth:

LoRaWAN: ~100kps

LTE CAT M: ~200kps

### Frequency band:

LoRaWAN: 433/868/780/915 MHz ISM

LTE CAT M: Cellular

### Channel width:

LoRaWAN; EU: 8x125kHz, US 64x125kHz/8x125kHz

LTE cat M: 1.4MHz

### Packet size:

LoRaWAN: Defined by User

LTE CAT M: ~100 ~1000 bytes

### End Node Transmit Power

LoRaWAN: EU: <+14dBm, US: <+27dBm

LTE CAT M: 100 mW.

Table 10 : Comparison of LoraWAN vs. LTE CAT M [10]

Standard Name	LoRaWAN	LTE CAT M
Frequency Band	ISM (433/868/780/915) MHz	Cellular
Width of Channel	For Europe: (8x125)kHz, For US (64x125)kHz/(8x125)kHz	1.4MHz
Range	For Urban (2-5)k, For rural is 15k	(2.5- 5)km
Transmit Power for End Node	Europe: <+14dBm, US: <+27dBm	100 mW
Size of Packet	User define	~100 ~1000 bytes typical
Data Rate for Uplink	EU: 300 bps to 50 kbps, US: 900-100kbps	~200kbps
Data Rate for Downlink	EU: 300 bps to 50 kbps, US: 900-100kbps	~200kbps
Devices per Access Point	Uplink: >1M, Downlink: <100k	20k+
Topology	Star on Star	Star
Roaming allowed for End node	Yes	Yes
Governing Body	LoRa Alliance	3GPP
Status	In deployment	Release 13 Expected 2016

## 10. CONCLUSION

The paper discussed an overview of LoRaWAN, its architecture, how it works, implementation, challenges and obstacles, market status and the design methodology of the main block sets used in LoRaWAN transceiver. LoRa Transceiver model was built with Matlab Simulink using fundamental components in Simulink to demonstrate how reliable complex modulation schemes can be built. The paper compared the simulation of LoRaWAN with the standard of LoRaWAN. We compare power and bandwidth because frequency band depend on the different regions, range is fixed, and packet size defined by the user. Comparison between LoRaWAN and LTE Cat M according to the network topology and coverage, communication performance, industry standards, and security is done.

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