LoRa

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***Abstract*—IoT is gaining high popularity in today's World. IoT connects various objects to enable exchange data between them and stay connected. LoRa is a technology adresses the requires of these systems such as consumes less power and covers longe distances. LoRaWAN (Long Range Wide Area Network) is an open grade secure standart for the IoT connectivity. This paper focuses on the LoRa technology. After defining the LoRa it presents features of LoRaWAN and its architecture. Furthermore it handles with the physical layer concept.**

***Index Terms*—IoT, LoRa, LoRaWAN, Physical Layer**

I. Introduction

Internet of Things (IoT: Internet of Things) applications have spread over large areas and have changed our lives. The number of application projects are increasing in the fields of smart city, smart agriculture, smart factory. Since the application scope expand and number of objects which will be used for IoT network increase, new needs show up for solutions. Especially in long distance data transmission, The need for new communication technologies that will allow sensors to work with low power consumption is rising. LPWAN(Low Powered Wide Area Network) technologies are the protocols to fill this space. Examples of these LPWAN technologies are LoRa [1], Sigfox [2] and Weightless [3]. These technologies are very useful to collect data from thousands of sensors in long distances with very low energy budget. These transceivers are potentially very useful to more generic IoT networks incorporating multi-hop bi-directional communications enabling sensing and actuation.

II. LoRa

LoRa is based on spread spectrum modulation techniques derived from chirp spread spectrum (CSS) technology by Semtech, which allows it to transmit data over long distances with low power consumption. Because of the modulation schemes the transceivers have unique features. So it is not efficient to use these transceivers with any existing Media Access Layer(MAC). These unique features should be taken into account when creating network with these transceivers. LoRaWAN is currently suggested MAC layer.

III. LoRaWAN

LoRaWAN is a Media Access Control (MAC) layer protocol built on top of LoRa modulation. LoRaWAN operates in the sub-gigahertz frequency bands, which allows it to transmit over long distances with minimal power consumption. It supports low bandwidth, making it perfect for IoT applications. In additionally it is a bi-directional communication protocol which is designed and maintained by the LoRa Alliance. It wirelessly connect devices to the internet and manages communication between end-node devices and network gateaways.

A. *LoRaWAN Architecture*

LoRaWAN architecture is deployed in start-of-stars topology. In the star topology the bridge or switches are directly connected to a small subset of bridge or switches deceasing complexity of the network. These provide a hierarchical infrastructure. They decrease the power consumption and battery life to a great extend.

On the other hand, most of the existing technologies are based on mesh network. In the mesh network each node receives and forward data from other node that might be irrelevant for it. This increases the range to a great deal but also adds complexity and decreases the battery life. Compared to this aspect LoRaWAN has more benefits.

A typical LoRaWAN network consist of 4 elements. Such that

1. End Devices

End devices can be a sensor, an actuator or both .They send LoRa modulated wireless messages to the gateaways or receive messages wirelessly back from the gateways. This is

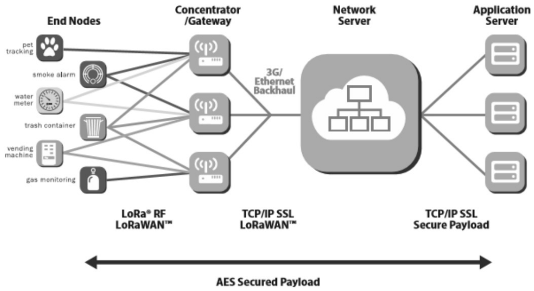

Fig. 1. LoRaWAN Network Architecture

the heart of an embedded system. For instance water meter, smoke alarm, gas monitoring and such applications.

2. Gateways

A gateway receives LoRa messages from end devices and forward them to the Network Server. Each gateway is connected to every end node. The data transmitted by the node is sent to all the gateways and each gateway which receives a signal transmits it to a cloud based network server via cellular, Ethernet, satellite, or Wi-Fi. There are two types of gateways which are micro and pico gateways. Micro gateways are used in public network to give city or nationwide coverage while the Pico gateway is used in hard to reach dense areas to improve the quality of service and network capacity.

3. Network Servers

A Network Server manages gateway , end devices ,applications and users in the entire LoRaWAN network .The data received from different gateways is filtered, security checks, adaptive data rates etc., are performed and acknowledgement is sent to the gateways . The network server is the one who identifies whether the data received is intended for any application server and is thus sent to the intended application server via some backhaul.

4. Application Server

A piece of software running on a server that is responsible for securely processing application data that received from end devices. It also generates all the application-layer downlink payloads and sends them to the connected end devices through the Network Server. A LoRaWAN network can have more than one Application Server.

B. Features of LoRaWAN Technology

Long Range : It is capable of transmitting data over long distances. The long range of the LoRa technology is due to its link budget and the chirp spread spectrum modulation that it employs.

(The chirp spread spectrum has a low transmission power requirement. Chirp is a signal whose frequency increases or decreases over time. Thus, a chirp signal can be up-chirp and down-chip. In the chirp spread spectrum modulation the wanted data signal is multiplied with the chirp signal. This spreads the bandwidth beyond the bandwidth of the original data.)

Long Battery Life : LoRa optimizes the battery consumption in a device and is most suited for battery operated embedded device. LoRa consumes the least power when compared to all the existing technologies. The low battery consumption in a LoRa networks accounts to the asynchronous communication of the nodes in the network

Security : LoRa network incorporate two layers of security: network security and application security. The network security is used for authenticating the node in the network while the application security protects the end user application data from the network operator. The LoRa technology uses two keys for the security and authenticity: NwkSKey (Network Session Key) and AppSKey (Application Session Key).

High Capacity : The LoRa network gateway receives data from large number of nodes. For this the gateway must have high capacity. This is achieved by adaptive data rate and multichannel multi-modem transceiver at the gateway.

Low Cost : LoRaWAN uses a decentralized network architecture, with devices communicating directly with gateways rather than relying on a central server or infrastructure. This further

reduces the cost of deployment, as it eliminates the need for expensive infrastructure such as base stations or cell towers.

C. MAC Protocol

The Media Access Control (MAC) protocol in LoRaWAN is responsible for managing the Access of devices to the shared radio frequency spectrum, as well as for handling the transmission of data over the network. The MAC protocol defines a set of rules and procedures that the devices use to communicate with each other and with the gateways.

Some of the key functions of the LoRaWAN MAC protocol include:

Channel Hopping: LoRaWAN uses a technique called frequency hopping spread spectrum (FHSS) to mitigate interference and improve reliability. The MAC protocol coordinates the hopping sequence between devices and gateways to ensure that they can communicate effectively.

Adaptive Data Rate (ADR): LoRaWAN uses ADR to dynamically adjust the data rate of a device based on the quality of the wireless link. The MAC protocol manages the ADR process to ensure that devices are able to transmit data at the highest possible rate while still maintaining a reliable connection.

Duty Cycling: To minimize power consumption, LoRaWAN devices spend most of their time in a low-power sleep mode. The MAC protocol coordinates the waking and sleeping of devices to ensure that they are able to communicate effectively while still conserving energy.

The end nodes in a LoRa network are divided into three basic classes according to their battery lifetime and the downlink communication latency. The class of an end node is determined by its firmware and hardware, and it cannot be changed after the device has been deployed. The choice of end node class depends on the specific requirements of the application and the trade-offs between energy efficiency and communication capabilities.

A. Bi-Directional End Devices (Class A)

Class A end nodes are the most common type of end node in LoRaWAN. These are the lowest powered end device system. They are designed to be energy-efficient and have two receive windows after each transmit window. The node transmits to the gateway when needed. After transmission the node opens a receive window to obtain queued messages from the gateway. Uplink slot is scheduled by End device itself based on its need. It is decided on random basis similar to ALOHA protocol. Following an uplink, a Class A end device opens a short receive window (Rx1) and, if no downlink is received during that period, it opens a second receive window (Rx2). The start time of Rx1 begins after a fixed amount of time following the end of the uplink transmission. Typically, this delay is one second, however this duration is configurable.

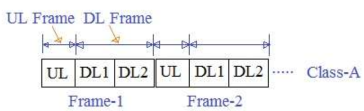

Fig. 2. Class A end device.

B. Bi-directional end-devices with scheduled receive slots (Class B)

In class B addition to the random receive slots of class A there is additional scheduled receive slots which are called ping slots. Therefore, there are more receive slots than class A which opens at scheduled times. This allows them to receive downlink messages from the network more frequently, at the expense of increased power consumption. For this to work, a time-synchronized beacon is broadcast periodically by the network via the gateways. The end device must periodically receive one of these network beacons so that it can align its internal clock with the network. Based on the beacon timing reference, end devices can open receive windows (ping slots) periodically. Any of these ping slots may be used by the network infrastructure to initiate a downlink communication.

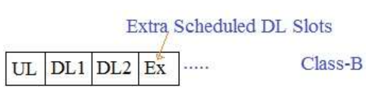

Fig. 3. Class B end device.

C. Bi-directional end-devices with maximal receive slots (Class C)

Unlike class A and class B, the class C devices open their receive slots all the time. The receive slot is closed only when the end device is transmitting. Since the class C end devices have their receive slot open all the time they consume more power than the other two classes. But these classes provide lowest latency for communication. These can be used for only those devices that do not have any power constrains.

Fig. 4. Class C end device.

IV. LoRa Physical Layer

A. Overview of Physical Layer

LoRa is a physical layer technology utilizing a spectrum spreading technique developed by SEMTECH Corporation called CSS(Chirp Spread Spectrum) modulation to transmit messages, giving high communication rates for range and energy consumption. Its modulation consists of the representation of bits 0 and 1 as a linear variation of frequencies.

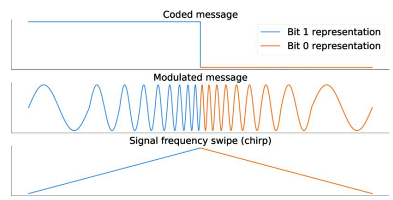

Fig. 5. Bit representation for LoRa-based networks.

This technology operates in an unlicensed ISM (Industrial, Scientific, and Medical) spectrum (900 MHz in the US) and (868 MHz in Europe).In order to limit interferences, regulatory authorities specified a duty cycle ranging from 0.1 to 1 depending on the used sub-band. While other IoT technologies are proprietary, LoRa network management is open and every person has the possibility to deploy LoRa stations or networks and to offer services as long he respects spectrum use regulations. The upper layers to LoRa can be proprietary or standardized. The most popular standard is LoRaWAN, which is implemented by LoRa alliance.

B. Parameters of Physical Layer

Several parameters are available for customizing LoRa modulation: bandwidth (BW), spreading factor (SF), and code rate (CR). These parameters directly affect the efficiency of the LoRa modulation bit rate , its decoding facility and its resilience to parasitic noise. The shift rate of frequency is controlled by a parameter called SF (Spread Factor). The higher this value, the better is the signal's immunity against noise, and the lower is the data transmission capacity of the link.

As it can be seen by the equation below, the BW and SF affect the symbol duration. For a fixed BW a higher SF results higher symbol duration.

Bandwidth(BW) is the range of frequencies in the transmission band. Higher BW gives higher bit rate, lower BW gives lower bit rate.

$$T_s = \frac{BW}{2^{SF}} \tag{12}$$

In addition, LoRa includes a FEC (Forward Error Correction) code, where the code rate (CR) is equal to 4/(4 +n), withn 1,2,3,4. Considering this, as well as the fact that SF bits of information are transmitted by symbol,the equation below allows us to calculate the useful bit rate (Rb).

$$Rb = SF \times \frac{BW}{2^{SF}} \times CR \quad (3)$$

C. LoRa frame Structure

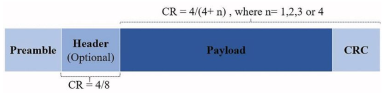

Fig. 6. LoRa full packet structure

Figure 6 shows a detailed LoRa frame structure.Generally, a LoRa message contains three main parts. The bandwidth and spreading factor are constant for a frame. A LoRa frame begins with a preamble.The preamble which is used to detect the Lora signal and enable to synchronize and cover the whole frequency band using the up-chips and down-chips sequences.The last two upchirps encode the sync word. The sync word is a one-byte value that is used to differentiate LoRa networks that use the same frequency bands. A device configured with a given sync word will stop listening to a transmission if the decoded sync word does not match its configuration. The sync word is followed by two and a quarter downchirps, for a duration of 2.25 symbols. It can be seen in the figure 7.

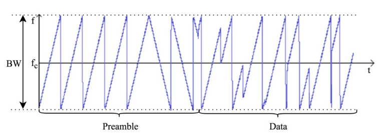

Fig. 7. Sample of a emitted signal.

In some cases, the packets may contain an additional element called the header. This element carries information in 4 bytes about payload length, the coding rate, and the Cyclic Redundancy Check (CRC) which is used to detect error blocks in digital data with the use of CR equals4/8. A payload is used to carry the data to be transmitted and the parity checks data.

According to the equation below, the number of symbols that can be carried on a single Payload depends on other parameters of the physical layer like CRC, payload length, SF, coding rate, preamble size frequently 8 bytes, and the presence or the absence of header in the LoRa packet. This number should be added to the number of symbols of the preamble, in order to compute the total size of the packet in symbols.

PL = payload size,

SF = spreading Factor

CRC = 16 if the CRC is enabled, 0 otherwise,

H = 20 when the header is enabled, 0 otherwise

DE = 2 when the low data rate optimization is enabled, 0 otherwise

CR = Code Rate

$$n_s = 8 + max\left(\left\lceil \frac{8PL - 4SF + 8 + CRC + H}{4 \times (SF - DE)} \right\rceil \times \frac{4}{CR}, 0\right)$$

Fig. 8. Formula of the number of symbols that can be carried on a single payload.

V. LoRaBlink

LoRaBlink, proposed in [4], was the first proposal that includes several points, such as multi-hop communications. LoRaBlink was proposed to provide low latency, reliable, and energy-efficient multi-hop communications in LoRa networks. It integrates MAC and routing in a single simple protocol. The proposed approach is divided into a beacon period for synchronization and a data period. The gateway which is connected to the network server initiates the entire network operation by sending a beacon. The direct nodes that can hear the gateway receive the beacon and use the flooding approach to transmit concurrently their own beacons. By exploiting the capture effect of the concurrent transmissions of LoRa, at least one beacon will be received by the other nodes that can not hear the gateway. The next nodes will perform the same process and increment the hop count by one. When a node receives a beacon, it checks if its hop count to the gateway is lesser than the hop count includes in the beacon message. If it is the case, the message will be discarded. After the beacon period, a node that has data selects a slot and broadcasts it. This message is flooded until it reaches the gateway. Nodes that receive the message check if their hop count to the gateway is lower than the source node hop count to the gateway. Only nodes with a lower hop count to the gateway will relay the message and send an Acknowledgment (ACK) to the source node. When the gateway finally receives the message after several hops, it replies with an ACK. The ACK is also flooded concurrently until it reaches the previously source node that sent the data. Although the proposed LoRaBlink is simple, it is not efficient in large-scale networks due to several collisions

Conclusion

As a result of the aforementioned technical advantages of its, the technology has developed and is being promoted and used worldwide. LoRa technology has the potential to be utilized in various emerging IoT applications. It provides a significantly greater communication range with low bandwidths than other competing wireless data transmission technologies. It is a preferred and most suited technology for the IoT applications that need to communicate a long distance and in which the battery lifetime and power consumption is a major limitation.

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