LoRa Technology

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Low-power wide-area networks (LPWANs) constitute a variety of modern-day Internet of Things (IoT) applications. Long range (LoRa) is a promising LPWAN technology with its long-range and low-power benefits. Performance enhancement of LoRa networks is one of the crucial challenges to meet application requirements, and it primarily depends on the optimal selection of transmission parameters.

LPWAN LoRa spreading factor

1. Introduction

The low-power wide-area network (LPWAN) is a promising technology for the growing Internet of Things (IoT) and machine-to-machine (M2M) applications offering wide-area communication among a large number of devices with benefits such as low power and low cost. It can cater to a wide range of applications, such as agriculture, healthcare, home automation, smart city, smart grid, monitoring of industrial assets, critical infrastructure, environment, wildlife, and many others. Long range (LoRa) is an LPWAN technology that requires low power and offers long-range communication. It uses the unlicensed industrial, scientific, and medical (ISM) band with frequency ranges such as 433, 868, or 915 MHz, and can support data rates up to 50 Kbps. A LoRa network is built on the star of stars topology that comprises multiple nodes that communicate with a gateway using the LoRaWAN MAC layer protocol, and the Chirp spread spectrum (CSS) modulation method. The gateways relay the messages from the end devices to the network server [1]. LoRa modulation offers several parameters for customization, such as channels, spreading factors (*SFs*), transmission power, bandwidth, and data rate. The choice of these parameters affects the transmission energy, range, time-on-air, coverage, capacity, and overall performance of the network [2]. The end devices communicate with the gateway using an available sub-channel and one of the six spreading factors. Collision may occur if different devices use the same channel and the same spreading factor simultaneously. Since there can be a large number of end devices in the network, the probability of collision increases, resulting in the degradation of network performance. Additionally, as the network grows, vulnerability and security issues arise wherein CSS used by LoRa seems to offer a robust approach [3]. In this context, machine learning algorithms can be utilized for optimal parameter selection to minimize interference and maximize energy efficiency, and, in turn, maximize the network performance [4]. Efficient resource utilization and adaptive transmission are approaches to achieve better energy efficiency in LPWANs [5].

Resource allocation or parameter selection approaches in LoRa networks can be categorized as a centralized and distributed approach. A device can individually select its data rate and transmission power or let the network control these parameters. The adaptive data rate mechanism (ADR), recommended by the LoRa Alliance and implemented by the LoRa network, is an example of a centralized approach. The network server controls the transmission parameters of the end node. It reduces the transmit power of a node by adapting the data rate. In such a case, the network needs the knowledge of the transmitted power of the node for about the previous twenty transmissions, and then it estimates the transmit power for the next transmission by changing the data rate and communicates it to the node. The node then uses the information received from the server and adapts its parameters. However, the disadvantage of this approach is that it is suitable only in stable RF situations where the end nodes do not move [1]. In practical situations, the nodes can be mobile. Even for the simplest configuration with assumptions such as the Poisson point process distribution, i.e., nodes are uniformly distributed around the gateway, constant transmit power, single channel, and no interference from non-LoRa nodes, selecting the optimal parameters is still a complex problem. The ADR algorithm also has some limitations. ADR allocates *SF* to a node, depending on the uplink signal-to-noise ratio (SNR), so that nodes closer to the gateway select lower *SF* and nodes farther from the gateway use higher *SF*. If all the nodes are closer, then ADR may allot the same *SF* to them, leading to collisions due to the overuse of the same *SF* and underuse of other *SFs* [6]. Additionally, ADR tends to reduce energy consumption but suffers large packet losses [2].

The distributed learning algorithms seem useful in such scenarios where the end devices are considered as intelligent agents that choose a particular parameter from a given set of values at a given time.

2. LoRa Technology

Long range (LoRa) is a proprietary technology by Semtech, which uses the chirp spread spectrum modulation method [7]. The default medium access control (MAC) protocol, LoRaWAN [1], is usually used with the LoRa networks. Chirp spread spectrum modulation has low-power characteristics similar to frequency-shift keying modulation, but provides a better communication range. The available LoRa transceivers work at a 137 MHz to 1020 MHz range of frequencies. Thus, they can work in licensed bands but are usually used in unlicensed ISM bands, such as 433 MHz, 868 MHz, and 915 MHz [8]. As illustrated in **Figure 1**, in a LoRaWAN network, the data transmitted by an end device can be received by multiple gateways in the neighbourhood. Each gateway forwards the packet from the end device to the cloud-based network server using some backhaul (either satellite, cellular, Ethernet or Wi-Fi). The network server manages the intelligent and complex tasks, such as removing redundant packets, sending acknowledgements through the suitable gateway, and performs adaptive data rates. Handover is not required from one gateway to another, even for mobile nodes. Nodes in the LoRa network are asynchronous and communicate when they have data to send, using pure ALOHA, which saves energy. The LoRa network uses ADR and a multi-channel multi-modem transceiver in the gateway, thus ensuring good network capacity. The capacity depends on the number of channels, data rate, and how often the nodes transmit. Different spreading factors lead to orthogonal signals and changes in the data rate. Thus, the gateway can receive multiple different data rates on the same channel simultaneously [1][9]. Several alternatives to increase coverage and data rates and avoid interference in LoRa networks are also being explored [10].

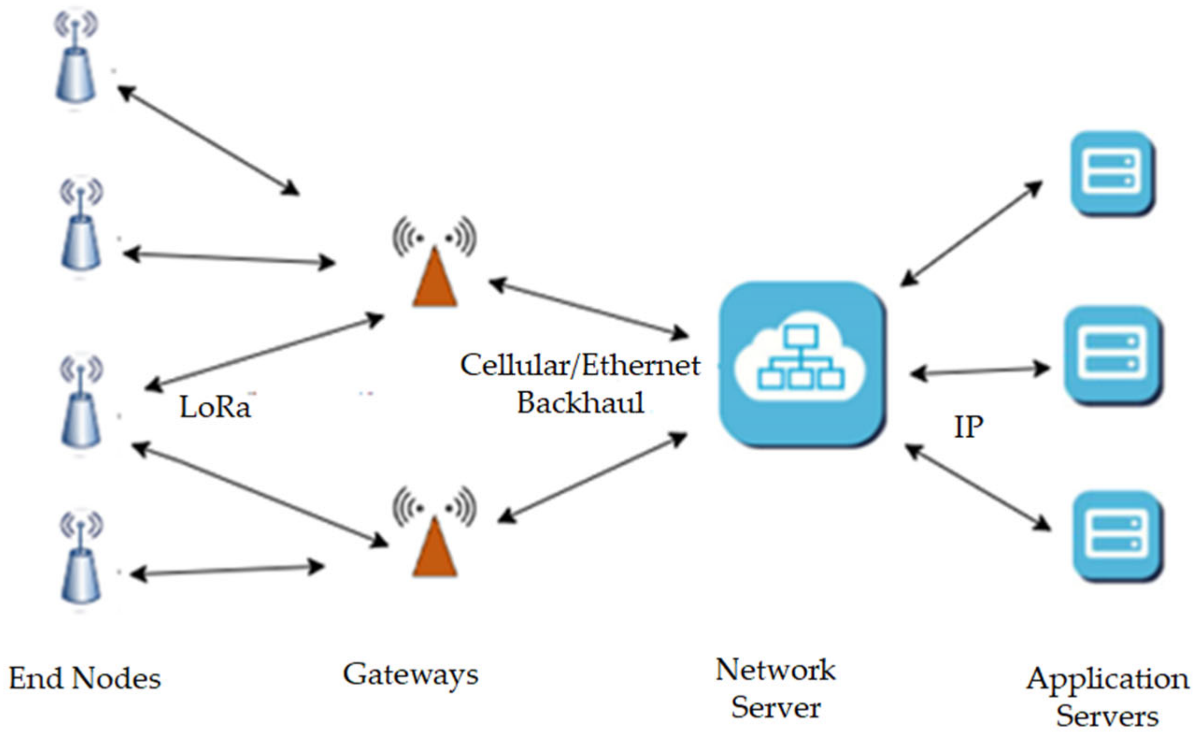

Figure 1. LoRa network architecture.

Any LoRa device can be configured for different parameters such as spreading factor, transmission power, carrier frequency, bandwidth, and coding rate [7]. As per the regulations, transmission power can be changed approximately in stages of 1 dB from 2 dBm to 17 dBm. The ratio of symbol rate to chip rate is termed as a spreading factor, and the higher the spreading factor, the more SNR, sensitivity, range, and also packet airtime. *SF* can be selected as any value from 7 to 12 [9]. A typical LoRa network works at a 125 kHz, 250 kHz, or 500 kHz bandwidth. A higher bandwidth gives a higher data rate, but the sensitivity reduces. The LoRa modem uses forward error correction (FEC) with a coding rate that can be set to 4/5, 4/6, 4/7, or 4/8. A higher coding rate means a better guard against errors but increases time-on-air.

The transmission power, the time for transmitting a packet, and the number of transmissions required for successful packet transmission are the important parameters for the improvement of network performance. The number of retransmissions is reduced if interference or collision are reduced. For LoRa, with an increase in the spreading factor (*SF*), the sensitivity improves, the need for retransmissions reduces, and then the average energy required for transmitting a packet also reduces. Based on the LoRa packet format, the time required to transmit a packet or ToA is given as [9]

An LPWAN network can be a single gateway or multi-gateway network comprising LoRa and non-LoRa nodes. LoRa uses a chirp spread spectrum with quasi-orthogonal spreading factors (*SF*). The typical *SF* values are 7, 8, 9, 10, 11, or 12. Interference can be from other LoRa nodes using the same *SF* (Co-SF), other LoRa nodes using different *SF* (Inter-SF), and other nodes using the same carrier frequency but not LoRa technology.

At the gateway, a signal is detected when the ratio of received signal to interference plus noise is greater than the receiver sensitivity for a particular *SF* at the desired LoRa node. For the high value of SINR, the interference power needs to be low, and the signal power should be high. For low-energy consumption, the signal power should be less. From the above equations, it is implicit that as *SF* increases, sensitivity improves, and the SINR required also decreases. For lower *SF*, ToA, average energy, and throughput are also low. As the network size *N* increases, the number of devices with the same *SF* would increase, and hence the probability of a successful transmission drops. There is always a trade-off between energy efficiency and interference avoidance.

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