

Analytic Model of a Mesh Topology based on LoRa Technology

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Abstract— In the last decade, the Internet of Things (IoT) technologies have brought a lot of applications in different fields. Many communication technologies have been developed in order to connect everything to each other and to the Internet. Besides, the long-range power-efficient wireless technologies have emerged such as LoRa (Long Range), which enables transmission over long distances with low energy consumption and can work within p2p, star or mesh topologies. In this paper, we analyze a model of a mesh topology for the LoRa network, which is attracting more interest in the applications of Smart City and Smart Agriculture. While the mesh topology is described by a graph, a method of route selection is considered based on the link quality related to Received Signal Strength Indication (RSSI) to find the optimal path from a source to a sink node. The network performance is evaluated by considering each node as a queueing system. As the analytic results, the routes are found from device nodes to the gateway, and the delivery latency is analyzed in the dependence on the load intensity and the number of relay nodes.

Keywords— Internet of Things, LoRa, mesh topology, routing method, latency

I. INTRODUCTION

Nowadays, info-telecommunication technology is one of the main infrastructures of any country or company. The advent of the Internet has helped change the approach to information. The Internet brings information to users, communicates people to the other, human to machine and machine to machine. This term is called the Internet of Things (IoT), where every device can connect to each other over the Internet, as described in [1], [2]. This leads to the expectation of the revolution Industry 4.0.

The Internet of Things has been attracting many interests in both scientific and commercial fields [3]. Many IoT applications have been developed as solutions for Smart Devices, Smart Home, Smart City, Smart Factory, etc. Parallel with that, communication technologies also have contributed greatly to the development of the IoT applications. Many technologies have been proposed in order to ensure the quality of connection in the network while the number of connected devices does not stop increasing. Each technology has different characteristics such as data rate, transmission distance, power consumption, etc. Based on those technologies network models are considered for different requirements. Low Power Wide Area Network (LPWAN) is a

group of networks, which allows long-range transmission and requires small power consumption [4]. Among LPWANs, LoRa (Long Range) is a promising technology for IoT applications, which do not need high-speed data rate and require energy saving with long-range transmission [5], [6].

Using LoRa as the physical layer, the project LoRaWAN (Long Range Wide Area Network) has been being developed widely with a large contribution by LoRa Alliance. In the LoRaWAN, the devices are managed by Gateway or Base Station. In this case, the star topology is used for constructing LoRa Networks. On the other hand, the mesh topology also is considered in different cases. In the Wireless Sensor Networks (WSN), for instance, ZigBee, Z-Wave, Bluetooth Low Energy 5.0, devices are connected in the mesh topology, each device can be a router relaying the packet of the other devices to the destination [7], [8]. The highlight difference of LoRa respected to these technologies is the ability of long-range transmission. This advantage can help expand the network model without needing additional base stations.

Smart City is a typical IoT application, where a large number of devices in the city is expected to communicate with each other and send data to the cloud server. For instance, a bus can inform directly the bus station about the destination time. The buses and bus stations are connected to each other, and exchange information with each other. The decentralized or mesh topology is applied to manage such applications.

Moreover, the mesh topology also is used in the networks such as VANET or FANET. In a search and rescue application, as can be seen in [9], [10], the UAVs (unmanned aerial vehicles) are connected to each other in a mesh topology. So, the data is transmitted through several UAVs to the destination.

The mesh topology for the LoRa network is considered as a solution to expand the number of connected nodes and the network coverage area. A LoRa-based network model using the mesh topology is proposed for these goals in this paper. In this topology, the routing option is one of the important parameters to ensure the quality of service. Considering the network model, the optimal route selection is found between the nodes based on the link quality. In addition, the delivery latency is considered in the influence of the load intensity, and the number of relay nodes.

The rest of the paper is organized as follows: Section 2 gives an overview of LoRa technology and its related works. A network model and a method of route selection are discussed in Section 3. Based on the network model, the analytic results in delivery latency are shown in Section 4. And the conclusion is presented in Section 5.

II. LoRa AND RELATED WORKS

Semtech Corporation is one of the leaders developing wireless chipset for IoT applications. Since when the first LoRa chipset launched by the company, LoRa technology has been attracting much interest in the development of IoT applications. In 2015, the LoRa Alliance was established to develop and support global network LoRaWAN. It is observed that LoRa has become a promising technology at the moment.

The special feature used in the LoRa physical layer is the Chirp Spread Spectrum (CSS) radio modulation technique, which provides advantages such as long-range communication and low power consumption. The unlicensed frequency band (867-869 MHz in Europe) is used for LoRa networks. Besides that the Data Rate (DR) theoretically is defined by three main parameters such as Bandwidth (BW), Spreading Factor (SF) and Coding Rate (CR=1...4), [5], [6]. The DR is determined in the formula (1):

$$DR = SF \times \frac{BW}{2^{SF}} \times CR \quad (1)$$

The high BW increases the DR, but decreases the decoding sensitivity. The high SF increases the decoding sensitivity, but decreases the DR. Therefore, with the low BW and high SF, the decoding sensitivity and transmission distance are increased, but the DR will be decreased. Depending on the application requirements, this combination of parameters can be configured.

The LoRa packet includes a preamble, header, payload, and checksum (CRC). According to [6], the transmission time of a data frame on-air is calculated in the dependence of the following programmable parameters: SF, BW, CR, number of preamble, explicit header (H=1 if isn't enabled, otherwise H=0), optimal low data rate (DE is used for only SF ≥ 11 and BW = 125 MHz).

Studies on LoRa technology get much attention from the physical layer to the application deployment. In recent years, research and development based on LoRa have gained many prospects. In the context of Smart Cities, there are several LoRa-based applications, such as for waste management [11], for water quality monitoring [12], or for street lighting, etc.

Since LoRa has high sensitivity, solutions for tracking or positioning were proposed in [13], [14]. It can be seen that the applicability of LoRa is used for many IoT applications. It is relevant to discover the other possibility of LoRa technology. Almost LoRa-based applications are deployed in cases when it is required to transmit on long-distance and to save energy consumption. To satisfy different requirements, the parameters can be set up to the LoRa network.

Thus, with the goal of using the LoRa's advantages a mesh topology model is analyzed for LoRa networks in the next sections.

III. ANALYTIC MODEL

A. Network model

In a mesh topology model, a network can be presented as a connected graph. For instance, as shown in Figure 1, the network includes device nodes and gateways connected in a graph. The device node can be either end-device or relay node, via which the data are relayed. The data received by the relay node will be forwarded to the next node according to the optimal route to the destination.

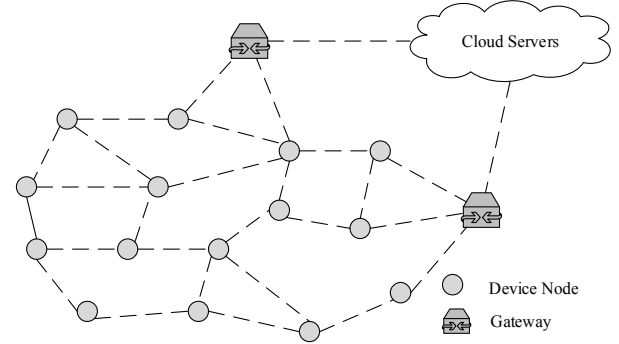


Figure 1. Graph of a network (nodes, and Gateways)

As shown in Figure 1, the mesh network model can be described by a Graph $G(V, E)$ with a set of Vertices – V , and a set of Edges – E . The set of vertices $V = \{v_{ij}\}$, $i = 1 \dots n$, which represents the set of device nodes in the network. The set of edges $E = \{e_{ij}\}$, $i, j = 1 \dots m$, which represents the set of communication links between the nodes in the network. Each node has a maximum communication radius R , within this distance the nodes can communicate with the others. If the coordinates of a node are described as (x_i, y_i) , the distance between 2 nodes i and j follows as:

$$d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (2)$$

Hence, there is a communication link between 2 nodes, if the distance between them is less than R . It can be illustrated by the following: if $d_{ij} \leq R$; $\exists e_{ij}$ and $E = \{e_{ij}\}$ with $i, j = 1 \dots n$.

Each edge between vertices is weighted by a set of link costs $C = \{c_{ij}\}$ with $i, j = 1 \dots n$, which represents the possibility of data transmission between two nodes. A low link cost means that this link is more suitable to exchange information.

B. Route Selection

In this case, the routing path is calculated to find the optimal route to the destination. The link cost is denoted by the parameter RSSI (Received Signal Strength Indication), which can be considered as the signal strength between transmitter and receiver. The link cost is represented as a dependent function of RSSI:

$$c_{ij} = f(RSSI_{ij}), \text{ } RSSI_{ij} \leq \text{threshold and } i, j = 1 \dots n$$

The matrix $C = \{c_{ij}\}$ with $i, j = 1 \dots n, s$ contains the characteristics of all communication links of the network (weights of edges of the graph).

$$C = \begin{bmatrix} c_{1,1} & c_{1,2} & \dots & c_{1,n} & c_{1,s} \\ c_{2,1} & c_{2,2} & \dots & c_{2,n} & c_{2,s} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ c_{n,1} & c_{n,2} & \dots & c_{n,n} & c_{n,s} \end{bmatrix}$$

In the graph G , there is a set of possible paths $\Omega = P_{i,s} = \{P_1, P_2, \dots, P_k\}$ between a node i and a sink node.

Thus, the total link cost of the path from the node i to the sink node $-s$ (gateway) is defined as follows:

$$w_{i,s} = \sum_{j=1}^{|P_{i,s}|-1} c_{i,j+1} \quad (3)$$

The optimal route from the node i to the sink node is computed as:

$$Route_{i,s} = \arg \min_{P_{i,s} \in \Omega} (w_{i,s}) \quad (4)$$

C. Queueing System

In the network, each node perceives and transmits data to the other. There are incoming packets and outgoing packets through the nodes. In order to evaluate the performance of this topology, it can be assumed that each node in the network is represented as a queueing system, which serves the incoming and outgoing requests, as shown in Figure 2.

In Figure 2, the incoming traffic is denoted by mean arrival intensity $-\lambda_i$ and is served by node i with a mean service intensity $-\mu_i$. There is an intensity of loading the system that is calculated by $\rho_i = \frac{\lambda_i}{\mu_i}$ (Erl). The load factor influences

serving time in the system, i.e. the delivery time will be influenced. By considering the queueing system, the network performance is evaluated to see the usage possibility in application deployment.

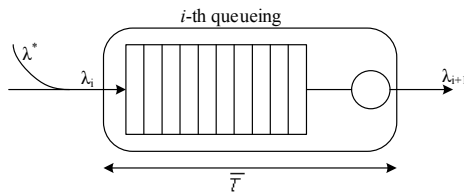


Figure 2. A node is represented as a queueing system

When considering the M/M/1 model for each node, we will use the formula to calculate the time of the application in the system [15]:

$$T_i = \frac{t_i}{1 - \rho_i} \quad (5)$$

where T_i is the mean delivery time to the node i (ms), and t_i is the mean duration of service requests (ms).

As described above, the transmission time of a LoRa data frame on-air depends on several parameters. This time on-air can be considered as the mean time t_i . The calculation of the time on-air is described in [6].

The number of relay nodes is denoted by m . Hence, the total delivery latency of a data frame through m nodes to the target node is computed as:

$$T = \sum_{i=1}^{m+1} T_i = \sum_{i=1}^{m+1} \frac{t_i}{1 - \rho_i} \quad (6)$$

IV. ANALYTIC RESULTS

Assume that the network model represents a set of device nodes and a gateway, as shown in Figure 3. There are 200 device nodes distributed randomly in a field with a size of 5000x5000 (m).

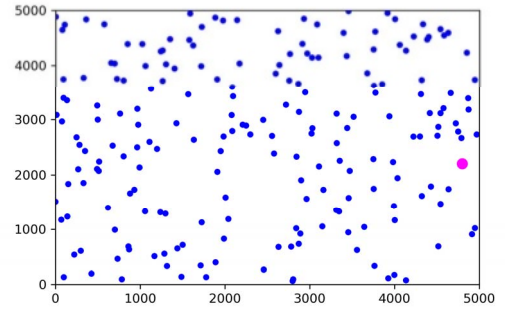


Figure 3. Network model

To make sure that there are available communication links between neighbor nodes, assume that each node has a coverage radius $R = 1000$ (m). The device nodes try to find optimal paths to deliver packets to the gateway based on the quality of signals, which are simulated for all nodes connected in their coverage radius.

As discussed in the previous section, the route selection is found based on the channel quality. On the other hand, the shortest path can be found based on the distance. In Figure 4, the shortest paths were found with both options in considering the link quality and the distance between nodes. There is a different number of relay nodes in these paths. It can be explained that the link quality choice might take more relay nodes, in order to guaranty the packet delivered successfully to the gateway.

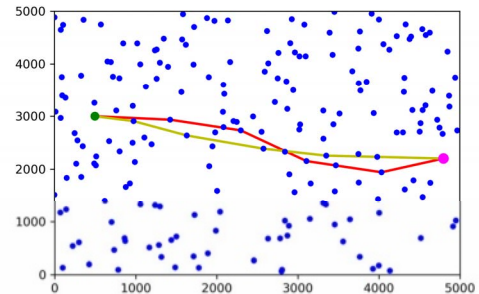


Figure 4. Two path options from a source node to the gateway

Moreover, all paths from the other nodes to the gateway are shown in Figure 5.

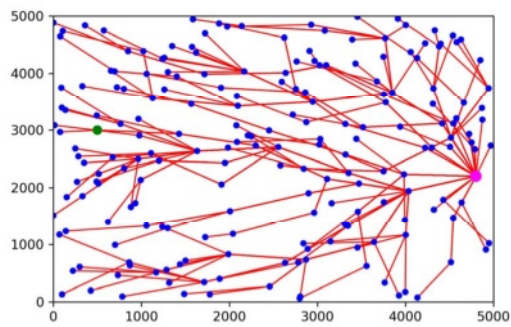


Figure 5. The shortest path from all nodes to the gateway

Furthermore, each device node is considered as a queueing system. Hence, the delivery latency in a communication link between two neighbor nodes is calculated according to the formula (5). And the delay time for transferring a payload size of 100 bytes is calculated when changing the load intensity. The calculation results are shown in Figure 6 with two cases of node configuration using SF=7 and BW=125, 250 MHz. According to Figure 6, the delivery time increases when the load factor increases. In addition, the difference in latency of two cases increases when increasing the load factor.

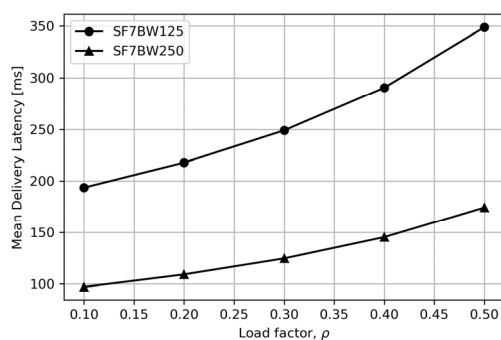


Figure 6. Influence of the load intensity on the delay

In the mesh topology model, the node receives and relays the packets to the next node. Therefore, the number of relay node that packet passes influences the delivery time to the destination. With the load factor equals 0.4 and the payload size of 100 bytes, as shown in Figure 7, the delivery latency increases linearly respect to the number of relay nodes.

In the case of using the bandwidth 125 MHz, the latency increase to 3.5 (s) via 10 relay nodes. This value can be accepted in some use cases, where the low latency isn't required, or in case of collecting sensor data with low frequent. Using LoRa technology may increase the transmission delay, but the transmission range and energy consumption are the main advantages for IoT applications.

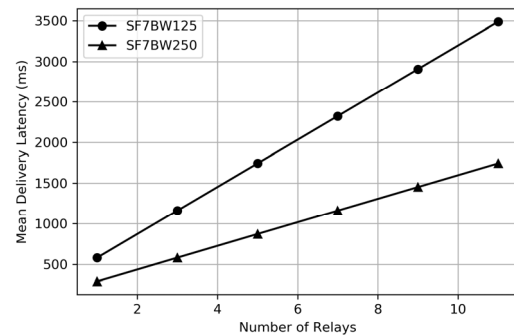


Figure 7. Influence of the number of relays on the delay

V. CONCLUSIONS

Nowadays, LoRa technology is used in the communication part for many IoT applications. Taking the advantages of LoRa, the coverage area of the network can be extended without adding more base stations. The model of a mesh topology used for the LoRa network was analyzed with considering the task of finding the optimal route, and the delivery latency over the network.

A method was proposed to find the optimal route base on the link quality denoted by the parameter RSSI.

The delivery latency was evaluated in the influence of the load factor and the number of relay nodes. The delay required to transmit a payload size of 100 bytes through 10 relay nodes can be accepted in some cases.

Thus, the mesh topology model combined with LoRa technology can bring more advantages in the wireless sensor network in terms of increasing the coverage area.

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