**Issues in Information Systems**
Volume 23, Issue 3, pp. 292-304, 2022

DOI: https://doi.org/10.48009/3_iis_2022_124

# Extending data transmission in the multi-hop LoRa network

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## Abstract

In recent years, with the widely available broadband network connectivity and sensing technology, the Internet of Things (IoT) provides a variety of smart services in both urban and rural environments. For example, sensing devices placed in the community not only provide environmental monitoring, but also are used to inform the public about rapidly changing real-time events. The data collected from sensors will help the community improve quality of life of citizens, and can be used for the city development. It has been known that LoRa (Long Range), a notable LPWAN (Low Power Wide Area Network) wireless communication technology, is suitable for providing IoT service with the help of wide coverage, long battery lifetime and low cost to deploy and operate. However, as the application of IoT is becoming increasingly complex, simple sensor data does not satisfy user requirements, and the demand for a variety of multimedia data transmission is increasing. Specifically, many applications require large image data transmission for improved service. A network based on LoRa supports data communication at up to 10 km range with the minimum data rate, and LoRaWAN is operated with a Star-of-Stars topology. However, due to the narrow bandwidth of LoRa, it takes a great deal amount of time to transmit large image files. A possible solution is to reduce distance between sensing devices and a gateway by deploying more gateways and maximize the data rate. However, as expected, particularly in case of monitoring rural environments such as farms, forests, mountains, etc., it is costly to provide the required power and network connectivity for the deployment of additional gateways. As a solution to two challenges, large image transmission and service coverage extension, multi-hop LoRa network is introduced. In this study, we implemented and tested a multi-hop LoRa network. In the experiment, we were able to transmit an image file through multiple end devices successfully.

**Keywords**: LoRa, LoRaWAN, LPWAN, IoT, Image transmission, Multi-hop, Relay

## Introduction

In recent years, with the widely available broadband network connectivity and sensing technology, the Internet of Things (IoT) is able to provide a variety of service in diverse fields such as environmental monitoring, public safety, transportation, smart city, industry, health, etc. For example, sensing devices placed in the community not only provide environment data in urban and rural environment such as temperature, humidity, gas, air quality, light, etc., but also inform the public about rapidly changing real-time events to allow them to avoid crowding and other environmental effects. These accumulated urban/rural data help the community improve quality of life for citizens and can be used to plan for the development of city growth.

Recently, LoRa (Long Range) network, one of the representative LPWANs (Low Power Wide Area Networks), is considered as one of the best solutions for IoT because of wide coverage, long battery lifetime and low cost to deploy and operate. However, as the applications of IoT grow, simple sensor data does not satisfy application requirements, and the demand for the transmission of a variety of multimedia data is increasing. Specifically, some applications require visual data to improve quality of service.

Visual IoT (Staikopoulos, Kanakaris, & Papakostas, 2020) is defined as a type of IoT dedicated to transferring multimedia data such as videos or images collected at devices with image or camera sensors. In order to enable a visual IoT, there are many aspects to be considered such as advanced multimedia efficient transmission technology, multimedia processing technology, etc. Staikopoulos et al. also introduced previous works about available methods to transfer images via LoRa infrastructure and pointed out the challenges in terms of image quality level, protocol level and physical level.

Generally, the LPWAN network faces limitations that hinder its usage for a visual IoT, due to narrow bandwidth of physical layer. Nevertheless, for multimedia transmission, there have been previous research and efforts to improve data transmission by proposing and adopting new technologies such as improved physical layer, MAC layer, new protocols, reduced transmitted image data, etc.

Fan & Ding (2018) presented a new network topology for wireless visual sensor networks which can be applied in an intelligent video surveillance system based on LoRa transmission technology. The authors proposed novel MAC layer protocols such as message structure for registering process, physical payload structure and MAC header/payload structure. However, the authors did not show experimental data for the proposed system.

Jebril, Sali, Ismail & Rasid (2018) demonstrated an experimental test of image transmission over LoRa physical layer. The authors proposed a technique to overcome the bandwidth limitation of LoRa. In their scheme, an image file produced as part of monitoring mangrove forests is split into multiple LoRa packets and transmitted in hexadecimal format from the sender node. The packets are received and assembled at the receiver node. For assessing the quality of image transmission, Packet Loss Ratio (PLR), Peak Signal-to-Noise Ratio (PSNR), and Structural Similarity (SSIM) are measured.

Wei, Chen, & Su (2019) proposed a new approach to transmit images using different spreading factors. In this approach, there are a group of senders and receivers, a sender – a receiver is constructed to perform packet transfer. Additionally, a group of senders and a group of receivers are connected over MQTT protocol. An image file is divided into multiple packets and distributed to the senders. Each sender transmits its packets to the corresponding receiver using a distinct spreading factor, respectively. When each packet is received at each receiver, these packets are delivered to the central receiver node and assembled into an image file.

Ji et al. proposed a new monitoring technique for agricultural monitoring system (Ji, Yoon, Choo, Jang & Smith, 2019). With an assumption that most agricultural areas are static environment with infrequent changes, in this scheme, an image is divided into small grid patches. When there are notable changes in grid patches, only those patches with changed data are transmitted. Therefore, this scheme can reduce bandwidth usage. Wei, Huang, Chang, & Chang (2020) proposed a time division multiplex (TDM) scheme over LoRa for image transfer. In this scheme, a gateway transmits different timing information to end devices, and end devices can only transmit packets at the timing given. They presented an image transmission method over LoRa and evaluated it using WebP image compression scheme (Wei, Su, Chang & Chang, 2021). The experimental test results showed that the performance of WebP compression + Base 64 coding is better than JPEG + Hexadecimal encoding in terms of image size, total number of packets, and transmission time.

LoRa can support a communication range up to 10km with the minimum data rate, and LoRaWAN is operated as Star-of-Stars topology. However, due to the narrow bandwidth of LoRa, more time is needed to transfer images. One of the possible solutions to transmit images is to reduce the distance between sensing devices and a gateway by deploying more gateways to maximize the data rate. However, as we expect, particularly in the case of monitoring rural environments such as farms, forests, mountains, etc., it is hard to provide supplies such as power and network connectivity. Therefore, the deployment cost related to the gateways will be increased. In order to surmount this obstacle, applying mesh network or multi-hop relay network could be a solution. There is a set of existing research efforts for mesh networks in which nodes perform relay.

Dias & Grilo (2018) proposed a multi-hop uplink solution which can act as an extension to the deployed gateways. Each node transmits data messages to intermediate nodes and intermediate nodes relay them to the gateways based on a simplified version of Destination-Sequenced Distance Vector (DSDV) routing. However, the proposed solution has no downlink transmission. Lundell, Hedberg, Nyberg, & Fitzgerald (2018) presented a new routing protocol to enable mesh networking with LoRa based on AODV (Ad-hoc On-demand Distance Vector) and HWMP (Hybrid Wireless Mesh Protocol), allowing for multi-hop networking between gateways to extend coverage. The routing protocol was tested in laboratory experiments for uplink transmission, but the downlink transmission was not tested.

Abrardo & Pozzebon (2019) proposed a linear sensor network topology based on multi-hop LoRa chain-type communications for underground environments. The authors found that the effective transmission range of LoRa is limited to a maximum of 200m, making the adoption of a classical star topology impossible. Thus, they proposed an ad-hoc transmission scheme to evaluate the wake-up time of all nodes to minimize the average energy dissipation deriving from clock offsets.

Huh & Kim (2019) proposed a new LoRa protocol to overcome the shortcomings of the existing LoRaWAN. Under the imbalanced transmission environment, the proposed LoRa protocol removes the gateway and the neighboring end-nodes from the mesh table, instead placing the relay node on top of the mesh table. The protocol was tested in fire pipe freeze monitoring system, streetlight control system, and toxic monitoring system. Ke, Liang, Zeng, Lin, & Lee (2017) developed a LoRa mesh network for a campus. Their experimental results showed comparison of packet delivery ratio of 1-hop, 2-hop and 3-hop, and the 3-hop increases the packet delivery ratio.

In this paper, we present the multi-hop LoRa mesh network as a possible solution to resolve two challenges of image transmission and service coverage extension. We developed a system that can perform fundamental multi-hop image transmission with LoRa technology and proposed a modified packet header for image transmission for multi-hop LoRa networks. Through experiments, we evaluated an image can be transmitted between multiple end devices successfully.

## Related Work

IoT can be defined as a system of sensors and actuators connected by networks to software. It can monitor and manage connected objects, machines, and even living things (Ménard, 2017). In particular, these objects or devices are connected by a variety of wireless technologies and networks to transmit and receive data. In this section, we describe wireless communication technologies that can be used for IoT.

**Wireless Communication Technologies**

When it comes to wireless communication for IoT, a variety of technologies are being employed considering performance and features and put in service for connections between end devices and gateways. According to service range and data rate, wireless communication technologies are categorized into Short-Range Wireless, Medium-Range Wireless, Cellular, Satellite, and LPWAN as shown in Figure 1. Many studies have investigated their similarity and the distinctive characteristics among them.

One of the representative technologies is cellular technology, such as LTE-M and NB-IoT that use licensed frequency bands standardized by 3GPP. Cellular technology provides long-range communication and high data rate, but it consumes considerable amount of battery power, incurs high costs, and requires licensed frequency bands.

Another category of technology is LAN (Local Area Network) technology such as Wi-Fi, Bluetooth, and ZigBee, which uses unlicensed frequency bands. LAN is suitable for short-range communication and high data rate, but it requires high battery power.

A key technology is LPWAN (Low Power Wide Area Network) technology such as LoRa/LoRaWAN and Sigfox, which uses unlicensed frequency bands. These LPWANs provide a relatively lower data rate than Cellular technology, but consumes low battery power and can realize long-range communication. In particular, among the LPWAN technologies, LoRaWAN provides advantages in terms of security, adaptability, and privacy.

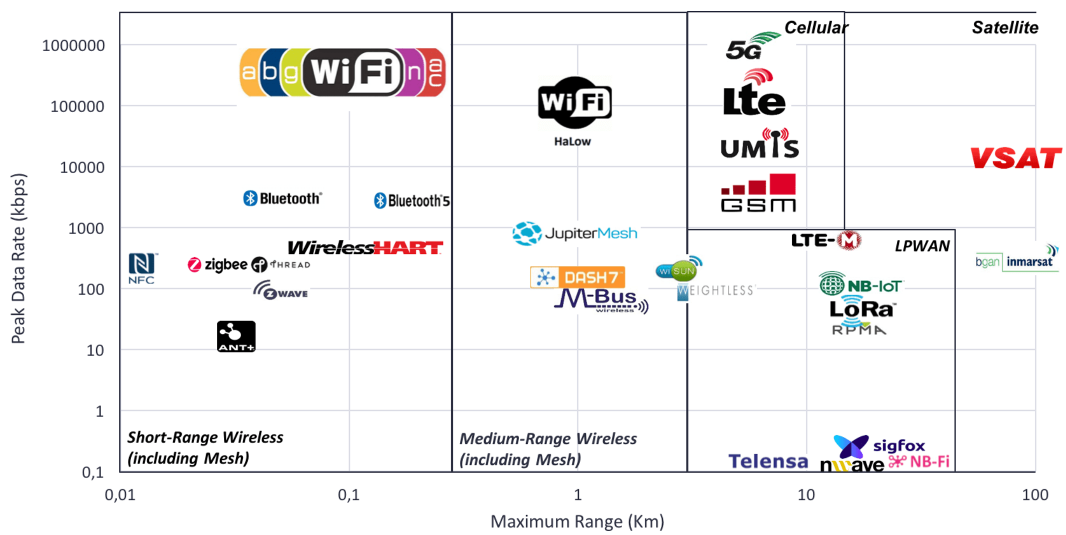

**Figure 1: Data Rate and Coverage of Wireless Technologies (Romeo, 2019)**

Table 1 shows a comparison of the three major LPWAN technologies: Narrowband IoT (NB-IoT), Sigfox, and LoRaWAN. Among various wireless technologies, LoRaWAN and NB-IoT are widely used for IoT. As a modulation technique, LoRaWAN uses the chirp spread spectrum (CSS) and NB-IoT uses quadrature phase shift keying (QPSK). LoRaWAN and NB-IoT exhibit maximum data rates of 50 kbps and 200 kbps, respectively. LoRaWAN allows private networks to be deployed, owing to the use of unlicensed industrial, scientific, and medical (ISM) frequency band, but this is not the case in NB-IoT.

**Table 1: Comparison of LPWANs**

| | NB-IoT | Sigfox | LoRaWAN |
|---|---|---|---|
| **Standardization** | 3GPP | ETSI and Sigfox Alliance | LoRa Alliance |
| **Technology** | LTE (rel.13) | Proprietary | Proprietary |
| **Topology** | Star | Star | A star of stars |
| **Frequency** | Licensed LTE band | Unlicensed ISM bands | Unlicensed ISM bands |
| **Duty cycle restriction** | No | Yes (typically 1%) | Yes (typically 1%) |
| **Modulation** | QPSK/BPSK (DL), GFSK (UL) | DBPSK (UL), GFSK (DL) | CSS/FSK |
| **Bandwidth** | 200 kHz | 100 Hz | 125/250/500 kHz |
| **Transmission technique** | FDD | UNB | Aloha |
| **Maximum data rate** | 200 kbps | 100 bps | 50 kbps |
| **Bidirectional** | Yes/Half-duplex | Limited/Half-duplex | Yes/Half-duplex |
| **Maximum messages/day** | Unlimited | 140 (UL)/4 (DL) | Unlimited |
| **Maximum payload length** | 1600 bytes | 12 bytes(UL)/8 bytes(DL) | 243 bytes |
| **Coverage/Range** | 1 km (urban), 10 km (rural) | 10 km (urban), 40 km (rural) | 5 km (urban), 20 km (rural) |
| **Maximum TX power** | 20 dBm/23 dBm | 14 dBm/22 dBm | 14 dBm/27 dBm |
| **Interference immunity** | Low | Very high | Very high |
| **Security** | LTE encryption | MAC verification | AES 128 |
| **Adaptive data rate** | No | No | Yes |
| **Handover** | End-device joins a single base station | End-device does not join a single base station | End-device does not join a single base station |
| **Localization** | No (under specification) | Yes (RSSI) | Yes (TDOA) |
| **Private network** | No | No | Yes |
| **Module cost** | <$5 | <$5 | <$10 |

## LoRa and LoRaWAN

LoRa/LoRaWAN provides several advantages for IoT services such as a wide coverage, long battery lifetime and low cost to deploy and operate. It is suitable for accommodating large number of end devices spread over the wide area and broadly used in a variety of services, such as smart cities, smart buildings, healthcare, public safety, smart environmental monitoring, smart agriculture, etc. LoRa/LoRaWAN is composed of a physical layer (LoRa) and a Media Access Control layer (LoRaWAN). Figure 2 shows the protocol layer of the LoRa/LoRaWAN, which consists of the physical, MAC and application layer.

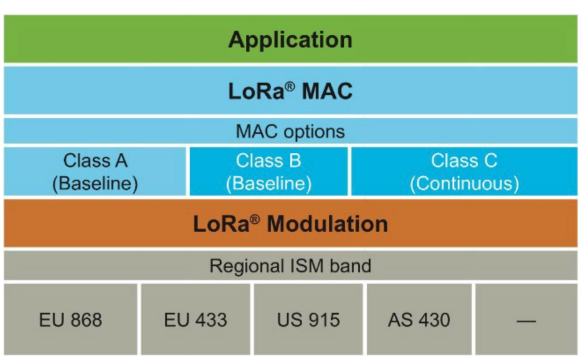


**Figure 2: Protocol Architecture of LoRaWAN (LoRa-Alliance, 2015)**

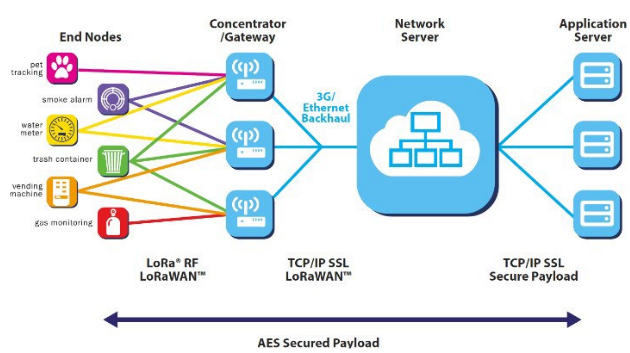


**Figure 3: Network Architecture of LoRaWAN (LoRa-Alliance, 2015)**

LoRaWAN is a media access control (MAC) layer and has been adopted as the communication protocol and system architecture for the network with LoRa physical layer. LoRaWAN is an open specification managed by LoRa Alliance (LoRa-Alliance, 2021) and operated in the upper layers of LoRa. As shown in Figure 3, the main components of LoRaWAN are end nodes, gateways, network servers, and application servers. The end nodes, such as sensors, collect data, and those data collected are transmitted to the gateways. The gateways convert LoRa RF (Radio Frequency) packets to IP packets and vice versa, forward the uplink/downlink packets transparently between the end nodes and a network server through back-haul networks such as cellular networks, Ethernet, Wi-Fi, etc.

## Network Topology

The network topology defines the nature and type of communication links between the member nodes. The demands of monitoring data transmission create a need to adapt the topology to the application. More specifically, effective topologies for monitoring the sensing data require the use of simpler star topologies where, allowed by the conditions of the application, but also the employment of mesh arrangements to ensure the network is connected.

### *Star Topology*

Figure 4 shows the star topology of the LoRaWAN network architecture. The main components of LoRaWAN are end devices such as sensors, actuators, etc., gateways, network servers and application servers. The star topology architecture imposes a limitation on the extension of service coverage. From a topological point of view, one solution to increase coverage is to deploy additional gateways. However, in this approach, it increases the cost of deployment and operation since additional power supply and backhaul network connection is needed. Another solution is to allow end devices to perform a relay role for neighbors, enabling packet delivery from neighbor end devices to gateways.

### *Multi-hop Relay Topology*

Several multi-hop topologies are introduced to extend the coverage. Figure 5 shows the relay LoRa network topology of end devices. End devices outside the gateway's service coverage transmit packets to adjacent end devices located in service area of the gateway. Then, end devices forward packets to gateways. This solution has the advantage of increasing service coverage without deploying additional gateways. This approach is suitable for rural areas such as farming, environmental monitoring, etc.

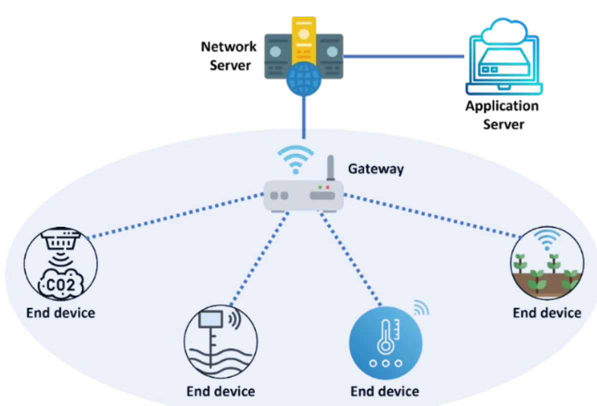


**Figure 4: Star Topology**

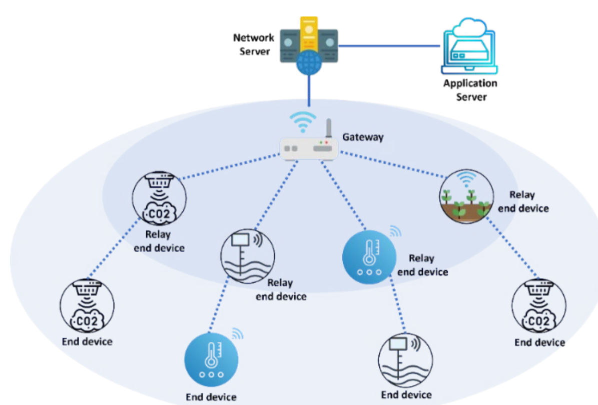


**Figure 5: Relay Topology of End Devices**

Figure 6 describes the relay LoRa network topology of gateways. The relay gateway aggregates packets from multiple end devices and forwards to a main gateway via wireless connection. Figure 7 describes the relay LoRa network topology of devices – gateways. This approach is a hybrid topology of a relay topology of end devices shown in Figure 5 and the relay topology of gateways shown in Figure 6.

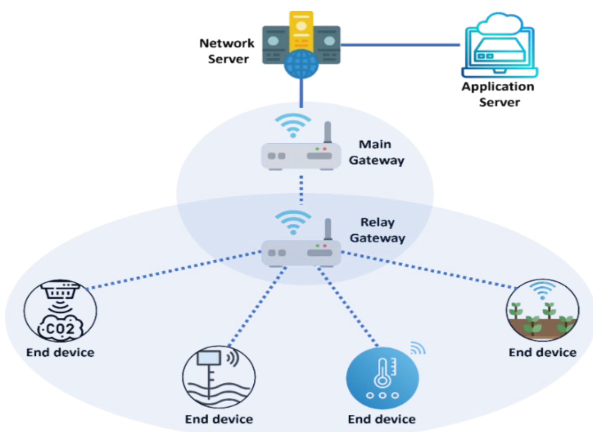


**Figure 6: Relay Topology of Gateways**

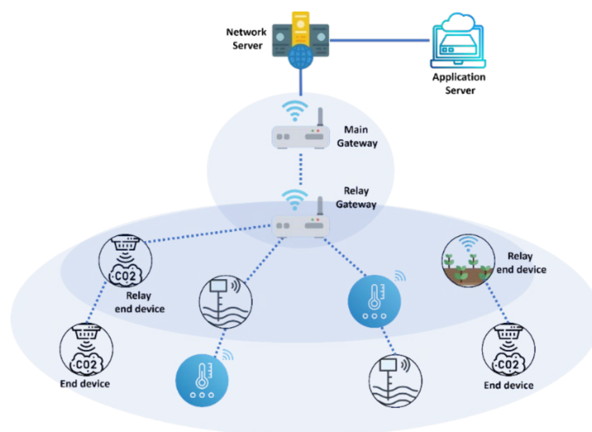


**Figure 7: Relay Topology of Devices – Gateways**

## Experimental Configuration and Results

Here, network tests performed for the feasibility of multi-hop LoRa network are detailed. LoRa networks traditionally use a star topology where a single gateway device receives communication from multiple end devices, but it does not support communication between end devices. In this test, we implemented a small-scale multi-hop LoRa network testbed to transmit and receive packets between end devices.

As shown in Figure 8, an end device is constructed based on a Raspberry Pi 4 Model B with a 1.5GHz processor, 4GB LPDDR4 memory, Wi-Fi and microSD memory card support. Each device is connected with Adfruit RFM95 LoRa Radio Transceiver Breakout to communicate which is operated at the license-free ISM band (American ISM @ 915MHz). This module consists of SX1276 LoRa based module with SPI interface and a simple wire antenna.

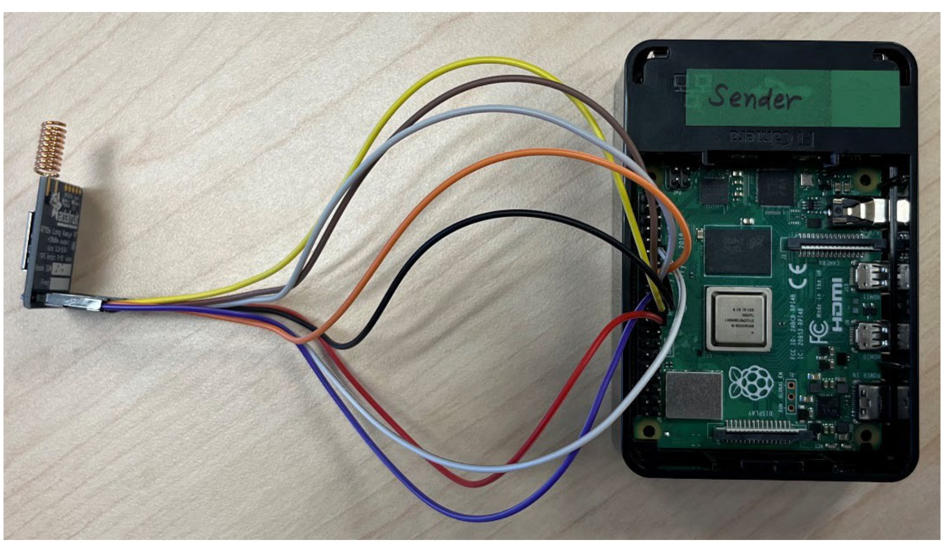


**Figure 8: End Device (Raspberry Pi with RFM95 LoRa Module)**

**LoRa Packet Header**

Image transmission test is based on the mesh lora project (Gallouédec, 2020). However, this reference work is only to transmit and receiver text messages. We implemented an image segmentation/reassembly module and modified the LoRa header packet for multi-hop relay transmission of segmented image packets. In this test, we used Radiohead packet radio library (RadioHead). The Radiohead library packet header configuration is shown in Figure 9, and it consists of fields for TO, FROM, ID, FLAGS, and DATA.

- TO: The first byte in the Radiohead packet header. It indicates the destination node identifier where the packet is being sent to
- FROM: The second byte in the Radiohead packet header. It indicates the source node identifier where the packet is being sent from
- ID: The third byte in the Radiohead packet header. It indicates the packet identifier which is distinct for each packet sent by a particular node
- FLAGS: The fourth byte in the Radiohead packet header. Upper 4 bits are reserved for use by Reliable Datagram Mode and lower 4 bits may be used to pass information
- DATA: It is used for payload (252 bytes)

| | |
|---|---|
| (The 1st byte) | **TO** – The destination node identifier |
| (The 2nd byte) | **FROM** – The source node identifier |
| (The 3rd byte) | **ID** – The packet identifier |
| (The 4th byte) | **FLAGS** |
| **DATA** (252 bytes) | |

**Figure 9: The Radiohead Packet Header Configuration Map**

| | | |
|---|---|---|
| (The 1st byte) | **TO** – The destination node identifier | |
| (The 2nd byte) | **FROM** – The current relaying node identifier | |
| (The 3rd byte) | **SRC** – The source node identifier | |
| (The 4th byte) | **FLAGS** (4 bits) | **APP_CTL** (4 bits) |
| (The 5th & 6th byte) | **ID** – The packet identifier | |
| (The 7th & 8th bytes) | **TOTAL_PKT_COUNT** | |
| (The 9th & 10th bytes) | **SEQ_ID** | |
| **DATA** (246 bytes) | | |

**Figure 10: The Modified Radiohead Packet Header Configuration Map**

For image transmission in the multi-hop relay LoRa network, we modified the Radiohead packet header as shown in Figure 10.

- TO: The first byte in the modified Radiohead packet header. It indicates the destination node identifier where the packet is being sent to
- FROM: The second byte in the Radiohead modified packet header. It indicates the current relaying node identifier
- SRC: The third byte in the modified Radiohead packet header. It indicates the source node identifier where the packet is originated from
- FLAGS/APP_CTL: The fourth byte in the modified Radiohead packet header. Upper 4 bits are reserved for use by Reliable Datagram Mode. Lower 4 bits may be used for distinguishing the type of packet, for example, control, image, text, etc.
- ID: The next two bytes in the modified Radiohead packet header. It indicates the packet identifier

- TOTAL_PKT_COUNT: The next two bytes in the modified Radiohead packet header. It indicates the total number of packets to construct an image file. If the size of an image file is larger than the maximum payload of LoRa, it should be split into multiple packets. TOTAL_PKT_COUNT is computed as:

$$TOTAL\_PKT\_COUNT = \left\lceil \frac{The\ size\ of\ file}{The\ LoRa\ packet's\ payload} \right\rceil$$

- SEQ_ID: The next two bytes in the modified Radiohead packet header. It identifies the order of packets of the same image file
- DATA: It is used for payload (246 bytes)

**Transmitting and Receiving Packets**

Figure 11 shows the flow chart of the thread that manages transmitting and receiving packets. If the image file is larger than the maximum payload size, the image file is split into multiple packets and store to the PACKET_TO_SEND. If there are no packets to send, wait a packet to be received. When a packet is received, if the packet is for me, store the packet to INBOX, but if the packet is a relayed packet, store to the PACKET_TO_SEND to forward.

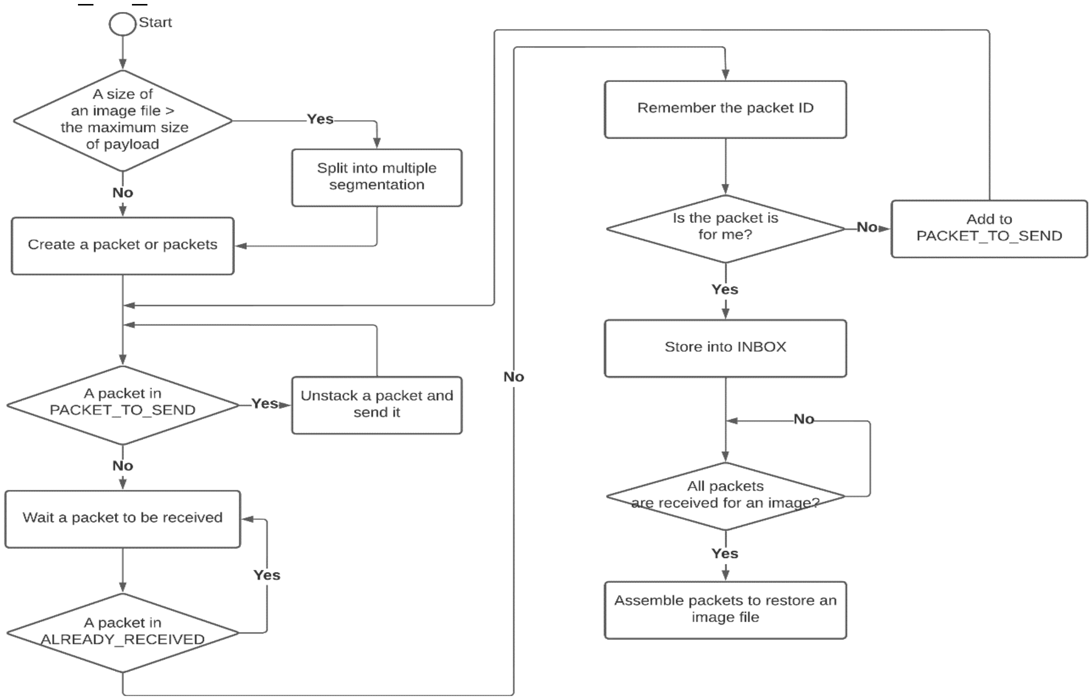


**Figure 11: Packet Processing Flow Chart at the Relay Node**

Figure 12 presents a data structure of the receiving end device for storing packets. This is implemented by array of arrays consisting of sender node id and the array of packets.

mySenderMsgList =
[
(senderNodeId1, [(Msg1_packetId1), (Msg1_packetId2), …, (Msg2_packetId*n*), …, (Msg*n*_packetId*n*)]),
(senderNodeId2, [(Msg1_packetId1), (Msg1_packetId2), …, (Msg2_packetId*n*), …, (Msg*n*_packetId*n*)]),
…
(senderNodeId*n*, [(Msg1_packetId1), (Msg1_packetId2), …, (Msg2_packetId*n*), …, (Msg*n*_packetId*n*)]),
]

**Figure 12: Data Structure of the Receiving End Device for Storing Packets**

At all nodes (the sender, the relay node, and the receiver), each node is operated on a thread basis in transmitting and receiving packets. Once nodes start working, the senders transmit their own packets repeatedly and the receiver is waiting for packets for an image. If all packets which consist of the image are not received at the receiver, packets received are stored at the data structure described in Figure 12 until all packets are received. Once all packets for the image are received, packets are combined and restored into a complete image.

### Multi-hop Image Transmission Test

We experimented with two types of image transmission tests. The configuration of tests are as follows:

- Single-sender test: a single sender node, a single relay node, and a single receiver node
- Multiple-sender test: two sender nodes, a single relay node, and a single receiver node

#### *Single-Sender Test*

In this test, there are three end devices total, and no gateway device is present. A Raspberry Pi and Adafruit RFM95 LoRa transmission module (915MHz) are combined to construct an end device shown in Figure 8. For initial testing setup, certain controls are enforced to reliably test the required functionality.

Figures 13 and 14 show the single-sender transmission test scenario. This test aims to transmit an image file that requires multiple packets to be transmitted. According to the LoRa specification, the maximum size of the data payload portion of a packet is 252 bytes. Thus, if the size of the image file is larger than the maximum payload size, the image file should be split into multiple packets for the packet transmission.

At the end device 1 (sender), a test image file is split into multiple packets and those packets are transmitted toward the end device 2 (relay node). After receiving packets from the end device 1, the end device 2 forwards packets to the end device 3. Once the end device 3 receives all packets from the end device 2, it reassembles packets in order, and restores the image file. Packets transmitted directly from the end device 1 to the end device 3 are blocked via software logic, but the end device 3 only accepts packets relayed from the end device 2. In this test, an image file (414 bytes) is split into two packets, the first packet of 250 bytes and the second packet of 164 bytes, and all packets are transmitted and restored successfully.

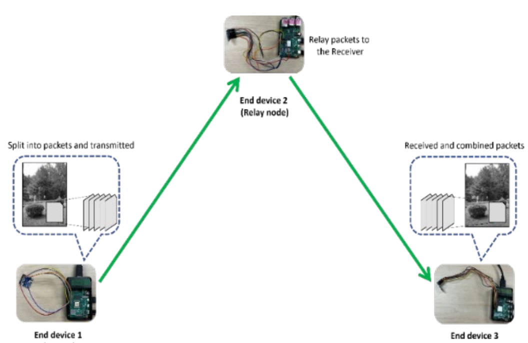

**Figure 13: Single-Sender Test Scenario**

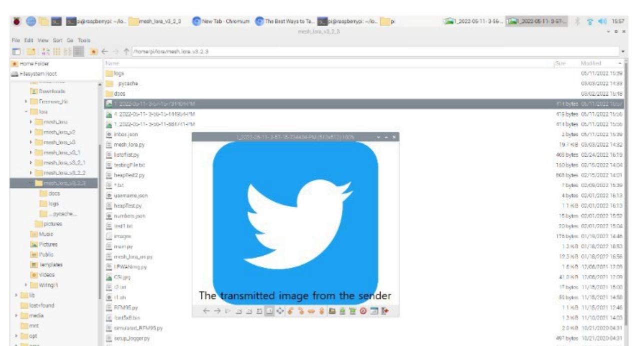

**Figure 14: The Transmitted Image of Single-Sender Test**

#### *Multiple-Sender Test*

Figures 15 and 16 show the multi-sender test scenario where there are four end devices total, and no gateway device is present. Two senders split their own image files into multiple packets and transmit them, respectively.

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Volume 23, Issue 3, pp. 292-304, 2022

In this multiple-sender transmission test scenario, the end device 1 (sender 1) and the end device 2 (sender 2) transmit their own image files, and the end device 3 (relay node) forwards all packets toward the end device 4 (receiver). Once the end device 4 (receiver) receives all packets from each sender, it reassembles packets in order, and restores the image files sent from each sender, respectively. Packets transmitted directly from the end device 1 or from the end device 2 are blocked via software logic, but the end device 4 only accepts packets relayed from the end device 3. In this test, two senders transmit image files of 414 bytes and 419 bytes, respectively, and all packets are transmitted and restored successfully.

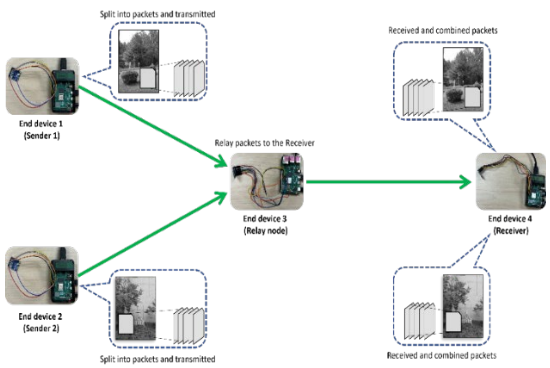


**Figure 15: Multiple-Sender Test Scenario**

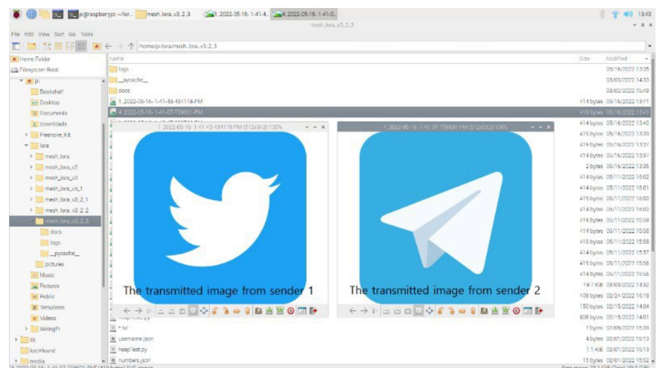


**Figure 16: The Transmitted Images of Multiple-Sender Test**

## Conclusion and Future Work

LoRa, one of the representative LPWANs (Low Power Wide Area Networks) technologies, is suitable for serving IoT applications with the advantages of wide coverage, long battery lifetime and low cost. However, due to the narrow bandwidth, it needs more time to transmit a larger amount of data such as an image. As a possible solution for the two challenges, which are large image data transmission and service coverage extension, we introduced image transmission via multi-hop LoRa network. In this study, we implemented and tested multi-hop image transmission based on LoRa and evaluated image transmission between multiple end devices successfully. However, this test aims to see the possibility of image transmission in the multi-hop LoRa network. In order to confirm robustness and rigor of the test results, the empirical performance studies such as packet error rate are required. Thus, as future work, the authors will improve the system and investigate on the numerical performance studies.

For the future research, since proprietary LoRa devices are currently designed for single hop star topologies, the implementation of relay in the network will require adjustments to compensate for the alterations to the connectivity. Further, the deployment of the proposed networks for applications used over a large land such as transportation or agriculture is expected to impose unique limitations on the topologies and protocols used. Additionally, it is important to further work on a set of parameters which facilitate the application of multi-hop mesh networking. LPWAN topologies that can distribute one node’s workload to a set of end nodes may be able to mediate the limitations, enabling more efficient protocols and increased packet delivery rates. To this end, we will consider the use of monitors per target as a key network parameter. Furthermore, we plan to investigate image processing techniques to reduce the size of image data with machine learning.

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