LoRa as a Mesh Networking Technology

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***Abstract*—Although LoRa is primarily known for the long distances it can cover it also has characteristics that make it attractive as a relay technology in mesh networks. Unlike other wireless network technologies where concurrent transmission by two or more nodes results in corruption of both messages at the receiver, a LoRa receiver synchronises with just one transmitter and treats any other concurrent transmission as noise. This greatly simplifies the design of network relays in that they do not need complex schemes to deal with contention. It also reduces the number of copies of a message received at the destination. This approach also reduces latency when compared with schemes such as CSMA/CA used in other networks. However, there is a cost in terms of reduced Signal to Noise Ratio (SNR) which has a consequent impact on message error rate at the receiver. In this paper we use a two hop LoRa network comprising a transmitter, multiple relays and a receiver to evaluate the impact of concurrent transmission on latency, the number of packets forwarded, the SNR, the Received Signal Strength Indicator (RSSI) and the error rate as the number of relays forwarding a copy of the same message is increased. We observed that LoRa receivers synchronise with just one transmitter and forward only one copy of a message. We also observed that there is negligible latency regardless of the number of relays at each hop. However, we see an impact on SNR and successful message delivery. SNR reduces as the number of relays transmitting concurrently increases and successful frame delivery deteriorates rapidly once more than four relays forward a message with 45% messages lost when there are seven relays.**

***Index Terms*—LoRa, Wireless Mesh Networks, IoT, Sensor Networks**

I. Introduction

LoRa (from "Long Range") is an increasingly popular technology for wide area networking of the Internet of Things (IoT) [1]. LoRa is a wireless technology most commonly used in agricultural applications and deployed as single hop network using the layer three technology LoRaWAN. However it has recently found use in developments as a multi-hop relay in linear networks, notably for undeground mining [2]–[13]. LoRa also has potential as a wireless mesh networking technology. In this paper we show that LoRa has attributes that make it an ideal candidate for wireless mesh networking and explore its performance when used as a relay in a mesh network.

A mesh network comprises Sources that generate data, Relays that forward the data onto other Relays or to the Destination, and Destinations. Mesh networking is particularly well suited to Internet of Things (IoT) applications where there may be a number of sources comprising sensors that monitor some physical metric such as soil moisture, temperature or wind speed in agricultural applications or deformation or vibration in structures such as buildings, bridges or tunnels or smoke and temperature in fire monitoring systems. The data gathered from these sensors is forwarded onto the destination via relays. The destination may be a cloud server or a messaging service or some other mechanism that can interpret and potentially act upon the data from the sensors.

A diagram of a mesh network is shown in fig. 1. In this diagram there are eight nodes, comprising two sources (labelled Source 1 and 2), five relays (labelled Relay 1 to 5) and two destinations (labelled Destination 1 and 2). The coverage of each node is shown by the colored dashed line boxes. Each node in the blue box can receive messages from any of the other nodes in the blue box. So Source 1 messages can be received by Relays 1 and 2. Similarly all the nodes in the red box can receive messages from all other nodes in the same box. That is Source 2 messages can be seen by all the relays, and messages from Relays 1 and 2 can be received by Relays 3, 4 and 5. Finally the green box shows that messages from Relays 3, 4 and 5 can be received by both Destinations 1 and 2.

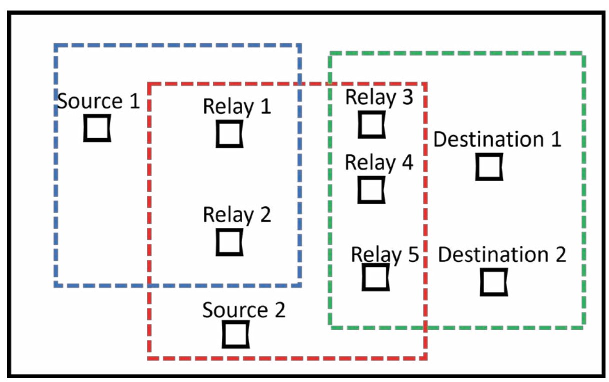

Fig. 1. Example Mesh Network Showing Coverage of Nodes

A challenging issue in mesh networks where coverage of relays overlaps is dealing with collisions. With most wireless technologies, concurrent transmission results in a collision which will corrupt both messages. To illustrate this problem, consider a message generated by Source 1. Relays 1 and 2 will receive it. They will then transmit it and it will be received by Relays 3, 4 and 5. If Relays 1 and 2 both transmit at the same time, Relays 3, 4 and 5 will receive concurrent messages from

Relays 1 and 2. In conventional wireless networks this will result in the two messages from Relays 1 and 2 corrupting each other. Relays 3, 4 and 5 will each receive corrupted messages from Relays 1 and 2.

WiFi and ZigBee address this problem by using CSMA/CA to avoid such collisions. In CSMA/CA upon receipt of a message a relay checks to see if the medium is clear. If it is it transmits. If it is not clear it waits a random amount of time before again checking the medium and, if clear, transmitting. There may also be an exchange of Request to Send and Clear to Send messages. Messages may also be acknowledged and if no acknowledgement is received, the message may be retransmitted.

This approach to resolving contention in a mesh network has a number of problems. First of all it introduces additional latency. The CSMA/CA scheme potentially introduces substantial latency because of the random backoff time and the exchange of RTS and CTS messages. Second, it also means that there will be multiple copies of a message received at each hop. If each relay forwards a copy of the message then the number of copies of a message increases exponentially as the number of hops increases resulting in wasted radio resources.

However, unlike conventional network technologies, LoRa intrinsically addresses this problem. LoRa's mechanism for dealing with interference also acts as a mechanism for dealing with collisions at a receiver when multiple relays transmit the same message at the same time. This greatly simplifies design of multi-hop networks, making LoRa a very attractive candidate for mesh networking. To explain why, we will briefly describe the LoRa physical layer.

LoRa makes use of Chirp Spread Spectrum in which over a symbol time the frequency changes linearly over the symbol frequency range (typically 125 kHz or 500 kHz). Different symbols are encoded by varying the frequency at which the Chirp starts. Once the maximum frequency is reached the chirp starts from the lower bound of the frequency range and increases until the end of the symbol duration. This is referred to as a 'cyclic shift'. Fig. 2 shows encoding of three different symbols. The solid lines in different colours each represent a different symbol.

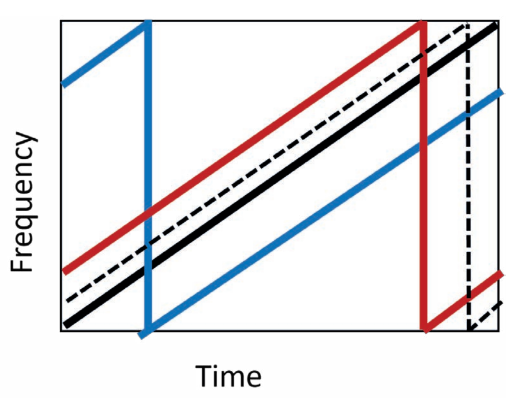

Fig. 2. LoRa Symbols

LoRa defines a frame structure for communicating between two nodes. A receiver will synchronise with a transmitter at the start of the frame transmission. Once synchronised only symbols that start at specific frequencies will be recognized. Any signal that starts at a different frequency will be treated as noise. In particular, this includes symbols from other LoRa transmitters. The situation is illustrated in fig. 2. The solid lines begin at valid frequencies while the dashed line does not. The dashed line represents a symbol from another LoRa transmitter that has not synchronised with the receiver. The receiver will treat the dashed line as noise.

This synchronisation mechanism solves the relay collision problem. Even though multiple relays may transmit the same copy of the message, the receiver (another relay or the ultimate destination of the message) will synchronise with just one relay and treat other messages as noise.There is no need for a complex CSMA/CA scheme. Only one copy of the message will be received and forwarded.

Nevertheless there is a price for this simplicity, and that is a reduction in the Signal to Noise Ratio (SNR). Because traffic from relays other than the one synchronised with are treated as noise, the SNR at the receiver will decrease as the number of relays increases.

In this paper we demonstrate the effectiveness of LoRa in addressing contention between multiple relay transmissions. We show that even though multiple relays transmit a copy of the message at the same time, the receiver only receives one of them and treats the others as noise. We show that the latency of transmission is less than when a scheme such as CSMA/CA is used. We also quantify the effect of multiple transmissions on SNR. We measure the SNR, the Received Signal Strength Indicator (RSSI), and determine the effect on transmission reliability as the number of relays within range of a transmitter and receiver increases. We find that the SNR decreases and the RSSI increases as the number of relays increase. We find there is no detectable effect on reliability for up to four relays but beyond that reliability (as measured by number of frames successfully transmitted) decreases dramatically with seven relays causing 45% of messages to be lost.

The rest of this paper is structured as follows. Section II describes related work. Section III describes the experiments we carried out while Section IV reports on our results. We conclude and discuss future work in Section V.

II. Related Work

Mesh networking has been an area of research interest for some time [14]. However, the implications of LoRa's handling of interference for the design of multi-hop networks has only recently been realised. It was first noted by Liao et al [7] and then developed by Rao et al [15] in the context of linear networks. Rao et al. noted that provided the relays were not perfectly co-located, then as a consequence of propagation delay there will be a very small difference in the times when the frames are received at the receiver. This time difference is sufficient for the receiver to synchronise with the first transmission and treat subsequent transmissions as noise. The receiver will synchronise with the first message it receives and treat other concurrent transmissions as noise.

The implications of LoRa's behaviour for mesh networking is yet to be explored. In this paper we address that research gap.

III. Experimental Methods

We carried out a series of experiments where multiple relay nodes relayed messages from a transmitter to a receiver. Each experiment was conducted for fifteen minutes. Messages were transmitted from the source node at 5-second intervals, which equates to a total of 180 messages sent per scenario. The LoRa nodes were set up to use 915 MHz, spreading factor of seven and 125 kHz channels. We varied the number of relays from one to seven. For each transmission we recorded SNR, RSSI and Frame transmission error rate. We then averaged this over the total number of frames sent to obtain a mean for each metric.

Fig. 3 and 4 illustrate the network architecture for three and seven relays respectively. Note that the relays are not perfectly colocated so there will be a very small time difference in when the relays receives messages from the transmitter. The transmitter sent a frame every five seconds. All relays forwarded the message one second after receiving it. Because they are not perfectly co-located there will be a small time difference in when the receiver receives the messages. The receiver will synchronise with the first message it receives and treat the other transmissions as noise. The results shown in fig. 5, 6 and 7 were all collected at the Receiver.

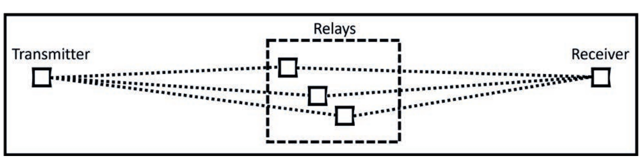

Fig. 3. Two Hop Relay Network with Three Relays

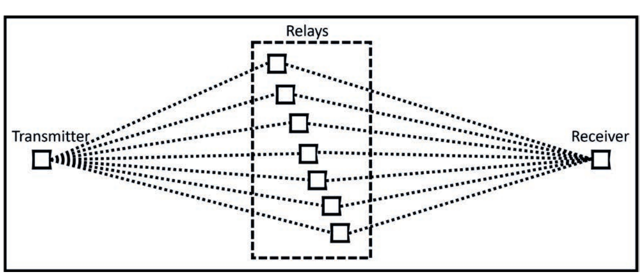

Fig. 4. Two Hop Relay Network with Seven Relays

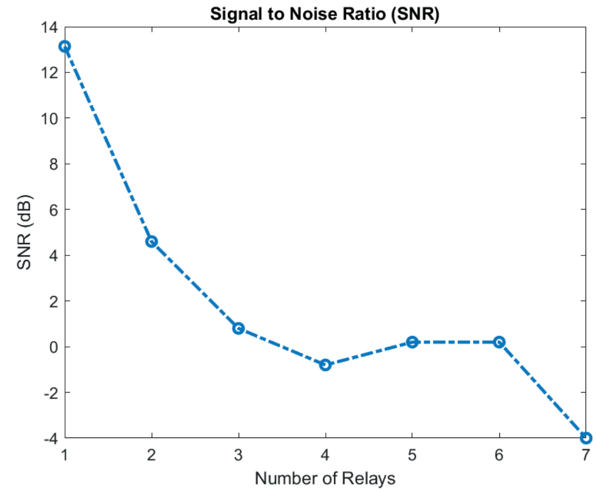

Fig. 5. SNR

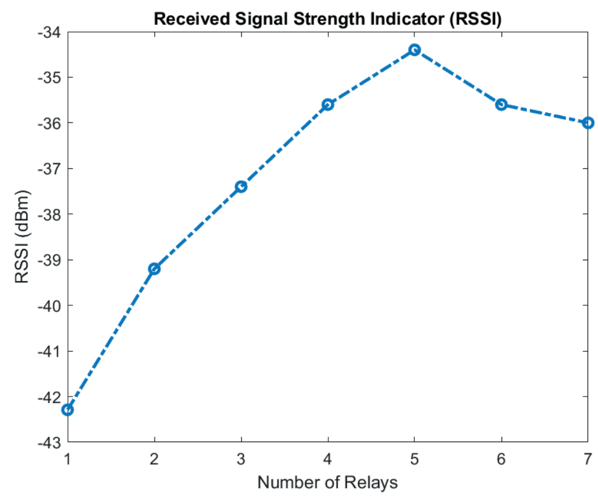

Fig. 6. RSSI

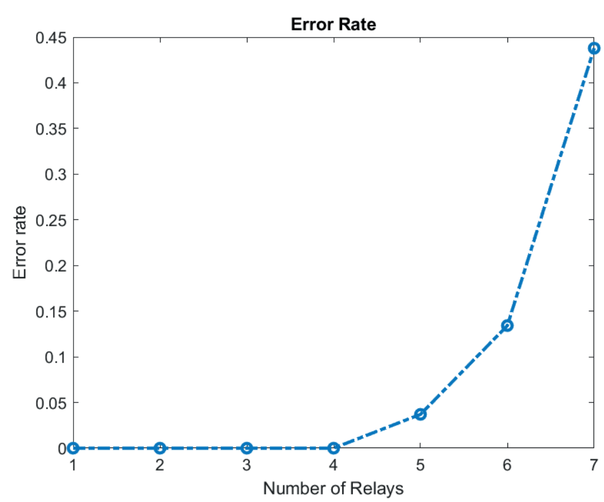

Fig. 7. Error Rate

IV. Results

The key results of our experiments were that we were able to confirm that LoRa does indeed synchronise with only one node and treats all other messages as noise. Regardless of the number of relays the Receiver received only one copy of the message.

We also noted that latency introduced by the relays was negligible. There was no measurable delay between the message being sent and received regardless of the number of relays. Finally we carried out a detailed exploration on the effect of the number of relays on SNR and frame loss.

Fig. 5, 6 and 7 show the results of our experiments. We see that the SNR decreases in a smooth fashion for up to four relays. With only one relay SNR is 13.1 dB, with two it is 4.6 dB, with three 0.8 dB and with four relays it is -0.8 dB. We then see some unexpected behaviour as the SNR appears to increase. However, this can be understood by examining fig. 7 where we see that once we have five relays, frames start to be lost. Consequently, our measure of SNR from five relays onwards is only of the frames that were successfully received. The frames that were lost would likely have much lower SNR resulting in a higher mean value for the SNR.

Fig. 6 shows the signal strength at the receiver. Once again we see a smooth increase from -42.3 dBm with one relay to -35 dBm with five relays after which it declines. Because the receiver measures RSSI based on packets received the large packet losses seen with six and seven relays will also affect the measurement of RSSI.

Finally and perhaps most importantly, fig. 7 shows the error rate as the number of relays increases. This comprises frames that were lost or corrupted during transmission. There is no frame loss or corruption for up to four relays after the error rate increases smoothly until it reaches 45% with seven relays.

V. Conclusion

Perhaps the most important message from this work is that LoRa makes relay design and mesh networking simpler than with other technologies. Because there is no need for complex collision avoidance schemes there is negligible latency, regardless of the number of relays at each hop. However, there is a cost. That cost is reduced SNR resulting in frame losses once the number of relays reached or exceeded four. Consequently, network planning needs to take into account the number of overlapping relays in a network. It cannot be unlimited.

Future research will attempt to reconcile theoretical models of the relationship between SNR, RSSI and frame loss with the experimental data we have recorded here. We also plan to construct some large mesh networks using LoRa to prove its effectiveness as a relay technology.

LoRa has great potential as a mesh networking technology. Nevertheless, it has some limitations. The work reported on in this paper has demonstrated both its potential and some of those limitations.

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