Infrastructure-less Long-Range Text-Messaging System

Batyrkhan Baimukhanov and Dimitrios Zorbas
Nazarbayev University, School of Engineering & Digital Sciences, Astana, Kazakhstan
Authors' email: batyrkhan.baimukhanov@nu.edu.kz, dimitrios.zorbas@nu.edu.kz

***Abstract*—This paper proposes an ongoing work on a novel Internet of Things (IoT) text-messaging system that leverages LoRa communications to interconnect end-users. The system aims to provide efficient and reliable communication between IoT devices by establishing a robust backbone network capable of combating packet flooding. With LoRa, the system achieves extended coverage, allowing devices in remote areas to stay connected while permanent network infrastructures are absent. Moreover, the system emphasizes the importance of user-friendly text messaging, providing a familiar and intuitive means of communication for end-users. By integrating the simplicity of text messaging combined with the long-range capabilities of LoRa, the system enables seamless and efficient communication across various IoT devices, enhancing user experience and promoting widespread adoption. Through extensive testing and evaluation, the system demonstrates its effectiveness in establishing a reliable and scalable IoT text-messaging infrastructure with a very low overhead.**

***Index Terms*—Internet of Things, Text-messaging, LoRa, Connected Dominating Set**

I. Introduction

Text-messaging systems play a crucial role in post-disaster management by enabling effective communication and information dissemination among affected individuals, emergency response teams, and the general public [1]. These systems utilize the widespread availability of mobile devices, IoT devices, and the ubiquity of text messaging to deliver critical alerts and instructions during the recovery phase of a disaster.

Various IoT solutions have been proposed to detect natural disasters such as forest fires [2], floods [3], and earthquakes [4]. Combining those disaster detection systems with automatic text-based notification system might prove to be more efficient in alerting the public than through traditional communication channels since they may be compromised or inaccessible. Ad-hoc text-messaging systems provide a direct and immediate way to reach a large number of people, enabling authorities to efficiently share vital information, such as evacuation orders, safety instructions, and updates on available resources and services [5]. By leveraging text-messaging systems, post-disaster management efforts can effectively disseminate information, enhance situational awareness, and facilitate coordination among stakeholders, ultimately aiding in the recovery and rebuilding process.

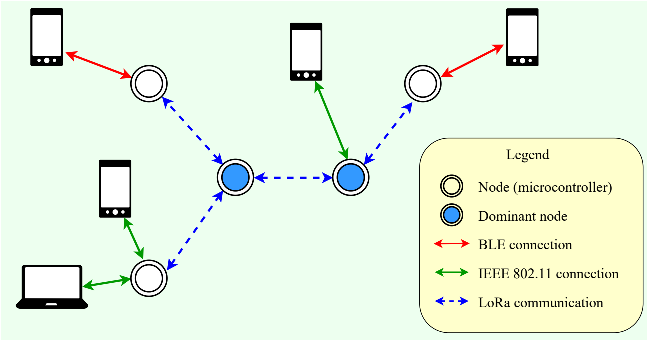


Fig. 1: The system architecture consisting of LoRa-devices and users connected to those devices via BLE or WiFi.

Prior research has focused on the development of low-power wide-area networks for emergency text messaging using the long range communication technology, LoRa. It is a proprietary chirp spread spectrum technology, which presents certain challenges in the system design [6] such as half-duplex transmissions and radio duty cycle restrictions. Cardenas et al. [7] introduced a system that employed smartphones and LoRa-devices. The LoRa-devices acted as message hubs, storing messages accessible through a dedicated webpage. The network coverage was expanded by allowing Internet users to exchange messages with the LoRa network. However, the proposed system lacked forwarding functionalities, which meant all LoRa transmissions were limited to a single hop. Macaraeg et al. [8] developed a similar system but with multi-hop transmissions enabled. The authors employed the ad-hoc on-demand distance vector routing algorithm (AODV) adapted to work with the Received Signal Strength (RSS). Although the performance of the algorithm exceeded the standard AODV, the system suffered from a high packet loss that progressively worsened with each hop due to point-to-point transmission limitations. Baumgartner et al. [9] proposed a geospatial routing approach for LoRa networks which relied on stationary relays with GPS modules. Unfortunately, the design required preliminary system setup before the deployment.

The above-mentioned works have proposed and developed text-messaging systems based on LoRa, providing user-friendly interfaces and long-range network coverage. However, what still poses a great challenge in designing LoRa mesh networks is implementing a reliable multi-hop forwarding with low packet loss and latency. In this paper, we propose an IoT text messaging system that employs a Connected Dominating Set-

979-8-3503-1951-4/23/$31.00 ©2023 IEEE

based flooding protocol to address this challenge.

II. SYSTEM ARCHITECTURE

The proposed system interconnects personal mobile devices (e.g., phones, tablets, laptops etc.) with battery powered LoRa-devices to deliver user text messages. The system dynamically creates a wireless, low-power, wide-area network as well as a backbone network to facilitate routing. This is done by establishing a Connected Dominating Set (CDS) over a LoRa network accounting for the underlying links Received Signal Strength (RSS). The network formation is done in a distributed and ad-hoc way without any requirement in permanent infrastructure. Technologies such as WiFi and Bluetooth, which are familiar to end-users due to their everyday use, facilitate the connection between mobile devices and LoRa-devices. A schematic diagram of a possible network arrangement is shown in Fig. 1.

A. *End-user – LoRa-device communication*

An end-user can connect to a LoRa device via Bluetooth Low Energy (BLE) or via WiFi. These two methods are explained below.

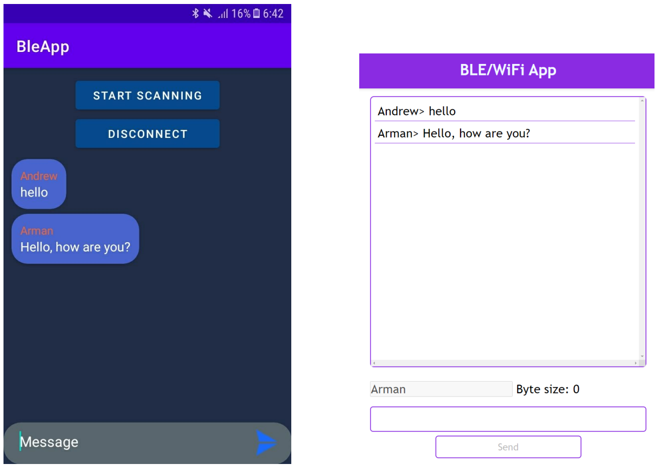
1) BLE Interface: In the proposed system, a LoRa-device acts as a peripheral device, advertises itself, and waits for a central device to connect to it. A smartphone acts as a central device, scans for beacons, and initiates the connection. After a BLE connection between the two devices has been established, the devices can start exchanging messages using two BLE GATT characteristics. An Android application was developed to provide a user interface for text messaging. Using the application, the user can scan for available devices, connect to one of them, and start messaging (see Fig. 2a).

2) WiFi Interface: Another interface through which the user can connect to a LoRa-device is the IEEE802.11 access point. By connecting to the access point, the users can access a webpage stored on the LoRa-device using their browser. As with the smartphone application, the users can read and send messages through the webpage (see Fig. 2b). Message exchange between the user browser and the LoRa-device is executed using the WebSocket protocol.

B. *LoRa-device – LoRa-device communication*

The system implements a custom LoRa-based protocol for packet forwarding, packet integrity, and duty cycle control mechanisms. The packet header consists of the packet type (beacon, neighborhood information, and user text message), the message ID, the hop count limit, and the checksum fields. The hop limit field prevents infinite packet circulation and the message ID field is used to identify packet duplicates.

1) Packet Forwarding: To disseminate packets in the network, a flooding technique is used. However, unlike other approaches in the literature, flooding is restricted among dominant members of the CDS, allowing to reduce network congestion.



Andrew
hello

Arman
Hello, how are you?

Andrew> hello

Arman> Hello, how are you?

Arman

(a) Android application interface for BLE connections.

(b) Web interface for WiFi connections.

Fig. 2: User interface of the mobile applications.

2) Packet Integrity: LoRa devices implement an internal cyclic redundancy check (CRC) to determine if all the bytes in the packet are received correctly. However, in some devices CRC is not enabled by default, which allows corrupt packets to be accepted. Secondly, LoRa receivers can pick up noise signals from the environment and accept them as legitimate packets because CRC flag is not set in the header. Due to these reasons, additional error detection methods are employed to ensure reliable data delivery over LoRa. For this purpose, a checksum header field is calculated by hashing an entire packet with the SHA256 hash function and truncating the result to 4 bytes. If a packet is to be forwarded, then a new checksum value is computed because the hop count value is changed.

3) Radio Duty Cycle Restriction: LoRa devices transmit in unlicensed sub-GHz spectrum. In many regions the use of this spectrum is regulated by the government to avoid harmful interference. Depending on the region and the radio band, the duty cycle of a node should not exceed 0.1%, 1%, or 10%. In the proposed system, nodes calculate the transmission time of each packet and make sure that enough time has elapsed before transmitting the next packet.

C. *Connected Dominating Set*

In ad-hoc networks, standard flooding suffers from excessive duplication and inefficient bandwidth utilization [10]. To mitigate these issues, we propose a CDS-based flooding where only dominant nodes broadcast packets to their neighbors, reducing the bandwidth usage while retaining full network coverage.

The proposed CDS algorithm is based on Wu and Li's algorithm [11]. The algorithm is distributed and each member of the network independently determines whether it should be a dominant node or not. Factors such as the neighbor connectivity, the presence of other dominant nodes, and RSS are considered during the decision-making process.

At the beginning, a node enters the neighbor discovery state and advertises itself with beacon frames. During this state, a node determines its one-hop neighbors and the corresponding

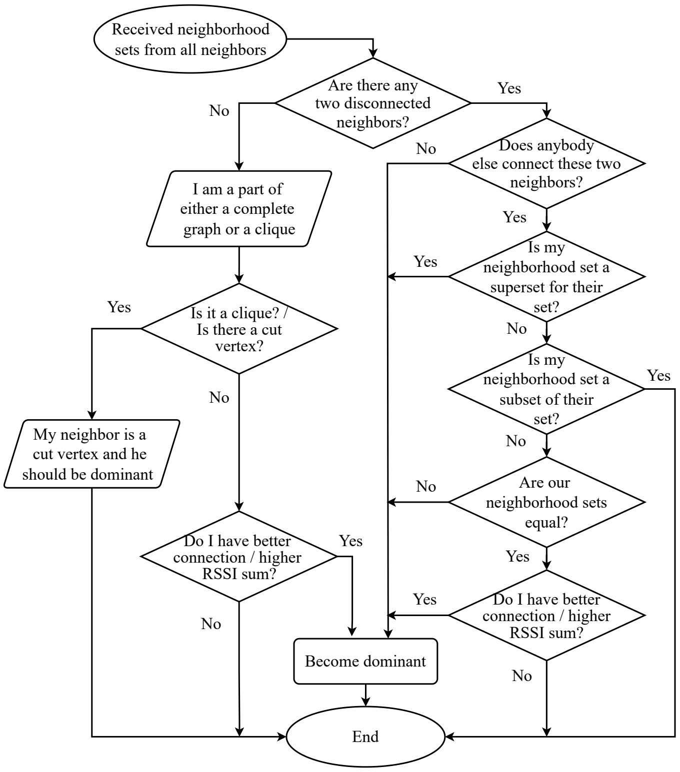


Fig. 3: Steps for finding a Connected Dominating Set.

RSS values. After a fixed amount of time, a node assumes that it has discovered all its neighbors and may exit the neighbor discovery state. The duration of the discovery state should be a multiple of the beacon interval to ensure that a node receives at least one beacon from each neighbor. After exiting the state, the node broadcasts its neighborhood information consisting of MAC addresses and RSS values. After doing this, the node waits to receive such information from all neighbors. Upon receiving the last packet, the node checks whether it should become dominant. The algorithm for deciding dominance is illustrated in the flowchart of Fig. 3.

Firstly, a node checks whether it has two disconnected neighbors. If all neighbors are connected, it implies that the node is a part of a complete graph or a clique. In this scenario, the node becomes dominant if and only if none of the neighbors are dominant, and the node has the highest sum of RSS values. If there are two disconnected neighbors, then the node is a candidate for a dominant position. Before assuming the dominant role, the node checks whether there is another candidate that connects those two disconnected neighbors. If no candidates are present, the node becomes dominant. If there is a dominant candidate, they resolve the conflict by comparing their neighborhood sets and RSS values. The node whose neighborhood set is a superset becomes dominant. If both candidates have identical neighborhood sets, then the one with higher RSS becomes dominant. If their sets are neither equal nor subsets nor supersets, both candidates become dominant.

III. PERFORMANCE EVALUATION

Several experiments were conducted to evaluate the performance of the proposed system in a small scale scenario. The main network metrics that were evaluated were the latency, the packet loss, the CDS construction rate, and the CDS recalculation time. Additionally, the proposed approach was compared to a standard flooding technique used in the literature. The system was implemented on Pycom Lopy4 devices using Micropython. The code for the project is available on GitHub[1].

A. *Packet delay*

The first experiment estimated the packet delay with round-trip time (RTT) in a network of 3 nodes. Packets with sizes of 16 bytes and 256 bytes were sent from one edge to another edge device through a dominant CDS node and back, totaling into 4 hops. The distance between nodes were set to 2m, 250m, 500m. SF of 7 and channel bandwidth of 125kHz were used for convenience. The coding rate (physical layer error correction) was set to 4/5. A channel with 10% duty cycle was employed (869.525 MHz).

The results presented in Table I reveal that the distance between the nodes has a minimal impact on the latency, whereas the packet size contributes much to the delay, which coincides with the results of [7]. RTT of 16 bytes packets was just under 450ms and RTT of 256 bytes packets was just under 2000ms for all distances. Considering that 256 bytes is the maximum allowed size of a packet for LoRa and assuming no collisions and packet corruptions, in a network with a graph diameter of 4 or less, devices are guaranteed to receive any packet in under 2 seconds.

B. *Packet loss*

The packet loss test was conducted using the same network scenario as in the first experiment. During the test, 2% of text packets were lost due to collisions with beacon frames. Another reason is that the dominant node was unable to forward packets more than once due to duty cycle restrictions. Having at least two dominant nodes in the network should decrease the packet loss rate due to redundant packet transmissions.

C. *CDS construction*

The algorithm to compute the CDS was tested in networks with different underlying graphs, ranging from trees to complete graphs with up to 5 devices. The devices were programmed to discover CDS within one minute. During that one minute, nodes broadcast beacons, exchange neighborhood information, and run the CDS algorithm. All network variations with cliques of four devices or less showed a success rate of 100%. However, in a network of 5 devices constituting a complete graph, the success rate dropped to 83%. The main reason for this decrease in performance is that the channel becomes congested with more devices and packet collisions become more frequent. To avoid such issues, more time should be allocated for the CDS discovery so that the beacon intervals can be larger, and thus, minimize the collision probability. Since

---

[1] https://github.com/BatyrkhanBaimukhanov/CDS-on-LoRa

TABLE I: Experimental results of the proposed solution.

Experiment	Setup Details	Result
Average Packet Delay over 4 hops	Packet Size of 16 bytes	< 450ms
	Packet Size of 256 bytes	< 2000ms
Packet Loss Rate		2%
CDS Construction Success Rate	Cliques of 4 devices or less	100%
	Complete graph of 5 devices	83%
CDS Recalculation Time	Departure of Dominant Node	4.37 min
	New Dominant Node Joining	1.83 min

TABLE II: Flooding with and without CDS.

Nodes	**Graph type**	**Duplicate packets**	
		Without CDS	**With CDS**
3	Complete	5	1
4	Complete	7	1
3	Path	4-5	1
4	Path	5-6	3

this is an on-going research, we plan to integrate and evaluate this feature in future versions of the system.

D. CDS recalculation

In addition to the discovery of the CDS, the proposed algorithm allows devices to detect changes in the network structure and enable them to adapt to such changes by updating the dominating set. To evaluate the algorithm's performance, two scenarios that trigger the CDS recalculation were examined: (a) when a dominant node quits the network, and (b) when a more suitable candidate for a dominant position joins the network. These tests were carried out on complete graphs consisting of 3, 4, and 5 LoRa nodes. The corresponding network response times were measured.

The experimental results shown in Table I indicate that, on average, the network required 4.37 minutes to identify the absence of a dominant node and select a replacement. Additionally, the network took an average of 1.83 minutes to identify a better candidate and choose it for the dominant node position. Given that changes in network structure are not expected to be frequent, the obtained results can be considered appropriate response times.

E. CDS-based flooding

The comparison results between the standard and the CDS-based flooding techniques is shown in Table II. The number of duplicate packets was tested on small graphs of 3, 4 devices with a hop limit of 3. The standard flooding generated 5 and 7 duplicates on complete graphs with 3 and 4 nodes, respectively. In path graphs with the same number of nodes, the packet was duplicated 4-5 and 5-6 times, respectively. On the contrary, CDS-based flooding generated only 1 duplicate on all graphs except the path graph with 4 nodes which exhibited 3 duplicate packets. Even though the tests were done on small scale scenarios, the proposed approach achieves considerable reductions in the packet duplication, and thus, in energy consumption and congestion.

IV. CONCLUSIONS & FUTURE RESEARCH

In this paper, we presented an infrastructure-less text messaging system based on LoRa and connected dominating set graphs. The system utilizes battery-powered ESP32-based microcontrollers and enables communication with smartphones/laptops through BLE and WiFi interfaces. We have developed a native Android application and a web-based interface for user interaction. A network backbone mechanism based on CDS was proposed to reduce the congestion in the network. The experimental evaluations have demonstrated the feasibility and effectiveness of the proposed system.

In the future, we plan to enhance the system performance by considering the dominant nodes as message storage medium, allowing for increased message resilience. Additionally, we aim to adapt the CDS calculating algorithm to consider battery levels and connectivity to an seamless power source such as the electrical grid.

ACKNOWLEDGEMENTS

This publication has emanated from research conducted with the financial support of Nazarbayev University grant No. 11022021FD2916 for the project "DELITMENT: DEterministic Long-range IoT MEsh NeTworks" and from Samruk-Kazyna JSC for the project "Development of a warning system for repair crews about the approach of a train" grant No. 280921SK0201 implemented by Nazarbayev University for National Railways company JSC.

REFERENCES

[1] M. Kamruzzaman, N. I. Sarkar, J. Gutierrez, and S. K. Ray, "A study of IoT-based post-disaster management," in *2017 international conference on information networking (ICOIN)*, pp. 406–410, IEEE, 2017.

[2] A. E. U. Salam, A. Arifin, M. Rizal, *et al.*, "Forest fire detection using lora wireless mesh topology," in *2018 2nd East Indonesia Conference on Computer and Information Technology (EIConCIT)*, pp. 184–187, IEEE, 2018.

[3] M. I. H. M. Yassin, A. T. Wan, S. S. Newaz, and S. Omar, "Lora based real-time flood detection and monitoring system: A brunei darussalam based study," in *2021 International Conference on Electronics, Communications and Information Technology (ICECIT)*, pp. 1–5, IEEE, 2021.

[4] V. Babu and V. Rajan, "Flood and earthquake detection and rescue using iot technology," in *2019 International Conference on Communication and Electronics Systems (ICCES)*, pp. 1256–1260, IEEE, 2019.

[5] P. P. Ray, M. Mukherjee, and L. Shu, "Internet of things for disaster management: State-of-the-art and prospects," *IEEE access*, vol. 5, pp. 18818–18835, 2017.

[6] P. Gkotsiopoulos, D. Zorbas, and C. Douligeris, "Performance Determinants in LoRa Networks: A Literature Review," *IEEE Communications Surveys Tutorials*, vol. 23, no. 3, pp. 1721–1758, 2021.

[7] A. M. Cardenas, M. K. Nakamura Pinto, E. Pietrosemoli, M. Zennaro, M. Rainone, and P. Manzoni, "A low-cost and low-power messaging system based on the LoRa wireless technology," *Mobile networks and applications*, vol. 25, pp. 961–968, 2020.

[8] K. C. V. G. Macaraeg, C. A. G. Hilario, and C. D. C. Ambatali, "Lora-based mesh network for off-grid emergency communications," in *2020 IEEE Global Humanitarian Technology Conference (GHTC)*, pp. 1–4, IEEE, 2020.

[9] L. Baumgärtner, P. Lieser, J. Zobel, B. Bloessl, R. Steinmetz, and M. Mezini, "LoRAgent: a DTN-based location-aware communication system using LoRa," in *2020 IEEE Global Humanitarian Technology Conference (GHTC)*, pp. 1–8, IEEE, 2020.

[10] E. Alotaibi and B. Mukherjee, "A survey on routing algorithms for wireless ad-hoc and mesh networks," *Computer networks*, vol. 56, no. 2, pp. 940–965, 2012.

[11] J. Wu and H. Li, "On calculating connected dominating set for efficient routing in ad hoc wireless networks," in *Proceedings of the 3rd international workshop on Discrete algorithms and methods for mobile computing and communications*, pp. 7–14, 1999.