Long-Range Low-Cost Networking for Real-Time Monitoring of Rail Tracks in Developing Countries

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Derailments present a frequent phenomenon in several developing countries, which result in massive loss of property along with death tolls. For preventing derailments, a real-time automated system is needed to detect uprooted or faulty rail blocks. One of the solutions in this context is to sense the vibration of the rail track having an incoming train and transmit the information to the train notifying it about the condition of the rail track ahead. However, existing studies in this regard are yet to present a pragmatic solution that enables much-demanded long-distance networking to transmit the sensed data. The demand for long-distance network communication between the sensor nodes and the incoming train is unavoidable, as stopping the train after sensing an uprooted or faulty rail block ahead needs a considerable response time and distance. Therefore, in this paper, we develop a low-cost, long-range, and highly reliable mobile multi-hop networking scheme to successfully transmit data sensed from rail tracks to an approaching train at a distance of around 2000m. By considering the effect of Fresnel's Region in our study, we determine the suitable placement of the networking module on the rail track, which leads us to achieve a delivery ratio of more than 99%. We confirm this finding through rigorous experiments over a real testbed scenario enabling mobile multi-hop networking.

CCS Concepts: • **Networks → Network experimentation**; • **Hardware → Wireless devices**.

Additional Key Words and Phrases: Networking, LoRa, Railway, Derailment

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1 INTRODUCTION

Derailments of train frequently happen in developing countries such as Bangladesh, India, Pakistan, Kenya, etc., [33], [2], [28], [21], [24], [20] (Figure 1). Such occurrences of derailments often result in lethal consequences, injuries, and

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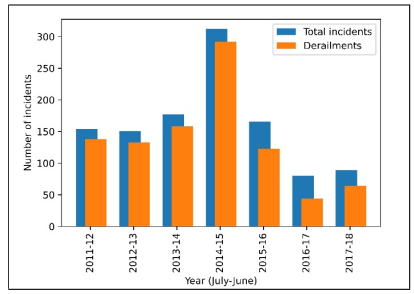
(a) Bihar, India (Feb 3, 2019) [19]

(b) Taxila, Pakistan (Oct 4, 2019) [12]

(c) B-Baria, Bangladesh (Jul 1, 2018) [31]



(d) Derailment statistics in Bangladesh [27]

Fig. 1. Derailment incidents in different countries

casualties, along with a huge amount of economic losses in addition to hampering rail communication. Accidents caused due to the derailments take a huge toll on economic growth and damage locomotives, train compartments, tracks, and other assets engendering substantial financial losses. To address this problem, a common initiative is to send a locomotive before setting off a passenger train for inspection over a short distance ahead. However, this does not curb the risk as it does not check the whole path ahead, and more importantly, uprooting a block can be done within a short period by a group of miscreants in developing countries. Moreover, many developing countries do not have enough extra functioning locomotives to assign for each passenger train [4, 32]. This calls for a pragmatic and automatic system for detecting missing rail blocks in real-time.

In road to developing a real-time pragmatic solution in this regard, a considerable challenge is to ensure enough response time for a driver to stop a running train in case of sensing any uprooted or faulty rail block ahead. Because of the speed and momentum associated, it is almost impossible to stop a running train just after visually identifying a missing rail block from the drivers' point of view. In this context, this paper aims to provide a real-time pragmatic solution to inform an approaching train at a sufficiently long distance after detecting discontinuity in rail tracks. We specifically focus on the networking challenge in this regard. Besides, we particularly focus on developing countries in this study.

The context of developing countries presents some crucial concerns in designing our solution. The most serious of these concerns is the limited capability for adopting such solutions at a large scale. Therefore, our study looks into developing a low-cost solution that will enable long-range communication network to detect transmitted data about missing rail blocks in real-time.

To do so, in this work, we thoroughly investigate the efficiency of an emerging networking module, called LoRa [22], in transmitting data over long range with the maximum possible delivery ratio. Accordingly, we design multiple experimental setups to get a vivid idea of the complex behaviors of the transmission module when deployed in a real-time rail environment. Based on the experimental results, we propose a suitable modality of networking that will enable low-cost long-range networking in the context of real-time missing or faulty rail block detection in developing countries. Based on our work, we make the following set of contributions in this study.

- We investigate different wireless networking paradigms to select a suitable mechanism for long-distance low-power communication to enable transmitting outcomes of the sensed data from rail tracks.
- We devise a suitable methodology to set up low-cost wireless communication network over rail tracks for enabling real-time derailment detection. Our proposed model exhibits more than 99% packet delivery ratio by reducing the transmission data failure.

2 RELATED WORK

As this study spans different parts (i.e., railway monitoring system, networking, etc.) needed for developing the intended real-time communication network for rail line monitoring system, we find related research work from different dimensions. We present each of them in the following subsections.

2.1 Railway Monitoring Systems

Many researchers exhibit a deep interest in designing and developing components and systems for modern railway operations. Most of the studies focus on detection of cracks, small breakages, stress, inclination, etc., in the rail-lines of the railway system [34], [36], [15], [6], [5], [7], [29], many of which are based on conventional track circuit based signaling [26]. Several methods are proposed for monitoring the overall railway infrastructures [6], [13], [25], [14]. Some researchers investigate on-board track monitoring systems with the help of machine vision systems, which capture high-resolution images of the rail track and then perform pattern recognition algorithms on the images to detect defects on the rail track [11], [16]. These studies mainly exploit expensive acoustic emission and long-range ultrasound techniques to monitor rail crack and breakage. Despite extensive research on this method, these systems cannot detect missing rail blocks in real-time due to lack of real-time sensing as well as proper communication network. However, developing countries often experience derailments due to missing or faulty rail blocks, where a real-time solution to detect missing rail blocks is of the utmost importance to ensure the safety of the trains.

2.2 Networking over Rail Tracks

A few studies focus on designing suitable network paradigm considering conditions of railway tracks [3], [14], [25], [30]. Here, one study proposes a wireless sensor network based on cellular systems [25]. Other studies utilize commonly-used standards such as Bluetooth, IEEE 802.15.4, and WiFi for communication between the sensor nodes[3], [14]. Besides, other communication standards such as GSM, GPRS, UMTS, and GSM-R are also explored for the same purpose. These solutions demand an expensive deployment of a complex network structure. The solutions, as mentioned earlier, are not very suitable in the contexts of low-income, and limited-resource (i.e., developing) countries such as Bangladesh, India, Pakistan, Kenya, etc., where long rail tracks are publicly open.

Additionally, in [8] a LoRa based less complex, linear, relay transmission network architecture is proposed. It reduces the effect of interference from multiple devices by introducing effective broadcast scheduling for avoiding network collision. However, in this work, the time delay increases due to the scheduling scheme, and this approach is not amenable in the case of real-time data communication over the rail tracks. By increasing the spreading factor of the transmission module, packets are transmitted within 1 km, however, in cost of some extra delay. This method is performed on a single-hop basis which can be used in underground mines, tunnels, and rail links.

For long-range communication, multi-hop transmission is essential. In [17] a much efficient multi-hop protocol-concurrent transmission is combined with the Lora module. The concurrent protocol allows synchronized packet collisions that need to be monitored carefully. In this study, by introducing timing offsets between relaying packets, the network's feasibility is improved.

In [1], a Linear Network topology is introduced based on multi-hop LoRa series chain communication which Increases the range of communication. An ad-hoc transmission protocol is proposed that optimally examines the wake-up time of the Lora modules, which results in a 50% reduction in power consumption when the non-optimized wake-up scheme is used. This method is successfully implemented in underground environments of Siena, Italy- indicating that the multi-hop linear network is a feasible choice in such environments where continuous, long-range, reliable, and energy-efficient transmission is required.

Corresponding studies regarding implementing low-cost and reliable networking modules into real-time deployment inspire us to use the Lora module in our study. Relay networking using multi-hop transmission for long-range communication and uplifting the placement of the networking modules are inspired from the concurrent studies, and substantial improvements are made.

2.3 Specialized Solutions for Developing Countries

There exist a few studies on real-time solutions for detecting missing rail in the context of the developing countries [9], [10], [23]. These solutions consider a networking distance of approximately 600m, which can be practically inadequate for stopping a train at a safe distance ahead of the fault. Moreover, these solutions did not extensively explore diverse situations for analyzing the communication network.

3 BACKGROUND OF OUR RESEARCH CONTEXT

In this section, we discuss the overall networking model with the communication scenarios detecting missing rail blocks as discussed in [9] and [10]. Later, we narrate the shortfall of the existing studies in our research context.

3.1 Networking

We aim to deploy sensing nodes on the rail tracks. Each sensing node consists of a sensing unit and a control unit along with a communication module. These nodes are static nodes and sense vibration on the rail tracks created by a moving train. While a train approaches by producing vibration signals, the sensor nodes on the rail tracks collect minimum information of the vibration pattern for classification of the state of the rail blocks. Any discontinuity on the rail tracks hinders or changes the propagation of vibration created by the approaching train from the ideal condition. Based on this information, the sensor node generates output data,and then passes it to the control unit. The control unit analyzes that data and detects any fault in the rail tracks by applying signal processing and machine learning methods over the received vibration data. Finally, through the communication module, the control unit notifies the train about the condition of the rail track. Eventually, the communication module on the train receives the result and takes necessary measures based on the received notification.

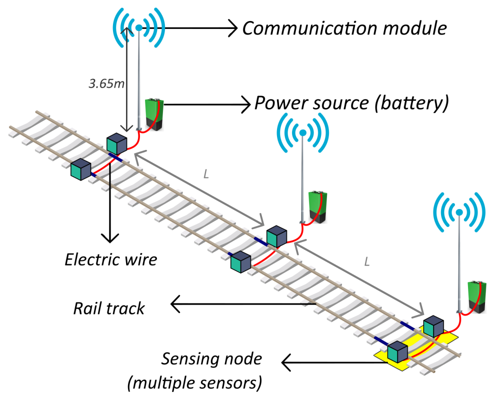


Fig. 2. Simplified diagram of our proposed system

3.2 The Insufficiency of The Existing Studies to Our Context

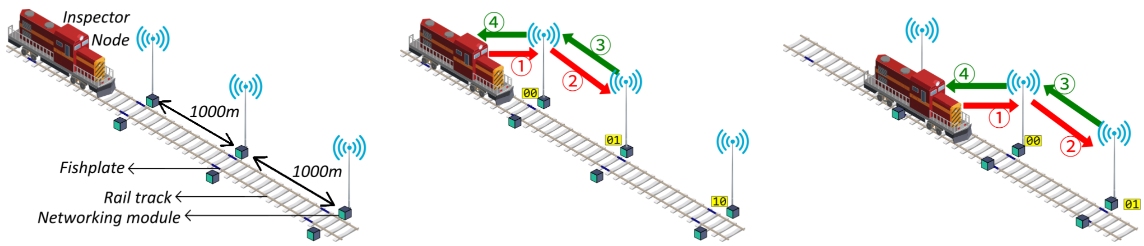
A real-time wireless sensing system for detecting missing rail blocks was first apprised in the study of [9]. The network paradigm and the protocol further elaborated in [10]. Nonetheless, the authors in [10] placed the transmitter and receiver antenna on the ground, which technically hampers the clearance distance defined by Fresnel zone [35]. Although a robust antenna system seems to depend only on the line-of-sight between transmitter and receiver, the Fresnel zone plays a vital role in this scenario. Therefore, we design the communication system considering the Fresnel zone, which successfully communicates data over 2000m. Moreover, the work in [10] lacks in incorporating the performance of long-range communication in some diverse situations. such as different heights of the communication modules, different velocities of the communication modules, etc.

4 PROPOSED METHODOLOGY

In this section, we portray our proposed architecture for the networking system being consistent as proposed in [10] and [9]. We present the simplified diagram of our proposed model in Figure 2.

Figure 3a illustrates our proposed networking system architecture along with the sensing system architecture for the real-time missing rail block detection system. The system consists of two different modules: (1) module on the rail track and (2) module in the train (indicated as the Inspector Node). The former has a sensing unit, a control unit, and a communication module. The latter has a control unit and a communication module. In Figure 3a, the sensing modules are placed on the adjacent rails blocks to collect vibration data from both rails on the track. Thus, they form a pair. For simplicity, we consider the nearest two pairs of sensor nodes from the Inspector Node. The second pair of sensor nodes is positioned 1 km apart from the first pair. The Inspector Node is placed 1 km apart from the first pair of sensor nodes. Thus, each of the communication modules are placed 1 km apart, making a total distance of 2 Km from the Inspector Node to the farthest sensor nodes pair under consideration.

We use LoRa [22] modules for the communication system. To avoid obstacles within the Fresnel zone clearance, we mount the LoRa module on a 3.65m tall pole. We consider the height of the train for choosing the height of the pole as 3.65m. An alternative communication architecture along with the communication paradigm of the system is demonstrated in Figure 3b. Here, the only mobile module is the Inspector Node, and the pairs of sensor nodes are



(a) (b) (c)

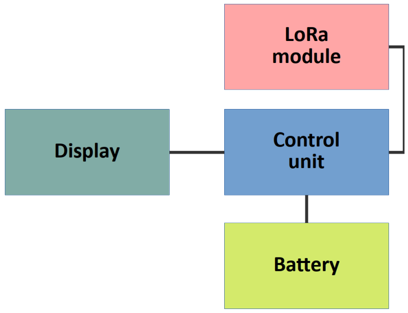
Fig. 3. The proposed system model

static. The first pair nearest to the Inspector Node acts as the parent node, and the second pair acts as the child node in the communication. Each pair of sensor nodes (parent nodes and child nodes) incorporates one network module. The inspector Node communicates with the consecutive pairs of the sensor node through two distinct communication channels to avoid possible interference. Thus, the inspector node communicates with the parent node through a fixed channel and with the child node through another fixed channel. For example, in Figure 3b, the train communicates with the sensor nodes indicated as 00 and 11 using the same channel (e.g., Channel 1), whereas the train communicates with the sensor nodes 01 and 10 using a different channel (e.g., Channel 2). Therefore we make allowances for two different communication channels to enable communications. The system consists of three nodes that are: (1) inspector node, (2) parent node, and (3) child node. Among them, the inspector node is placed on the train. Among the other two nodes, the parent node is the nearest node from the query node, and the child node is located 1000m away from the parent node. According to the communication paradigm, at first, the inspector node sends a query to the parent sensor node on the rail track ahead, which is denoted as 00 in Figure 3b, using Channel 1. After receiving the query, the parent sensor node 00 switches to a different communication channel, i.e., Channel 2, and forwards the query to the child sensor node, denoted as 01, using Channel 2. After reception of the query, the child node 01 replies with a monitoring report to the parent node 00 about the rail track based on analyzing the data collected from vibration generated by the approaching train. Next, the parent node switches channel from Channel 2 to Channel 1 and replies back to the inspector node with a combined monitoring report about the condition of the rail track of both the parent node and the child node. The combined monitoring report contains information about the condition of up to $\sim$ 2km rail track ahead. Such two-hop communication ensures that the approaching train learns about the condition of the rail track ahead from a substantial distance. Therefore, the approaching train will have sufficient time to stop at a safe distance from the occurrence of a missing rail block.

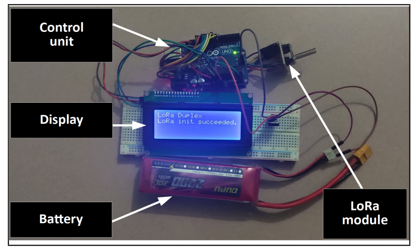
Next, as depicted in Figure 3c, the Inspector Node sends a query to the parent node 01, and the parent node 01 forwards the query to its next-hop child node 10. As previously mentioned, a similar two-hop communication is performed here by switching the channels to reply with a monitoring report to the approaching train.

5 EXPERIMENTAL SETUP

We perform a set of experiments for evaluating the performance of our proposed networking methodology in a real-world scenario. In this section, first, we present the experimental setup, followed by the testbed scenarios. Later, we delineate the collection and analysis of the collected data.



(a) Simplified block diagram of the communication module



(b) Communication module for the experiment

Fig. 4. The communication module

5.1 Hardware Design and Development

Our network module contains an RF-98 module having an operating frequency of 433 MHz. To serve our long-distance communication purpose, we utilize the Long Range networking module (LoRa RF-98) to achieve 1.5km to 2km long-range communication. We mount a 2dBi spring antenna with the LoRa module. We use ATmega328P as the micro-controller and Arduino Uno to program it. For the external power supply to the modules, we use an 11 Volt LiPo battery. We also attach an LCD with the LoRa module. Figure 4 shows the block diagram as well as the different hardware parts of the communication module.

5.2 Testbed Setup

We deploy the network module in different setups in our experiment. To explore a clearance for the Fresnel zone, we mount the communication module at the top of a variable height (maximum 3.65m) tall pole as shown in Figure 5. We set the signal bandwidth at 125kHz, spreading factor at 8, and the coding rate at $\frac{4}{5}$ for the LoRa module. Our overall testbed setup is illustrated in Figure 6, where we emulate the mobile inspector node with a motorbike, which carries one communication module. The motorbike is 1000m and 2000m far from the first and second static communication module respectively. Besides, in our experiments, we explore both single-hop and multi-hop cases for static and mobile nodes.

6 EXPERIMENTAL RESULTS

Our experiments include four diversified scenarios – static single-hop scenario, static multi-hop scenario, mobile single-hop scenario, and mobile multi-hop scenario. Below, we present the process of our data collection in these scenarios. Alongside, we analyze our data collected in these scenarios.

6.1 Static Single-hop Scenario

The location of this experiment was on the rail track of Banani Rail Station, Dhaka, Bangladesh. We deploy 2 LoRa nodes - inspector node and parent node, both in a static manner. The LoRa module in each node was attached to the top of a variable-length (up to 3.65m) pole to explore the relation between delivery ratio and height of the communication device from the ground. The two LoRa nodes were placed around 1200m from each other. In the previous section, we have shown that our sensing module can sense the vibration of an incoming train from around 1000m. Therefore, we

(a) Experimentation at Banani railway station.

(b) Experimentation at Purbachol highway.

Fig. 5. Experimentation of communication module

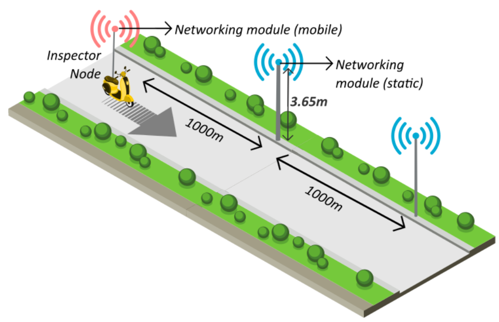
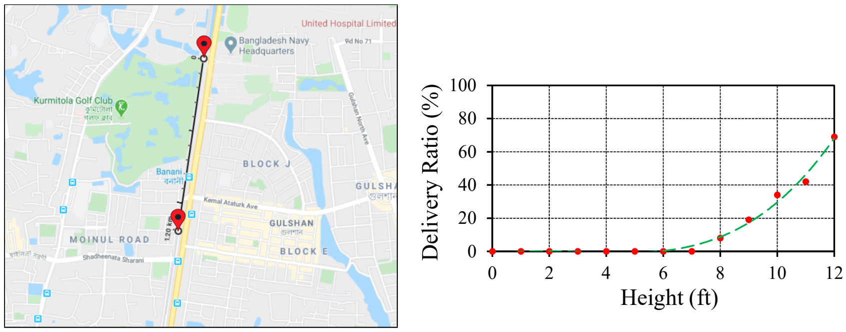


Fig. 6. Simplified diagram of our experiment setup

have to develop a communication system that can easily communicate from more than 1000m. Keeping it in mind, we have developed a communication system for Static Single-hop scenarios by maintaining a distance of about 1200m between the two static LoRa nodes. This experiment also helps us to find the optimal height of the communication device from the ground. We select the message length as 1 byte for query and acknowledgment. Also, there was a 200 ms delay between two consecutive data transmissions between the nodes.

We consider communication between the nodes as successful after completing all the following steps sequentially – (1) The Inspector Node sends a query to the parent node ahead. (2) The parent node checks the received message. After confirming that the received message is from the Inspector Node, it sends a predefined final response to the Inspector Node. (3) The Inspector Node checks the received messages and confirms that the received message is the expected as final response. At this point, the communication is considered a successful one.



(a) Banani Railway Station in the map (b) Delivery ratio vs height in Static Single-hop

Fig. 7. LoRa Static Single-hop communication testing from 1200m distance

Table 1. Experimental results for Static Multi-hop communication

Inspector node's distance (m)	Parent node's distance (m)	Child node's distance (m)	Delivery ratio (%)
0	700	1700	86.9
0	1000	2000	86.2
0	1000	2000	100

Figure 7 summarizes the results found in the Static Single-hop scenario. We varied the height of both nodes from 0m to 3.65m. We find no successful communication under 2m height due to cut off of the Fresnel zone. The delivery ratio increases with an increase in the height of the node. We achieve a maximum of 69% delivery ratio at a height of 3.65m. Accordingly we adopt this height of placement in our subsequent experiments.

6.2 Static Multi-hop Scenario

The location of this experiment was on the rail track of Banani Railway Station. We deployed 3 LoRa nodes in this experiment: Inspector node, Parent node, and Child node. All the nodes are static. The LoRa module in each node was attached to the top of a 3.65m tall pole to increase the clearance for the Fresnel zone and data loss. Communication between nodes was considered successful after completing all the following steps sequentially – (1) The inspector node sends a query to the parent node ahead. (2) The parent node checks the received message. After confirming that the received message is from the inspector node, it responds to the child node. (3) The child node checks the received message. After confirming that the received message is from the parent node, it responds to the parent node. (4) The parent node checks the received message and confirms that the received message is from the child node. Then it generates a response based on its data and data received from the child node. Later, it sends the response to the inspector node. (5) The inspector node checks the received messages and confirms that the received message responds from the parent node in a predefined format. At this point, the communication is considered a successful one.

We select the message length as 1 byte for query, parent node response, child node response, and final response. Also, there was a 1000 ms delay between two consecutive data transmissions between the nodes. We have sent around 140 to 170 packets from the inspector node. The experimental findings are summarized in Table 1.

Table 1 summarizes the results found in the Static Multi-hop scenario. We varied the distance between the inspector node and child node up to a maximum of 2000m, and the parent node was placed in the middle of those nodes. In the

Table 2. Mobile Single-hop experimental results

Average speed (km/h)	Packet sent	Packet received	Distance between nodes (m)	Delivery ratio (%)	Cases
10	1000	978	280	97.8	1, 2, 3
10	650	627	280	96.46	1, 2, 3
10	647	642	300	99.23	1
18	582	381	300	65.46	1, 2, 3
18	337	334	300	99.11	1
21	279	278	300	99.64	1
22	260	258	300	99.23	1
23	342	337	300	98.54	1
28	372	337	320	90.59	1, 2, 3

first two cases, the delivery ratio is mostly the same (i.e., 86%). In the third case, we got a perfect delivery ratio (i.e., 100%).

6.3 Mobile Single-hop Scenario

After successful Static Multi-hop communication experiments, we intend to perform mobile communication. However, before Mobile Multi-hop communication, we performed Mobile Single-hop communication, where only two nodes were considered. One of them is the inspector node, mobile, and the other one is the parent node, which was static. The height of the nodes was fixed by attaching them on top of a 3.65m tall pole. The mobility of the inspector node was emulated with the help of a bicycle that carried one pole. We considered both the cases of incoming (towards the parent node) and outgoing (away from the parent node) motion of the inspector node. The location of this experiment was on Zahir Raihan Road. Communication is considered successful when transmission and reception of the appropriate message occurs. The sender maintains a delay of 100 ms between two consecutive transmissions. It was strenuous to keep a constant velocity of the motorbike, as we faced several hurdles during this experiment. We categorize those hurdles in the following cases.

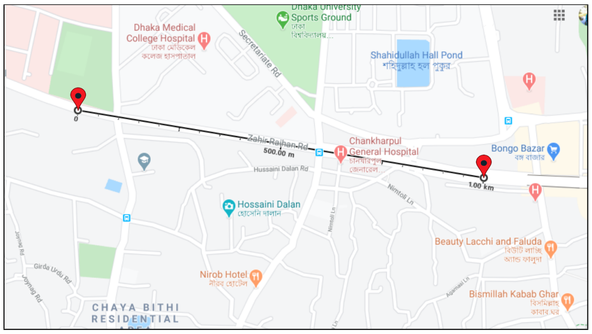
- **Case1:** Many trees were there on the line of sight between two nodes.
- **Case2:** People (as well as cattles) walked in the road.
- **Case3:** Several road curves between the two nodes.

Along with these cases, the relation between delivery ratio and speed of the vehicle is summarized in Figure 7.

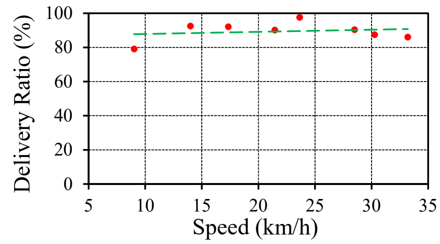
Figure 8 outlines the results specifically, the relation between delivery ratio and speed of the bicycle in the Mobile Single-hop scenario. We maintained the distance between the inspector node and the parent node at around 300m. Since we experiment on the road, we got several cases of obstacles. We got a lower delivery ratio, where all three cases were present. On the other hand, the rest of the data pointing to a higher delivery ratio (around 99%). These data have only one case of an obstacle. Therefore, we can corroborate that lower cases of obstacles lead to a higher delivery ratio.

6.4 Mobile Multi-hop Scenario

In this stage, all the setups and protocols were similar to the Static Multi-hop scenario, with one exception. Along with the inspector node and the parent node, we placed a static child node in this scenario. The height of the nodes was fixed by tying them at the end of the 3.65m tall pole. The mobility of the inspector node was achieved by using a motorbike, that carried one pole. We also considered both the cases of incoming and outgoing motion of the inspector node. The location of this experiment was in the Purbachol express highway. As we have sent packets maintaining a 200 ms delay



(a) Zahir Raihan Road in the map



(b) Delivery ratio vs speed in Mobile Single-hop

Fig. 8. LoRa Mobile Single-hop testing from 1000m distance

Table 3. Mobile Multi-hop experimental results

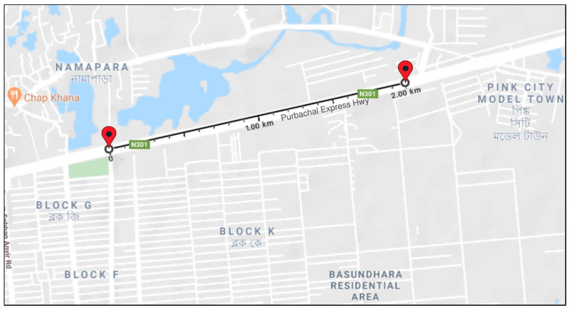
Average speed (km/h)	Packet sent	Packet received	Time (s)	RSSI	SNR	Delivery ratio (%)
25	180	145	78	-110	3	80.56
27	150	129	68	-118	3	86
30	150	116	61	-118	3	77.3
30	129	117	62	-118	3	90.7
36	113	93	50	-118	2	82.3
40	100	89	46	-118	4	89
45	113	90	42	-117	3	79.65
50	82	64	38	-119	3	78.05
50	57	39	37	-120	0	68.42
57	70	49	32	-120	0	70
57	75	61	32	-116	5	81.33
60	65	49	31	-120	3	75.28
62	60	36	29	-121	-1	60
70	57	36	41	-122	-1	63.16
50	90	84	42	-119	3	93.3
60	75	71	32	-119	2	94.67

every time and vary the speed of the query node, the total number of packets sent also varied. The relation between the delivery ratio and the speed of the vehicle is summarized in Figure 9.

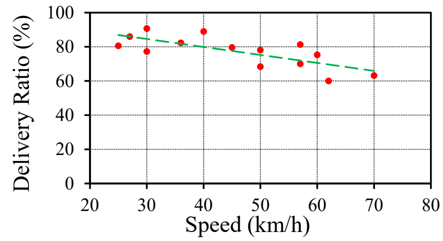
Figure 9 digests the results found in the Mobile Multi-hop scenario. The delivery ratio in this scenario varies from 60% to 95%. The packet delivery ratio slightly decreases with the increase of speed. Nonetheless, we need to ponder the fact of SNR as well. The experiment exhibits the lowest delivery ratio for the zero SNR and negative SNR, whereas positive SNR boosts the delivery ratio. An SNR of zero indicates that the desired signal is indistinguishable from the unwanted noise. Furthermore, noise dominates in the case of negative SNR. Hence, the positive SNR bolsters the higher delivery ratio.

7 DISCUSSIONS

In this section, we discuss the cost-effectiveness of our system, the applicability of the outcomes of our experiment in real contexts, and how this research fits in developing countries.



(a) Purbachol Express Highway in the map



(b) Delivery ratio vs speed in Mobile Multi-hop

Fig. 9. LoRa Mobile Multi-hop testing from 2000m distance

Table 4. Cost of hardware necessary in our solution

Component	Model name	Quantity	Price ($)
Microcontroller	Arduino Uno	1	5
	Arduino Mega2560	1	8
Power supply	LiPo battery (1000 mAh)	1	20
LoRa module	RF-98	3	3.5
Display	LCD display (20×4)	1	4.5
Breadboard	-	3	1
Total price		51 USD per node	

7.1 Cost Analysis

The cost of a complete system plays a very important role in the large-scale development and deployment of the system. For this reason, we try to develop a low-cost solution. Table 4 delineates the price per component and the total price of our solution as presented in this paper. Our proposed solution costs 51 USD per unit that can be further reduced in mass development and production.

7.2 Applicability of Outcomes in Real Contexts

Our experiments and analysis explore a long-range and real-time communication system amenable for networking over rail tracks (employing sensors for detecting derailments). In our study, we get an average packet delivery ratio of around 80% as shown in Figure 8 and Figure 9. Note that, in our experiment, we do not enable any data re-transmission for the transmission and reception process in case of packet transmission failure. Therefore, although we get the packet delivery ratio of around 80%, employing the packet re-transmission would significantly increase that delivery ratio. To be more specific in a theoretical manner, in the case of 80% delivery ratio, there can be 20% transmission failure. By incorporating re-transmission once, we can reduce the chance of transmission failure from 20% to 4%, which indicates a delivery ratio of 96%. By incorporating second re-transmission, the delivery ratio can boost up to more than 99%. Thus after adopting the notion of packet re-transmissions, we will get a high packet delivery ratio with a long-range networking capacity. This will enable our system to transmit data for any discontinuity or line break to notify an incoming train.

7.3 Fitting the Scenarios of the Developing Countries

We investigate establishing a long-range communication network suitable for outdoor long-term conditions of railway tracks in a cost-effective manner. Unlike several studies, [3, 14, 25, 30], which focus on expensive wireless sensor networks based on cellular systems or other standards, i.e., Bluetooth, IEEE 802.15.4, and WiFi, our proposed long-range networking model is very much suitable in the contexts of low-income, and limited-resource (i.e., developing) countries such as Bangladesh, India, Pakistan, Kenya, etc., where long rail tracks are publicly open. In addition, our proposed real-time networking model is simpler compared to those studies.

We achieve a larger communication distance in contrast to other studies [9, 10, 23], i.e., a networking distance of approximately 600m, which can be practically inadequate for stopping a train at a safe distance ahead of the fault. The open-rail tracks in developing countries often create challenges for a communication network, as vehicles, cattle, humans, etc. can cross the rail track at any point. These along with the tree and building structures beside the rail track can often produce obstacles for the communication network. The existing solutions [3, 9, 10, 14, 23, 25, 30] did not extensively explore such types of diverse situations. As opposed to those studies, we explore several diverse situations in our research to make the solution more suitable for developing countries.

8 FUTURE WORK

In this paper, we endeavor to improve the communicating range for detecting missing rail blocks in real-time. Beyond this work, we still have room for further research in this field. In this section, we present avenues of potential future work.

We are yet to explore the complex scenarios involving railway cross-junction for networking. Multiple rail tracks converge in or diverge from a single track in a railway cross-junction [18]. In a cross-junction, more rail tracks incorporate more nodes, which present a scope to increase interference to communication modules. We plan to perform extensive research on solving the networking challenges due to the cross-junction in the future.

We are yet to work on choosing a suitable power source. We employed an 11V DC battery as the power source in our experiments. However, in authentic contexts, we will need enough power supply to ensure sustainable operation. The rural areas of the developing countries are still deprived of proper electricity or power supply. Harnessing the energy in such a case would be a bonafide solution. Solar energy could be a reliable renewable source of energy. However, it comes with the risk of unavailability of energy during cloudy, foggy, or rainy days. Thus, we plan to develop a specialized energy scavenging solution suitable to our case.

Finally, security measures to ensure secure data transmission in our case are yet to be explored. It could be possible that the information about the rail track can be falsified or delayed maliciously or inadvertently. Hence, ensuring the security of our system is a salient research domain. We are aiming to investigate this aspect in the future.

9 CONCLUSION

Derailments often happen in developing countries resulting in death tolls and loss of property. However, a real-time solution for the problem amenable to its practical contexts is yet to be developed in the literature. Besides, existing research studies in this domain are limited to a networking range of only 600m, which might not be enough in factual circumstances. Therefore, in this paper, we investigate the scope of extending the communication range in a pragmatic and low-cost manner.

Our work comprises several multitudes of research activities covering embedded system development, on-field deployment, real data collection, etc. We rigorously collect a vast amount of real-time data by varying distances, speeds, and height of our developed networking module in the context of a developing country. Further, we propose a new wireless networking modality to achieve a long coverage of around 2000m over rail lines. Here, we adopt multi-hop networking over LoRa at an elevated positioning going beyond the ground positioning as proposed in the existing research studies. In the future, we plan to investigate other unexplored aspects that are needed for the intended complete solution, such as energy scavenging, packaging of the sensing node ensuring anti-theft measures, and enabling cyber-security aspects.

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