International Journal of Nanotechnology

ISSN online: 1741-8151 - ISSN print: 1475-7435
https://www.inderscience.com/ijnt

Remote IoT correspondence for coordinating end-devices over MANET via energy-efficient LPWAN

Vikram Narayandas, Archana Maruthavanan, Raman Dugyala

DOI: 10.1504/IJNT.2023.10056475

Article History:

Received:	01 September 2021
Last revised:	31 December 2021
Accepted:	16 February 2022
Published online:	31 May 2023

Remote IoT correspondence for coordinating end-devices over MANET via energy-efficient LPWAN

Vikram Narayandas*
and Archana Maruthavanan

Faculty of Engineering and Technology,
Department of Information Technology,
Annamalai University,
Chidambaram, Tamil Nadu, 608002, India
Email: vikramnarayandas16@gmail.com
Email: archana.aucse@gmail.com
*Corresponding author

Raman Dugyala

Computer Science and Engineering Department,
Chaitanya Bharathi Institute of Technology,
Hyderabad, Telangana, India
Email: raman.vsd@gmail.com

Abstract: The Internet of Things (IoT) is associated with billions of gadgets and their collaborations with one another. The new phase of the network model in IoT indicates the association of diverse progressions of remote wireless developments in unlicensed bands with a massive number of advances. These are based on ZigBee, Wi-Fi, and LoRa. The contemporary studies involve evaluating capacities and practices of these advancements for framing a mobile ad hoc network (MANET) as for IoT utilising various estimations including range, speed, and network size. IoT needs to work together with MANET to make it significantly more feasible for IT associations in building applications for the future. It is surmised that there is a need to develop a multi-layered innovative approach to manage interoperable IoT devices to frame a correspondence alongside the MAC layer to make a key course of action for the arrangement of a MANET for energy-efficient routing using LPWAN. In this work, we provide a comparative study between Wi-Fi, Zigbee, and LoRa, based on cup carbon simulation using varying attributes distance, nodes and packet loss, etc. The results prove the better performance of LoRa in terms of packet loss and nodes usage.

Keywords: LoRa; ZigBee; WiFi; LPWAN; low power wide area networks; MANET; mobile ad hoc networks; Bluetooth; CupCarbon.

Reference to this paper should be made as follows: Narayandas, V., Maruthavanan, A. and Dugyala, R. (2023) 'Remote IoT correspondence for coordinating end-devices over MANET via energy-efficient LPWAN', *Int. J. Nanotechnol.*, Vol. 20, Nos. 1/2/3/4, pp.346–360.

Biographical notes: Vikram Narayandas, Research Scholar, Department of Information Technology, Annamalai University, Tamil Nadu, India, and working as an Assistant Professor in Computer Science and Engineering Department, MVSR Engineering College, Hyderabad, India.

Archana Maruthavanan is an Assistant Professor at the Department of Information Technology, Faculty of, Engineering and Technology, Annamalai University, Chidambaram, Tamil Nadu, India.

Raman Dugyala is a Professor at the Department of Computer Science and Engineering, Chaitanya Bharathi Institute of Technology, Hyderabad, India.

1 Introduction

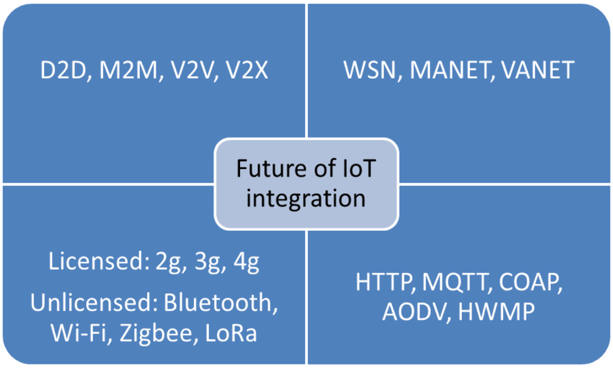
The Internet of Things (IoT) indicates billions of electronic devices connected to the networks for sharing data. Correlating up all these different things and adding sensors to them enhances a level of cutting edge and enables them to give consistent data. Internet of Things (IoT) builds up an association of heterogeneous devices transient on and exchanging data among themselves to offer more smart types of help to customers. The field of IoT has quickly developed a heterogeneous network of associated sensors and actuators joined to a wide variety of things and improvement in a couple of utilisation zones like Smart home technologies formation, shrewd security, observing road traffic, and emergency response infrastructures. Portable and remote devices advancement because they arranged low, ultra-force, short, and long reach innovations keep on driving the advancement of interchanges and availability in the IoT.

The 802.11 convention with its 802.11a/b/g/n variations is among the main evident innovation possibility with varying applications in the IoT are introduced in Li et al. [1]. These networks are colossal in scale and cover devices like radio frequency identification (RFID), mobile phones, global positioning system (GPS), infrared sensors, scanners, actuators, remote local area networks (LANs), and LANs interfaces [2]. wireless sensor network (WSN) and RFID are the fundamental main features for IoT and these are associated with the web for controlling remotely and procuring data from the environment [3].

Shortly we will see the evolution of brilliant and low-power consuming gadgets interfacing with one another and to the internet utilising, generally, solid low-power remote transmissions. Such mechanisms, implied as sensor center points, have low interaction capacity and limited battery life. Numerous IoT gadgets require the utilisation of minimal effort and low-power remote innovation when associating with the internet [4]. The current literature shows WSNs are dealing with the challenge of inadequate power and memory. A major challenge for the IoT when coordinating with heterogeneous networks is their data transfer success rates [5]. Technology for various gadgets with wireless technologies such as Wi-Fi, Zigbee, LoRa, and WiMAX make possible the connections among devices for allowing ad hoc infrastructure over the internet.

Figure 1 shows the integration of future IoT with various networks. The collaboration of IoT-MANET and WSN based cross-section geographies make them more attractive to integrated and tree-based topologies, where hubs are openly connected in the small zone to each other and also different hubs of various clusters.

Figure 1 Future of IoT integration (see online version for colours)



To associate multi-hop connections efficiently, devices need a routing protocol for energy-efficient routing that can be derived from mobile ad hoc network routing protocols and wireless sensor networks. To form IoT as a shrewd network, low power wide area networks (LPWANs) meet numerous necessities of IoT, like energy-efficient, the huge scope of deployment, and low power. This paper examines and associates a part of the progressing and empowering wireless developments for the IoT with the integration of MANETs. It investigations the abilities of IEEE 802.15.4 advancements, Wi-Fi, ZigBee, and LoRa advancements. LoRa WAN are the most recent innovations in long-reach and low-power WAN. The LoRa WAN targets key prerequisites of the IoT like secure bi-directional communications, portability, and localisation facilities.

The rest of the paper is organised as sections. Section 2 describes the related works, with comparisons between LoRa, ZigBee and WiFi technologies. In Section 3, we explain the Experimental setup using Cup carbon simulation in detail. Section 4 gives the discussion on the corresponding evaluations. Section 5 gives experimental results with different scenarios followed by conclusions and future scope.

2 Related work

Bluetooth [6] is built for remote communication dependent on radio signals intended for short-range transactions. The gadgets can be utilised for interchanges between PCs connected with different devices or networks which act as Adhoc infrastructure. It facilitates voice and data at high speed by radio waves with a frequency range of 2.4 GHz to 2.483 GHz. Wi-Fi (wireless fidelity) is one of the most broadly utilised non-cell wireless infrastructure frameworks that utilise the IEEE 802.11 norms for wireless local area networks (WLAN), Wi-Fi is a remote systems administration innovation that permits gadgets like PCs (workstations and work areas), cell phones (PDAs and wearables), and other devices (printers and camcorders) to interface with the internet and evolution of broadband wireless systems. And standard uses a 2.4 GHz bandwidth speed of 54 Mb/s. [7]. ZigBee is a standard-based innovation [8] pointed towards minimal cost, low-power sensor-and control establishments for self-arranging networks.

The ZigBee Alliance has built up the ZigBee advanced since 2002 to upgrade the IEEE 802.15.4 norm by adding a network, security layers, and an application system. ZigBee expanded upon the PHY and MAC as it was characterised in the IEEE Standard 802.15.4 in 2003. ZigBee utilises DSSS and OQPSK with carrier sense multiple access with collision avoidance and supports a 2.4GHz ISM band as indicated by IEEE 802.15.4 [9]. The ZigBee Alliance [10] was set up by ventures in 2002 with the motivation behind giving a standard lattice network determination and free application layer principles for the IoT. Its wide-going worldwide enrolment works together to make and develop general open norms for the IoT. "ZigBee PRO" is the Alliance's lead network standard, intended to associate and work with interoperability between savvy gadgets with an extremely minimal expense, low-power-utilisation, two-way, remote correspondences arrangement. The ZigBee PRO stack design is composed of a bunch of squares called layers. Each layer performs a particular arrangement of administrations for the layer above. An information element gives an information transmission administration and an administration element offers any remaining types of assistance. Z-Wave, a standard created by Zensys Inc., has as of late been procured by Silicon Labs Inc.

Table 1 Comparison between LoRa, ZigBee and WiFi

Attributes	*Wireless Technologies supporting MANET in IoT*		
	LoRa	*ZigBee*	*WiFi*
Inclusion distance	2–5 Km (inner-city areas), 15 Km (outer areas)	10–100 meters	42–92 meters
Reappearance (Frequency) Bands	863–870 MHz, 779–787 MHz	868 MHz, 915 MHz, 2450 MHz	2.4 GHz/5GHz ISM band
Power consumption	*Lower compare to ZigBee*	*Low*	*Very high*
Data rate	0.3–22 Kbps (LoRa modulation) and 100 Kbps (using GFSK)	20 Kbps (868 MHz), 40 Kbps (915 MHz), 250 Kbps (2450 MHz)	54 Mbps to 1 Gbps
Network Architecture	Includes of LoRa Gateway, personnel and end gadgets	Covers of organiser, switches and end gadgets.	Wireless local area networking (WLAN)
Applications	used as wide area network	Operated as LR-WPAN for example low-rate remote single region network	Used to relocation files and wireless communication
Standard/Alliance	IEEE 802.15.4g, LoRa Alliance	IEEE 802.15.4 (defines PHY and MAC), Zigbee Alliance (outlines network, security)	IEEE 802.11 standard for the operation of various wireless devices

The Z-Wave innovation has made a few advancements since its creation. Interoperability is another vital element of Z-Wave, which permits Z-Wave gadget equipment, what's more, programming to cooperate, so clients may work their whole keen home from one savvy home application. With interoperability worked in at the application layer, all Z-Wave gadgets from different brands and merchants are in reverse and forward viable and work together in a home or building. While both ZigBee and

Z-Wave give inclusion of up to 300m per radio jump, they are not implied for long-reach low force remote organisations. This clarifies why LoRa [11] and Sigfox [12] were presented. LoRa is driven by Semtech Inc. furthermore, LoRa radios work at the unlicensed ISM groups of 868 MHz and 915 MHz and have a further transmission scope of up to 10Km. LoRa is intended for IoT and M2M organisations. Sigfox, then again, is likewise a restrictive low force, low information rate, long reach remote innovation working at 868 MHz/902 MHz. Both LoRa and Sigfox show star network geography and are appropriate for smart grid and smart metering applications. The comparison on LoRa, ZigBee, WiFi is discussed in Table 1.

In this era, wireless communications are empowering connections between various objects which will ultimately permit people to communicate with billions of gadgets [13]. Transmission of critical multimedia healthcare data is required to be transferred in real-time for saving the lives of patients using better quality networks [14]. Internet of things (IoT) is also functioning as an impetus to upgrade the force of AI applications in medical services [15]. To build multi-hop links and to define the network topology, a mesh grid needs a routing protocol to communicate and direct resolutions for Adhoc networks that can be directing conventions for Adhoc networks that can be named as proactive and reactive protocols and When the movement of nodes is measured, infrastructures refers to mobile ad hoc networks (MANETs), such as smart devices, tablets, and sensors deployed with wireless technologies like Bluetooth, WiFi, Zigbee and LoRa. Proactive routing protocols [16] are uses the small number of nodes maintaining the routing table to communicate and are so-called table-driven. Reactive routing protocols form multi-hop links only on-demand requests and are categorised by a complete overhead and established on the perception of flooding [17]. As Sensor hubs are straightforward gadgets with restricted assets [18], the significant issue is the way to interface such gadgets to a between the associated web of things. A few models have been proposed to associate WSNs to the internet via a combination of IPv6 addresses in sensor networks and gateways to route information to end devices using 6LoWPAN [19] developed by the Internet Engineering Task Force (IETF). The implementation of routing protocols for mobile Adhoc networks is directing conventions due to portability conditions and the restricted assets of hubs. Routing protocols of mobile Adhoc networks concentrated on ensuring quality of service (QoS) measurements such as data transmission and start to finish delay [20]. The routing conventions for WSNs are centred on expanding an organisation's lifetime by decreasing energy utilisation [21]. Routing protocols for the IoT should ensure availability, connectivity, and QoS between the hubs both in ad-hoc and infrastructure networks using access points. Fog processing achieves the low-inactivity necessity of QoS in time-delicate constant IoT-sensor applications [22,22].

Internet of things (IoT) is also functioning as an impetus to upgrade the force of AI applications in medical services [24].

3 Experimental setup

This section presents the experimental setup using the CupCarbon network simulator. CupCarbon simulates WSN networks. We can create scenarios for the simulation of discrete events in WSNs. CupCarbon also simulates the ZigBee, LoRa, and WiFi protocols.

4 Evaluation metrics

4.1 Power consumption

These measures include reducing power use during both active and sleep modes, reducing inference among the same protocol device or with other protocols devices, selecting the frequency according to the transmission distance, and having different transfer modes according to the size of the payload.

Figure 2 represents the power is consumed during the data transfer in the Zigbee framework, If the data transfer is in between the 50 km distance, The nodes required is 556 nodes but compared between 2 nodes to measure power consumption.

Figure 2 Zigbee power consumption graph (see online version for colours)

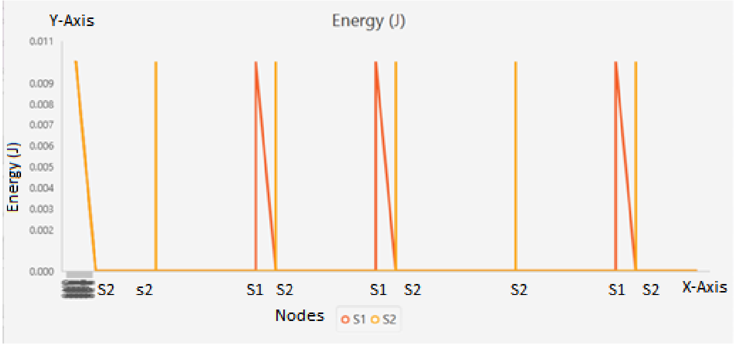


Figure 3 represents the power is consumed during the data transfer in the WiFi framework. If the data transfer is in between the 50 km distance, the number of nodes required is 115 but compared between 2 nodes to measure power consumption.

Figure 3 WiFi power consumption graph (see online version for colours)

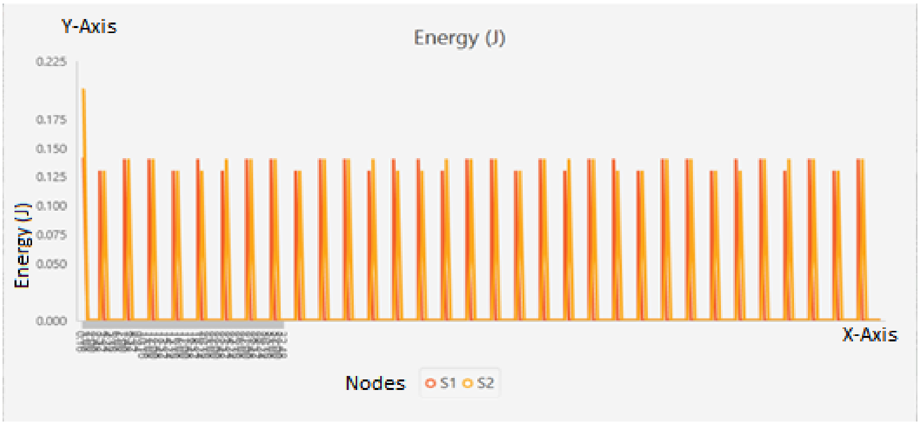
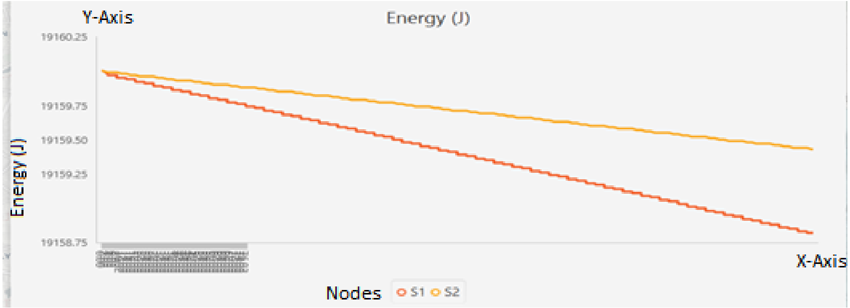


Figure 4 represents the power is consumed during the data transfer in the LoRa framework, If the data transfer is in between the 50 km distance, The nodes required is 10 nodes but compared between 2 nodes to measure power consumption.

Figure 4 LoRa power consumption graph (see online version for colours)



4.2 *Throughput*

Throughput refers to how much data can be transferred from one location to another in a given amount of time.

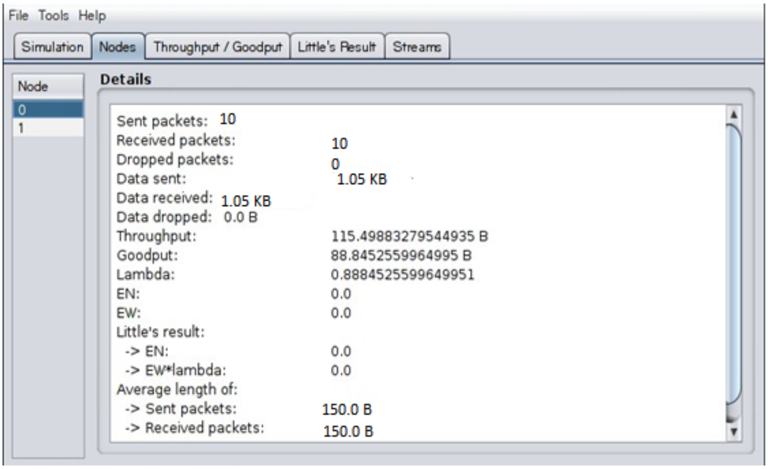
From Figure 5, The accuracy of the proposed work analysed by using various attribute values from the simulation, analysed number of sent packets is 10, with the 0 dropped packets and received10 packets with the amount of data sent is 1.05 KB, as there is no any loss of packets the amount of received data is also same as the amount of data sent i.e., 1.05 KB, finally throughput value is 150.0 B for both sent and received packets.

4.3 *Distance*

The distance between two hubs is the length of the most limited way.

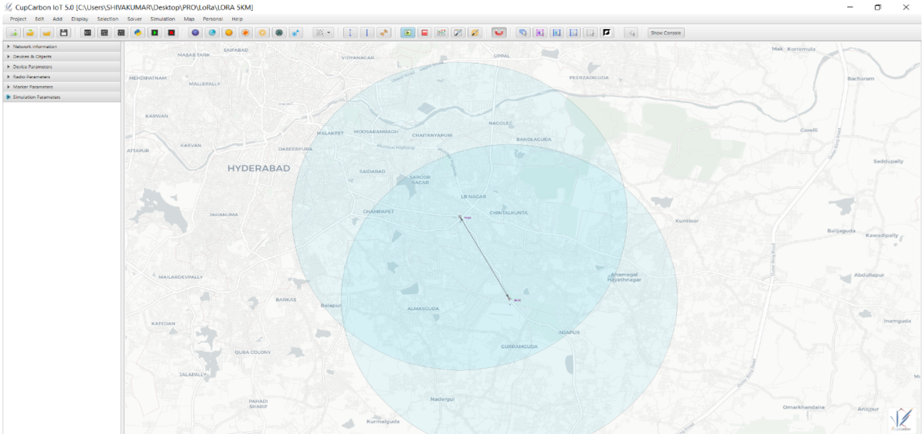
In the LoRaWan (Figure 6) framework, the node radius is about 7–10 km, covering most of the distance by the single node about to 15 km for data transfer with less power consumption.

Figure 5 Throughput in trace metrics (see online version for colours)



```
Sent packets:  10
Received packets:              10
Dropped packets:               0
Data sent:                      1.05 KB
Data received:  1.05 KB
Data dropped:   0.0 B
Throughput:                    115.49883279544935 B
Goodput:                       88.8452559964995 B
Lambda:                        0.8884525599649951
EN:                            0.0
EW:                            0.0
Little's result:
  -> EN:                       0.0
  -> EW*lambda:                0.0
Average length of:
  -> Sent packets:            150.0 B
  -> Received packets:        150.0 B
```

Figure 6 Distance between two nodes in LoRa (see online version for colours)



5 Experimental results

The steps involved in the setup are demonstrated in Figure 7.

5.1 Configuring nodes

Creating a node and Configuring a node with attributes like network ID, sensor radius, latitude, and longitude. After installing the protocols that might be ipv4 or ipv6 to the nodes, then assign some unique name to that node and install the applications to the nodes such as FTP, client-server application.

5.2 Establishing network

After configuring a node N, discovering the neighbouring *N*–1 nodes, and registering *N*–1 neighbouring nodes' details for establishing a network path between the two or more nodes to transfer the simple packets, it waits for the confirmation whether the receiver receives the packet or not. If the sender does not get any confirmation of whether the packet is received at the receiver end. Then the sender retransmits the same packet to the receiver.

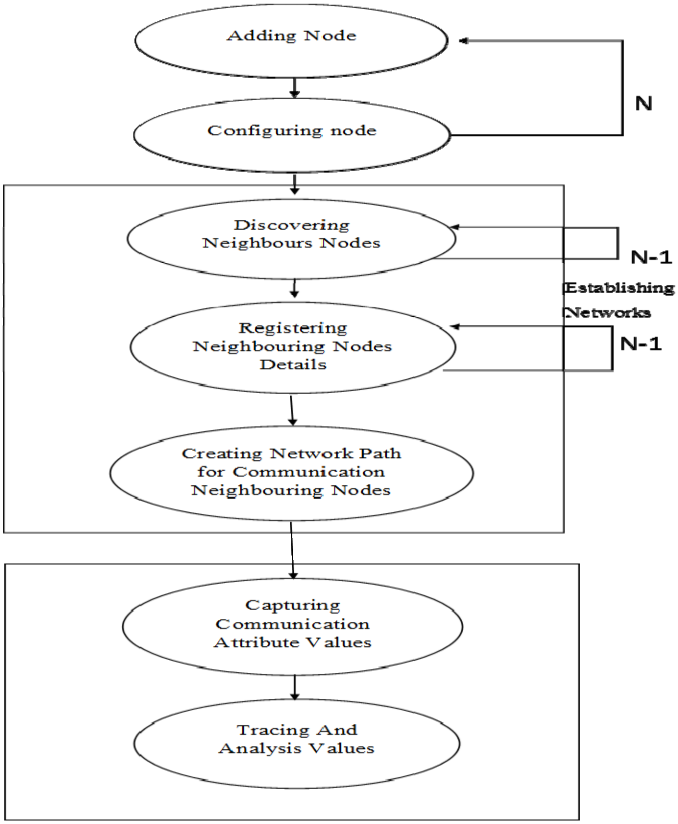
Following are the LoRaWAN characteristics:

Low energy consumption: LoRa technology consumes less power energy as it covers a large radius with less number of nodes.

Time efficient and long range: The LoRa covers a long-range radius with few nodes for data transfer in an efficient way.

Transfer data with lesser packet loss: The LoRa enables the long-range which is more than 10 km with low power consumption and has smaller packet loss at the time of transferring the data between the nodes. The LoRa technology covers the physical layer while other technologies such as LoRaWAN and other protocols cover the upper layers. It can achieve data rates between 0.3 kilobits per second and 27 kilobits per second depending upon the spreading factor.

Figure 7 Proposed design module using LoRaWan (see online version for colours)



5.3 *Simulate network*

Simulate a network to check whether the connection is established between the nodes or not. After establishing a network the sender sends a packet to the receiver. In that time the packet will transfer over the number of nodes between the sender and receiver. At the time of transferring packets, the packets may be lost at some nodes.

5.4 *Capturing communication attribute values*

Data will be captured in the network, that how the data is transferred from sender node ID to receiver node ID, it also checks whether all the packets are received at the receiver node.

5.5 *Tracing and analysing results*

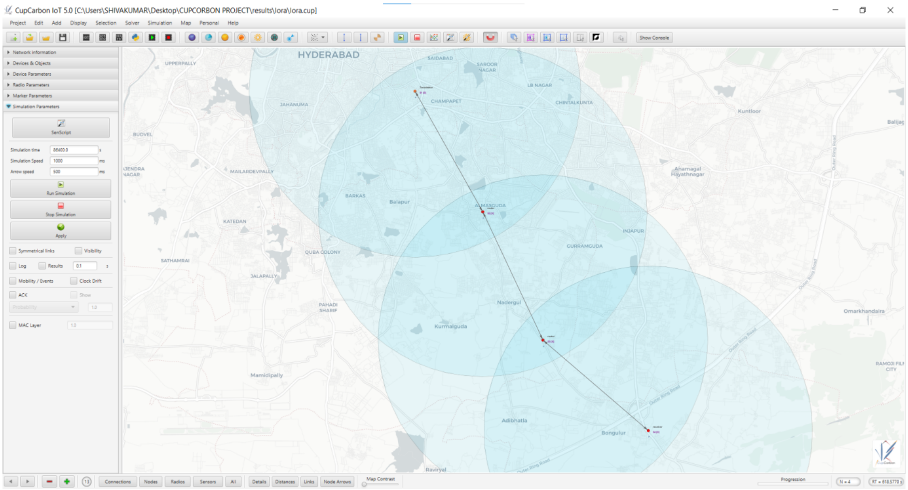
After capturing communication attribute values, identify the accuracy of the results and trace results for *N*–1 nodes using cup carbon simulation.

The following are the scenarios created**:**

Scenario-1: Establishing communication among nodes using LoRa as a medium.

Create a node by using network IDs, select and assign protocols like LoRa, ZigBee, and Wi-Fi to the nodes with source codes to the sender node, receiver node, and between the routers nodes. And also assign remaining parameters such as longitude, latitude, sensor radius, and GPS, and then set simulation speed, simulation time, and arrow speed. Users can see the power consumption graph, logs, acknowledgment, and mobility. The simulation for various protocols is simulated for 2 minutes and results are compared with varying distances with different scenarios. In Scenario-1 Figure 8, LoRa used only 3–4 nodes communication range for the 20 km from sender to receiver. At the end of the simulation, the time taken to send and received packets is 92.0033 s as per the simulation for the LoRa protocol as demonstrated in Figure 9.

Figure 8 Communication among nodes using LoRa (see online version for colours)



Simulation time 86400.0 s
Simulation Speed 1000 ms
Arrow speed 500 ms
☐ Symmetrical links ☐ Visibility
☐ Log ☐ Results 0.1 s
☐ Mobility / Events ☐ Clock Drift
☐ ACK ☐ Show
☐ MAC Layer

Outcome of Scenario-1:

Figure 9 LoRa result (see online version for colours)

Console

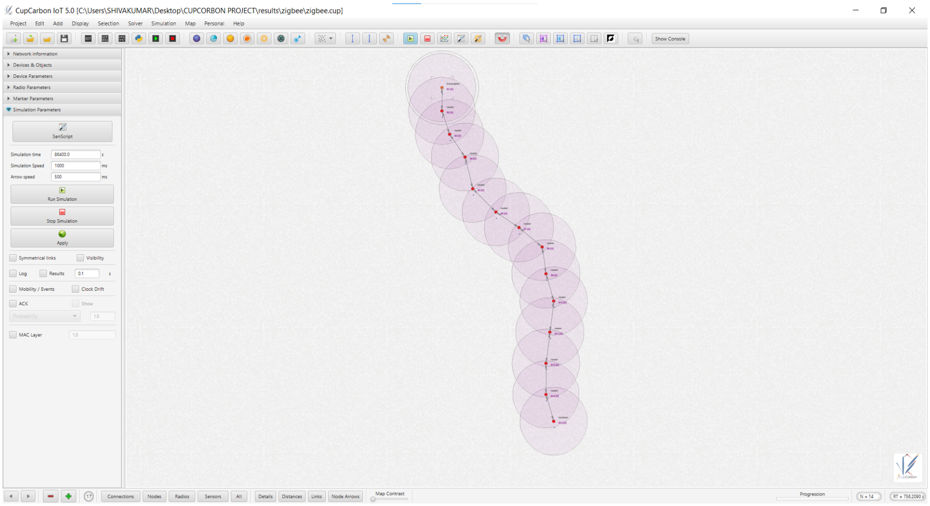
```
Mobility: false
Generate Restul File: false
Initialization ...
End of Initialization.
Start Simulation ...
Simulation stopped!

End of Simulation.
136.827 sec
Time: 92.0033 s
Number of SENT messages: 92.0 [552.0]
Number of RECEIVED messages: 92.0 [552.0]
Number of SENT & RECEIVED messages: 184.0 [1104.0]
Number of ACK messages: 0.0 [0.0]
Number of LOST messages: 0.0 [0.0]
Number of Marked Sensors: 0
```

Scenario-2: Establishing communication among nodes using ZigBee as a medium.

In Scenario-2 as shown in Figure 10 by using ZigBee protocol 13–14 nodes are used for communication for the 20 km between sender and receiver. At the end of simulation time taken to send and received packets is 102.0542 s as per simulation for ZigBee protocol as demonstrated in Figure 11.

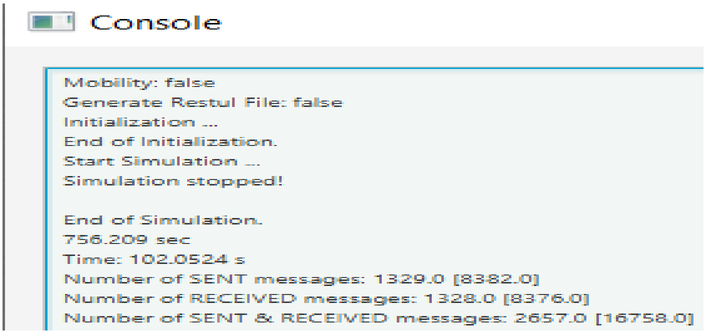
Figure 10 Communication among nodes using ZigBee (see online version for colours)



CupCarbon IoT 5.0 [C:\Users\SHIVAKUMAR\Desktop\CUPCORBON PROJECT\results\zigbee\zigbee.cup]

Simulation time 86400.0 s
Simulation Speed 1000 ms
Arrow speed 500 ms
N = 14
RT = 756.2090 s

Figure 11 ZigBee result (see online version for colours)



```
Mobility: false
Generate Restul File: false
Initialization ...
End of Initialization.
Start Simulation ...
Simulation stopped!

End of Simulation.
756.209 sec
Time: 102.0524 s
Number of SENT messages: 1329.0 [8382.0]
Number of RECEIVED messages: 1328.0 [8376.0]
Number of SENT & RECEIVED messages: 2657.0 [16758.0]
```

Scenario-3: Establishing communication among nodes using WiFi as a medium.

In scenario-3 as shown in Figure 12 by using Wi-Fi protocol 14–15 nodes are used for communication for the 20 km between sender and receiver. At the end of simulation time taken to send and received packets is 93.8785 s as per simulation for Wi-Fi protocol as demonstrated in Figure 13.

Table 2 compares various simulation scenarios of LoRa, ZigBee, and WiFi with different attributes like distance, the number of nodes required, and messages sent from the source and received or lost by the receiver. Different scenarios with various distances with the required number of nodes are discussed clearly in Table 2. Finally, the performance of LoRa, ZigBee, and WiFi protocols are defined as per the graph shown in Figure 14.

As per scenario 1, the distance of LoRa, Zigbee, WiFi is 5 km with 2 min simulation time, the number of nodes used for LoRa is 2, 40 nodes for ZigBee, and WiFi 7 nodes, with all these requirements, transfer data from the sender to receiver with no packet loss in LoRa, In ZigBee, there is a one packet loss, even in WiFi one packet is loss as per observation similarly about to 10 scenarios the simulation test covered from 10 km to 50 km. Finally by analysing all scenarios. Figure 14 shows the performance of LoRa, Zigbee, and WiFi in form of the required number of nodes to create the topology formation between the source node to the final destination node. The values for LoRa node represented as LN, for Zigbee as ZN and WiFi as WN, LMS, LMR, and LML defined as LoRa node Messages sent, LoRa Node Messages Received, and LoRa node Messages lost.

Figure 12 Communication among nodes using WiFi (see online version for colours)

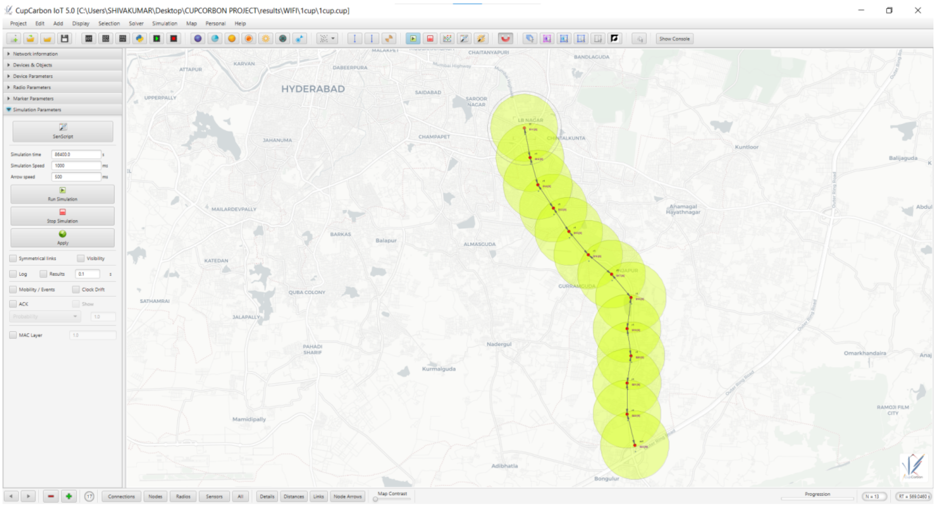
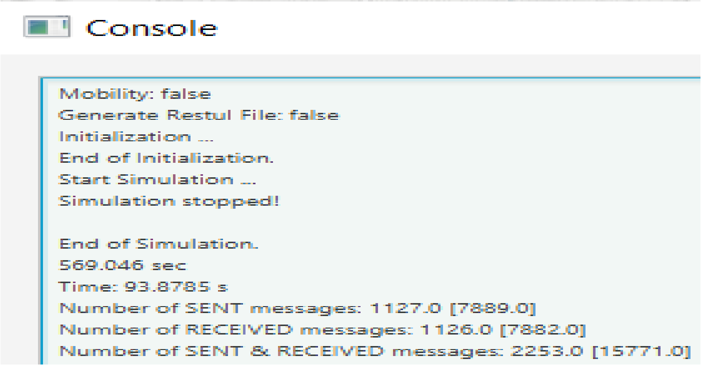


Figure 13 Result of WiFi (see online version for colours)



```
Mobility: false
Generate Restul File: false
Initialization ...
End of Initialization.
Start Simulation ...
Simulation stopped!

End of Simulation.
569.046 sec
Time: 93.8785 s
Number of SENT messages: 1127.0 [7889.0]
Number of RECEIVED messages: 1126.0 [7882.0]
Number of SENT & RECEIVED messages: 2253.0 [15771.0]
```

Figure 14 Performance scenario of LoRa, ZigBee and WiFi (see online version for colours)

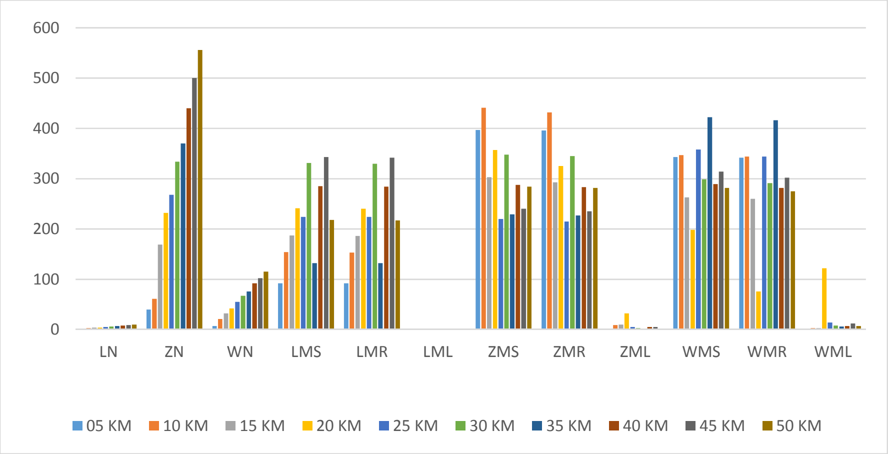


Table 2 Simulation scenarios of LoRa, ZigBee and WiFi

			Nodes Required			*Messages Sent(S), Received(R), Lost(L)*								
						LoRa			*ZigBee*			*WiFi*		
Scenario	*Distance (km)*	*Simulation time (min)*	*LoRa*	*ZigBee*	*WiFi*	*S*	*R*	*L*	*S*	*R*	*L*	*S*	*R*	*L*
1	05	2	2	40	7	92	92	0	397	396	1	343	342	1
2	10	2	3	61	21	154	153	1	441	432	9	347	344	3
3	15	2	4	169	32	187	186	1	303	293	10	263	260	3
4	20	2	4	232	42	241	240	1	357	325	32	198	76	122
5	25	2	5	268	55	224	224	0	220	215	5	358	344	14
6	30	2	6	334	67	331	330	1	348	345	3	299	291	8
7	35	2	7	370	76	132	132	0	229	227	2	422	416	6
8	40	2	8	440	92	285	284	1	288	283	5	289	282	7
9	45	2	9	500	102	343	342	1	240	235	5	314	302	12
10	50	2	10	556	115	218	217	1	284	282	2	282	275	7

The LoRa performed well as it requires less number of nodes with more radius, which covers the more distance very effectively. Whereas ZigBee and WiFi have used more nodes with less distance coverage.

Finally per observations and comparisons among the ZigBee, LoRa and WiFi, the LoRa protocol is the best framework for transferring data in the long range with low power consumption along with energy efficiency and less time taken to receive packets among the other two protocols with any loss of packets.

4 Conclusion and future scope

The research carried out was into working with simulated long-range communication among IoT nodes in comparison with unlicensed band technologies such as ZigBee, Wi-Fi, and LoRa. It was sought to be that LoRa is more favourable with possible integration of MANET into the IoT. LoRa having the downside of data transfer rates can be cancelled off as the data sent by IoT nodes is very minimal as compared to regular network communication among general-purpose end devices.

There are further investigations necessary for enhancement and real-time implementation of LoRa in IoT integrated with MANET to fulfil future technological needs. Such enhancements include working on bringing dynamic routing topologies into the existing framework to perform efficient communication. In the future, another feature to be included is a working model with energy optimisation to increase the up-time of the network to support data delivery among IoT nodes using MANET protocols using AODV and Hybrid Wireless Mesh Protocol (HWMP).

References

1 Li, L., Xiaoguang, H., Ke, C. and Ketai, H. (2011) 'The applications of WiFi-based wireless sensor network in internet of things and smart grid', *2011 6th IEEE Conference on Industrial Electronics and Applications (ICIEA)*, Beijing, China, pp.789–793.

2 Zhao, K. and Ge, L. (2013) 'A survey on the internet of things security', *Proceedings of the 2013 Ninth International Conference on Computational Intelligence and Security (CIS '13)*, IEEE Computer Society, USA, Emeishan, China, pp.663–667, doi: 10.1109/CIS.2013.14.

3 Xu, G., Ding, Y., Zhao, J., Hu, L. and Fu, X. (2013) 'Research on the Internet of Things (IoT)', *Sens. Transducers*, Vol. 160, No. 12, p.463.

4 Want, R., Schilit, B.N. and Jenson, S. (2015) 'Enabling the internet of things', *Computer*, pp.28–35.

5 Bessis, N., Asimakopoulou, E., French, T., Norrington, P. and Xhafa, F. (2010) 'The big picture, from grids and clouds to crowds: a data collective computational intelligence case proposal for managing disasters', *5th IEEE International Conference on P2P, Parallel, Grid, Cloud and Internet Computing (3PGCIC 2010)*, 4–6 November, pp.351–356.

6 IEEE Std 802.15.1 (2002) *Information Technology — Telecommunications and Information Exchange between Systems — Local and Metropolitan Area Networks — Specific Requirements Part 15.1: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Wireless Personal Area Networks (WPANs).*

7 Nwabueze, C.A. (2009) 'Wireless fidelity (Wi-Fi) 'broadband network technology: an overview with other broadband wireless networks', *Niger. J. Technol.*, Vol. 28, No. 1, March, pp.71–78.

8 ZigBee Alliance. Zigbee technology. http://www.zigbee.org/About/AboutTechnology/ZigBee Technology.aspx (Accessed 6 October, 2012).

9 Lee, J-S., Su, Y-W. and Shen, C-C. (2007) 'A comparative study of wireless protocols: Bluetooth, UWB, ZigBee, and Wi-Fi', *The 33rd Annual Conference of the IEEE Industrial Electronics Society* (*IECON*), 5–8 November, Taipei, Taiwan.

10 ZigBee Alliance – https://www. ZigBee.org (Accessed 4 March, 2019).

11 LoRa Alliance – https://LoRa-alliance.org/ (Accessed 4 March, 2019).

12 Sigfox – http://www.sigfox.com (Accessed 4 March, 2019).

13 ABI Research (2020) *The Internet of Things Will Drive Wireless Connected Devices to 40.9 Billion in 2020*, Available online: https://www.abiresearch.com/press/the-internet-of-things-will-drive-wirelessconnect/ (Accessed 25 March).

14 Perkins, C.E. and Bhagwat, P. (1994) 'Highly dynamic destination-sequenced distance-vector routing (DSDV) for mobile computers', *SIGCOMM Comput. Commun. Rev.*, Vol. 24, pp.234–244.

15 Johnson, D., Hu, Y. and Maltz, D. (2007) *The Dynamic Source Routing Protocol (DSR) for Mobile Ad Hoc Networks for IPv4. RFC 4728*, Internet Engineering Task Force, Available online: https://tools.ietf.org/html/ rfc4728 (Accessed 15 April, 2019).

16 Cristin, D., Reinhardt, A., Parag, S., Mogre, P.S. and Steinmetz, R. (2009) 'Wireless sensor networks and the internet of things: selected challenges', *Struct. Health Monit.*, Vol. 5970, pp.31–33.

17 Jeonggil, K., Terzis, A., Dwason-Haggerty, S., Culler, D.E., Hui, J.W. and Levis, P. (2011) *Connecting low-power and lossy networks to the internet*, Vol. 49, pp.96–10.

18 Hanzo, I.I.L. and Tafazolli, R. (2007) 'A survey of QoS routing solutions for mobile ad hoc networks', *IEEE Commun. Surv. Tutor.*, Vol. 9, pp.50–70.

19 Akkaya, K. and Younis, M. (2005) 'A survey on routing protocols for wireless sensor networks', *Ad Hoc Netw.*, Vol. 3, pp.325–349.

20 Kishor, A., Chakraborty, C. and Jeberson, W. (2021) 'Reinforcement learning for medical information processing over heterogeneous networks', *Multimed Tools Appl.*, Vol. 80, pp.23983–24004, https://doi.org/10.1007/s11042-021-10840-0

21 Kishor, A. and Chakraborty, C. (2021) *Artificial Intelligence and Internet if Things Based Healthcare 4.0 Monitoring System*, Wireless PersCommun, https://doi.org/10.1007/s11277-021-08708-5

22 Kishor, A. and Chakarbarty, C. (2021) *Task Offloading in Fog Computing for Using Smart Ant Colony Optimization*, Wireless PersCommun, https://doi.org/10.1007/s11277-021-08714-7

23 Bounceur, A. (2016) 'CupCarbon: a new platform for designing and simulating smart-city and IoT wireless sensor networks (SCI-WSN)', *Proceedings of the International Conference on Internet of Things and Cloud Computing (ICC* '16) *Association for Computing Machinery*, New York, NY, USA, Article 1, p.1, https://doi.org/10.1145/2896387.2900336

24 Elkhodr, M., Shahrestani, S. and Cheung, H. (2016) 'Emerging wireless technologies in the internet of things: a comparative study', *Int. J. Wirel. Inf. Netw.*, Vol. 8, No. 5, October.