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Data Collision and Interference Minimization in Wireless Sensor Network using Node Data Addressing with Random Access Time

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ABSTRACT

A wireless sensor network (WSN) refers to a spatially dispersed network of sensors that monitor and collect environmental data and forward the collected data to the central station. WSN has been widely used in daily life and industrial applications, ranging from surveillance, military, healthcare, habitat monitoring, and agriculture application. However, WSN that uses radiofrequency (RF) communication may suffer from noise and interference caused by two or more radios that uses the same frequency. Data collision is also expected within the wireless network especially when numerous sensor nodes are transmitting their data to the base station (BS) through a shared medium. Hence, this research contributes in mitigating the RF interference and data collision in the network to increase the network's data reliability by using the concept of Time Division Multiple Access (TDMA) protocol where each sensor node will be transmitting their data at a different time to avoid collision and interference in the shared medium. However, in this research, each sensor node will access the channel or the transmission medium at a random time. To prove the concept of the proposed method on data collision and interference minimization, an Internet of Things (IoT) based wireless sensor network for alerting application will be designed and implemented in the fire station. It has been found from the experimental result that RF interference and data reliability in the network can be reduced by 90% with the proposed algorithm by allowing the sensor node to access the RF channel and transmit the data at a random time.

Keywords: Wireless sensor network; RF interference; data collision; packet loss, random access time

INTRODUCTION

A wireless sensor network (WSN) is a wireless network that comprises autonomous devices such as sensors that are spatially distributed in a large area. WSN is build up from a large number of sensor nodes that are assigned to a specific role. In WSNs, the main goal is often to collect sensing data from the sensor nodes and transmit it to the base station (BS) to perform further analysis based on the data gathered. Therefore, data collection is the most common application used in the wireless sensor network (WSN) where it is widely practiced in agriculture by Jaideep et al. (2017), healthcare as studied by Rahman et al. (2017), environment monitoring as presented by Abdullah et al. (2017), and battlefield by Jaigirdar et al. (2016).

Every year, a high number of fatalities were reported globally from natural disasters such as hurricanes, floods, earthquakes, fire, and storms. Based on global statistics by Ian (2020), it shows that roughly about 11,000 death reported were caused by natural disasters worldwide from 2000 to 2019. In natural disasters event, one might face death or physical injury, includes losing of properties, possession, and community. One example of a deadly natural disaster is fire. Fires commonly occur in hot and dry areas, such as bushes, deserts, forests, and farms. Without quick action, lots of damage to buildings, land, and property could occur, including fatality are expected. Thus, proper prevention is crucial to combat fire hazards. With the emerging technology, firefighting departments should grow accustomed to the latest technologies by improving their communication system. Seba (2019) had mentioned that it is crucial to establish a wireless communication network for data collection and data exchange purposes in emergency response and crisis management situations. Therefore, in this research, an IoT-based wireless sensor network for an automated emergency notification was designed and developed to improve firefighter's communication systems to ease data update and data exchange.

In a conventional WSN, multiple sensor nodes use a different transmission medium to transmit signals or data. For such data or signal transmission, there is no collision of data is expected, however, the radio channels are limited and cannot be further expanded as stated from the radio frequency (RF) transceiver module, HC-12 UART-RF datasheet from Cytron (2014). Furthermore, the multiplexing time or delay in data transmission will occur as the BS need to perform multiplexing on RF channels to acquire data packets from respective sensor nodes. This issue arises with the high number of sensor nodes in the wireless sensor network. Consequently, the BS takes a long time to scan different RF channels to acquire data packets from each sensor node, thus lower the data reliability and quality of services. Thus, this research proposed data transmission using a common transmission medium or one frequency channel for many users to reduce the multiplexing time of the BS.

However, as the WSNs often comprise a large-scale network with numerous sensor nodes, the chances of data collisions and packet loss in the network are high as each transmitter is sharing the same RF channel (Sainuddin et. al. 2019). A data packet is a unit of binary data that consists of useful information and can be routed out through a computer network. In addition, packet loss is defined as the failure of the transmission of one or more data packets to its intended receiver (Subramani et. al. 2013). By identifying the packet loss in the wireless network, a necessary measure can be considered to improve the packet delivery ratio, and the packet loss rate (PLR) can be calculated as in Equation (1), where N^tx and N^rx are the total number of the transmitted and received packet respectively.

$$PLR = N^{tx} - N^{rx} (N^{tx})(100\%) \qquad (1)$$

It has been proven by (Abid et al. 2012; Dandare & Chole, 2016) that the occurrence of data packet collisions in the communication network between a shared medium is higher than in single-channel transmission. Some of the important criteria in developing a WSN include security, scalability, the lifespan of the network, and data reliability (Williams et al. 2017; Nouh et al. 2017). Data packet collision that occurs in the network can degrade the system performance as the percentage of data losses, the lifespan of the WSN, and wastage in the bandwidth is increases. Another issue that arises includes interference problems and data corruption as the packages might not be delivered to the intended receiver and discarding of package.

Channelization is a multiple-access technique where the available bandwidth of a medium is shared in terms of time, frequency or code, between different users or transmitters. Channelization protocols include Frequency Division Time Access (FDMA) (Faruque, 2019), Time Division Multiple Access (TDMA) (Nando et al. 2019), and Code Division Multiple Access (CDMA) (Petrosky et al. 2018). Therefore, since the data transmission will take place in a common medium channel, medium access control is implemented in this research by utilizing the Time Division Multiple Access (TDMA) method. Based on a research study from Piyare et al. (2018) on LoRaWAN technology for IoT applications, it has been found that this technology has drawbacks in data latency, end node control by the gateway, and also suffers from data collision within the network. Thus, a high-efficiency on-demand TDMA protocol was implemented and an energy-efficient network architecture was constructed to overcome energy drawbacks and data latency issues. With the proposed network and protocol, an ultra-low-power system with a low data packet collision within the network has been achieved. Next, Shahin et al. (2018) shown that the old collision avoidance method that is based on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) has failed to mitigate data collision in a dense network where a high number of end-user or devices are accessing the common centralized access point (AP). The authors had proposed a hybrid slotted-CSMA/CA–time-division multiple access (TDMA) (HSCT) medium access control (MAC) protocol for a large-scale network for IoT applications and had achieved a substantial improvement, compared to contention-free transmission.

Apart from data reliability improvement in WSN, the lifespan of the WSN is also important in designing the architecture of the network. Islam et al. (2020) have shown concern about increasing the lifetime and throughput of WSN by allocating a timeslot for the sensor node by the cluster head. In this clustering method, the sensor nodes will transmit their data to the cluster head during its located time, based on the TDMA technique. In their study, it has been shown that throughput and delay time in the network can be improved using the proposed TDMA based allocating system. Similar work has been done by Kaur et al. (2016) which in this study, TDMA-based MAC protocol has been implemented to encounter energy consumption constrain caused by a long idle listening state, mitigate data collision and solve the overhead issue. This scheduled-based protocol had overcome data collision issues in the network that contention-based MAC protocol could not solve. As in contention-based protocol, the transmitter will access the channel or transmission medium along with the CSMA mechanism, resulting in a data collision. Therefore, a scheduling-based protocol could mitigate and resolve the issue by accessing the channel at a different time. All the authors mentioned have been focusing on collision avoidance only, however, there is no detection of data package losses due to the collision. Therefore, this paper works on collision avoidance along with an addressing scheme to resolve the issue with the aim that data lost identification can be done. Besides, the issue mentioned can be solved with only a simple addressing and a random low power mode.

METHODOLOGY

SYSTEM ARCHITECTURE

The proposed system architecture is demonstrated in Figure 1-4. A printed circuit board (PCB) design will be fabricated with the designated components for one base station and three sensor nodes.

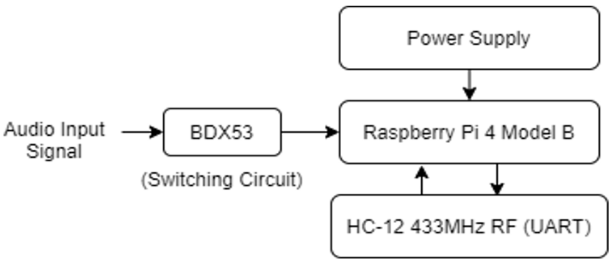

FIGURE 1. Base station architecture block diagram

Figure 1 illustrated the block diagram of base station architecture. BS plays a major role and acts as the main node, where it will collect and gather data transmitted by the other sensor node, which is sensor node 1 and sensor node 2 before transmitting it to the cloud for data visualization. BS consists of a Raspberry Pi 4 microprocessor, taking an audio input signal from the alarm siren for actuating node 1. The triggering signal will be transmitted by the BS through RF.

The first sensor node as pictured in Figure 2 is based on Arduino Uno, which is triggered by the BS. The signal received from the BS will activate the output devices, which are the siren and LED strobe. As these output devices are actuated, the timer will be turned on. The second sensor node as in Figure 3 will be used for vehicle detection, as it will detect the leaving of the firetruck to turn off the timer. Hence, the turnover time of firefighters can be measured once an emergency call is received until the rescuers depart from the station.

In this research, the second sensor node that will be used for vehicle detection will be placed in the engine bay. As it is located in an open environment, an ultrasonic sensor from Maxbotic Ltd. has been chosen. The ultrasonic sensor is low cost, less complex in terms of design and application, and is not highly affected by the environment such as light intensity, moisture, and temperature. In addition, the sensor's response is fast and is easy to be interfaced with the microcontroller.

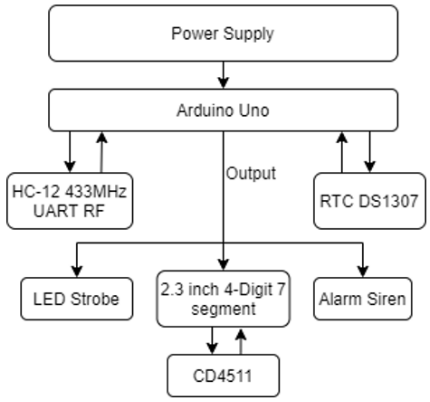

FIGURE 2. Block diagram of node 1 architecture

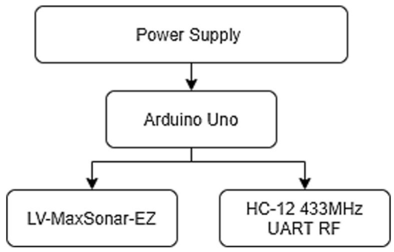

FIGURE 4. Block diagram for node 3 architecture

Lastly, the third sensor node is used for firetruck tracking, which is based on Raspberry Pi 3 Model B+ with a GPS and GSM module, SIM7600E-H 4G HAT. The live location of the firetruck will be updated to the cloud and be monitored from the IoT platform.

EXPERIMENTAL DESIGN AND PROCEDURE

The following Figure 5 demonstrated the overall project flow in terms of hardware design and workflow. In this research, a wireless sensor network that consists of one base station and three sensor nodes will be designed and developed for firefighting purposes. Starting with microcontroller unit initialization the base station will turn into low power mode if there is no alarm has been detected. The base station will be awake from the low power mode by using an interrupt service routine (ISR) concept, in which it will be triggered if the alarm has been detected from the audio output. The alarm will be detected directly from the audio input/output (I/O) of the main personal computer in the control room to discard any environmental noise. Sound filtering will be done once the audio signal is received by the base station, to ensure that the signal received is the designated alarm, not an unknown or other audio signal. The alarm duration should be a maximum of 2 seconds for a single continuous sound and is repeating regularly (long-term periodicity). Otherwise, the base station will turn into low power mode again.

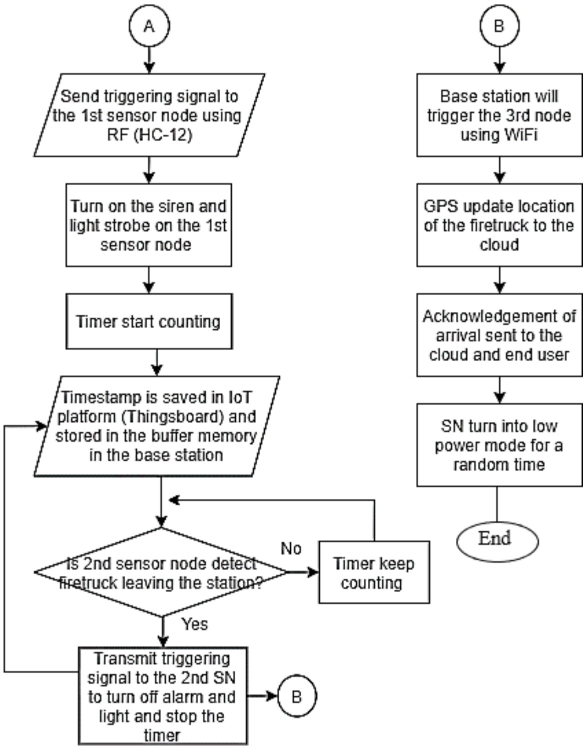

FIGURE 5. Project flow in wireless sensor network

Next, if an emergency alarm is detected, an emergency alert notification will be sent to the end-user (firefighter), informing the emergency so that the rescuers can respond on time, hence reduce their dispatch and turnout time. At the same time, a triggering signal will be sent to the first sensor node, to turn on the siren alarm and light strobe, and hence start counting the dispatch time. This timestamp will be sent to the cloud for monitoring purposes. For the second sensor node, once the ultrasonic sensor detects the firetruck leaving the station, a triggering signal will be sent from the second sensor node to the first sensor node to stop the siren alarm and light, and hence stop the timer and upload the timestamp to the cloud. This process is to calculate the response time of the firefighter to the emergency cases, which includes their dispatch and turnout time. Lastly, the third sensor node is equipped with GPS and GSM module. Once the firetruck leaving the fire station, this sensor node will update its real-time location and send an arrival acknowledgment once firefighters reach the scene. All this data can be monitored and visualized in Thingsboard, which is an IoT data platform.

SOFTWARE ALGORITHM

The flowchart shown in Figures 6&7 shows the flow of the software algorithm in reducing data collision and RF interference. Once the microcontroller (MCU) is initialized, the base station turns into low power mode to reduce and save power, and will only be activated once the event of interest is detected. Once the event of interest is detected, the MCU awake and sends the data package or the triggering signal to the first sensor node. The base station will create a unique identity address for each node as shown in Figure 5. The data package will be capsulated with a unique node identity and data identity before being transmitted to the intended receiver to avoid data collision and overhearing between the sensor node in the network. If the data transmitted failed to reach the receiver within a given time, the data package will be retransmitted again for few times.

Node ID	/	Package ID	/	Data 1	/	Data 2	/	Data 3

FIGURE 5. Node's data addressing package

Once the data package is transmitted is received, the receiver will scan through the data package to determine whether the destination address or the node ID is matched with the receiver. Next, if the data package indeed reaches the right destination, the sensor node will check the whole data package to see whether it is corrupted or no. Once finished, the sensor node will send an acknowledgment of the data received to the transmitter.

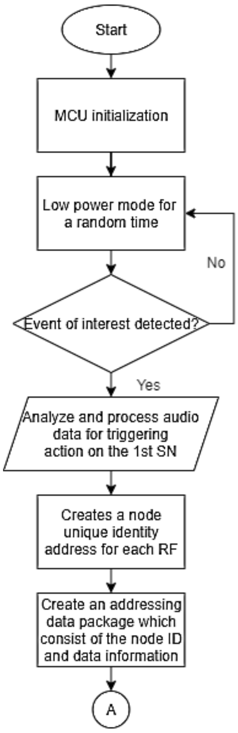

FIGURE 6. Software algorithm on data collision avoidance and RF interference mitigation scheme

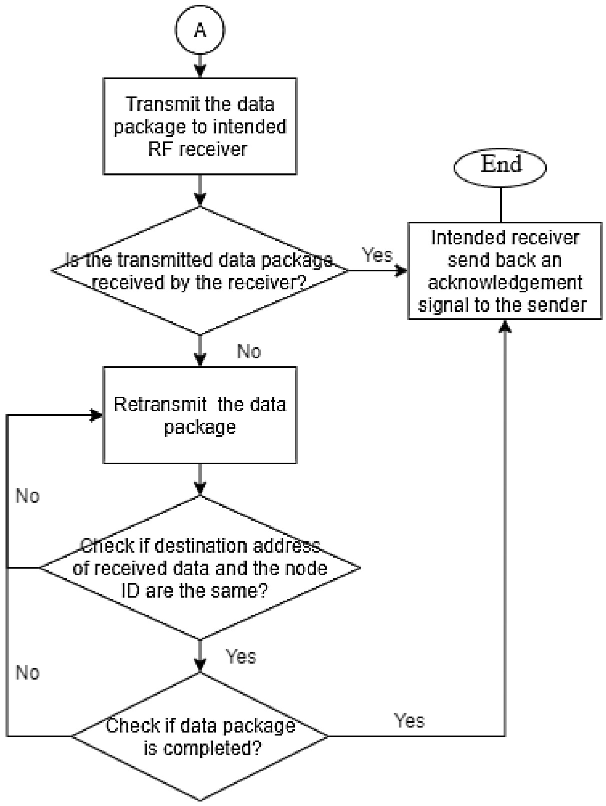

FIGURE 7. Software algorithm on data collision avoidance and RF interference mitigation scheme

Wireless Sensor Node's Routine Pseudo-Code

In this research, data collision and interference are minimized by accessing the transmission channel at a random time. The proposed algorithm is as the following pseudo-code:

1. Initialize the sensor node MCU.
2. Enter low power mode for a random time.
3. Create the node data string which includes [Node ID/ Package ID/ Data from Sensor 1/ Data from Sensor 2/ Data from Sensor 3].
4. Transmit out the addressing string to the base station.
5. Jump to 2.

After the initialization of the microcontroller unit, the sensor node will turn into a low power mode at a random time. By accessing the transmission channel at a random time, the data collision could be avoided. When a sensor node is ready to transmit out a data package, a node's data string will be created to help the base station in identifying the node identification. Each sensor node will create a unique identification, therefore, the base station could differentiate the identity of the transmitter each time a data package is received. Package ID will help in identifying the sequence or the number of the package sent by the transmitter. For example, the first data package will be identified with number 1, whereas the second data package will be identified with number 2. The package ID will help in detecting a lost data package, hence, a data collision can be detected. When each sensor node had succeeded to transmit out their data package, it will turn into a low power mode for a random time which is in a matter of milliseconds. With this routine, data collision could be minimized and power consumption can be reduced.

RESULTS AND DISCUSSIONS

DATA COLLISION AVOIDANCE

In reducing channel interference in the network and data collision, the proposed addressing scheme algorithm is implemented in the wireless sensor network as mentioned in the methodology section. Add on, since the WSN in this project is working in a star topology, overhearing between the sensor nodes can be avoided as the sensor nodes will only transmit its data package directly to the base station. Overhearing in WSN occurs when a sensor node receives a data package that was meant for another sensor node or the base station. Next, the proposed addressing scheme is tested and evaluated in a controlled environment with three sensor nodes sending 100 numerical data to the base station. Each sensor nodes will be evaluated with 3 different time interval, which is 40 milliseconds, 80 milliseconds, and 120 milliseconds to monitor the effect of time interval to the data packet losses.

The result shown in Figure 8 proved that the sink station was able to detect and differentiate the multiple node data with the help of the proposed addressing scheme. With the provided time interval for data transmission in the network, the sensor nodes take turns to access the transmission medium and transmit their data through a random transmission time and turn into low power mode for a random time, and hence avoid data collision from happening. The period of the random low power mode of each sensor node should be within 0.60 to 0.70 milliseconds, as it takes around 0.58 milliseconds to transmit the data package from each sensor node. Therefore, each sensor node will be in a low power mode until it is considered enough for the other sensor node to take a turn in transmitting their data. Furthermore, with the proposed addressing scheme, the package ID will help in detecting the occurrence of the package's collision and data losses if happened. Therefore, it is easy for the user to clarify if there is any collision occurred from the package lost ID.

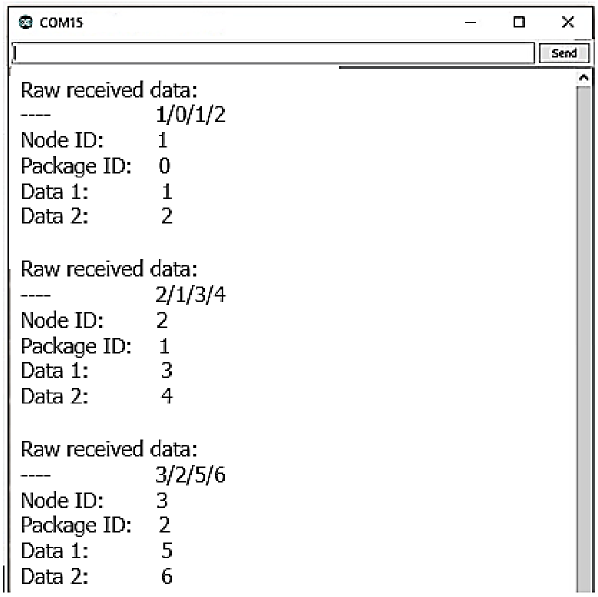

FIGURE 8. Data packages received

Figure 9-11 shows the number of data received and lost by using different collision avoidance approaches for a different time interval. Figure 9 shows the number of data packages received and lost by using three different nodes using different transmission protocols with 40 milliseconds time intervals. In the RAINBOW protocol, it does not include an RF evading or interference minimization method, and channel allocation was random. This has put RAINBOW protocol at disadvantage as the probability of data losses is high. As in GMAC protocol, it is based on the frequency hopping spread spectrum (FHSS) protocol to mitigate RF interference and data collision. However, the channel allocation in this protocol does not guarantee a free data collision, and it allocates only one session for each slot resulting in high traffic during retransmission. Another disadvantage of these two protocols is that the sensor node will wait for the transmission of data from the other package to be completed which causes a long period of idle time and caused energy waste and high power consumption. This approach also suffers from the hidden terminal problem that occurs when sensor nodes in the network cannot detect each other as they are far from each other or out of range and cause a lot of time wasted. Add on, this drawback can increase the probability of data collision as the sensor nodes in the same transmission medium cannot sense if the other sensor nodes are transmitting their data or not.

RAINBOW can be defined as a multiple access protocol that proposed a solution on data transmission through a shared transmission channel, while the GMAC protocol approach is by accessing the medium channel at a random time, without idle session and retransmission of data package in case of transmission failure. In this rainbow protocol, the transmitter will send data whenever there is data present and will send again the same data if the receiver does not respond with acknowledgment of data received within a specified time. If the transmitter detects that the data was not received by the receiver, it will wait for a random time to resend again the data. This process, however, consumes a lot of power and time, and therefore it is considered not efficient.

As a result, about only 15% of data packages have been lost by the three sensor nodes using the proposed algorithm, while GMAC AND RAINBOW protocol showing a 60% and 48% data packet loss rate respectively. These data packages are lost or received as a corrupted data package due to the collision occurrence. On the other hand, Figure 10 shows the result of the same testing but with 80 milliseconds time interval for data transmission. It shows that the data losses are reducing for all approaches, but the proposed protocol showed the lowest data packet losses at only 9% rate.

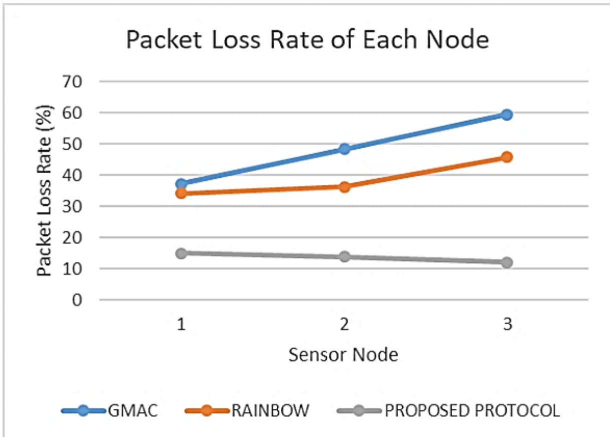

FIGURE 9. The packet loss rate for data interval of 40 milliseconds

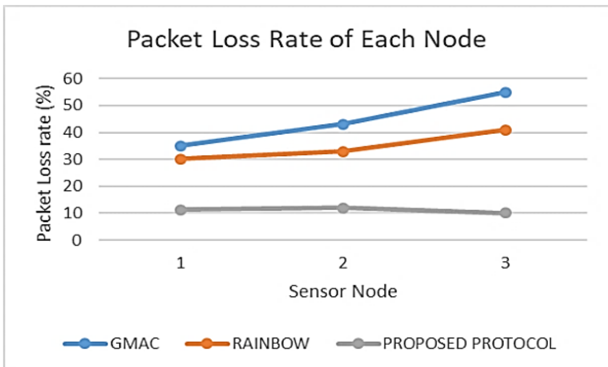

FIGURE 10. The packet loss rate for data interval of 80 milliseconds

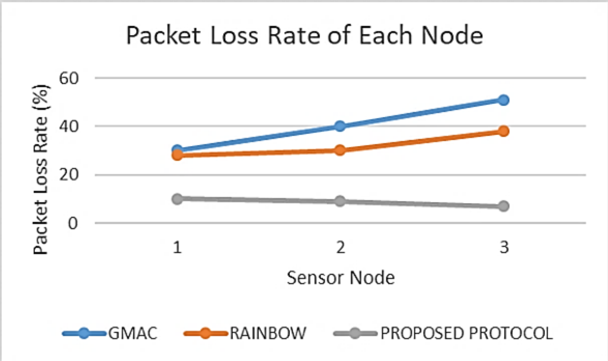

FIGURE 11. The packet loss rate for data interval of 120 milliseconds

Next, the same experiment was repeated with a 120 milliseconds time interval. As a result, data collision using the proposed method is greatly reduced to 5%, outperformed the other two communication protocols. The overall result shows that by increasing the time interval of the proposed approaches, the data package's losses rate can be reduced greatly, reaching only 5% losses. In conclusion from this analysis, the proposed collision avoidance method shows a higher data throughput and efficiency, and also reduces the collision occurrence by 90% compared to the mentioned previous works. From observation on the results displayed in Figures 9-11, it can be concluded that the higher the time interval, the lower the collision rate, as the RF data will have more time to access the channel at different times, and thus avoid the collision.

CONCLUSION

The emergency system in a fire station department plays a huge role in reaching the right people at the right time. However, the current communication system in the fire department is not as efficient and is not automated since they are still using the conventional paging system for data and information exchange. Due to the improper manual data processing and data exchange, firefighters at times tend to fail and rush to the incident accordingly as expected. Therefore, in this research, an IoT-based wireless sensor network automated notification system was designed. However, since WSN may suffers from data collision and interference when using the same transmission channel, this research had proposed a node addressing string with a random access time to reduce the data collision in the network. From the experimental result, the proposed data collision and interference minimization scheme had reduced up to 90% of the collision compared to the existing protocol. Hence, as the data packet loss has been reduced, an improved data reliability can be achieved in the network.

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DECLARATION OF COMPETING INTEREST

None

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