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A LoRa Based Reliable and Low Power Vehicle to Everything (V2X) Communication Architecture

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***Abstract*—The industrial development of the last few decades has prompt to increase in the number of vehicles multi-fold. With the increased number of vehicles on the road, safety has become one of the major concerns. Inter vehicular communication, specially Vehicle to Everything (V2X) communication can address these pressing issues including autonomous traffic systems and autonomous driving. Extensive research is going on to develop a reliable V2X communication architecture with different wireless technologies like Long Range (LoRa) communication, Zigbee, LTE, and 5G. The reliability and effectiveness of V2X communication greatly depend on communication architecture and the associated wireless technology. In this conquest, a LoRa based reliable, robust, and low power V2X communication architecture is proposed in this paper. The communication architecture is designed, implemented, and tested in a real world scenario to evaluate its reliability. Testing and analysis suggest a vehicle in the road can communicate reliably with roadside infrastructures at different speeds ranging from (10-30) Miles per Hour (MPH) with the proposed architecture. At 10 MPH, a vehicle sends one data packet of 40 bytes every 27 meters and at 30 MPH, it sends the same data packet every 53 meters with smooth transitioning from communicating with one infrastructure to another.**

***Index Terms*—Vehicle to Everything (V2X), Vehicle to Vehicle (V2V), Vehicle to Infrastructure (V2I), LoRa, Reliable V2X communication.**

1. Introduction

While the world is advancing, the number of vehicles on the road is also increasing. For vehicles to drive safely, it will be imperative that the implementation of a reliable Vehicle to Everything (V2X) communication system is created to ensure that potential problems that occur can easily be resolved. V2X is the communication of a vehicle to any unit, such as other vehicles or roadside infrastructures [1]. Sub-categories of V2X communication include Vehicle to Vehicle (V2V) and Vehicle to Infrastructures (V2I) communication. V2V communication is the communication among vehicles on the road whereas V2I is the communication of the vehicles with road side infrastructures like traffic signals, control tower or other infrastructures intending to avoid the collision, reduce travel time, autonomous driving, etc. In V2X, vehicles share their instantaneous information such as their speed, coordinates, and acceleration to other vehicles and necessary infrastructures [2]. One of the major challenges of V2X communication is the time criticality and latency intolerance of the applications. Security and privacy are other important aspects of this communication. Building an appropriate architecture and choosing the right communication technology is very important for addressing the existing challenges.

In V2X communication, the vehicles have an embedded system containing necessary sensors and processing units which is termed as On-Board Unit (OBU). OBU is also equipped with a wireless transceiver to communicate wirelessly with other cars and infrastructures around it. On the other hand, the infrastructures along the road are equipped with processing unit and transceiver, combinedly termed as Road Side Unit (RSU) which is capable of communicating with the cars going by the roads. Both OBU and RSU have the capability of communicating with another OBU or RSU. All the cars carrying OBU collect the necessary data with the integrated sensors and send the data to the processing unit of the OBU. The processing unit parses, refines, and stabilize the received data and make the data packet ready to send by the transceiver. The number of vehicles and infrastructures which will receive this data is predefined by the system architecture. Upon receiving the data by other vehicles, they can warn themselves of accidents and suggest directions if necessary. Similarly, the receiving RSUs also warn and suggest a direction to the other vehicles depending on the data received by them.

The system can be implemented using different wireless technologies such as LoRa, Zigbee, Wi-Max, and 4G [3] [4]. There are different challenges associated with these technologies also. Communication latency, transmission range, transmission throughput, and power consumption are a few important challenges that need to be considered while choosing any of those technologies for V2X [5]. WiMAX tower and 4G cell tower have the transmission range of around 50 km and 16 km respectively [6]. But these technologies are energy-hungry and their frequency bands are not dedicated to V2X communication. Moreover, with the increase of the range, each gateway has to communicate with an increased number of vehicles and predict traffic and directions which

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would overburden the computational unit and will introduce higher latency. Zigbee is low power wireless communication technology which is based on IEEE 802.15.4, but it has a range of only 100 meters which makes it unsuitable for V2X communication [7]. On the other hand, LoRa does the balance between transmission range and the data transmission rate. The transmission range of the LoRa is few kilometers with the data transmission rate of 300 bps - 37.5 kbps [8] [9]. It is also based on the low power communication standard of IEEE 802.15.4. These properties of LoRa make it suitable for a simpler but efficient V2X communication which can transmit data reliably with low latency and power consumption.

Extensive research is going on in LoRa based V2X communication. Even though these research works have faced few challenges which include defining a robust and reliable architecture, testing the reliability and performance in a real-world scenario with actual cars at higher speeds. In a conquest to address these existing challenges a LoRa based reliable and low power, V2X communication architecture is proposed in this paper. A performance test is also conducted with real vehicles to analyze the reliability under different speeds. Section 2 of the paper describes the relevant and ongoing research of the field, section 3 depicts the proposed system architecture, section 4 illustrates the design and implementation of the system, section 5 presents the outdoor testing and analysis and lastly, the paper is concluded in section 6.

2. Related Works

Researchers have been working with different wireless communication technologies for defining a reliable architecture and also for various applications in the field of V2X communication. Cheung et al. propose an autonomous vehicle communication in V2X with LoRa protocol where they minimize the latency and transmitted data size [10]. The system is comprised of four components: end-nodes, gateways, servers, and applications. The end-nodes are embedded in vehicles and they collect the necessary data from the vehicle with equipped sensors and transmit the collected data to the servers via the gateway. This system is tested in practical scenarios and shows good results in terms of latency. This has been tested by sending only five packets every minute but it doesn't show how many data packets the end-nodes can send in every unit distance, which would have presented the reliability in time-critical applications.

Lie et al. propose a LoRa based V2X communication scheme and conduct performance tests with different parameter configuration [11]. This research made a point that LoRa should be configured with higher bandwidth and lower spreading factor in V2X to avoid fast fading which is caused by the Doppler effect. This research group has introduced LoRa and enhanced Machine-Type Communication (eMTC) for V2X communication in [12]. This work simulates the Bit Error Rate (BER) performance of LoRa under different scenarios of speed and different Doppler shifts. Han et al. improved the security of the V2X communication with LoRa based physical layer key generation [13]. The system is implemented and tested in an outdoor environment but this work does not address the performance and challenges of the time-critical applications at higher speeds.

Sanchez-Iborra et al. focus on integrating LoRa in-vehicle communication using IPv6 to interconnect with Future Internet scenarios and evaluating its performance under real environments [14]. Experiments were conducted in the V2I architecture and V2V scheme. In the V2I scenario, a suburban environment with different obstacles was evaluated. The obtained coverage was found to be much longer than the range obtained by a high-bandwidth technology, such as 4G. The V2V coverage was studied on a college campus and it was discovered that it covered the entirety of the campus with no shadow areas, so any incident can be reported anywhere on campus. Sanguesa et al. present a V2X-d architecture that uses wireless sensors and combines V2V and V2I communications to make accurate traffic density estimations [15]. this work proposes to place RSUs around a city to help vehicles communicate with one another, helping to reduce traffic jams and make driving more efficient.

The key limitation in all of these works is the lack of using these systems in a real fast-paced scenario, opting to use toy cars instead, in a controlled environment, which is drastically different. Moreover, most of these research works do not focus on the reliability and robustness of V2X communication architecture in terms of real-world scenarios. So, the proposed research work aims to address this challenge by developing a low power and reliable architecture with LoRa and evaluate it with vehicles on the move.

3. Proposed V2X Communication Architecture

The performance of any low power wireless communication vastly depends on its link quality and data overheads. Link quality is measured with received signal strength and error rates, the better the link quality more reliable the communication is. Received Signal Strength Indicator (RSSI) of any received data depicts the quality of any wireless link. It estimates the power level of a received data from any sender or access point. RSSI is measured in dBm and the higher the value of the RSSI, the better the link quality. For obtaining a reliable communication link with lower overheads, the proposed architecture utilizes RSSI values to choose a better communication link.

V2X is mainly sub-categorized into two: Vehicle to Vehicle (V2V) communication and Vehicle to Infrastructure (V2I) communication. The proposed architecture is comprised of two types of units: On-Board Unit (OBU) and Road Side Unit (RSU). OBU is the unit that remains embedded in every communicating vehicle of the system. OBU collects the necessary data with various integrated sensors and they are also equipped with LoRa radio transceiver. An OBU can communicate and send data to RSU and other OBUs. RSU is consist of a LoRa transceiver and a processing unit, and it remains embedded in roadside infrastructures.

RFM69HCW LoRa module is used as the transceiver which operates on 915 MHz and has a maximum throughput of 300 kbps with up to 100 mW of transmitting power [16]. Though it has an official transmission range of 500m at the direct line of sight, a simple quarter-wave monopole wire antenna is used in the transceiver module which might affect the range. Moreover, RSUs and OBUs will surely not be at an ideal location with a direct line of sight all the time. The research group has tested that, on a regular road with obstacles like moving cars and pedestrians, RFM69HCW placed at 1 m height can communicate consistently with almost no packet drop up to 160 m with an RSSI value of approx. -60 dBm. At 40 m distance, the RSSI value improved to a value of approx. -35 dBm.

It is also mention-worthy that, RSSI measurement in a mobile environment is less trustworthy and sometimes it fluctuates from the actual value. Kalman filter is used to stabilize the RSSI measurement by discarding the outliers. Kalman filter is comprised of two main steps: (i) prediction step and (ii) update step. The prediction step does the prediction of the next RSSI from the earlier value whereas the update step estimates the current RSSI value from the value received at that step. Equation 1 & 2 shows the prediction step and the update step of the Kalman filter respectively [17].

$$X_{\overline{K}} = A_{\text{K-1}} X_{\text{K-1}} + B_{\text{K}} U_{\text{K}} \tag{1}$$

$$P_{\text{K}} = A_{\text{K-1}} P_{\text{K-1}} A^{\text{T}}{}_{\text{K-1}} + Q_{\text{K-1}} \tag{2}$$

Here, X is the mean estimation of the RSSI, P is the prediction error covariance, A is the transition matrix, Q is the noise covariance matrix, B is the input effect vector and U is the control input.

For V2I communication, firstly, an OBU broadcasts a 'Hello' message in its transmission range. The RSUs in the vicinity of that OBU receive the 'Hello' message and send an acknowledgment (ACK) back. From the ACKs received, OBU knows the RSSI values received from all the respective RSUs. It is mention-worthy that, while doing any RSSI measurement, the measured values pass through the Kalman filter for stabilization. From the Kalman filtered RSSI values, OBU knows that which RSU has the better link quality to send the collected sensor data. The OBU chooses the RSU with maximum RSSI value to send the sensor data. RSU receives the data packet from the OBU and sends the ACK. Upon receiving the ACK from the receiver RSU, OBU updates the RSSI thus link quality. That OBU keeps sending the data to that particular RSU until the RSSI value reaches a certain predefined threshold value. In this case, the threshold RSSI is set to -60 dBm as it is mentioned earlier, up to this RSSI value the communication is consistent in real roads with the RFM69HCW module. When the RSSI from the receiving RSU crosses the threshold, the OBU broadcasts the 'Hello' message again to repeat the same procedure. By this algorithm, an OBU always remains connected to the most reliable RSU in its transmission range and it switches to another RSU only when the link quality degrades to a certain level to hamper communication link. The described V2I communication algorithm is depicted by algorithm 1.

Algorithm 1 Sending Data from OBU to RSU

```
while Serial reading available do
  cardata ← Sensorsdata
  if radio available then
    Broadcast to wait 'Hello' to RSUs
    Receive ACKs from RSUs
    R_1...R_N ← Kalman filtered RSSI of RSU_1...RSU_N
    R_max ← maximum RSSI value from R_1...R_N
    RSU_max ← RSU with maximum RSSI
  else
    print Can't find any RSUs
  end if
  while R_max > −60 do
    Send to wait cardata to RSU_max
    Receive ACKs from RSU_max
    R_max ← Kalman filtered RSSI of RSU_max
  end while
end while
```

For V2V communication, an OBU broadcasts the 'Hello' message again for all the vehicles in transmission range as like in V2I communication. Upon receiving the data by other OBUs, they send the ACKs back and let the sender know the RSSI. When the sender OBU receives the RSSI values through Kalman filter from other vehicles, it decides which vehicles it will be sending the car data to. OBU does not send the car data to all the vehicles in the range which will make it inefficient, rather it sends the data to the closer vehicles only for making them aware of its location, direction, and acceleration. It is found that, with RFM69HCW, the RSSI value reaches -35 dBm (approximately) when the sender and the receiver are at a distance of 40 m on a regular

Algorithm 2 Sending Data from OBU to Another OBU

```
while Serial reading available do
  cardata ← Sensorsdata
  if radio available then
    Broadcast to wait 'Hello' to OBUs
    Receive ACKs from OBUs
    R_1...R_N ← Kalman filtered RSSI of OBU_1...OBU_N
    R_1...R_M ← (R_1...R_N) > −35 {M number of OBU has RSSI greater than -35}
    Send to wait cardata to OBU_1...OBU_M
    Receive ACKs from OBU_1...OBU_M
  else
    print Can't find any OBUs
  end if
end while
```

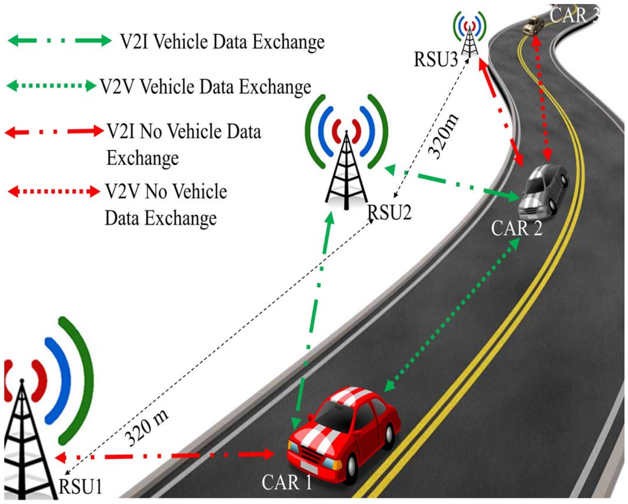

Figure 1. The proposed V2X communication architecture

road with usual traffic. In the proposed architecture, OBU sends the data to the vehicles within a radius of 40 m making it coherent and efficient. OBU compares the RSSI values of other vehicles to check if they are greater than -35 dBm and send the data packet to the vehicles within that perimeter. Algorithm 2 presents the V2V communication protocol for the proposed architecture.

The whole V2X communication architecture is described in Fig. 1 for better understanding. The green links denote the exchange of car data whereas the red links denote that, cars or RSUs are within the transmission range of each other but do not exchange the car data according to the defined algorithms. While going through a road, the OBU in the car communicates with RSUs in its vicinity. CAR1 finds RSU1 and RSU2 within its transmission range whereas CAR2 finds RSU2 and RSU3 within its range. Depending on the higher RSSI value from the RSUs, CAR1 starts sending sensor data to the RSU2 and maintain sending the data to it until it reaches a certain threshold value, in this case, it is -60 dBm. At the same time, it looks for any other vehicle within its radius of 40 m. CAR1 finds CAR2 and vice-versa within the designated range and sends the vehicle data to each other. Though RSU1 is within the transmission range of CAR1, it keeps sending data to the only RSU2 to reduce the data overheads. Similarly, CAR2 sends data to RSU2 only following the V2I algorithm even after having RSU3 in the transmission range. Moreover, CAR2 does not send sensor data to CAR3 as it is out of the designated perimeter.

4. Design and Implementation of the Proposed System

Two of the main components of the proposed architecture are OBU and RSU. As OBUs are integrated into vehicles to collect and send vehicle data to another vehicle and infrastructure, they are equipped with sensors

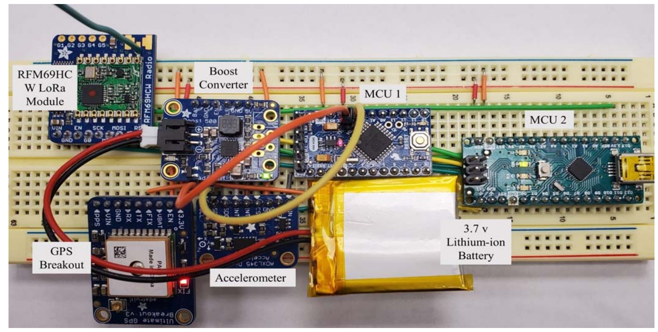

Figure 2. Designed prototype of the On Board Unit (OBU)

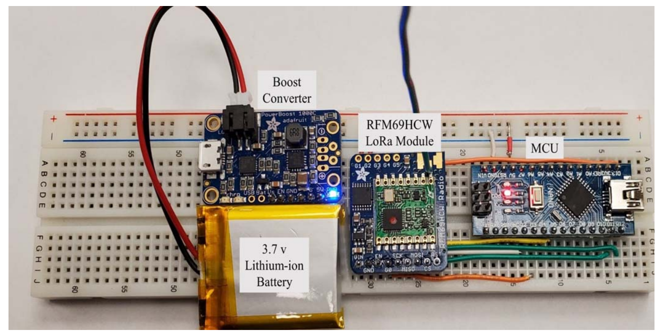

Figure 3. Designed prototype of the Road Side Unit (RSU)

and transceivers. To make it computationally efficient maintaining the low power consumption, OBU is comprised of two Micro-Controller Units (MCU). One MCU process and parse the sensor data and communicate serially to transfer the data to the second MCU which remains connected to the RFM69HCW module. Arduino pro mini and Arduino nano boards are used as MCU1 and MCU2 respectively and both the boards use the same ATMega328p microcontroller chip which has the Static Random Access Memory (SRAM) of only 2 KB and a clock speed of 16 MHz. ADXL345, a digital 3 axis accelerometer, and an MTK3339 chipset based GPS module are integrated to the MCU1 with Inter-Integrated Circuit (I2C) serial bus and software serial respectively. MCU1 gets the data from the sensors and parse them to prepare the required vehicle data. X, Y, Z-axis acceleration data along with latitude and longitude data are sent to MCU2 with serial communication. MCU2 is integrated with the RFM69HCW transceiver module with the Serial Peripheral Interface (SPI) bus. A TPS61090 based boost converter is used both in OBU and RSU to supply 5v from a very compacted 3.7v Lithium-Ion battery. RSUs are much simpler in construction in comparison to OBUs. RSUs have only one MCU unit integrated with the same RFM69HCW LoRa module with the SPI bus. Fig 2 and 3 shows the prototypes of the OBU and RSU respectively.

For exchanging the car data collected by the sensors, a data packet of 40 bytes is sent each time from OBU to RSU or other OBUs. This data packet is comprised of metadata and payload. Of the metadata, preamble data, network id,

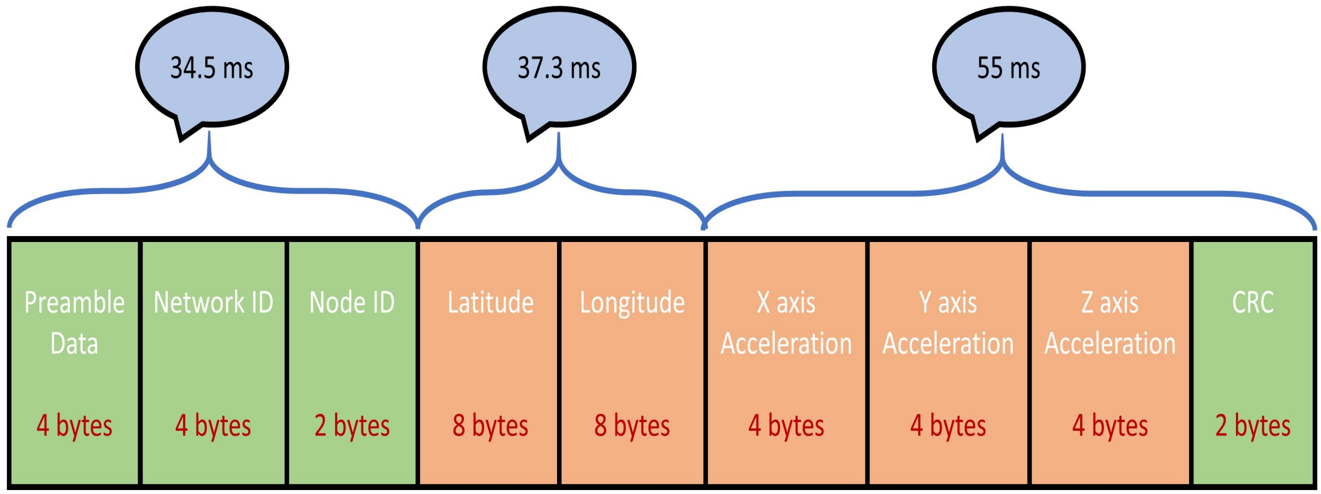

Figure 4. Data packet components and respective data bytes along with their reception time.

node id, and CRC takes 4, 4, 2, and 2 bytes respectively. The reception of preamble data, network id, and node id altogether take a mean duration of 34.5 ms. Latitude and longitude take 8 bytes of data each and they take a mean time of 37.3 seconds. X, Y, and Z-axis acceleration data takes 16 bytes together and they take an average time of 55 ms to be received and processed at the receiver end for both OBU and RSU. Fig. 4 shows all the data components and respective data bytes they take along with their reception time.

5. Outdoor Testing and Analysis of the Prototypes

Outdoor testing of the prototypes is conducted with actual cars on road, by placing the OBU at car roof and RSUs connected with computers for data analysis. As the earlier tests suggest, RFM69HCW can communicate consistently up to 160 m in a mobile environment with regular traffic on the road. Distances between two consecutive RSUs are maintained to 320 m allowing each RSU to have a radius of 160 m. Fig. 5 presents the part of the testing set up with OBU on the car roof and testing car on the track.

Extensive testing is conducted with one OBU and three RSUs placed at 320 m apart from each other with different speeds of the car to analyze the reliability of the communication. Most of the applications of V2X is very time-critical and need an instantaneous response. It is also needed to have a continuous exchange of vehicle data with a short interval of time among vehicles and infrastructures. So, the number of data points received by any RSU while crossing a particular distance is very important. It explains both the reliability and stability of V2X communication architecture. Tests are conducted with three RSUs at a distance of 320m from each other with different speeds of the car from 10 MPH - 30 MPH. It is tested with multiple trials to record the number of data points received by each RSU for different speeds of the car. Fig. 6 shows the number of data points received by RSUs at different speeds of the car.

(a) OBU setup (b) Testing car on track

Figure 5. The testing set up with (a) OBU on car roof and with (b) testing car on track.

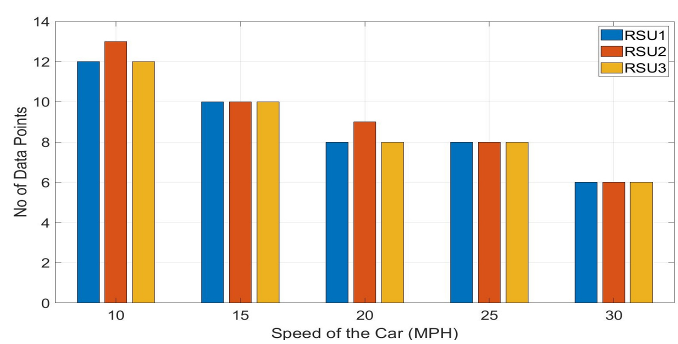

Figure 6. The number of data points received by each RSU (within 320m length for each) at different speeds of the car

The figure shows that the number of data points received by RSU1, RSU2, and RSU3 at any particular speed is almost the same which depicts the smooth switching of the RSUs by the data sending-car. The discrepancy that present might be caused by the asymmetrical movement of the traffic and erratic behavior of the radio signal. At 10 MPH, RSUs received a minimum of 12 data packets which implies the reception of one data packet every 27 meters. Similarly, with 15 MPH and 20 MPH, each data packet is received in every 32 m and 40 m. This clearly shows a regular pattern of increased distance to receive one packet of data from the car. So, with higher speed like 25 MPH and 30 MPH, the OBU can transmit a data packet in each 40 m and 53 m respectively with smooth transitioning between receiving RSUs which denotes the stability and reliability of the proposed architecture.

Energy efficiency is another major concern of these standalone OBUs and RSUs. To improve energy efficiency, the units are designed with low power micro-controller chips and LoRa transceivers. Table 1 denotes the current consumption for both encrypted and unencrypted data transmission.

TABLE 1. CURRENT CONSUMPTION FOR BOTH ENCRYPTED AND UNENCRYPTED DATA TRANSMISSION.

Unit Name	Current Consumption with Encrypted Data (mA)			Current Consumption with Unenncrypted Data (mA)		
	Max.	Min.	Mean	Max.	Min.	Mean
OBU	140.66	61.54	69.23	136.26	60.66	68.24
RSU	119.78	24.62	33.85	101.09	24.62	32.86

The table shows that the average current consumption of OBU with encrypted and unencrypted data is 69.23 mA and 68.24 mA respectively. This current consumption is very less compared to the task it is performing. On the other hand, RSU consumes less than half of the power that OBU consumes. The mean current consumption for RSU with encrypted and unencrypted data is 33.85 mA and 32.86 mA respectively.

6. Conclusion

This paper presents a reliable and robust architecture for V2X communication with LoRa which involves the design, implementation, and real-world testing with the prototypes. OBU and RSU are two main components of the designed architecture. OBU collects latitude, longitude, and 3-axis acceleration data and exchanges the data reliably with RSUs and other OBUs. For exchanging the data with available vehicles and infrastructure, the architecture depends on two algorithms based on distances and RSSI measurement. Both OBU and RSU also show good performances in energy efficiency with the mean current consumption of 69.23 mA and 33.85 mA respectively for data transmission with encryption. The future work includes implementing the architecture with other wireless technology like Zigbee and Wi-Max and analyzes how they perform in comparison to LoRa based architecture.

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