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RESEARCH ARTICLE

LoRaline: A Critical Message Passing Line of Communication for Anomaly Mapping in IoV Systems

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ABSTRACT The importance of road safety is felt nowadays more than ever, where various technologies, including self-driving cars, have become abundant. Nowadays, it has more demand to build autonomous and electrical vehicles with information retrieval systems within the received sensory data not only from the local sensors but also the online and live streaming data over networks. To increase road safety dissemination of critical information, including the possibility of an obstacle or danger being in the middle of the road, automotive navigation and control systems are required. A novel method is proposed to make this critical communication possible over a specially designed vehicular ad-hoc network, where natural or urban barriers can prevent signal propagation. The network is implemented using the LoRaWAN interface and SX127x LoRa Radio module. The SX1272MB2xAS is fitted with the SX1272 transceiver, which added to a high-performance FSK/OOK RF transceiver modem. Additionally, LoRa long-range modem provides highly power-efficient communication. For this aim, two new mechanisms have been proposed. The first mechanism enables the nodes to receive data from a suggested communication link. While the second mechanism is designed to extract vital information such as establishing the connection, closing the connection, successful data transmission, errors, etc. The findings demonstrate that the proposed mechanisms have successfully enabled LoRaWAN to operate in IoV environment. The evaluation reveals that metrics such as battery consumption and covering range outperform similar technologies. Finally, this paper proposes a message-passing strategy based on Belief Propagation (BP) which provides more accurate marginal probabilities to overcome the low data rate as a foundation for our future work.

INDEX TERMS Internet of vehicles (IoV), LoRaline, LoRaWAN, vehicular ad-hoc networks, message propagation, anomaly mapping.

I. INTRODUCTION

Artificial Intelligence (AI) allows systems and machines to learn from experience, adapt to new inputs, and perform complicated tasks, from chess-playing computers to self-driving cars. The high speed of development and progress in artificial intelligence-based systems shows the rapid process of intelligentization in all fields. Among the sectors affected is the automotive industry. Today, automobile manufacturers have introduced vehicles to the markets using automatic decision-making systems equipped with artificial intelligence. Tools such as obstacle detection, environmental light monitoring, environmental humidity measurement, routing, rapid movement control system around the vehicle, and others can be

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called among the gadgets used in today's cars. Most of these tools work dependently in a system, but to improve the outcome, systems need to connect. This connection is for sharing the environmental data for collective decision-making. Finding a modeling pattern is crucial for the learning system used in artificial intelligence. A link to share the data is demanded to recognize patterns in the behavior of the surrounding (nearby) vehicles and the environment (potential high-risk areas or obstacles on-road). The demanded communication is made by the internet of vehicles (IoV) network. This paper proposes a new approach to provide a wide area network stream that uses low power. Such a system might be particularly useful to make an approximate kind of potential high-risk area mapping. Therefore there'll be a communication link between vehicles' autonomous systems based on message propagation in a cooperative network with asynchronous receptions. A Low Power Wide Area (LPWA) networking protocol is designed to wirelessly connect battery-operated "things" to the internet in regional, national, or global networks. The newly proposed protocol targets key autonomous systems requirements such as bi-directional communication and end-to-end security. The main contributions of this paper are:

1) Designing a layered architecture for universal and especially IoV networks, as a heterogeneous network to map the road, environmental errors, and obstacles through sharing the vital data with other decision-making vehicle systems.
2) Simulating an offline ad-hoc data link to share data to the within-range nodes (vehicles). The simulation was conducted with an open-source Mbed simulator with the implementation of the system-embedded code using c++ programming language.
3) The proposed system offers a maximum range coverage supported by LoRaline technology compared with the current IoV solutions, with decent saving power ability and less energy consumption.

This paper proceeds as follows: Section II reviews the related works. Section III presents the motivation to conduct this study. Section IV introduces the proposed mechanisms of LoRaline. Section V presents the possible scenarios for LoRaline alongside the simulation settings. The network model followed by implementation steps, findings, discussions, and the proposed message-passing strategy are demonstrated in Section VI. Finally, the paper concludes itself and presents future work in Section VII.

II. RELATED WORKS

Designing a layered architecture for universal and especially for IoV networks, as a heterogeneous network, can be daunting. The mechanism used in the proposed method has a high potential to solve challenges, including the machine-to-machine communication in IoV systems, where the LoRaWAN communication protocol itself has an immense role [1], also an off-line data link for environmental inference.

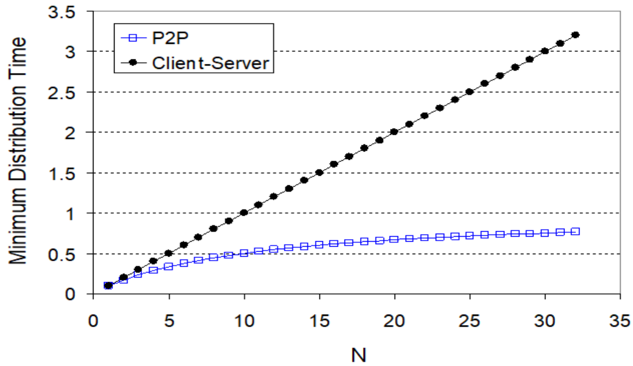

FIGURE 1. Data distribution time in P2P networks versus client-server-based networks [20].

Today, most electronic driving systems, using artificial intelligence and semi-autonomous decision-making systems [2], [3], have the ability to detect obstacles and choose the best path and method to prevent collisions with obstacles. But collective decision-making and sharing of this vital data play an important role in preventing car accidents or common problems in driving vehicles common problems [4], [5].

A. CURRENT NETWORKING ON THE INTERNET OF VEHICLES (IoV)

Current types of networks providing IoV connections use the global system for mobile communication (GSM), which has over five generations of mobile networking technologies. Vehicular Ad-hoc Networks (VANETs) architecture using equipment related to Wireless Access Technology (WAT) such as 802.11a/b/g and satellite communications [6], [7], [8], [9]. Various protocols, together with WAVE [10], C2C [11], and CALM [12], are endorsed to be used in VANET-associated projects. Due to the existence of various barriers in cities (buildings and concrete barriers, tunnels, etc.) or non-urban areas (lack of proper access to Internet services or the existence of natural barriers such as heights), effective communication through the Internet is not possible. The VANETs-based services may be suitable to make this connection between vehicles locally possible. But, the limitations of range-based techniques in vehicular environment [9] and also in case of energy consumption, high amount of electricity consumption are two serious issues for using these techniques [13].

B. AD-HOC NETWORKING USING LoRaWAN FOR IoV

Establishing a connection among the nodes in the IoV environment for long ranges would be challenging using the traditional client-server model, which requires a solid infrastructure. The client-server model faces serious challenges in a dynamic environment, such as in IoV. Therefore, the P2P network, which is infrastructureless, would be the first choice in such a scenario. The ad-hoc network enables vehicles with LoRaWAN system to quickly exchange data with each other without setting up any central networking equipment.

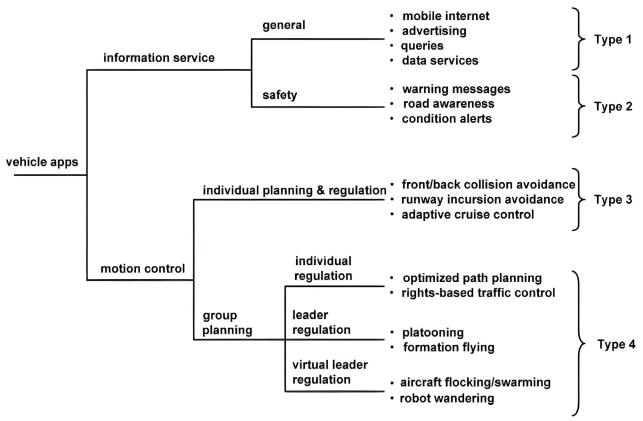

FIGURE 2. **A taxonomy for Inter-Vehicle Communication (IVC) applications.**

The P2P paradigm is especially useful for a small group of vehicles where these vehicles should be able to share files without accessing any central wireless network or in remote regions. Figure 1 above shows that the response of the P2P networks after increasing the number of peers concerning distribution time for getting the data has a better performance in comparison with client-server-based networks, which leads to the fact that P2P networking is more suitable option to apply in the current approach.

The ultimate purpose of coordinating the communication is to send messages to the intended recipient groups as quickly as possible. To enhance speed and preserve network resources, groups should specify feasible margins or select the right interconnection topology for the cause of the dynamicity structure of the nodes. Selecting the right technology is as important as developing the application and models to control. In this special type of network, the message's creator does not remain in a certain location to ensure that the message is continually propagated. In another example, in crashes where a disabled vehicle acts as a repeater, a message propagation node may sometimes exist or alert about the road condition, which comes from passing vehicles. Hence, a network with a dynamic structure is needed, and therefore a repeater cannot be used as a static point, while every vehicle should act as a message propagator.

C. OVERVIEW OF CURRENT APPLICATIONS

The importance of the Road Safety approach, Anomaly Mapping, and the effectiveness of the methods made a massive competition in making new applications for vehicles. The need for inter-communication between applications made engineers and scientists targeting for the most reliable, effective, and secure way of message distribution. Information services often distribute messages to vehicle groups within an area or throughout the network. The ability to create groups to organize nodes for more efficient multi-cast or broadcast communication or to give sources a way to subscribe to the vehicles of common interest has led to being categorized the applications as Figure 2 shows.

In other recent studies, the use of effective communication methods to connect to the car and build a secure network to transfer data retrieved by cars from their environment has already been done, known as the Internet of Vehicles (IoV). Among the areas for improvement of these methods are the use of high-cost communication technologies in terms of electronics, lack of proper coverage, the need for algorithms, and complex software and algorithmic methods for implementation [24]. Also, lack of possibility to use most of the security protocols in the existing methods to ensure privacy, security, and end-to-end communication and data exchange [25], [26].

The work presented in [28] investigated new methods that provide secure communication methods for IoV networks using the LoRa technology. Among the limitations of these methods is the lack of proper communication services for locating vehicles connected to the network, which is estimated by the Time Difference of Arrival (TDoA) of signals that not all devices gateways can provide an accurate value [28]. In addition, the communication method and the protocols used are not clarified [29]. Furthermore, no evaluation has been conducted against the well- known and existing communication methods [30].

Proposing a flexible system that performs well in different scenarios and environments was the main motivation to focus on diversification in cloud platforms. In [27], authors have proposed adding such diversity to support a variety of IoT and IoV platforms to increase flexibility. The proposed system is valid and well-covered. However, different and new network protocols for further optimal performance should have been considered. Additionally, a central antenna is implemented, which establishes the communication relying on a specific point, limiting the mobilization of nodes compared to ad-hoc networks.

III. LoRaWAN FOR IoV

Electric vehicles will shape the future of our transport system. Although lithium-ion batteries are used as energy storage systems, batteries and energy saving are crucial for all-electric vehicles, plug-in Hybrid Electric Vehicles (PHEVs), and Hybrid Electric Vehicles (HEVs). Hence, the existence of a technology that connects electric vehicles with reliable communication, and a low power consumption rate, is a very significant and powerful gadget to be included in electric vehicles.

LoRaWAN covers all the previous features and even more. According to LoRAWAN Alliance, 2015'' LoRaWAN outperforms its rival ''SIGFOX'' (SIGFOX was designed for outdoor environment to cover long distance as the case in LoRaWAN) in terms of battery lifetime by 15 weeks for 2000 mAh battery, security, interference immunity, max messages per day, mobility/localization, and coexistence [31]. In the IoV environment, close distance between electric vehicles is not guaranteed, electric battery consumption power

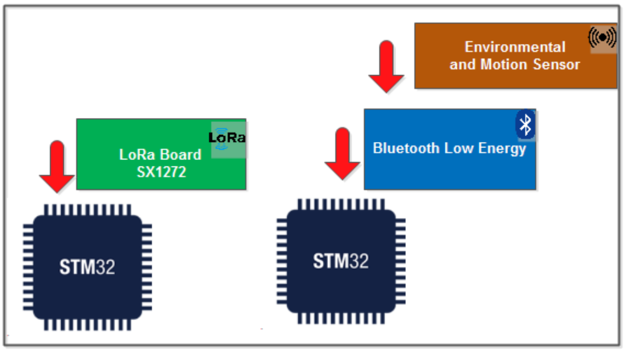

FIGURE 3. The simplicity of LoRa system installation.

is crucial, and interference immunity is so important due to the dynamic driving conditions. Therefore, all the aforementioned features have motivated us to adopt LoRa in IoV environment due to its few cons and many pros as follows:

- LoRa is empowered by the ISM band 868MHz/915MHz available worldwide. This maximizes the battery life as well as the overall capacity of the LoRa network.
- It is widely implemented and optimized for M2M/IoT applications.
- Powerful CSS modulation is applied.
- It uses 6 SFs (spread factor) from SF 7 to 12. This allows orthogonal transmission with different data rates.
- LoRa supports three different device types.
- LoRa supports fast and secure data transmission methods with the advantage of being compatible with almost all communication media security protocols.

Up to our knowledge and after going through the most recent state of the art in this domain, we haven't encountered a mapping protocol that supports a LoRaWAN-based network as an Ad-hoc topology. Whereas in this research, we came up with two newly proposed mechanisms. The first mechanism enables the nodes to receive data from a suggested communication link. In contrast, the second mechanism is designed to extract vital information such as establishing the connection, closing the connection, successful data transmission, errors, etc. Figure 3 presents the simplicity of the LoRa system versus other technologies.

IV. MECHANISM OF THE LORALINE

The proposed LoRaWan-based network uses Ad-hoc topology to provide a P2P line of communication between nodes. Each device sends its package of data to another device with the strongest signal value in the network. This package includes the following components:

The data package shared in the network for the reachable nodes includes sections labeled as Header, Identifier, and Data Package sections (Data and Checksum). The structure implementation will be applied in the application layer of the network model. Every receiver device will modify the header section based on their identification data. Then add their environmental retrieved data into the package (FILO stack) before passing it to the next device with the most suitable situation. Each item in the data package is filled using the FILO stack method with flags of the surrounding points' status based on this structure. The status flags are (00) for no risk detected, (01) for risk of obstacle nearby, (10) for moving obstacle distanced, and (11) for static obstacle distanced. LoRaWAN protocol specifies varieties of mechanisms that ensure reliable and secure communication. Here the proposed mechanism for communication of IoV systems over ad-hoc network topology is described. Figure 4 presents the format for the data packets structure based on 51 bytes of data.

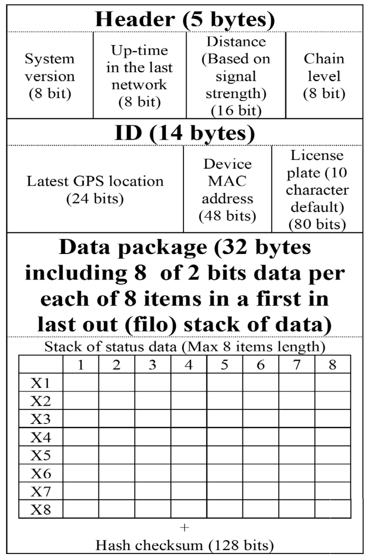

FIGURE 4. Data packet format.

A. NETWORK MODEL

Design teams faced challenges implementing the electrical network's physical layer - the hardware implementation of the network's architecture, topology, and interconnects. The main objective of analyzing the physical layer is to identify and evaluate signal integrity issues for the network. Physical layer verification requires that design teams check the transmission and receiving waveform against the system specification are valid enough. Design teams must ensure that the physical layer allows safe and secure protocol data transmission. Any problems related to the physical layer will impact the entire communication system, slow down the network performance, or cause errors in the control system behavior. If these problems persist, network reliability will be compromised.

- *Data-Packets (Message) Propagation Method:* Figure 5 demonstrates a partial communication between nodes. The communication will be established based on the signal range and quality of the communication line. Here, Vehicle x is starting to share critical data about obstacles in the path. The message packet journey goes through some preprocessing steps first. The system

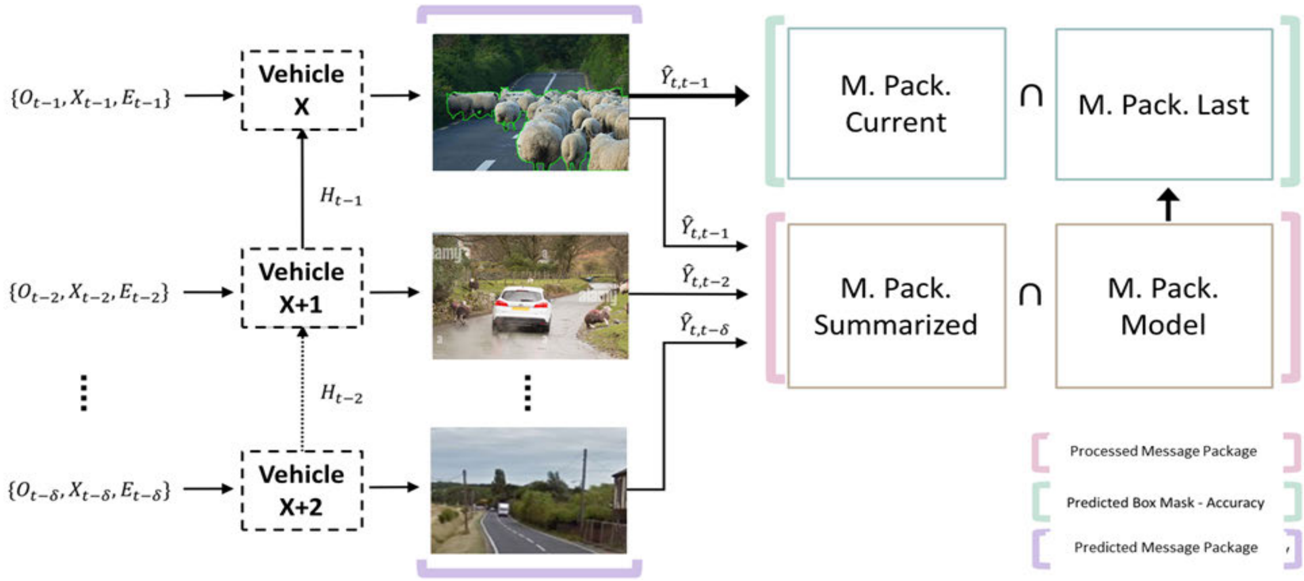

FIGURE 5. **Schematic of the method in action highlighting the anomaly.**

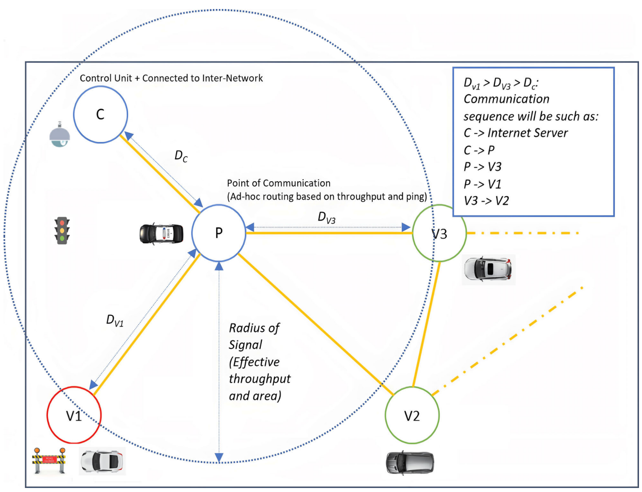

FIGURE 6. **A real traffic scenario in IoV using LoRaline.**

will look for common items in newly propagated and old message packets as predicted box mask accuracy is applied. Also, a summarized version of the messages model will be extracted from a sequence of messages to determine the stress of reporting critical messages in the processing messages step. This process will help to propagate the critical data about obstacles or disasters faster between the ad-hoc network nodes. The messages passed in the network will be ranked based on three factors O (optimized message packet), x (estimated GPS-free locational data based on the signal, movement, and sensory data), and E (estimated critical factors). The proposed vehicle safety information service sharing point is a context-specific procedure for extracting the safety alert from the normal data. Finding the potential dangers or abnormal situations needs to make a model and only pass the changes in the data packets. Figure 5 demonstrates from top to bottom, vehicle (x) finds an immediate obstacle, it will share the Message Packet with the vehicle ($x + 1$), which is in the back with a distance, no ability to see the obstacle. There's a mechanism to find out the common content between message packets which may end up with a model for the normal situation of the road, to find out the anomaly and warn the autonomous control system of the vehicle ($x + 1$) about the possibility of immediate speed changes due to the obstacle observance by next vehicles. Figure 6 demonstrates how vehicles using LoRaline communicate via an Ad-hoc network. Routing in Ad-hoc is based on the availability of throughput and ping. Vehicle P first checks its communication status with the other vehicles in the communication range by estimating two variables: ping and throughput. Device C, with the ability to connect to the Internet and communicate with an external secure server for data exchange, is selected due to its low ping and high throughput relatively compared to other nearby devices. In this case, all other vehicles may access the network via P if located within its signal range. In case a vehicle such $V2$ is located out of the coverage, connecting to the network is feasible via vehicle $V3$.

B. IMPLEMENTATION

The LoRa module is a functional wireless transceiver module based on the SX1272 chip and built at a frequency of 433 MHz. These modules are suitable for long-range and wide-range communications and simultaneously have low power consumption. The LoRa module is very easy to connect and set up, and the proposed technology can be easily implemented using a suitable power supply and a suitable long-range antenna. In the software section, the use of the Lora.h library is considered, based on which the designed function is also based.

The designed method was evaluated after selecting the desired board and modules according to their outputs and efficiency in a simulated environment. In order to optimize and ensure the outputs, the simulation was conducted in the JavaScript environment using the "Mbed" simulation environment infrastructure. C++ programming language was used to implement the main functions of the proposed method. Then, by analyzing the existing method's outputs in the implementation of the IoV, the performance of the proposed method was evaluated based on board outputs such as link budget, RF output power, and maximum throughput. In light of what was noted above, the performance of the proposed method depends on the module, board features, and limitations as well.

The selected board and module for this study are supportable with various components, such as Ultralow power P-NUCLEO-LRWAN1 (NUCLEO-L073RZ), which supports the expansion board model SX1262MBDAS. For instance, RPSReal LoRa Arduino and RPSReal LoRa Raspberry pi modules are available to implement the LoRa board programs in Raspberry Pi and Arduino environments.

- *Module and Platform:*
  The development board is based on the ASR6501 main chip with the internal core of ARM Cortex M0 and IC LoRa SX1272 designed by LoRa development board and can be connected by SPI protocol. With these features, this board is suitable for applications such as the Internet of Things, smart home, security systems, etc., with low power consumption and a small current of about 3.5 micro-amps during sleep.
- *Hardware Programming:*
  The module sends a data package as linked values (only for testing data transferring) over LoRaWAN using STM32WL supported by Mbed OS LaRaWAN stack.

The function is designed to follow the sequence in a loop to receive the data from the proposed communication link, then follow the protocol by calling the vehicle's control unit to process the data and fill the buffer using retrieved sensory data provided by the system. Then, it'll follow up the sequence by calling out the other connected (nearby) vehicles using the communication link. Here is how Mechanism (1) operates. Making the communication possible through a bi-directional (full duplex) chirp spread spectrum of LoRaWAN ad-hoc network needs a loop setup that indicates the Pass in, Call, and Pass out, along with the event handling section. Data will be sent on a stream, so LoRaWAN header file functions will be used to retrieve what's spreading on the dedicated port. The stream size is coming as a buffer size, which we may agree on based on making a standard (Mechanism 1- line 2). For

```
1  FUNCTION main
2   stream_data = lorawan.receive(MBED_PORT, buffer_data
     );
3   PASS In:
4     IF retcode IS LESS THAN 0:
5      print("receive() - Error code ", retcode);
6      return;
7     ENDIF
8     FOR each element in the stream_data array
9      ADD element to FILO(buffer_data)
10    ENDFOR
11  ENDPASS
12  CALL:
13   buffer_data= ControlSystem.Process(buffer_data)
14  ENDCALL
15  PASS Out:
16   retcode = lorawan.send(MBED_PORT, buffer_data);
17   IF retcode IS LESS THAN 0:
18    retcode == LORAWAN_STATUS_WOULD_BLOCK ?
19     print("send - duty cycle violation\n"):
20      print("send() - Error code ", retcode);
21   ENDIF
22  ENDPASS
23 ENDFUNCTION
```

```
static void send_message() {
    uint8_t tx_buffer[50] = { 0 }; //A total
        buffer of 50 bit will make a loop to get
         the data in queue.
        sprintf((char*) tx_buffer,  Data   = ",
            sva21.getSensitiveData()); //SVA21
            will recieve the critical from core
            system.
    int packet_len = strlen((char*) tx_buffer);
        //Buffer reallocation using the
        retrieved data size.
    printf("Sending %d bytes: \"%s\"\n",
        packet_len, tx_buffer); //Making a user
        friendly console environment for
        launching the send code.
    int16_t retcode = lorawan.send(
        MBED_CONF_LORA_APP_PORT, tx_buffer,
        packet_len, MSG_UNCONFIRMED_FLAG);
    if (retcode < 0) { //If there is an error.
        retcode == LORAWAN_STATUS_WOULD_BLOCK ?
            printf("send - duty cycle violation\
            n"): printf("send() - Error code %d\
            n", retcode);
        return;
    }
```

```
static void receive_message(){
    uint8_t rx_buffer[50] = { 0 }; //A total
        buffer of 50 bit will make a loop to get
         the data in queue.
    int16_t retcode; //Getting the converted
        data retrieval status code, which
        handled by event_handler.
    retcode = lorawan.receive(
        MBED_CONF_LORA_APP_PORT, rx_buffer,
        sizeof(rx_buffer),MSG_CONFIRMED_FLAG|
        MSG_UNCONFIRMED_FLAG);
    if (retcode < 0) { //If there is an error on
         communication line.
        printf("receive() - Error code %d\n",
            retcode);
        return;
    }
    printf("Data received on port %d (length %d)
        : ", MBED_CONF_LORA_APP_PORT, retcode);
        for (uint8_t i = 0; i < retcode; i++) {
        printf("%02x ", rx_buffer[i]); //Send
            the received data into the console
            system.
    }
    printf("\n");
}
```

Listing. 1. The prototype function for LORALINE communication loop setup.

instance, in this research, we used 51 bytes of the data package for every node to send/receive, which contains critical data about obstacles and possible errors. So, it takes 102 bytes to make communication between two nodes possible. Pass in section defines a situation in which the program cycle passes the data packages, element by element, to a variable for the next actions, based on the first in last out queue system (Mechanism 1- lines 8, 9, 10). For every switch-case section, an error-catching method is deployed to avoid any fatal errors which make the loop stop. Correspondingly, it does send the error using a friendly defined event handler message to the console to log everything (Mechanism 1- lines 4, 5, 17). The actual code for mechanism 1 is shown above.

The event Handler function (Mechanism 2) is to make the report extraction simpler for the user interface. Every callback from the lora API will be monitored and described to the users in the console system. Therefore, event handling is necessary to ensure that communication and logging information are clear and valid. The raised event will be received from lora_event_t class, which will be coded like "RX_DONE" (Mechanism 2: line 1). Using the switch case command, the different events will return a user-friendly message to the console to be logged or shown (Mechanism 2: line 2). Here, 12 events are determined as the lora_event_t messages, including "CONNECTED," "DISCONNECTED," "TX_DONE," "TX_TIMEOUT," "TX_ERROR," "TX_CRYPTO_ERROR," "TX_SCHEDULING_ERROR," "RX_DONE," "RX_TIMEOUT," "RX_ERROR," "JOIN_FAILURE," "MBED_ASSERT." The mentioned events are defined as: "CONNECTED": When the connection is complete (Mechanism 2: line 31). "DISCONNECTED": When the protocol is shut down in response to the disconnect command (Mechanism 2: line 5). "TX_DONE": When a packet is transmitted (Mechanism 2: line 8). "TX_TIMEOUT": When the stack is unable to send a packet in the TX window (Mechanism 2: line 10). "TX_ERROR": A general TX error shows an error occurred while transmitting packets due to carrier errors (duplex mismatch, faulty cable), FIFO (First In, First Out) errors, heartbeat errors, and window errors. (Mechanism 2: line 11). "TX_CRYPTO_ERROR": If Message Integrity Code (MIC check) fails or any other crypto-related error (Mechanism 2: line 12). "TX_SCHEDULING_ERROR": When the stack cannot schedule a packet (Mechanism 2: line 13). "RX_DONE": When a packet is received (Mechanism 2: line 15). "RX_TIMEOUT": When the stack is unable to send a packet in the TX window (Mechanism 2: line 18). "RX_ERROR": A general RX (receiving packets success error) (Mechanism 2: line 19). "JOIN_FAILURE": OTAA (Over the Air Authentication) failure and entered identification keys should be rechecked (Mechanism 2: line 21). "MBED_ASSERT": Stands for an unknown error (Mechanism 2: line 24). The actual code corresponds to mechanism 2 is shown next, while Figure 7 demonstrates exchanging data in the proposed system.

```
1  FUNCTION lora_event_handler using lora_event_t event
     :
2   SWITCH (event)
3    case CONNECTED:
4     print: "Connection-Successful"
5    case DISCONNECTED:
6     ev_queue.break_dispatch()
7     print: "Disconnected Successfully"
8    case TX_DONE:
9     print: "Message Sent to Network Server"
10   case TX_TIMEOUT:
11   case TX_ERROR:
12   case TX_CRYPTO_ERROR:
13   case TX_SCHEDULING_ERROR:
14    print: "Transmission Error-EventCode=%d", event
15   case RX_DONE:
16    print: "Received message from Network Server"
17    receive_message()
18   case RX_TIMEOUT:
19   case RX_ERROR:
20    print: "Error in reception-Code=%d", event
21   case JOIN_FAILURE
22    print: "OTAA Failed-Check Keys"
23   default:
24    MBED_ASSERT: "Unknown Event"
25  ENDSWITCH
26 ENDFUNCTION
```

```
static void lora_event_handler(lorawan_event_t
    event) {
            switch (event) {
                case CONNECTED:
                    printf("Connection -
                        Successful\n");
                    break;
                case DISCONNECTED:
                    ev_queue.break_dispatch();
                    printf("Disconnected
                        Successfully\n");
                    break;
                case TX_DONE:
                    printf("Message Sent to
                        Network Server\n");
                    break;
                case TX_TIMEOUT:
        case TX_ERROR: //Tx error displays the
            error related to transmitted data
            packets.
case TX_CRYPTO_ERROR:
        case TX_SCHEDULING_ERROR:
            printf("Transmission Error -
                EventCode = %d\n", event);
            break;
        case RX_DONE:
            printf("Received message from
                Network Server\n");
            receive_message();
            break;
        case RX_TIMEOUT:
        case RX_ERROR: //Rx error displays the
            error related to received data
            packets.
            printf("Error in reception - Code =
                %d\n", event);
            break;
        case JOIN_FAILURE: //Join OTAA
            negotiates keys with the server
            printf("OTAA Failed - Check Keys\n")
                ;
            break;
        default:
            MBED_ASSERT("Unknown Event");
    }}
```

Listing. 2. **Event Handler to make the report extraction simpler for the user interface.**

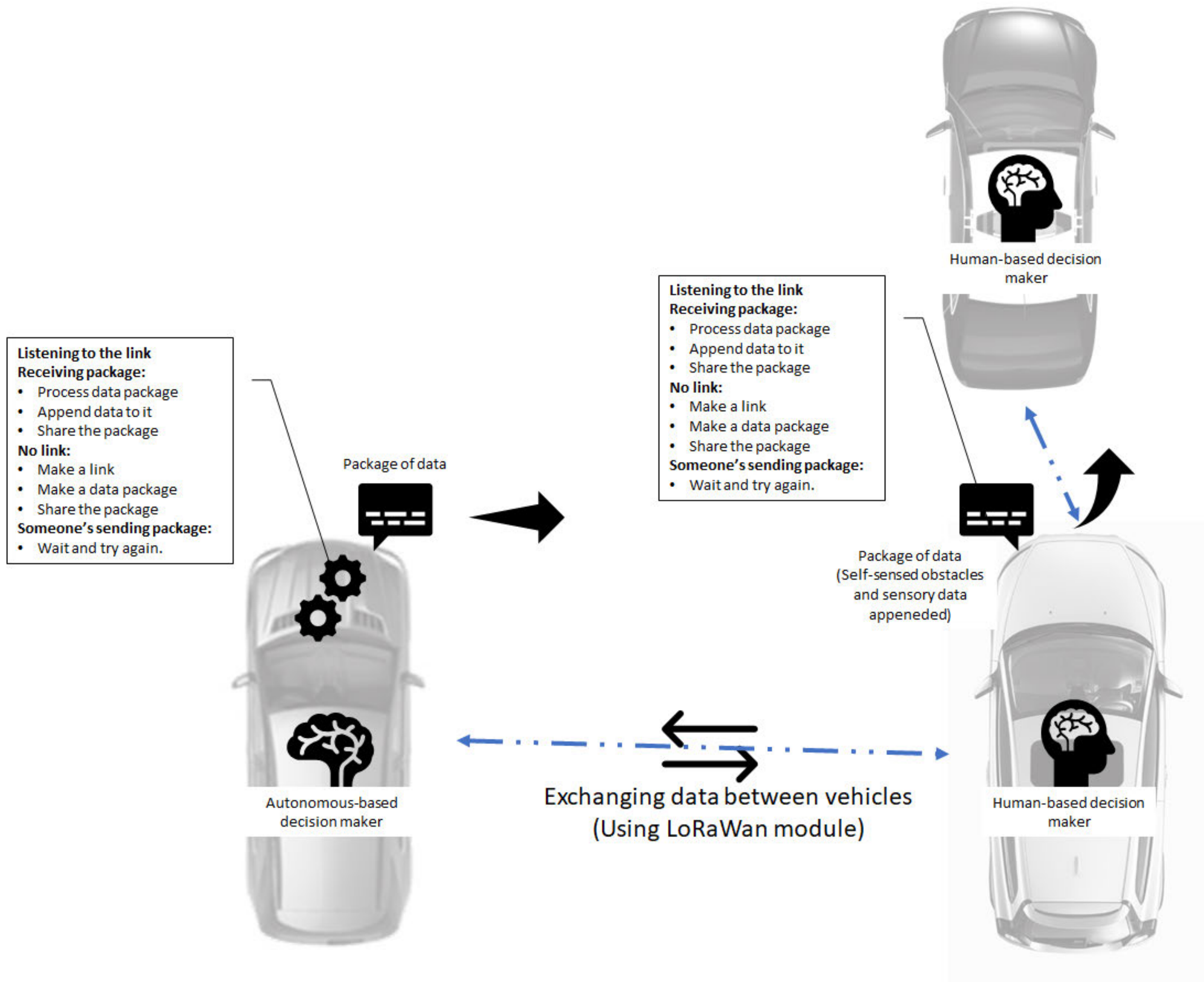

FIGURE 7. Exchanging data between vehicles using LoRaWAN module.

C. CAPACITY AND NETWORK SIZE LIMITATIONS

The LoRaWAN network scale concerning the proposed technology data rate throughput per channel is up to 150 bps. This rate enables each vehicle to have a full-duplex data package transmission every 2.79 nanoseconds based on the 51bytes structured packages. The maximum network coverage range of up to 100 km means the network size and coverage are enough to map the vehicles on the longest street in the world, Yonge Street in Ontario, Canada. The technology over ad-hoc enables each device to transmit the data packages between 120 other end devices. Data transmission timestamp over maximum supported distance with a spreading factor of 12 shows the performance of the network data transmission is rarely affected by obstacle barriers or other variables. The average transmission time for each data package is estimated to be 2.8 nanoseconds with LoRa modulation at different distances.

D. RELIABILITY AND FEATURES OF THE NETWORK

In this section, the reliability of LoRaline is introduced under specified conditions, such as circumstances of different distances and speeds of vehicles, for a specified time (i.e., battery durability performance to run the components using the proposed method). The key features of using LoRa-based networking technologies are: • Long-range: >15 km / 9 mi Range. • Low-power: 5-10 years expected battery lifetime. • Low-cost: from end-node sensor cost to upfront infrastructure investment. • Secure: with embedded end-to-end AES-128 encryption of data. • Geo-location: enables indoor/outdoor tracking without GPS. The range and bandwidth comparison limits in this technology compared to the other mentioned ones are demonstrated below. The results of using the proposed technology have a positive impact on improving the performance of sending information services data between vehicles. Figure 8 illustrates the superiority

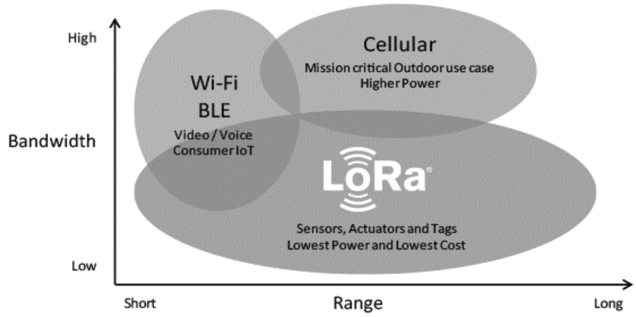

FIGURE 8. LoRa technology features versus other technologies [21].

of the LoRa technology in terms of distance coverage and bandwidth.

V. SIMULATION SCENARIOS AND SETTINGS

This Section presents four possible scenarios for the proposed LoRaline method. The first scenario introduces the connectivity among the nodes in the presence of urban places or landforms, which is the main goal of this study. The second scenario covers low power consumption when power outages which is the main advantage of using LoRaWAN in our proposed method. The third scenario, when network sniffing occurs, while the last scenario is applicable but has yet to be covered in this paper (futuristic scenario) proposed in VI-C.

First Scenario: In the case of establishing communication, due to the dynamicity of the surrounding environment, connecting these nodes in IoV environment using the event handler, sending and receiving messages will be applied as mentioned in IV-B. Therefore, LoRaWAN uses Chirp Spread Spectrum modulation. In this case, the interference, multipath propagation, and fading will not affect nodes' connectivity due to the applied Chirp Spread Spectrum modulation and various phase-shifted frequencies.

Second Scenario: When power outages occur due to car breakdowns, accidents, or parking, the computing mechanism operates using low power consumption modularity. LoRaWAN technology is one of the lowest power commutations. The battery life is up to 10 years. The method proposes real-time computing software, which can also be used for safety-critical applications to share critical data between vehicles and IoV mobile components.

Third Scenario: Suppose network deception or sniffing traffic in the network is detected. In such cases, LoRaWAN messages are encrypted and signed using an AES-128 key, providing strong protection against deception, data sniffing, and data breach in transit.

Fourth Scenario: This scenario currently applies to the proposed LoRaline method but has yet to be covered in this study. The GPS-free tracking and navigation system has a long range (1 to 10 KM), low interface communication, and modular software implementation. The method also supports a modular range of applications that can run through the synchronized board by the internal clock. IoV ad-hoc dynamic servers will have pre-configured position mapping as beacons to trace the location of the other vehicle systems. Hence, if a vehicle doesn't have any GPS or GSM system, it can be monitored using the proposed system. Mbed simulation settings are shown in Table 1, and a summary of the discussed scenarios are listed in Table 2.

TABLE 1. Experiments setup settings.

Settings	Value
Simulator	Mbed
Number of nodes	10
Number of packets	9044
Size of packet	51 Bytes
Call duration (establishing connection till the ping)	840 nanosecond
Total call duration	1000 nanosecond
Flows (links number among nodes)	15

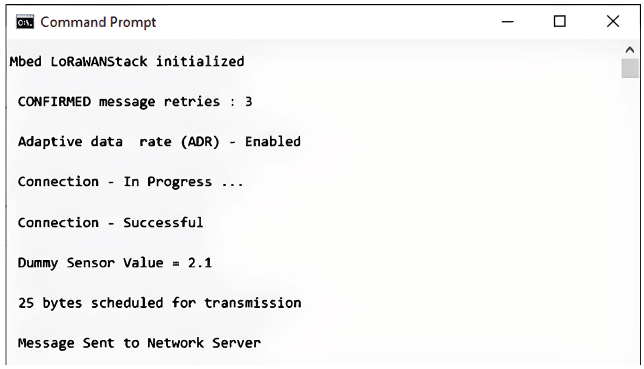

FIGURE 9. Mbed simulator terminal output.

VI. RESULTS AND DISCUSSION

The LoRaline software core code is designed for maximum flexibility through the use of embedded C++ libraries. Implementing code to send the proposed data package includes both message buffering and port handling. Through the official MBed (development software kit tools for boards design and programming based on Arm Cortex processors and micro-controllers (https://mbed.com/#lorawan)) C++ metatemplate development board is used to simulate both performance and stability of the system over a million iterations. The LoRaline core code can also be run in either serial or parallel. The fluid algorithm allows the developers to adjust the data package size using the third-party compression methods and algorithms developed and incorporated into the code. A similar console output of simulation for the communication through the LoRaWAN with proposed method interactions is presented. The results of using the proposed technology have a positive impact on improving the performance of sending information services data between vehicles. Figure 9 displays the serial terminal output for successful data transmission between two systems in several iterations.

TABLE 2. Summary of scenarios.

Scenario No	Scenario	Mechanism	Result
1	Losing communication due to the presence of urban or natural resources.	Using Chirp Spread Spectrum modulation of LoRaWAN.	LoRaWAN senses the interference, multipath propagation and fading.
2	The ability to communicate during power outages.	Real-time computing mechanism using low power consumptions modularity.	The method performs real-time computing calculations to share the critical data between vehicles and IoV mobile components.
3	Deception of network or sniffing traffic in network Security AES 128.	Using LoRaWAN network infrastructure for communication purposes.	LoRaWAN messages are encrypted and signed using an AES-128 key.
4	GPS-free tracking and navigation system.	Low interface communication and modular software implementation.	Monitoring vehicles even though when GPS or GSM services are unavailable.

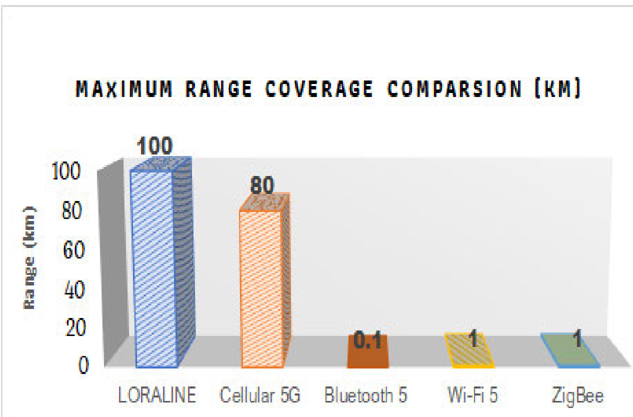

FIGURE 10. Maximum range coverage comparison based on (km).

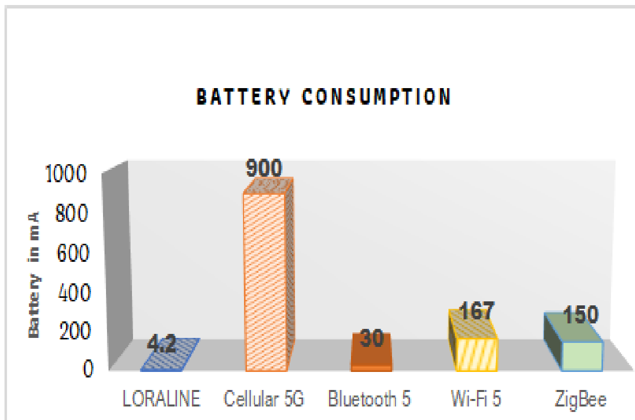

FIGURE 11. Battery consumption comparison based on (mA).

A. MAXIMUM RANGE COVERAGE AND BATTERY CONSUMPTION

In Figure 10, the comparison of the maximum range coverage in the well-known technologies in inter-vehicle communication and IoV demonstrates the efficiency of the proposed technology. It is evident that Bluetooth 5, WiFi-5, and ZigBee can't compete with Cellular 5G and LoRaline for maximum coverage. Cellular 5G has better maximum coverage but not enough to overcome LoRaline, which has more coverage range with a massive power consumption advantage.

The comparison of power consumption shown in Figure 11 is conclusive evidence with the maximum range supported by LoRaline technology. This efficient power consumption and energy savings level is suitable and particularly useful in electric and battery-based vehicles with a limited energy source.

B. SIGNAL RATE, SHORT AND LONG RATE DISTANCES

Figure 12 presents the signal elements transmitted per second. After calculating the amount of power reduction and the degree of impact from the free space environment, it can be observed that the signal throughput rate by LoRaWAN is up to 700 km while 5G wouldn't exceed 100 km. IoV is a network of vehicles equipped with sensors, software, and intermediary technology between them, intended to connect and exchange data over network media according to agreed standards. Critical messaging applications that require low-latency, near-real-time communication over the wireless medium are the next frontier in data communications. 5G and LoRaWAN offer more opportunities to build stable and secure networks with significantly longer ranges.

The coverage of the proposed technology is compared with 5G technology, which is obtained by calculating the amount of signal loss using the free space path loss factor

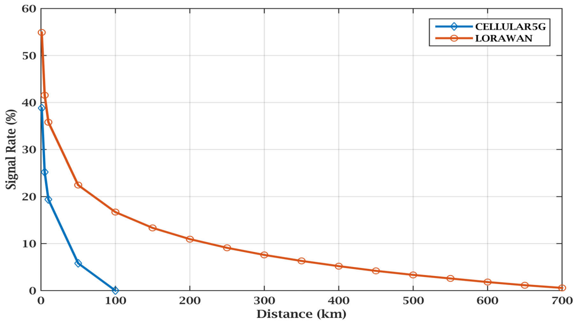

FIGURE 12. Signal rate comparison based on (km).

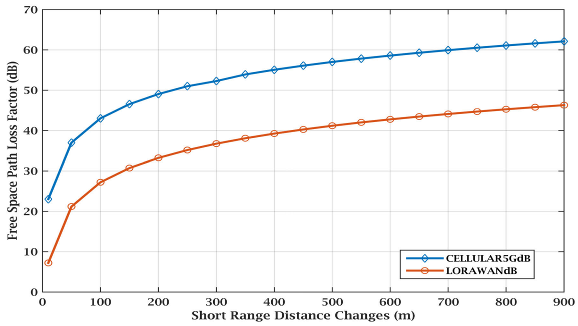

FIGURE 13. Short range coverage based on (m).

estimation method. This comparison has been made in two modes which are: short and long-range coverage for more in-depth evaluation. By examining the results obtained for a short-range scale, it can be concluded that the amount of signal loss in short distances using the proposed technology is between 10 to 15 dB less than 5G technology. For long-range distance, 5G coverage is completely overwhelmed by the coverage provided by LoRaWAN as shown in Figures 13 and 14, respectively.

Using Equation 1 below, the evaluation between Cellular 5G and LoRaWAN enabled in IoV by the proposed method LoRaline is conducted. The signal fades due to the amount of energy lost in free space over a distance between T_x and R_x known as path loss. The farther away T_x is from R_x, the lower the energy is. Path loss has been calculated using via widely used logarithmic formula for free-space attenuation:

$$1FSPL(\text{dB}) = 20\log_{10}(\text{d}) + 20\log_{10}(\text{f}) + 20\log_{10}\frac{4\pi}{C} - G_t - G_r \quad (1)$$

where FSPL is Free Space Path Loss, d is the distance between T_x and R_x in meters and f is the frequency in Hz, C is the speed of light in vacuum, G_t is the gain of the transmitting antenna, and G_r is the gain of the receiving antenna. The frequency for Cellular 5G is 850 Mhz, and the gain for T_x and R_x is 14 dB, whereas the frequency for LoRaWAN is 868 Mhz and the gain for T_x and R_x is 22 dB.

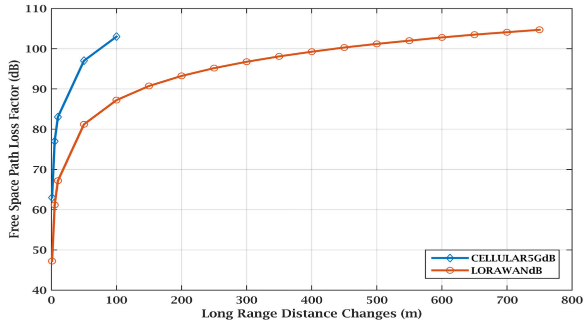

FIGURE 14. Long range coverage based on (km).

C. OVERCOMING THE LOW DATA RATE

LoRaWAN struggles in terms of data rate. This limitation is one of the few disadvantages of this technology. To overcome this issue, this discussion is paving the way for our next future work. There are two methods to be tested and the method that provides better performance will be considered.

The first method is based on effectively reducing the metadata stack to allocate most of the throughput exceedingly for exchanging the actual data. The current method of mapping and determining the position of each of the nodes involved in an ad-hoc network requires the need to use the metadata in the package received from the node or to connect positioning sensors. This method increases the amount of data sent and demands the system to require more sensor devices. The proposed idea is to cope with the allocation of distributed digital navigation systems (control nodes) by implementing Belief Propagation (BP), as an inference set of rules that has currently sparked by message passing system within the network [22], [23]. For instance, each neighborhood and worldwide collection of digital vehicles' sensory system parameters can be distinct as much as unknown similarity due to the variety of devices and software standards, which calls for iterative reparameterizations using the BP application. BP equation for this example is addressed as follows: $m_{v1} \rightarrow v_2$. Applying the BP equation for the given example yields:

$$b_5 = k\,[\phi_4]\left[m_{v_1} \rightarrow m_p \rightarrow m_{v_3}\right] \quad (2)$$

where b_5 is the belief propagation equation with 5 nodes, k is a normalization constant and m is message appending to the current status messages. For security concerns, it is worth mentioning that the presented method supports security protocols that include AES-128 and other IEEE protocols that maintain privacy and integrity.

The second method is based on graph-based neural network, such as Graph Convolutional Networks alongside with Gated Recurrent Unit (GCN-GRU), where the algorithm has to be trained for IoV network traffic data set. However, further investigation is required since the Ad-hoc environment is dynamic which affects the accuracy of network graph. Table 3 Summarizes the evaluation between the top four most common technologies attributes used in IoV communication systems versus the proposed technology.

TABLE 3. Summary of evaluation between the top four most common technologies attributes [8], [14] [15], [16] [17], [18] versus LoRaline.

Technology	ZigBee	Wi-Fi 5/WLAN	Bluetooth Low Energy (BLE) V5	Cellular 5G	LoRaline (Proposed Technology)
Protocol	IEEE 802.15.4	IEEE 802.11 /a/b/g/n/ac	GATT (Generic Attribute Profile)	GSM	LoRa (Official), supporting UART, ZigBee protocols.
Maximum Throughput per Channel	250 kbps	600 Mbps	1 Mbps	250 Mbps	150 bps
Bandwidth	2.4 GHz	5 GHz	2.4 GHz	900 MHz	125 kHz
Max. Range	Up to 100 m	Up to 100 m	Up to 100 m	Up to 80 km	Up to 100 km
Power Consumption	150 milliamperes (mA)	167 milliamperes (mA)	30 milliamperes (mA)	Antenna (9090 milliamperes (mA)) Module (167 milliamperes (mA))	4.2 milliamperes (mA)
RF Output Power	12 dBm	50 dBm	20 dBm	50 dBm	22 dBm
Features Highlights	Low latency data-rate change over distance, Low power consumption	Low latency data-rate change over distance	Low power consumption (only in BLE version)	High speed data rate	Class C low latency data-rate change over distance, high range, open user-definable end-to-end encryption, low power consumption

VII. CONCLUSION AND FUTURE WORKS

Due to the daily growing range of IoT sensors installed on vehicles and other safety tools, it's a matter of time till vehicle technology companies, manufacturers, and road safety administrators would reconsider the standards for transportation protocols to connect every vehicle and safety control system over a secure, long-range, and optimized power consumption network. This research was motivated due to the versatility of LoRaWAN, such as cost, battery lifetime, coexistence, and interference immunity.

This paper presents a LoRaline technology with low power consumption as the key point for IoV systems. For enabling LoRaline adaptation in IoV, two mechanisms have been developed. The first mechanism is to receive and send the data. This is achieved by following the sequence in a loop to receive the data from a candidate link, then processing the data by calling the vehicle's control unit and filling buffer space. The second mechanism is to handle the main events to obtain the required crucial information by developing Event Handler function, which is designed to extract the reports for the user interface in simple manner. Every callback from the lora API will be displayed and described to the users in the console system. Therefore, event handling is crucial to ensure having clear communication and valid logging information. The proposed method will ensure the connectivity range between different devices in different environments with civic obstacles or natural ones. Moreover, this paper introduces two more possible scenarios for the proposed LoRaline in IoV systems to handle power outages and sniffing traffic or network deception in addition to the main aim (goal) scenario. The fourth scenario is a futuristic one and not implemented yet in this study. This work was implemented via SX12672 chip, empowered by LoRaWAN features such as Chirp Spread Spectrum modulation using Mbed simulator.

The performance of LoRaline was evaluated against Wi-Fi, ZigBee, Bluetooth, and 5G. The simulations revealed that LoRaline outperformed all the aforementioned technologies with respect to maximum range, battery consumption, long and short rates coverage, and signal rates. Furthermore, the LoRaline security, with the use of WSN resources, makes this communication line more secure against noise and external inference. Examining the performance concerning the cost and consumption of the devices shows the high efficiency of the method. The main drawback of the proposed method is related to the throughput limitation. Nevertheless, overcoming this issue for the current time can be solved by relying on network data compression and other optimization methods.

For our future work, this study will take a step forward to avoid the low data rate in LoRaWAN. The main idea is to eliminate most of the metadata to make every bit count for transferring the data. When implementing BP, iterative reparameterizations are called because sensory system parameters are well-defined, while devices and software standards vary. Another LoRaline use case is enabling the transport systems to allocate assets without global positioning systems. The allocation will be based on vehicle license or digital ID, which is shared using LoRaline. The positioning system will provide a dynamic simultaneous localization to map the assets in the network using the vehicle plat or LoRaline ID.

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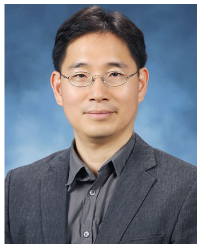

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