A Scalable Hybrid MAC Strategy for Traffic-Differentiated IoT-enabled Intra-Vehicular Networks

Md. Arafatur Rahman[a,*], A. Taufiq Asyhari[b,*], Ibnu Febry Kurniawan[c], Md Jahan Ali[d], Md Mustafizur Rahman[e], Mahima Karim[a]

[a]*Faculty of Computing, University Malaysia Pahang, Tun Abdul Razak Highway, 26300 Gambang, Kuantan, Pahang, Malaysia*

[b]*School of Computing and Digital Technology, Birmingham City University, Birmingham, B4 7XG, UK*

[c]*Centre for Data Science, Coventry University, Coventry, CV1 5FB, UK*

[d]*School of Engineering, Computer and Mathematical Science, Auckland University of Technology, New Zealand*

[e]*Faculty of Mechanical and Automotive Engineering Technology, University Malaysia Pahang, Tun Abdul Razak Highway, 26300 Gambang, Kuantan, Pahang, Malaysia*

Abstract

The increasing popularity of Internet of Things-enabled Intra-Vehicular Wireless Sensor Networks (IoT-IVWSNs) relying on IEEE 802.15.4 standard has generated a massive amount of wireless data traffic and put a great pressure in the network functionalities. Along this trend, the existing medium-access control (MAC) protocol struggles to keep up with the unprecedented demand of vehicle monitoring sensors simultaneously emitting data, which can lead to packet collisions, severe network congestion and lost of time-critical data, due to the inflexible characteristics of the protocol. In order to mitigate these issues, this work proposes an enhanced MAC scheme that is scalable to account for diverse sensor-traffic quality of services. The hybrid scheme aims to effectively combine two procedures, namely history- and priority-based MAC, to allocate appropriate network resources for smooth transmission flow from multiple sensors. History-based MAC exploits historical contention data to optimize a near-future contention window that aims to minimize packet collision and expedite the average data delivery. Priority-based MAC assigns priority based on the time-criticality of the sensing data, which is subsequently being used to schedules network resources. Numerical results show the desirable performance of the hybrid scheme for IoT-IVWSNs in comparison to the existing MAC and sole history-based or priority-based strategies in the context of packet delivery ratio and transmission delay.

Keywords: Automotive, Congestion, Intra-vehicular Network, IoT, MAC strategy, Medium access, Packet delivery ratio, Vehicle.

*Corresponding authors

Email addresses: arafatur@ump.edu.my (Md. Arafatur Rahman), taufiq-a@ieee.org (A. Taufiq Asyhari), ibnufebry@unesa.ac.id (Ibnu Febry Kurniawan), mdjahan.ali@aut.ac.nz (Md Jahan Ali), mustafizur@ump.edu.my (Md Mustafizur Rahman), mahimakarim54@gmail.com (Mahima Karim)

1. Introduction

With the help of advanced communication technology and electronics, various kinds of physical objects are getting interconnected with each other and to a wider internet, encapsulated within a single framework named the Internet of Things (IoT) [22, 24, 32]. Concerning the development of smart systems, e.g., in agriculture, city, home automation, car and transportation, these physical objects often have the responsibility to monitor and control the smart environment with limited human interaction [2, 8, 6, 1]. Each object is typically attached with a sensor node to collect real-time information for analysis and make a decision for further data-driven processes. To make the system more intelligent, an increasing scale in the number and variety of sensors has been investigated to provide a richer set of sensing data.

A growing successful instance of IoT can be found in the automotive sector [28] where state-of-the-art vehicles are furnished with different kinds of sensors, actuators and communication devices to monitor the critical part of a vehicle. The main aim of the network is to collect real-time information to administer the vehicle operation smoothly [12]. Currently, different types of sensor nodes inside a vehicle are connected to the Electronics Control Unit (ECU) by physical wires. To link these sensors together, there are several popular wired technologies used such as Controller Area Networks (CAN) [21], ByteFlight [3] and FlexRay [25]. Unfortunately, the wired connectivity inside the vehicle suffers from non-flexibility and non-scalability due to the complex operating environment and compacted space. This will be further challenging when the numbers of sensor nodes and associated applications grow significantly [37] since reliance on wired technology requires massive installments. Thus, there is a growing demand for designing a reliable IoT-enabled vehicle system in which wireless technology replaces the wired links around the sensor nodes. Moreover, reducing wire connections can help minimize the weight of a vehicle, which in turn leads to cut down the fuel cost significantly [11, 18]. In brief, the benefits of intra-vehicular wireless technology over wired one include: (i) reduction of the weight of the vehicle, (ii) enhancement of the fuel efficiency, (iii) minimization of the manufacturing cost, (iv) ease installment of sensor nodes in the critical part of the vehicle, and (v) promoting a viable and flexible in-vehicle system architecture.

The challenge of providing a scalable architecture through wireless technology is given by the ever-increasing quantity of sensor nodes inside the modern vehicle to provide data intelligence for vehicle safety, driver assistance and risk-free road transportation. While the existing emerging low-cost wireless technologies like ZigBee that supports IEEE 802.15.4 MAC with a low-rate and latency communication protocol [12, 9, 36] can be adopted, this protocol often suffers from a potential collision and congestion problem of the network due to a huge quantity of sensors and high data traffic, which can lead to significant reduction of the performance from the perspectives of throughput, delay and data loss [31].

The deteriorating performance is mainly caused by the limitation of existing MAC protocols. Different congestion control mechanisms have been tested to mitigate collisions for the IEEE 802.15.4 protocol [26, 10, 7]. For example, General Distributed Congestion Control Algorithms (GDCCA) [14], Congestion Control for Multi-class Traffic (COMUT) [34], Z-MAC [35] have been proposed with contention-based hybrid protocols for light load and with schedule-based protocol for heavy load. A common principle drawback of these proposals is given by the inability to adapt with variation in the traffic quantity and differentiation as well as the unsuitability to work for large network size.

Contribution of this work: To deal with the above issues, this work proposes the design of a scalable MAC strategy in the Carrier-Sense Multiple Access/Collision Avoidance (CSMA/CA)–IEEE 802.15.4 standard tailored for IoT-enabled Intra-Vehicular Wireless Sensor Networks (IoT-IVWSNs). Our key contributions are summarized as follows.

- We combine previously developed CSMA/CA mechanisms, namely the history- and priority-based, in the form of hybrid scheme to reduce the inter-packet transmission time during normal conditions and to prioritize packet transmission during event-driven critical situations.
- We model each component of the hybrid scheme using Markov chain to illustrate transitional conditions during data transmission by taking into accounts key variables of IEEE 802.15.4 CSMA/CA.
- We assess the effectiveness of the proposed hybrid MAC scheme using several experiments and measurements of key performance metrics, i.e., packet delivery ratio (PDR), throughput and transmission delay.

The subsequent sections are structured as follows. Section 2 summarizes existing works on Intra-Vehicular Network with different practical technologies. Section 3 discusses the developed two mechanisms, namely history-based and priority-based MAC. Section 4 then presents the hybrid approach that is a combination of strategies presented in Section 3 with the corresponding Markov chain representation. Section 5 compares these methods under different simulation scenarios and draws relevant insights. Finally, a summary of important findings is provided in Section 6.

2. Related Works

2.1. Intra-vehicular Wired Networks

The increasing trend of automotive development has shifted equipment form from analogous to digital. This new paradigm has made component-to-component communication available with the help of installation of wired network. A number of intra-vehicular wired communication protocols, namely CAN [21], ByteFlight [3] and FlexRay [25] have been proposed to provide high transmission rate, high reliability and interference immunity.

CAN [21] was commonly used in factory automation and inter-microprocessors communication within automobile. This protocol is able to provide communication with the rate of 1Mbps over two wires installation. Due to its abundance amount of potential usage, the technology could be found in wide range of vehicle from city car to military boat [16]. However, its asynchronous mechanism has made difficult to well-predict and, thus, motivated ByteFlight [3] and FlexRay [25] proposal. These protocols offered deterministic communication that incorporates time-base signals in microseconds precision. Additionally, both protocols are able to carry out time-driven and event-driven packet transmission simultaneously. In other words, event-critical notification could occur without deteriorating performance of timely message transmission. To achieve this, ByteFlight features SYNC master functionality, while FlexRay introduces static-dynamic segmentation in its communication cycle.

2.2. *Intra-vehicular Wireless Networks*

In the past few years numerous studies have investigated in the various scenarios of intra-vehicular network wireless communication with promising technology [11, 18, 15, 20, 29]. The researchers and automotive engineers have been working on with various sections related to IVWSNs including the design architecture [11], Quality of Service (QoS) [30, 29], network scenario design [29, 31], communication routing protocol [33, 31], effect on propagation inside vehicle [15, 13], and the MAC protocols [5, 4, 19]. However, the primary idea of IVWSNs is the like Wireless Sensor Networks (WSNs), but it has some special characteristics that need to consider uniquely in order to system design issues and the communication protocol design. Generally, the sensor nodes are connected with ECUs inside vehicle within a small area, there is lot of vehicle's metal, obstacles, and other barriers inside vehicle that create a very challenging critical environment in term of radio propagation effect as well as Doppler effect[11]. Furthermore, it is highly demand to design a reliable and robust communication medium that will take less latency in IVWSNs.

To establish a reliable communication in IVWSNs, numerous investigations have been carried out with different technologies including Bluetooth Low Energy (BLE), ZigBee, Radio Frequency Identification (RFID), Ultra-Wideband (UWB), coexistence with Wi-Fi and Bluetooth, and 2.4 GHz Radio Frequency (RF). The work in [15] investigated the communications using UWG technology over intra-vehicles and focused on the testing with time-bandwidth variation.

The authors in [27] have developed a detection algorithm based on the Neyman–Pearson (NP) classifier to monitor the blind zone alert system in IVWSNs to prevent the possible collision. They have implemented the sensors in the front and back side of the vehicle to continues monitor surrounding with the help of RSSI. Each sensor node sends four beacons packets in every second to differentiate the various positions of the neighbour obstacle. The proposed NP classifier system achieved a promising detection rate about 95-99% for blind zone alert for the intra-vehicular network. The system is suitable for few numbers of implemented sensors other than 50-100 sensors in the vehicle as they did not consider any packet coalitions mechanism in their developed algorithm. Moreover, the radio channel characteristics like path loss and lag time speed have been compared in the intra-vehicular network by utilizing ultra-wide frequency in a vector network analyser in [37].

A secured intra-vehicular wireless network design has been proposed in [20] to eliminate security-related concerns like integrity or authentication by applying Host Identity Protocol (HIP). They have improved two types of communication planes namely control and data plane in which the control plane is responsible for controlling the traffic of data based on their priority (highest to lowest) and the data plane manages the multimedia data in the network.

The proposed model outperforms the existing intra-vehicular wireless network secure design by boosting up the network throughput and plenty of security performance. Recently Mirza et al. in [23] have presented an approach to establish a reliable wireless communication model using Bluetooth Low Energy (BLE) and Engine Control Unit (ECU) through the assistance of vehicular ad hoc network inside the vehicle to maximize the packet delivery ratio and less energy consumption. They have also compared BLE and Zigbee with the Controller Area Network (CAN) to evaluate the performance in terms of Packet Delivery Rate (PDR), throughput, latency, energy-efficient requirements. However, they did not determine the network performance when the traffic load become exponentially high by increasing the number of sensor nodes.

The authors in [31] have introduced the Internet of Things (IoT) concept in IVWSNs with a huge number of sensor nodes to investigate the performance in the network. They have revealed that with the increasing of the sensor node in IVWSN, the performance of the network deteriorates significantly because of congestion and collisions among the traffic of the sensor nodes. They have suggested that the existing IEEE 802.15.4 can perform collision-free transmission up to 50 sensor nodes but it not suitable for scalable network especially when network becomes large.

However, since the requirements of installing a significant quantity of intra-vehicular sensor and communication nodes are increasing to achieve driverless smart vehicles, the existing works are inappropriate for designing IVWSNs. Therefore, this work presents twofold efforts to design and develop IoT enabled IVWSNs to obtain reliable communication. Firstly, the paper identifies the demand of designing emerging MAC protocol for the intra-vehicular wireless network, secondly, a suitable hybrid MAC strategy is developed by merging history-based and priority-based MAC techniques to achieve congestion and collision-free communication among the sensor nodes in a scalable fashion.

3. History- and Priority-Based MAC

In this section, we discuss the main building blocks for the hybrid MAC scheme, namely history-based an priority-based MAC. While the preliminary ideas of these two techniques were discussed in [17], this paper advances the development by detailing the algorithmic implementation via pseudo-codes. In the following history based MAC is firstly discussed with the purpose of mitigating the network congestion and collision that significantly affect the performance in terms of average end-to-end delay. Priority based MAC is then presented to ensure the reliability and QoS of the network.

3.1. History Based MAC

To deal with the data collision and congestion of the network, we proposed a historic based MAC strategy especially for IVWSNs using emerging IEEE 802.15.4 MAC protocol. The historic based CSMA/CA algorithm is designed over the original standard of this protocol with several modifications as shown in Algorithm 1.

The CSMA/CA mechanism uses the Binary Exponential Backoff (BEB) algorithm to minimize the recurring chance of congestion and packet collisions from varioюns nodes sharing the same wireless channel. The history based procedure is described step by step in the following points.

- **Parameter Initialization:** When a node need to transmit a data frame, it sets initial values of appropriate basic variables, including the default number of backoff stages (NB), contention windows (CW) and backoff exponent (BE). For a given node, the successful transmission parameter of BE is stored as Saved BE (SBE) and of NB is saved as Saved NB (SNB). While a node is at a first data transmission mode, it sets the macMinBE, BE and NB to values 3 (default), 0 and 0, respectively. Hence, the IoT-IVWSNs is supposed to congested because of high traffic load and large number of sensor node, the parameters like BE and NB of traditional one is set every time for each node that leads to waste of Contention Access Period (CAP). In that case, we choose the value of BE and NB from previous successful transmission history of the node for preventing the wasting of CAP.

- **Decremention of Backoff counter:** While a node intends to transmit a data frame, it chooses a value for the backoff counter in the range [0, 2^{BE}-1] with equal probability. This quantity is subtracted by one at every time slot, irrespective whether the medium is busy or idle.

- **Channel Sensing:** Suppose that the medium is free in two consecutive CCAs. Then, the values of BE and NB will be increased with the range of $[0, 2BE - 1]$ for random time up to BE $\leq$ aMaxBE.

- **Access Failure:** The same process will continue up to a successful completion of a transmission. The MAC algorithm will end while NB $>$ macMaxCSMABackoff that indicates a failed channel access. If this failure is caused by collision, then the sensor node continues to retry the iterative process upper-bounded by the aMaxFrameRetries timeframe.

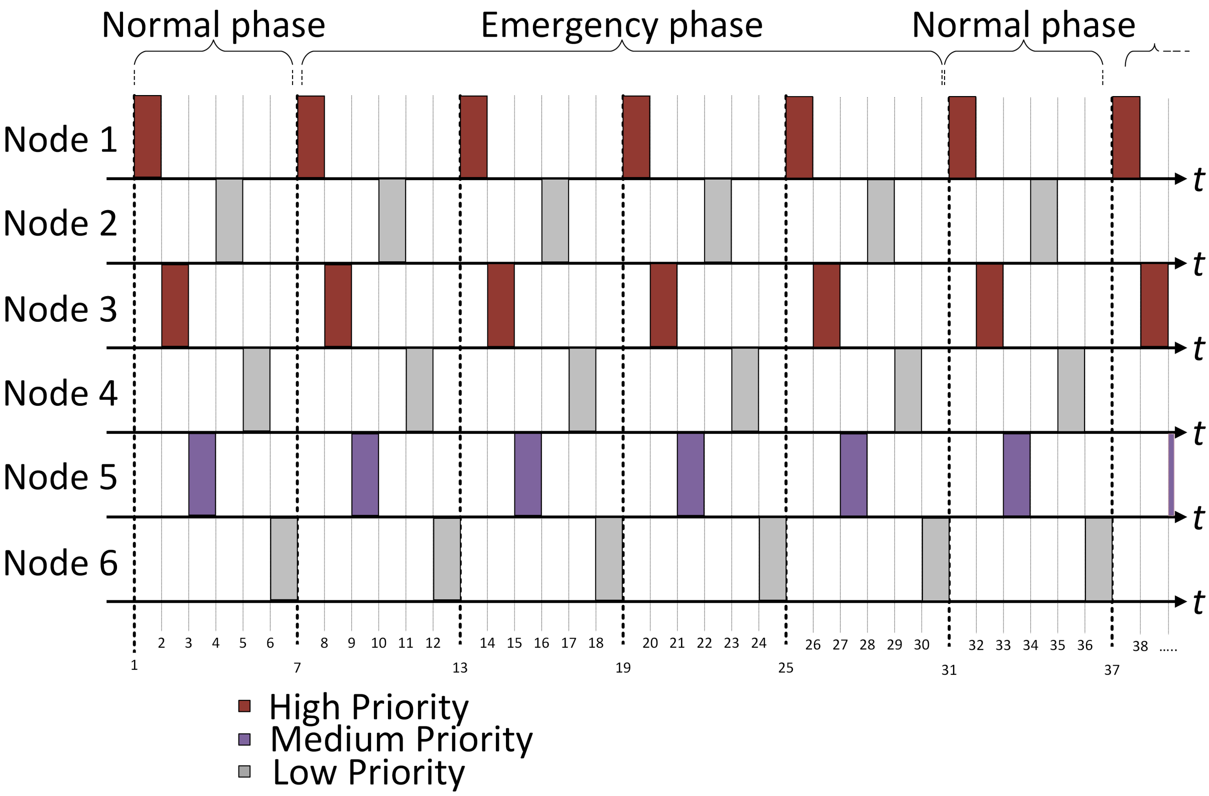
- **Successful Transmission:** Suppose that the communication medium is free at two successive CCAs, then it begins to send the data and assign the value of SNB to be max[NB-1,0] and the value of SBE to be BE. These historical quantities will be utilized for subsequent transmission.

An IoT-IVWSN refers to a networking environment in which a huge quantity of sensors are linked one another to carry out acquisition of the vehicle status information, which can be then exploited to construct an intelligent vehicle system. The multitudes of different sensing and communicating nodes increase significantly because of demanding vehicular applications in various functions for monitoring and controlling. In that case, it is very necessary to investigate whether the existing protocol is working with large network and high traffic load or not. The performance investigation of the original IEEE 802.15.4 MAC protocol along with the history based MAC strategy for an IoT-IVWSN is discussed in Section 5.

Algorithm 1 History-based MAC Strategy

```
CW ← 2                                          ▷ initialization
if First transmission then
  NB ← 0
  if Battery Life Extension disabled then
    BE ← macMinBE
  else
    BE ← min(2, macMinBE)
  end if
else
  NB ← SNB
  BE ← SBE
end if
Locate Backoff Period Boundary
while NB ≤ macMaxCSMABackoffs do
  BE ← BE − 1                                   ▷ Decrementing Backoff Counter
  while CW ≠ 0 do
    Do CCA
    if Channel is available for Tx then
      CW ← CW − 1
      if CW = 0 then
        Transmit packet
        SNB ← NB
        SBE ← BE
      else
        go to 16
      end if
    else
      CW ← 2
      NB ← NB + 1
      BE ← min(BE+1,aMaxBE)
    end if
  end while
end while
```

Figure 1: **Slotted diagram illustration for the CSMA/CA with priority-based transmission.**



3.2. Priority-based MAC

The IoT-IVWSN is related with large scale of sensor nodes and heavy loads which increases the probability of collision and congestion among the packets in the network. The performance of CAP of IEEE 802.15.4 MAC protocol is significantly responsible for the collision probability and the network throughput. Because, if a lot of nodes are densely deployed in a small territory, the contention complexities increase significantly which lead to high probability of collision and energy consumption. The main objective of the proposed priority based MAC especially for IoT-IVWSN is to ensure the QoS of each and every packet and overall lower-down the power consumption of the network by minimizing the complexity of CAP.

The monitoring and surveillance of WSN applications are divided in major two categories, the regular and emergency monitoring. Vehicle has a lot of critical components, which are directly related to the life of drivers and passengers such as engine temperature, blind zone alert system, tyre pressure monitoring system, and driver fatigue detection system. Some sensor information are considered as a normal monitoring purpose for instance, water level sensor, parking sensor, fuel tank ejection sensor, rain sensor, and etc. The priority based CSMA/CA algorithm is proposed to ensuring the different safety level in IoT-IVWSNs.

Algorithm 2 Priority-based MAC Strategy

```
flag ← 0                                        ▷ Currently not node's Tx Round
Rx State ← idle
Schedule next transmission at delay d           ▷ Wait Tx slot
if in Emergency state then
  if MAC is currently idle then
    while Packet Queue ≠ 0 and flag = 1 do
      Do CCA
      if Channel is available for Tx then
        Transmit packet
      end if
      if Tx slot expires then
        flag ← 0
      end if
    end while
  else
    go to 3
  end if
else
  if delay d expires and Tx slot obtained then
    flag ← 1
    go to 5
  end if
end if
```

Table 1: Sensor priority based on component safety level.

Component Type	Sensor Name	Priority Level
Critical safety	Heat, Tire pressure monitoring, Blind zone detection proximity, Driver fatigue detection, Break, Door	High priority
Regular monitoring	Door, Fuel level monitoring, Ultrasonic, Rain, Oxygen, Water level monitoring, Over speed	Low priority

Here, we set the priority of each sensor node according their component type of the vehicle shown in Table 1. All the relevant sensor nodes transmit their information in periodic fashion. However, if any emergency happens within the sensor nodes, they transmit their information according to high to low priority manner shown in Fig. 1. The CSMA/CA with priority-based transmission emits a single packet for a given time. As a result this mechanism prevents the congestion and collision without any data drop in the IoT-IVWSNs. The priority is set according to emergency to regular monitoring of various safety components of the vehicle mentioned in Table 1.

4. Hybrid MAC Strategy

In this section we describe our proposed hybrid MAC strategy that combines the techniques previously explained in Section 3. We incorporate both algorithm and Markov chain representation for illustration.

4.1. Algorithm Implementation

Based on the corresponding strengths of each individual strategy, the hybrid MAC scheme flexibly utilizes a combination of history-based and priority-based strategies. In the overall picture, the scheme attempts to maximize the packet delivery rate according to sensing data requirements as categorized by normal and emergency periods. The algorithm implementation is presented in Algorithm 3 with details of Algorithms 1 and 2 being given in Section 3. This algorithm operates based on an event-driven condition. For instance, when any of the critical safety sensors (e.g., in Table 1) are active, the strategy changes from normal operation (history-based) to emergency operation (priority-based).

Algorithm 3 Hybrid MAC Strategy

```
if Emergency condition occurs then
    Execute Priority-based MAC Algorithm 2
else
    Execute History-based MAC Algorithm 1
end if
```

Note that whenever the sensor nodes are in normal period (i.e., regular monitoring of the intra-vehicle environment), the MAC parameters BE and NB will be set to SBE and SNB according to the historical contention data. Meanwhile, during the emergency stage priority-based will be chosen in order to ensure packet delivery. This configuration is expected to improve the transmission behavior with the history-based MAC as compared to the original protocol. The priority-based solution can accommodate up to a certain number of transmitting sensing devices, depending on the priority as set in Table 1. Since the priority-based part has similar operation to time-division multiple access, the scheme will struggle to keep up with an increasing number of sensors with a larger transmission delay being anticipated to happen. Furthermore, a higher processing delay as a result of re-configuration might be more frequently occurring in critical conditions since the hybrid scheme requires some transition time between the normal and prioritized transmission.

4.2. Markov Chain Representation

Based on the algorithm construction in Section 4.1, we illustrate the working principle using Markov chain representation. We provide information on symbols used in the model, which are summarized in Table 2. The overall Markov chain diagram is given in Fig. 2 with detailed Priority- and History-based segment illustrated in Fig. 3 and 4, respectively.

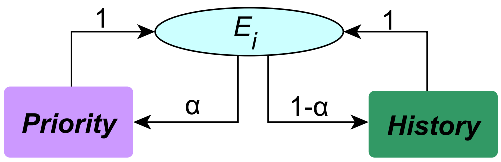


Figure 2: Markov Chain Illustration for Hybrid-based Scheme

From the figure, we can observe that the hybrid scheme combines two previous schemes with parameter α governing the probability of entering an emergency phase. After each successful transmission, the system will re-inspect an incoming packet. If the packet contains urgent data, then it will use the priority mechanism. Otherwise, the history-based approach will be used.

The priority-based part attempts to ensure there is only one node transmitting at a certain period. Given a set of transmitting nodes $N_t = \{n_0, n_1, n_2, ..., n_{N-1}\}$, denote P_i as the probability of $n_i \in N_t$ entering the "on" period or being permitted to begin the transmission process. Assuming a uniform distribution, we have

$$P_{on} = \frac{1}{|N_t|} \tag{1}$$

where $|N_t|$ is the total number of nodes in the topology. A node may start the backoff period based on the probability of packet arrival. Once a node becomes relevant for transmission, it assesses the channel twice. At the end of the assessment, it will start transmission with probability of collision P_c. The collision may still have a chance to occur during the transition of transmission round.

Table 2: First-type symbols $\{s(t), b(t), w(t), r(t)\}$.

Symbol	Meaning
$s(t) \in [0, m]$	time-t NB with m being $macMaxCSMABackoff$
$b(t) \in [0, W_i - 1]$	*backoff counter* at time t where $W_0 = 2^{macMinBE}$ and $W_i = W_0 2^{min(i, aMaxBE - macMinBE)}$, $1 \leq i \leq m$
$w(t) \in \{1, 2\}$	leftover CCAs for time-t transmission
$r(t) \in [0, R]$	retransmission plane at time t where $R = aMaxFrameRetries$

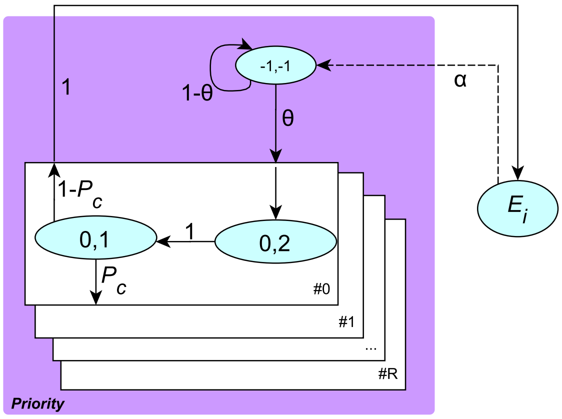


Figure 3: Markov Chain Model of Hybrid-based - Priority Segment

For the history-based part, we note the following observations. Since we use slotted MAC scheme, there is no deferred transmission that is caused by the CAP mechanism. Since the parameter NB of current transmission will be set based on the last successful transmission, the transition probability will have to calculate from SNB to m where m denotes the maximum CSMA backoff time.

In addition to the history-based and priority-based parts, the following states are introduced in the hybrid scheme as shown in Fig. 2.

- $E(t) \in [0, Tr]$ that represents a current emergency state of the current transmission attempt.
- $\{r(t), w(t)\}, r(t) \in [0, m]$ and $w(t) \in \{1, 2\}$ that corresponds to the current retransmission plane and captures the CCA value during the priority-based mechanism.
- $\{s(t), b(t), w(t), r(t)\}$ corresponds to state representation that is similar to that of history-based mechanism.

Remark that the transition probability from state $E(t)$ to $\{r(t), w(t)\}$ or $\{s(t), b(t), w(t), r(t)\}$ is not independent. Herein the calculation should include the value of α, the probability of entering an emergency period.

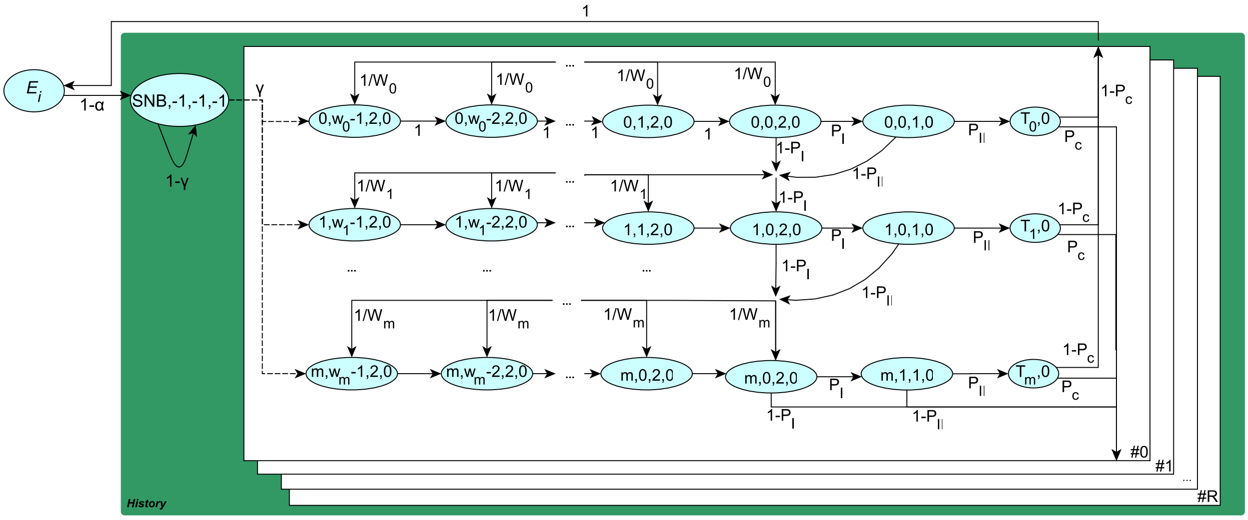


Figure 4: Markov Chain Model of Hybrid-based - History Segment

5. Performance Analysis

In this section, we discuss our conducted experiments for highlighting the necessity of designing an efficient MAC strategy compared to the traditional MAC in IoT-IVWSNs. To this aim, the first part of the proposed protocol (i.e., history-based) is compared with the traditional/original MAC (i.e., from IEEE 802.15.4 standard). We utilize a network simulator to measure the performance by adjusting different communication parameters as shown in Table 3. The P_t indicates the transmits power with -15 dBM which is suitable for a sensor node of the ZigBee module in OPNET. After highlighting the necessity of the efficient MAC in IoT-IVWSNs, we then explain performance comparison among history-based, priority-based and hybrid MAC using Network Simulator 3.

5.1. The Needs for Designing Efficient MAC in IoT-IVWSNs

First of all, we design several network scenarios for analyzing the result for traditional MAC strategy for IoT-IVWSNs, four types of network scenarios are considered with varying traffic load. In order to investigate the network performance in a scalable fashion, different sizes of networks are considered. We investigate the performance considering the measurement metrics end-to-end delay of Cumulative Density Function (CDF), energy consumption, PDR.

In terms of average transmission (end-to-end) delay, we evaluate the network by changing different combination of traffic intensities as shown in Table 4. This section analyses the performance of the network in a scalable fashion. IVWSNs become more congested with the increasing of traffic load. The phenomena of congestion problem of network which deteriorates performance measures such as transmission delay is investigated and alleviated through the history based MAC strategy.

Table 3: Suitable communication parameters for IVWSNs [29].

Name	**Value**
P_t	-15 dBM
C_f	2.4 GHz (ISM band)
R_s	-95 dBM
Transmission Period	120 ms (low traffic) and 60 ms (high traffic)
Packet Size	210 bits
Channel	Rayleigh fading, Pathloss exponent with NLOS $\gamma = 4$
ACK wait duration	0.05 s
Number of retransmission	5
Minimum backoff exponent	3
Maximum number of backoffs	4
Channel sensing duration	0.1 s

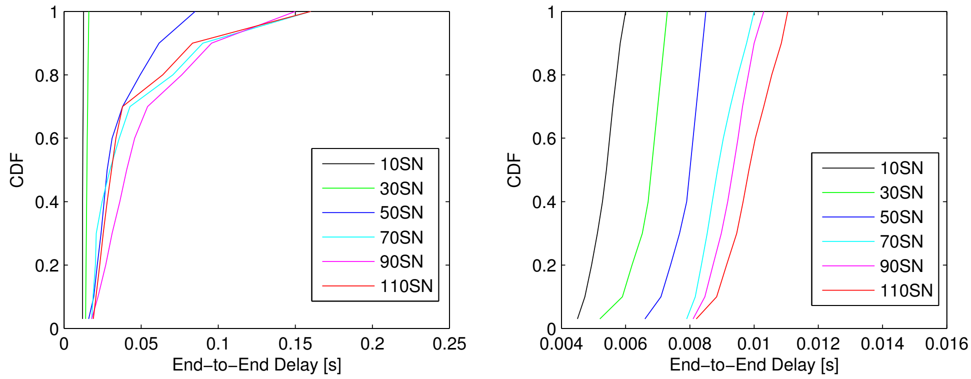
Table 4: Two cases for different combinations of traffic load.

Number of SNs	**Scenario I**		**Scenario II**	
	G	Y	G	Y
10	5	5	3	7
30	15	15	9	21
50	25	25	15	35
70	35	35	21	49
90	45	45	27	63
110	55	55	33	77

Fig. 5 depicts the comparison of delay CDF under varying number of SNs for Scenario I. Herein we see that as the number of SNs grows IoT-IVWSNs, the CDF curve shifts to the right, implying a gradual degradation of the network performance because of the collisions. Basically, after a collision occurs, the SN pauses for a given interval (i.e., backoff plus sensing). The SN again begins to retransmit the packet that previously cased collision when the channel is free. This recursive phenomena can be understood from the mechanism of CSMA/CA. It is clear to explain that the network collision is happened with the increasing of high traffic as a result the network delay performance increases.

A similar trend is also observed for Scenario II as demonstrated in Fig. 6. Here the performance becomes worse when the traffic load of SNs increases because of the collision among the packets arising from the original/traditional MAC protocol.

Additionally, by expanding the number of SNs in the network with high traffic load, congestion and collision continue to increase in IoT enabling environments. In fact, the IEEE 802.15.4 network may be able to serve requesting traffic until a given threshold beyond which congestion starts occurring. This will affect the delivery of packet with many potentially being delayed for a complete transmission. A higher level of congestion means a larger number of delayed packets. From the aforementioned discussion, we can summarize that, the collision rate and packet losses are increasing unprecedentedly and the throughput deteriorates as we increase the number of SNs. Under those circumstances, the existing



(a) Traditional case

(b) History-based MAC in scenario I

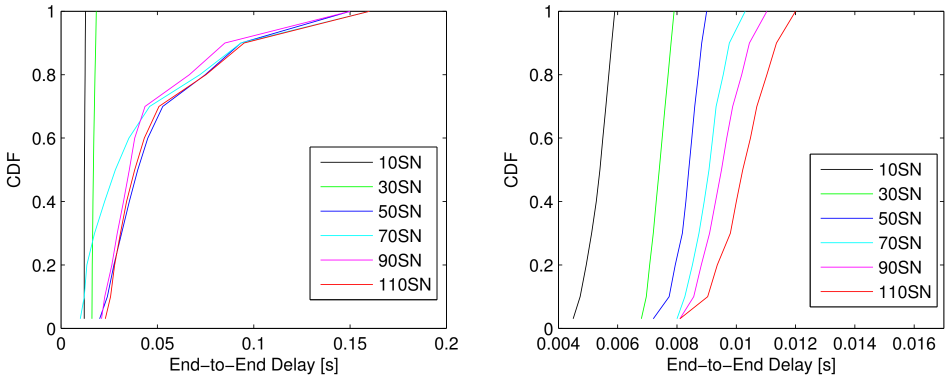
Figure 5: Traditional/original versus History-based MAC for Scenario I.

different types of MAC protocols are performing poorly for a large network. In this case, the scalability of this protocol needs to be enhanced for designing such a communication system in the IoT environment in near future.

Basically, after the collisions occur, every time the sensor node needs to wait (backoff + sensing period) for the next free channel of time slots.The each sensor node attempts to retransmit the unsuccessful packet iteratively which cause collision subsequently. The algorithm CSMA/CA defines this recursive technique in the MAC protocol. Usually, when the network becomes more congested due to deploy more sensor nodes, the packets delivery ration becomes more exacerbated which is responsible to maximize the transmission delay and degrades the overall network performance. However, the history-based MAC strategy lowers down the transmission delay in the network considerably as this technique uses the values from the previous successful transmission rather than initiate relevant parameters each time for every transmission. Therefore, the history-based MAC outperforms the existing MAC techniques in IVWSNs. We notice that, Fig. 5, and 6, the collision rate among the packet decreases significantly compared to traditional MAC protocol.

To verify in specifically, we also setup one more experiment to verify the effectiveness of the history-based MAC protocol as shown in Fig. 7. We investigate the performance of double BS for traditional MAC with a single BS of proposed history-based MAC. We notice that the traditional MAC with double BS performs comparable to the single BS of history-based MAC. Generally, the network performance is getting better when more BS are added within the network. But adding more BS in a network causes more complexity of network routing and imposes high installation cost.

From the above discussion, it is clear that the collision and congestion among the packets decrease the network performance significantly. But the history-based MAC strategy is still unable to provide the desirable performance that is completely suit for IoT-IVWSNs. In the consequent section, a priority based MAC protocol is proposed to get reliable performance of the network by avoiding the collision and congestion phenomena.



(a) Traditional case (b) History-based MAC in scenario II

Figure 6: Traditional/original versus History-based MAC for Scenario II.

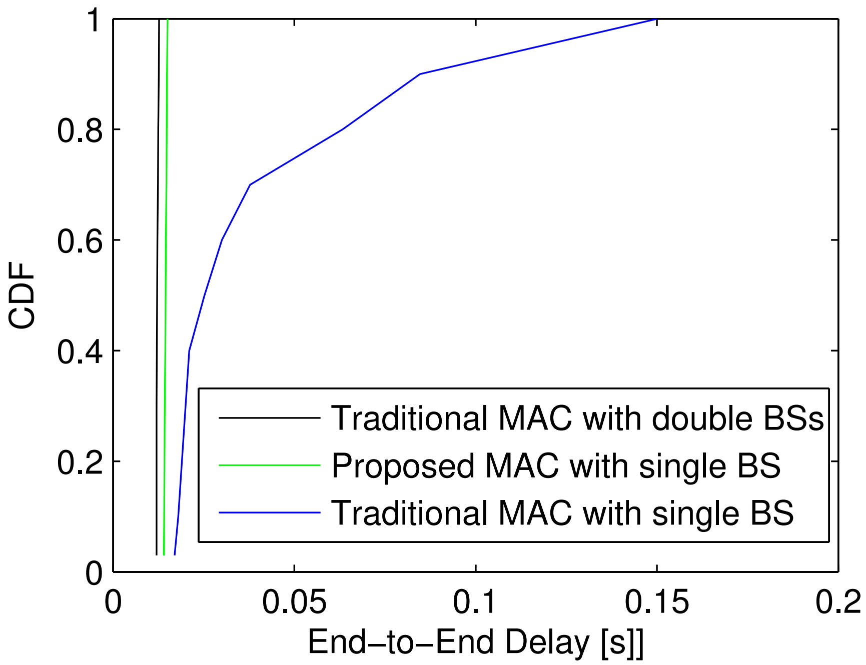
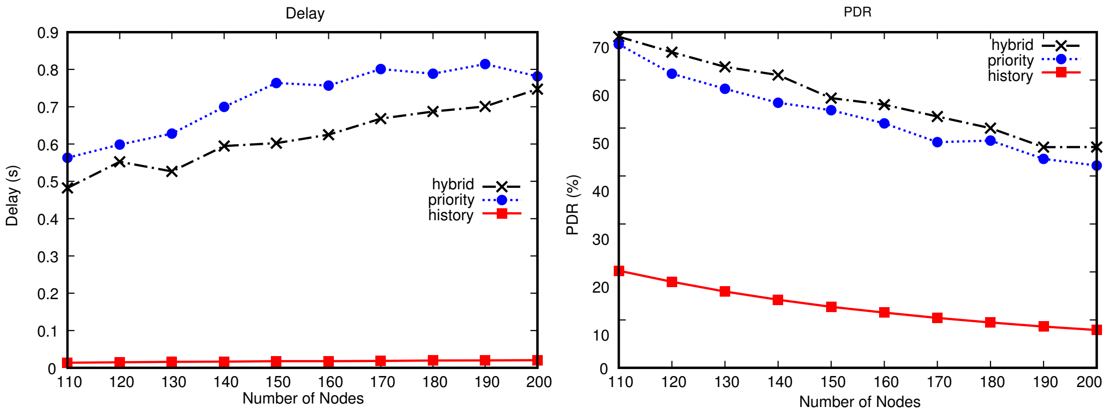


Figure 7: Performance analysis among Proposed (i.e., History-based) MAC, single BS with traditional MAC and double BS with traditional MAC.



(a) Delay (b) PDR

Figure 8: Performance comparison using fixed value of α

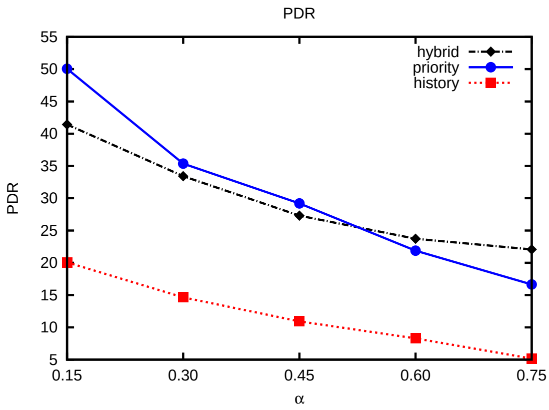
5.2. Comparison among History, Priority and Hybrid

This section will show how well proposed MAC strategy perform under increasing traffic load. To begin with, delay and PDR of three strategies over high-density network are compared. Then, the behavior of the network are changed to see how performance metric of these strategies.

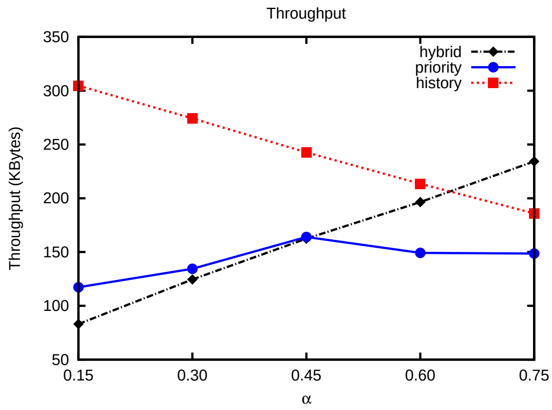
Figure 8 shows how MAC strategies behave under dense network where the vehicular infrastructure has over hundreds of SNs. History-based has the lowest delay and decreasing PDR among other schemes. This is due to the SNB and SBE can reduce transmission time for each node with the trade off to PDR. Meanwhile, Priority produces highest amount of delay and comparable PDR rate to Hybrid under the same condition. The scheduled transmission slot among SNs can maintain good delivery rate inside the network. However, the Hybrid approach outperforms the others MAC protocols.

Figure 9 provides information on how history, priority and hybrid scheme perform in dynamic network condition. Probability of emergency condition, represented by α, has been set variously to see how PDR and Throughput metric are affected. The variable manages the number of nodes enter emergency period which further cause the need to prioritize the packets. It can be seen from these figures that PDR for history scheme are far less than other two schemes. Hybrid strategy has relatively close PDR metric with priority until $\alpha < 0.5$. In such condition, there are half number of SN that are in emergency period and need to be prioritized during packet transmission.

It is worthwhile noticing that the hybrid MAC strategy performs worst in Figure 9(b) when $\alpha < 0.45$. In such a condition, there is less emergency traffic but the algorithm still needs to allocate equal time-slots to all nodes in the case of emergency. This will reduce the number of completed packet transmissions and cause a lower throughput. However, at the end, this strategy performs well whenever there are more emergency traffic. During this situation, the strategy can provide a high transmission rate for fewer normal nodes by using the SBE and SNB while allocating time-slots for the prioritized packet delivery.



(a) PDR (%)



(b) Throughput

Figure 9: Performance comparison using values of α

6. Conclusion

We have presented an improved MAC strategy to address potentially increasing packet collisions due to an expanding quantity of sensor nodes being installed in the IoT-IVSNs. The proposed hybrid MAC scheme has been designed to account for diversifying intra-vehicular sensor data characteristics and comprised of history- and priority-based mechanisms. The history-based technique has been shown to reap the benefit of learning from past contention data for rapidly tuning appropriate network parameters whereas the priority technique could be employed to provide prioritization based on the time-criticality of the sensing data. Our evaluation has demonstrated desirable features of the suggested scheme, exhibiting advantageous performance in the PDR, throughput and transmission delay.

Finally, we note that the scheme has been proposed to address the concerns of CSMA/CA as the original protocol for IEEE 802.15.4 to meet the traffic (normal/emergency) requirements in the IVWSNs. We would anticipate that for a similar MAC protocol (e.g., CSMA/CA) in other wireless standards, a similar conceptual development of the hybrid solution could also be accommodated to tune the required parameters and modify the MAC strategy, depending on the traffic requirement.

References

[1] Azad, S., Rahman, A., Asyhari, A.T., Pathan, A.K., 2017. Crowd associated network: Exploiting over a smart garbage management system. IEEE Communications Magazine 55, 186–192.

[2] Bandyopadhyay, D., Sen, J., 2011. Internet of things: Applications and challenges in technology and standardization. Wireless Personal Communications 58, 49–69.

[3] Berwanger, J., Peller, M., Griessbach, R., 2000. ByteFlight-A New Protocol for Safety Critical Applications, in: FISITA World Automotive Congress.

[4] Blumenstein, J., Mikulasek, T., Prokes, A., Zemen, T., Mecklenbrauker, C., 2015. Intra-vehicular path loss comparison of uwb channel for 3-11 ghz and 55-65 ghz, in: Ubiquitous Wireless Broadband (ICUWB), 2015 IEEE International Conference on, IEEE. pp. 1–4.

[5] Chen, K.C., Lien, S.Y., 2014. Machine-to-machine communications: Technologies and challenges. Ad Hoc Networks 18, 3–23.

[6] Da Xu, L., He, W., Li, S., 2014. Internet of things in industries: A survey. IEEE Transactions on industrial informatics 10, 2233–2243.

[7] Di Francesco, M., Anastasi, G., Conti, M., Das, S.K., Neri, V., 2011. Reliability and energy-efficiency in ieee 802.15. 4/zigbee sensor networks: an adaptive and cross-layer approach. IEEE Journal on selected areas in communications 29, 1508–1524.

[8] Gubbi, J., Buyya, R., Marusic, S., Palaniswami, M., 2013. Internet of things (iot): A vision, architectural elements, and future directions. Future generation computer systems 29, 1645–1660.

[9] Han, D.M., Lim, J.H., 2010. Smart home energy management system using ieee 802.15. 4 and zigbee. IEEE Transactions on Consumer Electronics 56.

[10] Hanzálek, Z., Jurcik, P., 2010. Energy efficient scheduling for cluster-tree wireless sensor networks with time-bounded data flows: Application to ieee 802.15. 4/zigbee. IEEE Transactions on Industrial Informatics 6, 438–450.

[11] Hashemi, M., Si, W., Laifenfeld, M., Starobinski, D., Trachtenberg, A., 2013. Intra-car wireless sensors data collection: A multi-hop approach, in: Vehicular Technology Conference (VTC Spring), 2013 IEEE 77th, IEEE. pp. 1–5.

[12] Hiep, P.T., 2014. Statistical method for performance analysis of wban in time-saturation. EURASIP Journal on Wireless Communications and Networking 2014, 221.

[13] Iturri, P.L., Aguirre, E., Azpilicueta, L., Garate, U., Falcone, F., 2014. Zigbee radio channel analysis in a complex vehicular environment [wireless corner]. IEEE Antennas and Propagation Magazine 56, 232–245.

[14] Jiang, L., Shah, D., Shin, J., Walrand, J., 2010. Distributed random access algorithm: scheduling and congestion control. IEEE Transactions on Information Theory 56, 6182–6207.

[15] Jin, Y., Kwak, D., Kwak, K.S., 2012. Performance analysis of intra-vehicle ultra-wide band propagation in multi-user environments, in: Vehicular Communications, Sensing, and Computing (VCSC), 2012 IEEE 1st International Workshop on, IEEE. pp. 1–4.

[16] Johansson, K.H., Törngren, M., Nielsen, L., 2005. Vehicle Applications of Controller Area Network, in: Handbook of Networked and Embedded Control Systems. Birkhäuser Boston, Boston, MA, pp. 741–765.

[17] Kurniawan, I.F., Rahman, M.A., Asyhari, A.T., Bhuiyan, M.Z.A., 2018. Performance evaluation of history-based and priority-based mac for traffic-differentiated intra-vehicular network, in: 2018 IEEE 16th Intl Conf on Dependable, Autonomic and Secure Computing, 16th Intl Conf on Pervasive Intelligence and Computing, 4th Intl Conf on Big Data Intelligence and Computing and Cyber Science and Technology Congress(DASC/PiCom/DataCom/CyberSciTech), pp. 689–694.

[18] Lin, J.R., Talty, T., Tonguz, O.K., 2015a. A blind zone alert system based on intra-vehicular wireless sensor networks. IEEE Transactions on Industrial Informatics 11, 476–484.

[19] Lin, J.R., Talty, T., Tonguz, O.K., 2015b. On the potential of bluetooth low energy technology for vehicular applications. IEEE Communications Magazine 53, 267–275.

[20] Liyanage, M., Kumar, P., Soderi, S., Ylianttila, M., Gurtov, A., 2016. Performance and security evaluation of intra-vehicular communication architecture, in: 2016 IEEE International Conference on Communications Workshops (ICC), IEEE. pp. 302–308.

[21] Lynch, K.M., Marchuk, N., Elwin, M.L., 2016. Controller Area Network (CAN), in: Embedded Computing and Mechatronics with the PIC32. Elsevier, pp. 249–265.

[22] Lyu, Y., Yin, P., 2020. Internet of things transmission and network reliability in complex environment. Computer Communications 150, 757 – 763.

[23] Mirza, N., Khan, A.N., 2017. Bluetooth low energy based communication framework for intra vehicle wireless sensor networks, in: 2017 International Conference on Frontiers of Information Technology (FIT), IEEE. pp. 29–34.

[24] Nour, B., Sharif, K., Li, F., Biswas, S., Moungla, H., Guizani, M., Wang, Y., 2019. A survey of internet of things communication using icn: A use case perspective. Computer Communications 142-143, 95 –

123.
[25] Paret, D., 2012. The FlexRay Protocol, in: Flexray and its Applications. John Wiley & Sons, Ltd, Chichester, UK, pp. 41–76.
[26] Park, P., Di Marco, P., Fischione, C., Johansson, K.H., 2013. Modeling and optimization of the ieee 802.15. 4 protocol for reliable and timely communications. IEEE Transactions on Parallel and Distributed Systems 24, 550–564.
[27] Qu, F., Wang, F.Y., Yang, L., 2010. Intelligent transportation spaces: vehicles, traffic, communications, and beyond. IEEE Communications Magazine 48.
[28] Rahim, M.A., Rahman, M.A., Rahman, M.M., Asyhari, A.T., Bhuiyan, M.Z.A., Ramasamy, D., 2019. Evolution of iot-enabled connectivity and applications in automobile industry: A review. Submitted to Vehicular Communications (Elsevier) .
[29] Rahman, M.A., 2014a. Design of wireless sensor network for intra-vehicular communications, in: International Conference on Wired/Wireless Internet Communications, Springer. pp. 29–40.
[30] Rahman, M.A., 2014b. Reliability analysis of zigbee based intra-vehicle wireless sensor networks., in: Nets4Cars/Nets4Trains/Nets4Aircraft, pp. 103–112.
[31] Rahman, M.A., Ali, J., Kabir*, M.N., Azad, S., 2017. A performance investigation on iot enabled intra-vehicular wireless sensor networks. International Journal of Automotive and Mechanical Engineering 14, 2809.
[32] Rahman, M.A., Asyhari, A.T., 2019. The emergence of internet of things (iot): Connecting anything, anywhere. Computers 8.
[33] Rahman, M.A., Kabir, M.N., Azad, S., Ali, J., 2015. On mitigating hop-to-hop congestion problem in iot enabled intra-vehicular communication, in: Software Engineering and Computer Systems (ICSECS), 2015 4th International Conference on, IEEE. pp. 213–217.
[34] Sergiou, C., Antoniou, P., Vassiliou, V., 2014. A comprehensive survey of congestion control protocols in wireless sensor networks. IEEE Communications Surveys & Tutorials 16, 1839–1859.
[35] Sitanayah, L., Sreenan, C.J., Brown, K.N., 2014. A hybrid mac protocol for emergency response wireless sensor networks. Ad Hoc Networks 20, 77–95.
[36] Toscano, E., Bello, L.L., 2012. Multichannel superframe scheduling for ieee 802.15. 4 industrial wireless sensor networks. IEEE Transactions on Industrial Informatics 8, 337–350.
[37] Tuohy, S., Glavin, M., Hughes, C., Jones, E., Trivedi, M., Kilmartin, L., 2015. Intra-vehicle networks: A review. IEEE Transactions on Intelligent Transportation Systems 16, 534–545.