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Original Article

Roadside Unit Transmission Control for Energy Efficiency in Vehicle-to-Infrastructure Communication Network

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Abstract *- In recent years, intelligent transportation systems (ITS) have improved road safety. This has led to new communication systems such as vehicle-to-infrastructure (V2I) and vehicle-to-vehicle. This technology has attracted the attention of many researchers due to its deployment cost and energy efficiency challenges. Roadside units (RSUs) powered by renewable energy are mainly concerned with energy efficiency because of the intermittency of renewable energy resources. This paper proposes a solution for energy efficiency in the V2I network to minimize the energy consumption of RSUs deployed in an urban area. The problem has been formulated as an RSU transmission control problem based on the traffic flow at road intersections. This method is compared with the traditional RSU transmission mode, and the study is conducted in two phases. The first phase is to model a section of the road network of Nairobi using OpenStreetMap and SUMO. The second phase is to define and validate the solution's effectiveness in terms of connectivity, energy consumption, packet delivery ratio (PDR), and average downlink end-to-end delay. The results show that the proposed solution is energy efficient for small and large packets and has good communication performance.*

Keywords *- Basic Safety Message, Energy Consumption, Road Safety, Roadside unit, Vehicle-to-Infrastructure.*

1. Introduction

Over the past few years, the population of vehicles has increased, and it keeps increasing substantially, as the total number of accidents worldwide. According to the world health organization (WHO), the number of people who die in road accidents every year is evaluated at 1.35 million people, and injury affects 20 to 50 million people [1]. Most road accident analyses revealed that 90% of road collisions are caused by human hazards [2]. Many solutions have been proposed for road safety improvement. One of these solutions is the introduction of autonomous vehicles (AVs) to reduce human errors in road accidents [3]. AVs are dedicated to collecting information about their surrounding environment to drive safely. They use different information acquisition systems like Vehicle-to-Vehicle (V2V) [4] and vehicle-to-infrastructure (V2I) systems [5]. These two systems are included in the vehicular ad hoc network (VANET), which is the main part of intelligent transportation systems (ITS) [6]. V2I communication enables exchanges of safety/real-time warning messages between roadside units (RSUs) and vehicles [7]. The information recorded from vehicles by RSUs is the vehicle's speed, the vehicle position, the travel times, and the traffic flow, amongst others [8]. An RSU is a piece of wireless equipment similar to a base station that uses the dedicated short-range communication (DSRC) technology defined under the IEEE 802.11p standard [9] with an operating frequency of 5.9 GHz [10] [11].

V2I communication system has numerous benefits in applications, road safety, traffic management, and communication [12]. One of the motivations of V2I communication is to reduce congestion and injuries related to traffic accidents [13] [14]. This is achieved by improving traffic management [15] and delivering suitable traffic information to vehicles to guarantee safe driving [16]. V2I communication is also used to maximize the fuel-saving of AVs by determining their position and motion through traffic information in real-time [17]. Furthermore, a cognitive vehicular network has been proposed in [18] to improve the dissemination of vehicular safety messages. In [19], a new technique was proposed to ensure the outcomes of file transfer between vehicles and RSUs.

Moreover, several routing protocols have been proposed for V2I communication. In [20], for example, the authors developed an improved genetic algorithm technique

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to address the issue of determining the most reliable communication route in a V2I communication system. In [21], a hybrid routing protocol for VANETs was proposed by assembling DSRC technology and long-term evolution (LTE). That notwithstanding, V2I communication faces some challenges regarding network security [22], energy consumption [23], and frequent interruption of established connections due to the dynamic changes of the network topology, that increase the complexity of designing an accurate routing protocol [24].

A lot of research has been conducted and is still ongoing in vehicular networks because it is hoped that the development of this field can drastically reduce the number of road accidents and help in other domains. Nevertheless, vehicular network faces the issue of energy consumption which has been the research interest of some researchers, especially as RSUs are beginning to be powered by renewable energy systems such as solar. Knowing the intermittency of solar energy, minimizing the energy consumption of RSUs has been of prime importance to utilize renewable energy systems to power this technology fully and make them grid-independent. In [25], the authors proposed a solution to maximize the energy efficiency of parked cars that serve as RSUs in an urban area. They assumed that parked cars are not completely powered off, and the battery's remaining energy could be used to enable them to serve as RSUs. The authors achieved good results by considering the channel resource allocation and the transmission power control. In [26], the authors proposed a mechanism based on real-time energy-saving for the internet of vehicle systems. They assumed that multiple RSUs are deployed on a road section and must be continuously assigned and reassigned to the vehicles. Their problem was formulated as an uncapacitated facility location problem to manage the RSUs switch-on and off phases. It was proved that; this method is more effective than the static approaches listed in the latter paper. In [27], the authors proposed a multi-level greedy algorithm to solve the RSU on-off scheduling problem and found a better time slot allocation scheme in sparse VANET by considering a bidirectional vehicular traffic scenario. The proposed algorithm gave good results in terms of energy consumption and could be used as a reference in VANET for efficient scheduling.

In [28], the authors proposed two approaches to mitigate the issue of energy consumption by RSUs and enable a uniform energy consumption across neighboring RSUs. They considered that RSUs are deployed in rural areas and are powered by renewable energy. This research was based on the fact that no RSU should be over-utilized while others are under-utilized. The results showed that these approaches were 10% more efficient than single RSU scheduling algorithms such as the nearest faster-set scheduler. In [29], it was also considered that RSUs are powered by renewable energy and investigated the challenge of scheduling the downlink communication from RSUs towards vehicles. The problem was considered in two settings to maximize the number of served vehicles. The first setting was an offline setting where RSUs are assumed to know the amount of energy to be harvested based on the advanced knowledge of the incoming requests from vehicles, and the second was an online setting where two different solutions were investigated. The first one considers distributed scheduling control between RSUs, and the second one considers centralized scheduling control. In [30], the authors studied the deployment of uncrewed aerial vehicles as flying RSUs (UAV-RSU) based on the energy-efficient of providing V2I links in a region. They also proposed a communication problem that aimed at minimizing the total power consumption of both communication powers and hovering. Other parameters, such as average packet size, backhaul link load, and latency, were also considered. The results revealed that the UAV-RSU height and the average packet size were the major performance indicators for this network. In addition, other research works related to the energy consumption of V2I communication systems have been conducted based on different aspects such as RSU handover [31] and V2I routing protocol [20]. The above-related works mainly focus on the on/off RSU scheduling algorithms. Some of the limitations of these algorithms include; that when the RSUs are constantly switched off, they might take a certain time before they are completely switched on when needed. Also, the dynamic vehicle speed can make the on/off scheduling algorithms very complex in terms of design and implementation. UAV-RSUs also have the constraint of energy because their energy consumption depends not only on network parameters but also on the fact that they are mobile.

Therefore, the work presented in this paper focuses on the energy consumption of static RSUs in a V2I communication system deployed in a section of Nairobi, Kenya. This research assumes that RSUs exchange Basic Safety Messages (BSM) with vehicles within their coverage range and are deployed at road intersections. All the vehicles are autonomous and can communicate with each other. The energy consumption of each vehicle is not considered in this work but will be taken into account in the future scope of this research. The contributions to this paper to the body of knowledge are:

- The use of an effective RSU transmission control to minimize the total energy consumption of RSUs deployed in an urban area.
- A new parameter, traffic flow, is used to calculate the packet delivery ratio (PDR) of each RSU in a broadcast scenario.

The rest of the paper is structured as follows; Section 2 describes the methodology, and section 3 discusses the solution's results and discussion. At the end of the paper, there is a conclusion.

2. Methodology

In this paper, two packet sizes are considered for simulation to analyze the effectiveness of the proposed model based on the energy consumption of RSUs, their connectivity, the packet delivery ratio, and the average downlink end-to-end delay. These packet sizes are 200 bytes and 1024 bytes taken as short and long packets.

2.1. Road modeling

Nairobi is the capital city of Kenya, and it is classified as one of the most populated cities in East Africa. Its population was estimated to be 4.5 million in 2017 [32]. Currently, the city is updating its road infrastructure with the construction of roads and the deployment of new systems such as digital traffic lights, among others [33]. In this research, the Kilimani-Hurlingham (a section of Nairobi) road network is the study area since it has been revealed that most of the accidents in this area occur at road intersections or some few meters away [34]. This section has an area of 19446130.67 m^2 and about 20 hospitals, 10 schools, a few churches, and mosques which are places of high inflow of people. Therefore, road safety measures need to be applied in that road section.

Different steps are used to model the study area. These steps are illustrated in Fig. 1. The first step is to use OSMnx, a python package, to retrieve geospatial data from OpenStreetMap, project, visualize, and analyze road networks [35]. OSMnx helped identify and count the number of road intersections present on the map. Fig. 2(a) shows the map of the Kilimani-Hurlingham road network, the study area. A total of 940 road intersections coordinates were counted on the map. Fig. 2(b) represents all the road intersections present on this road section in blue. The next step is to use the OSMWebWizard tool to generate traffic flow for the given area. This traffic comprises cars and buses commonly called Matatu in Kenya. Their mobility is simulated in SUMO (Simulation for Urban MObility) as shown in Fig. 3 and saved as a Tcl file for V2I network simulation.

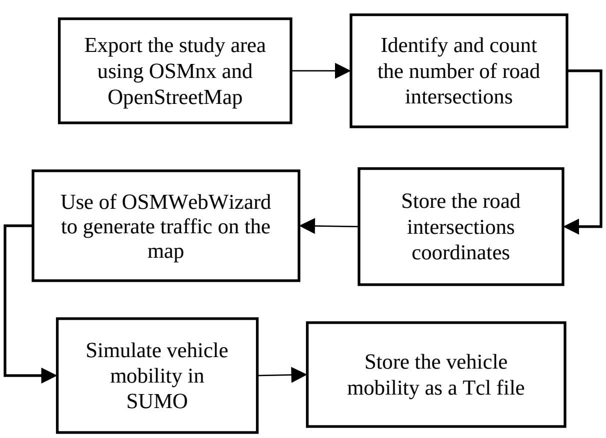
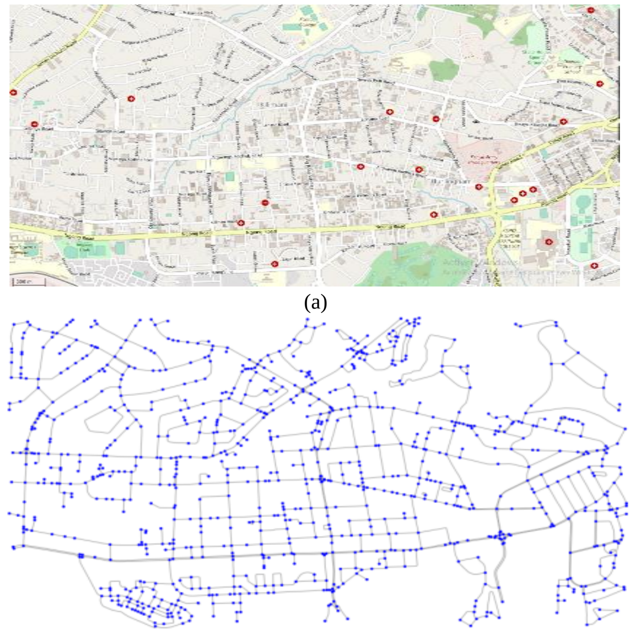


Fig. 1 Road modeling.



(a)

(b)

Fig. 2 Kilimani-Hurlingham road network. (a) OpenStreetMap road network view. (b) Representation of road intersections.

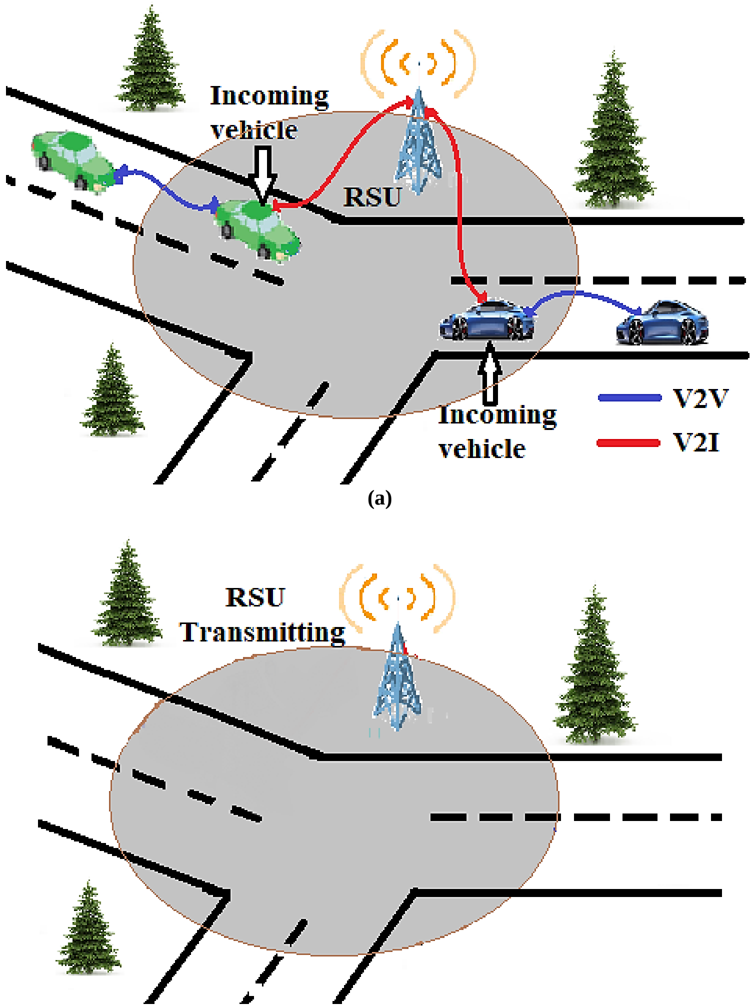
Fig. 3 Traffic simulation of Kilimani-Hurlingham road network in SUMO

2.2. Traditional RSU transmission mode

In the traditional RSU transmission mode, RSUs broadcast information every 100ms in its coverage range whether they have detected vehicles. The number of packets broadcasted by each RSU is equal for all the RSUs in the network. For a given time of simulation t, the total number of packets broadcast by each RSU is t divided by 100ms. In this study, t = 301s, the number of packets per RSU is 3010. Fig. 4 describes the scenario.

2.3. The proposed RSU transmission control

In the road modeling step, 940 road intersections coordinates were retrieved from the map. Out of this number, 590 intersections are chosen to deploy RSUs based on the total number of vehicles an RSU can detect during the simulation. A first simulation was done, and the 590 intersections represent the positions where an RSU can detect at least 5 vehicles during the simulation. The main



(a)

(b)

Fig. 4 Roadside unit without transmission control. (a) Roadside unit broadcasting with vehicles in its coverage range. (b) Roadside unit broadcasting without vehicles in its coverage range.

This part aims to propose a novel operation mode for RSUs to minimize their energy consumption, then analyze the communication parameters like connectivity, PDR, and average downlink end-to-end delay. The simulation of V2I communication is done using network simulator 3 (NS3) with the configuration parameters presented in Table 1.

2.3.1. Description of the proposed model

At the beginning of the simulation, all the RSUs are in idle mode. In NS3, a vehicle starts broadcasting every 100ms BSM message when it enters the network and stops when it exits the network. The entering and the exit time of vehicles in the network are read in the mobility tcl file. On the other hand, an RSU, instead of broadcasting BSM messages every 100ms, will only broadcast information depending on whether there is an incoming vehicle in its coverage range. Fig. 5 describes the scenario.

Table 1. Simulation parameters

Parameter	Value
Short packet size	200 bytes
Long packet size	1024 bytes
Transmission power	23 dBm
Sensitivity	-82 dBm
Vehicle Broadcast interval	100 ms
Bandwidth	10 MHz
Data rate	6 Mbps
Frequency	5.9 GHz
RSU antenna height	8 m
vehicle antenna height	1.5 m
RSU supply voltage	48 Volt
Transmission current	0.5 A
Current in receiving state	0.313 A
Current in idle state	0.273 A
Number of RSU	590
Number of vehicles	461
Simulation time	301 seconds

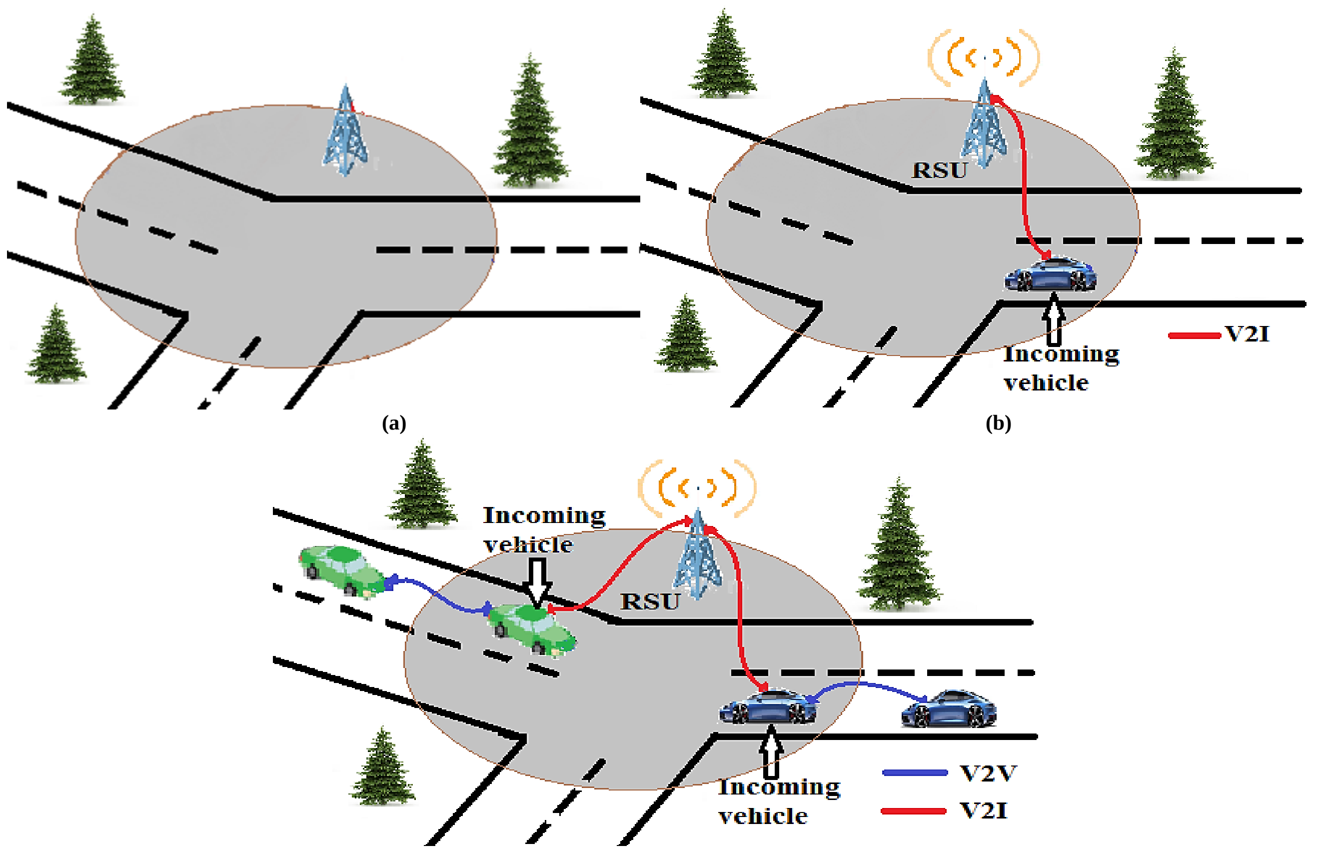


Fig. 5 Transmission control of the roadside unit at an intersection. (a) Roadside unit on idle mode. (b) The roadside unit broadcasts once a message to the incoming vehicle. (c) The roadside unit broadcasts twice for the two incoming vehicles.

In the simulation, the set of RSUs is denoted as $S_{RSU}=\{RSU\_1,....., RSU\_n\}$ and each RSU is denoted as RSU_i where n is equal to 590 and i = {1, 2, …., n}. This work assumes that each RSU can detect the presence of a vehicle only if it receives a message from the vehicle which explains the vehicle's presence in the RSU coverage range. The packets broadcast by each vehicle in the network contain the vehicle identification number (Id), its position (coordinates), its velocity, the packet's time, and a payload of 200 bytes for short packets and 1024 bytes for long packets. The first action computed by the RSU when it receives a packet from a vehicle is to store the packet information in a database if the vehicle Id is not yet present in that database. Then the RSU broadcasts information within its coverage. In case the vehicle Id is already registered in the RSU database, the RSU will compare the vehicle's last connection time with the new connection time, and if the difference is equal or more than one minute, the RSU will broadcast information; if not, the RSU will update the last connection time with the vehicle and no information will be broadcasted. This RSU mode of transmission considers that if a vehicle passes through an RSU coverage range more than one time during the simulation, it will still be able to receive new information from the RSU. The summary of the RSU transmission control steps is given in Algorithm 1.

Algorithm 1: RSU Transmission Control

```
Initialize each RSU_i database T as an empty database.
RSU_i on reception mode
While simulation time = TRUE and RSU_i detects a
vehicle presence do
    check if the vehicle Id is in T
    if the vehicle Id is not in T, then
        Add the information about the vehicle to T
        // Id_number, velocity, position
        //time of the first connection
        // time of the last connection
        RSU_i broadcast BSM messages
    end if
    if the vehicle Id is in T, then
      time = packet reception time - last connection
time
      if time >= 1minute then
          RSU_i broadcast BSM messages
      end if
      update the vehicle's last connection time
    end if
end while
```

2.3.2. Mathematical expression of parameters

Four parameters are evaluated in this work. The first parameter is the RSU connectivity which is the total number of vehicles detected by the RSU during the simulation. This value is computed by counting the number of vehicle Ids present in the database *T* of each RSU.

The second parameter is the energy consumption of RSUs, which is a function of the power supply, time, and current. Its expressions are given by Equations 1, 2, and 3.

$$Ec_t(Joule) = I_t \times V \times t \quad (1)$$

$$E_t(Joule) = E_0 - Ec_t \quad (2)$$

$$Ec_{Total}(Joule) = \sum_{t=1}^{K} (Ec_t) \quad (3)$$

where Ec_t is the RSU energy consumption at a given time *t* depending on whether the RSU is transmitting, receiving, or is in idle mode; I_t is the RSU current used at a given time *t* depending on whether the RSU is transmitting, receiving, or is in idle mode; *V* is the RSU supply voltage; *t* is the time taken during the transmission, reception, or idle mode; E_t is the RSU remaining energy; E_0 is the RSU initial energy; Ec_{Total} is the RSU total energy consumption. The RSU energy consumption algorithm steps are illustrated in Algorithm 2. The energy consumption is frequently calculated during the simulation depending on whether it is transmitting, receiving, or idle. Then, the total energy is calculated and saved for further analysis at the end of the simulation. During the simulation, the remaining energy in the RSU is always evaluated after transmission, reception, or idleness. Et denotes this remaining energy, and its value replaces the initial energy during the simulation. Moreover, three other parameters, Ec_{tx}, Ec_{rx}, *and* Ec_{idle}, represent the energy consumption after transmission, the energy consumption after the reception, and the energy consumption after idle mode.

The third parameter is the PDR, representing the ratio of the number of packets received over the number of packets sent. In this study, this parameter was calculated considering the broadcast scenario. The assumption is that a packet sent by an RSU is successfully received if all the vehicles present in the RSU coverage range have successfully received the packet at the transmission time. In other words, if a packet was sent when two vehicles, for example, were present in the RSU coverage, the PDR for that packet will be 100% if the two vehicles had received the packet; 50% if only one vehicle had received the packet; and 0% if none of them had received the packet. The PDR is determined as follows:

$$PDR(\%) = \frac{R_{packet}}{S_{packet}} \times \frac{VR}{V_{present}} \times 100 \quad (4)$$

Where *R_packet* is the number of packets received; *S_packet* is the number of packets sent; *VR* is the number of vehicles that received the packet; *V_present* is the number of vehicles present in the coverage range.

The fourth parameter is the average downlink end-to-end delay *Avg_delay*, representing the average time for all the packets to live the RSU and reach the vehicles. Its expression is given by Equations 5 and 6.

$$delay(seconds) = Rx\_time - Tx\_time \quad (5)$$

$$Avg\_delay(seconds) = \frac{\Sigma\, delay}{k} \quad (6)$$

where *the delay* is the duration for a packet to live an RSU and reach the vehicle; *Rx_time* is the reception time of the packet; *Tx_time* is the packet's transmission time, and *k* is the number of delays for an RSU.

The summary of the proposed solution is presented in the flowchart (see Figure 6).

Algorithm 2: RSU energy consumption evaluation

Inputs: RSU initial energy E_0, supply voltage *V*,
transmission current T_{Tx}, receiving current I_{Rx}, idle
current I_{idle}
initialize Ec_{tx}, Ec_{rx}, Ec_{idle}, E_t and Ec_{Total}
While simulation time valid **do**
    if *RSU_i* is transmitting **then**
        $Ec_{tx} = I_{Tx} \times V \times t$
        $E_t = E_0 - Ec_{tx}$
        $E_0 = E_t$
        save Ec_{tx}
    end if
    if *RSU_i* is receiving **then**
        $Ec_{rx} = I_{Rx} \times V \times t$
        $E_t = E_0 - Ec_{rx}$
        $E_0 = E_t$
        save Ec_{rx}
    end if
    if *RSU_i* is idle **then**
        $Ec_{idle} = I_{idle} \times V \times t$
        $E_t = E_0 - Ec_{idle}$
        $E_0 = E_t$
        save Ec_{idle}
    end if
end while
// calculate the total energy consumption
$Ec_{Total} = \Sigma\, Ec_{tx} + \Sigma\, Ec_{rx} + \Sigma\, Ec_{idle}$
Save Ec_{Total}

3. Results and Discussion

The simulation results of the proposed RSU transmission control are shown in this section.

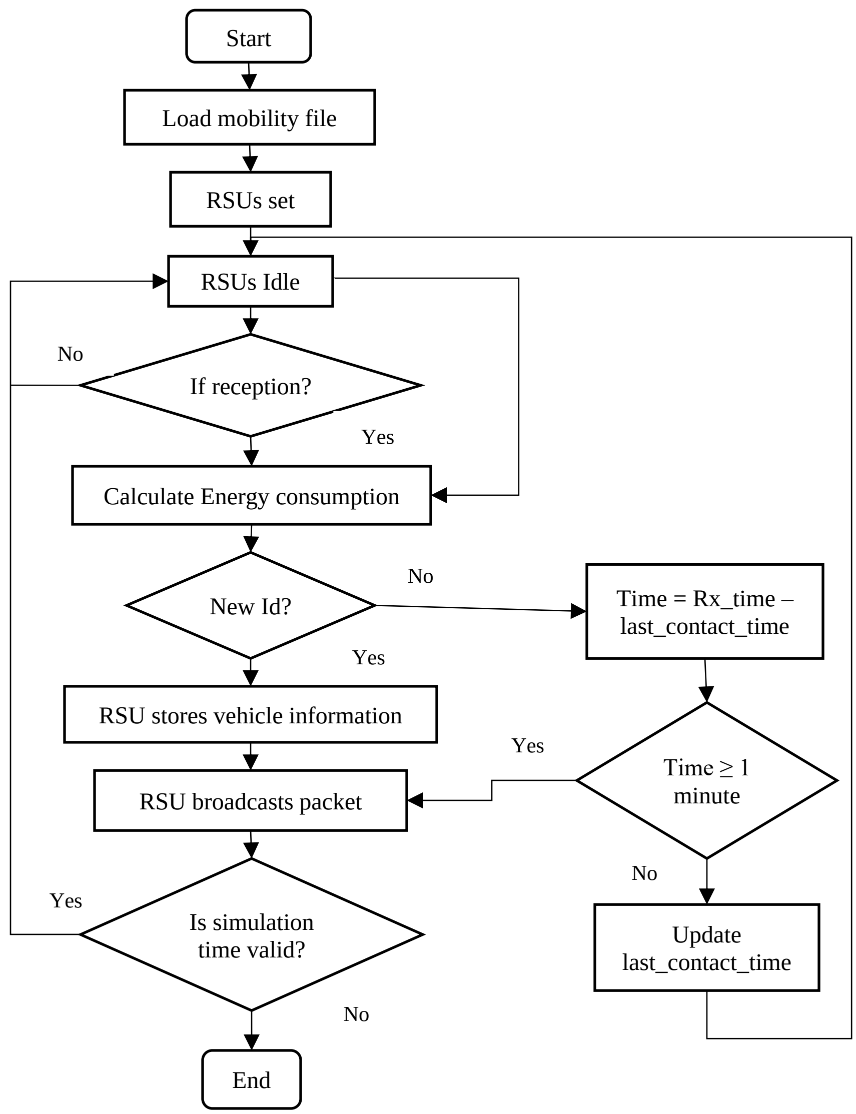


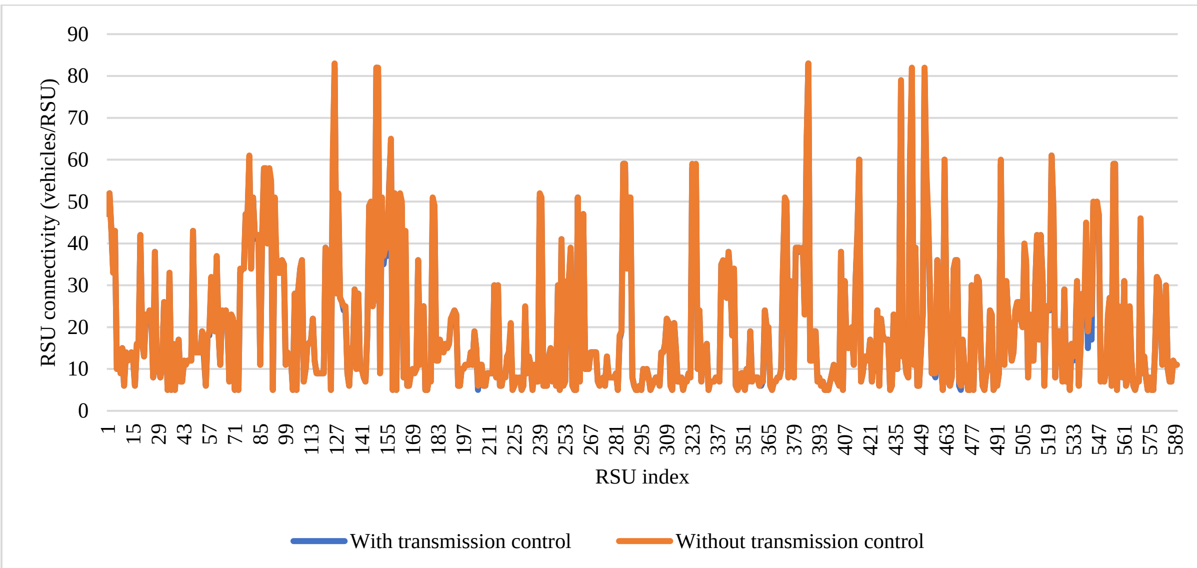
Fig. 6 Proposed solution flowchart

3.1. RSU Connectivity

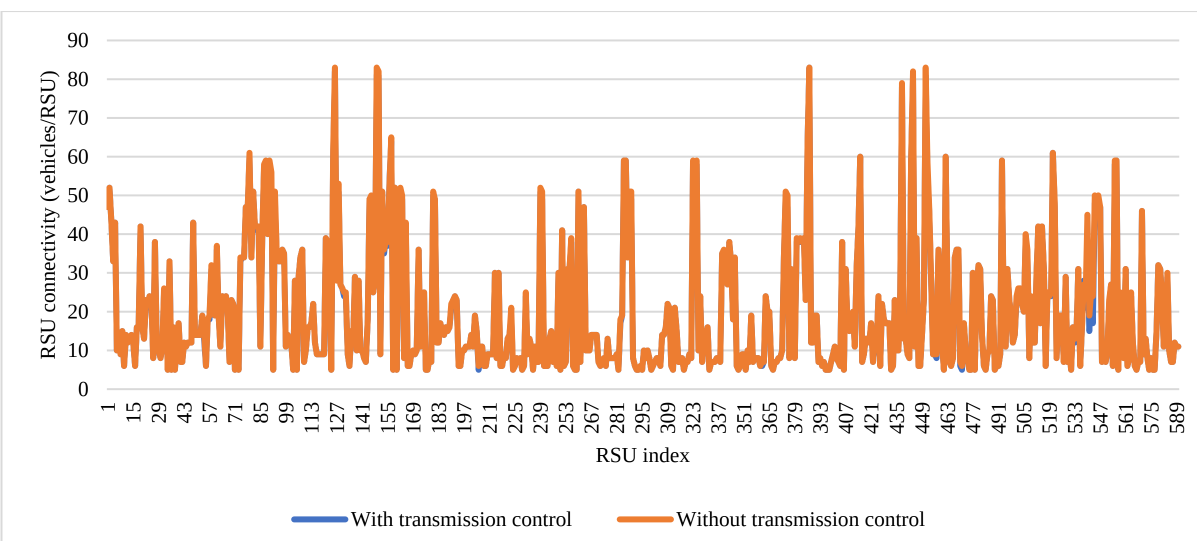
This parameter represents the number of vehicles detected by each RSU during the simulation. Figure 7 presents the connectivity of each RSU in both cases for short packets (see Figure 7(a)) and long packets (see Figure 7(b)), and the result shows that the connectivity is the same. Nevertheless, some RSUs have lower connectivity when using the proposed model. In this case, the reason could be that the RSU does not receive and transmit simultaneously; packet collision might have occurred during the transmission of packets by the RSU.

3.2. Energy Consumption of RSUs

Energy consumption was analyzed critically in this work for the 590 RSUs. Figures 8 and 9 present a comparative result between energy consumption with the proposed transmission control and the energy consumption without the transmission control. For short packets (see Figure 8(a)) and long packets (see Figure 8(b)), it is observed that the energy consumed by each RSU is lower for the two types of packets when it operates as per the proposed mode of operation. The amount of energy consumed by an RSU depends on the number of vehicles that pass through its coverage range and whose BSM message has successfully reached the RSU to actuate data transmission. It also depends on the number of packets received by the RSU and its moments of idleness. Each case has it is current, as shown in table 1, and the time used for calculations is variable as the simulation goes by. For an urban deployment of 590 RSUs in the Kilimani-Hurlingham road section, Figure 9 shows that the amount of energy saved using the proposed method is 1225.27 Joules in 301 seconds of simulation for short packets which means that for a simulation of one hour, the amount of energy saved could be 14654.4 Joules. For 24 hours, it could be estimated to be 351705.41 Joules. Likewise, for long packets, the energy saved is 5079.38 Joules in 301 seconds of simulation, which leads to an estimation of energy saving of 1458001.44 Joules for 24 hours. This is a lot of energy saved for urban usage. Nevertheless, in Figures 8(a) and 8(b), some RSUs have a bit higher energy consumption with the transmission control than without transmission control. This could be due to the variation in the number of packets received by the RSU and the amount of time it was in idle mode. For some RSUs, the number of packets received when using the proposed transmission control is larger than that received when there is no transmission control. This situation could be due to collisions between broadcasted packets by the RSU and the vehicles in the case of no transmission control. In addition, the energy consumption for long packets is higher than the energy consumption for short packets in both cases because radio energy is a function of time and the transmission time of a packet depends on its size. The more it is large, the more its transmission time increases. Also, the results show that energy saving is more significant for long packets than for short packets (see Figure 9).

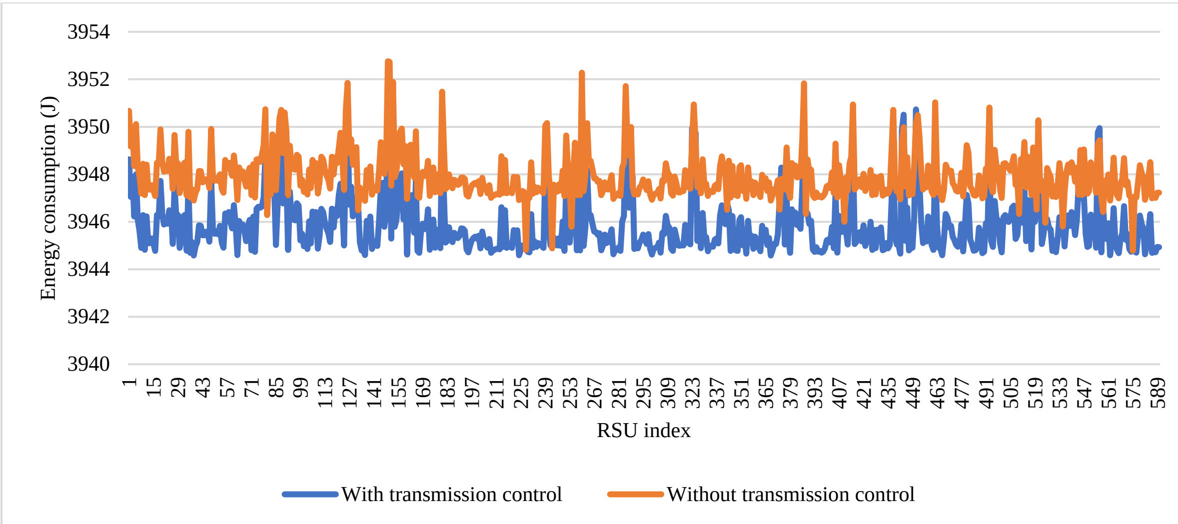


(a)

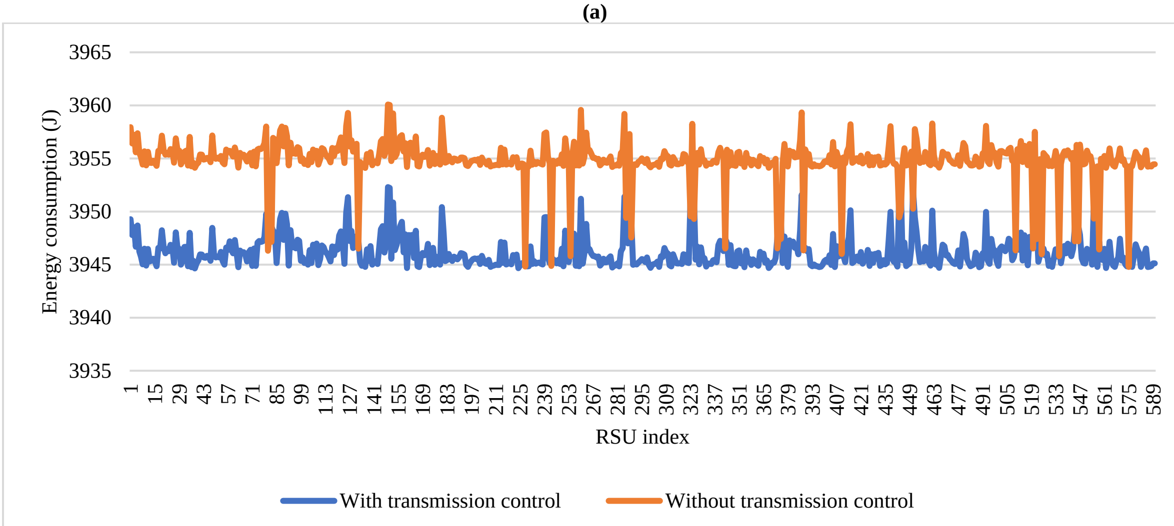


(b)

Fig. 7 RSU connectivity. (a) 200 bytes packet size. (b) 1024 bytes packet size.



(a)



(b)

Fig. 8 Energy consumption of each RSU with and without transmission control. (a) 200 bytes packet size. (b) 1024 bytes packet size.

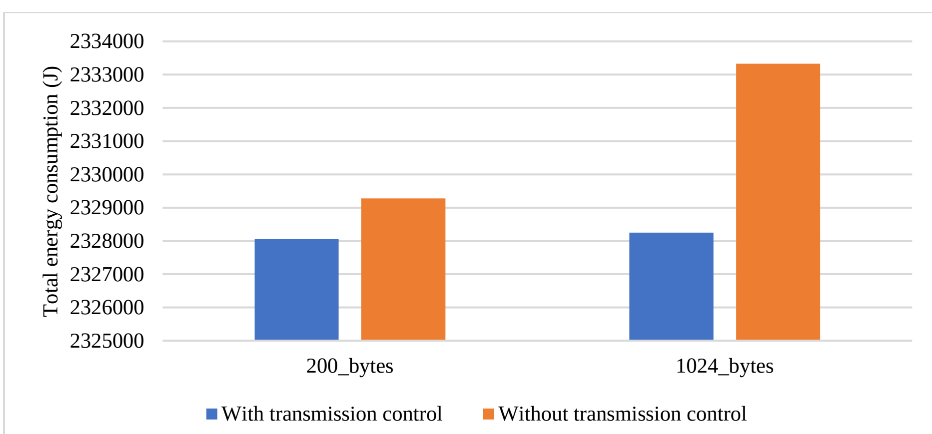
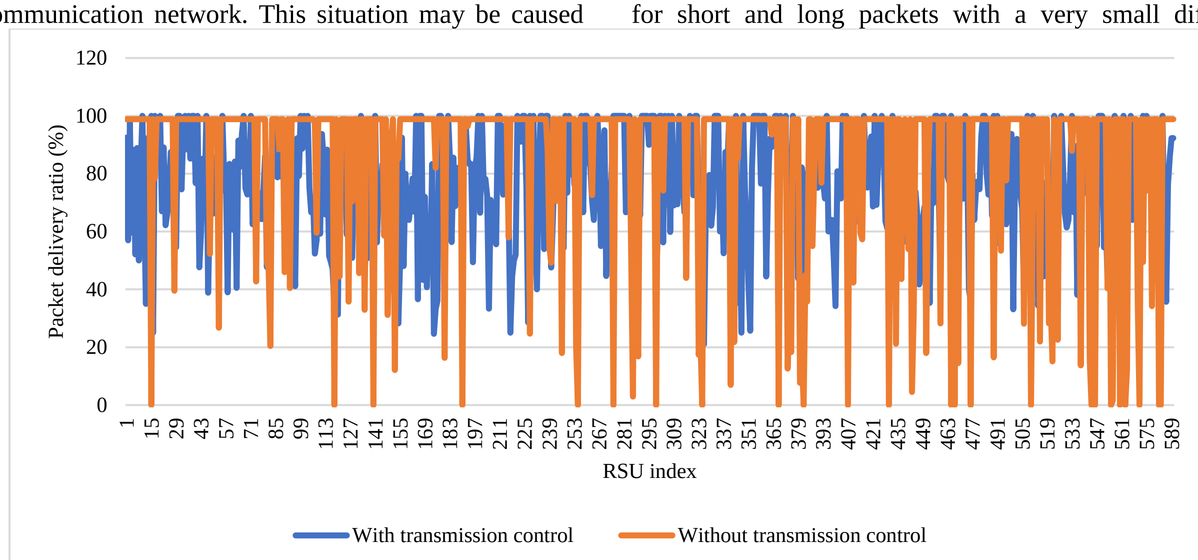


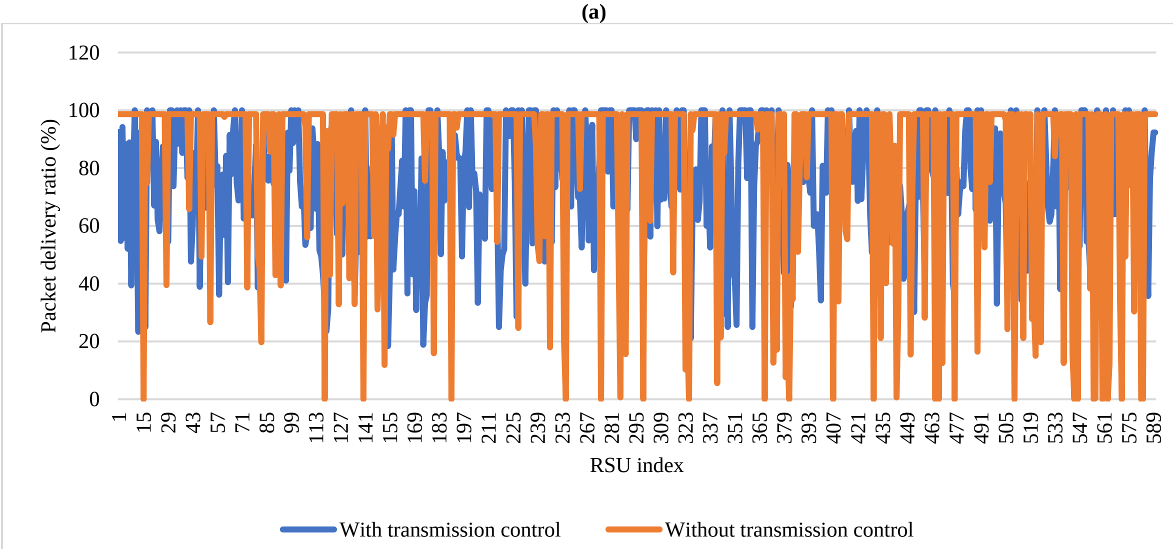
Fig. 9 Total energy consumption with and without transmission control for all the RSUs.

3.3. Packet Delivery Ratio (PDR)

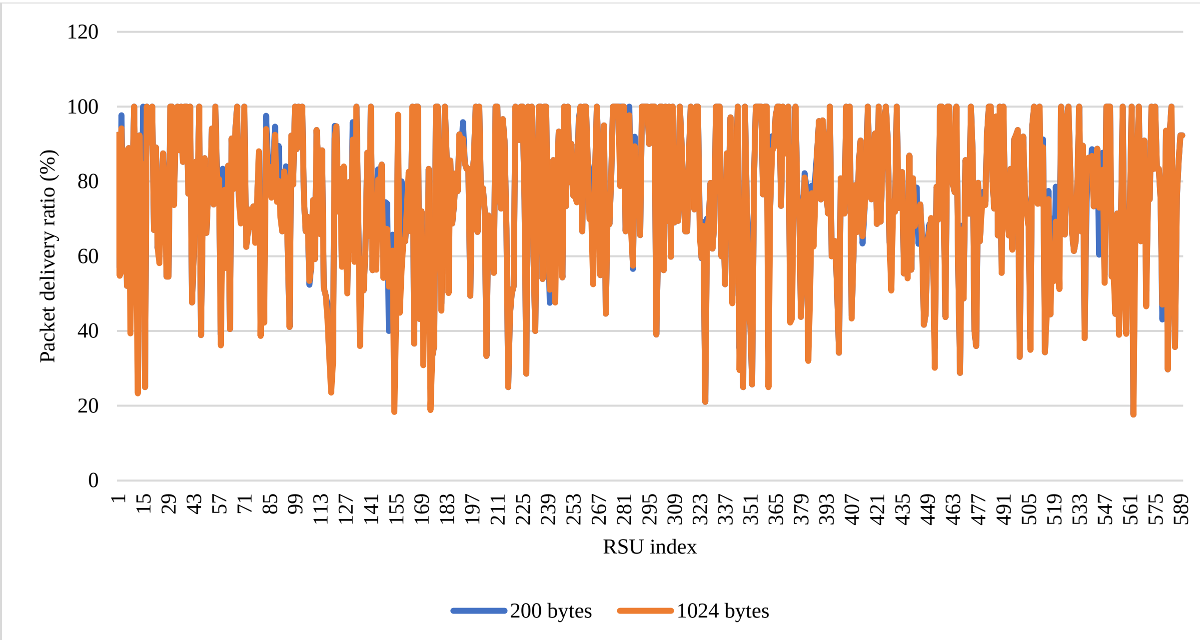
The third parameter evaluated in this study is the PDR. Figures 10(a) and 10(b) show the PDR of the 590 RSUs for short packets and the PDR of the 590 RSUs for long packets calculated using Equation 4. For short and long packets, it is clearly illustrated that packets are 100% successfully delivered for some RSUs in the case with transmission control, and the PDR values are between 17% and 100%. In the case without transmission control, the highest values are 98.84% for short packets and 98.67% for long packets with a minimum PDR of 0%. In this case, PDR may rarely reach 100% because RSUs are frequently transmitting whether there are vehicles in their coverage range or not. A PDR of 0% means that packets from some RSUs have not been received during the entire simulation, which is critical for a V2I communication network. This situation may be caused by packets collision, which generally occurs when multiple users try to use the same channel and when the number of packets exchanged in the network is large. In addition, the variation of PDR could be a result of fading due to either multipath propagation or shadowing from obstacles. The proposed transmission control model allows RSUs with a PDR of 0% (in the case without transmission control) to be useful in the network during the entire simulation because some of them have a PDR higher than 70%. This can be proved by data presented in **table 2**, where connectivity is the number of vehicles detected by the given RSU, PDR_Txcon is the PDR when using transmission control, and PDR_woTxcon is the PDR when there is no transmission control. Furthermore, results in **Figure 10(c)** reveal that the PDR in the case of transmission control is almost the same for short and long packets with a very small difference.



(a)



(b)



(c)

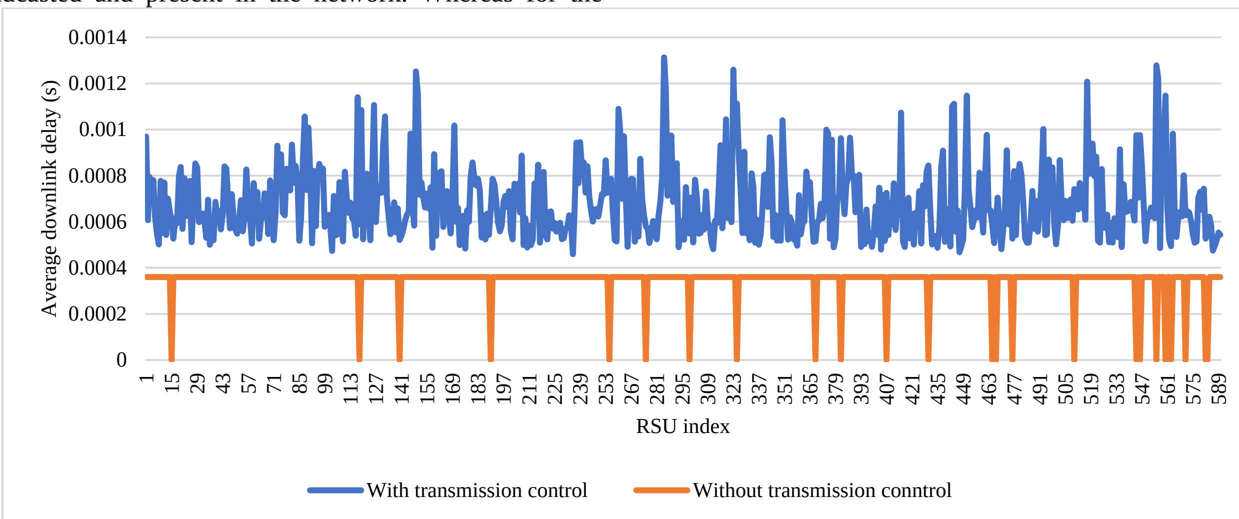
Fig. 10 Packet delivery ratio for each RSU, (a) 200 bytes packet size, (b) 1024 bytes packet size, (c) packet delivery ratio for 200 bytes and 1024 bytes packet size.

Table 2. Values of connectivity and PDR for some RSUs with transmission control and without transmission control with a packet size of 200 bytes.

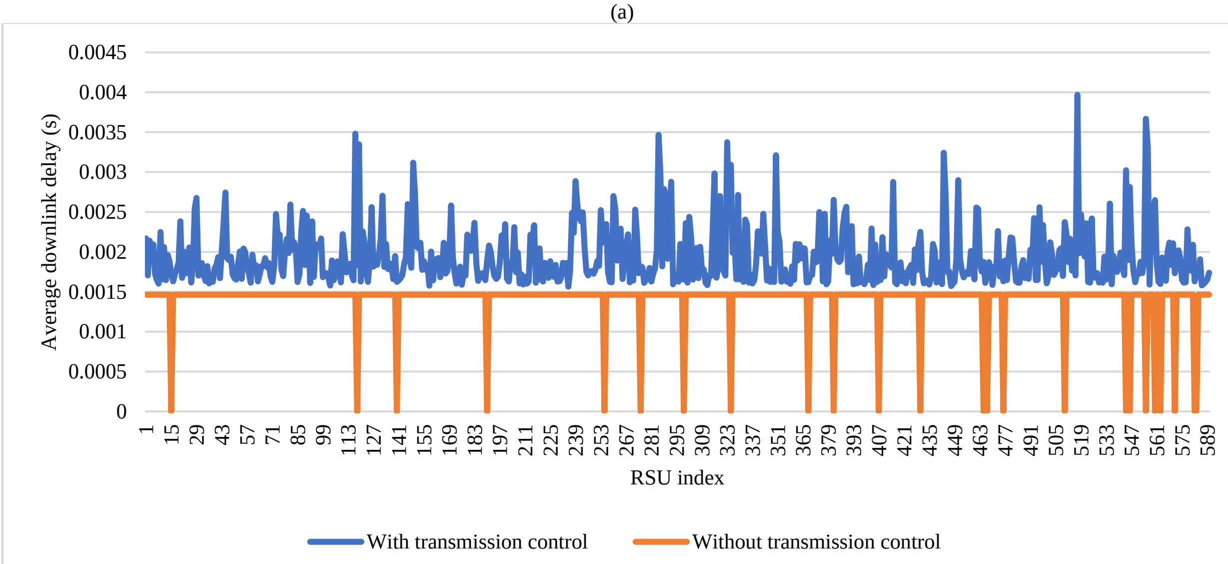
RSU		**15**	**118**	**140**	**190**	**255**	**275**
Connectivity		12	9	10	22	31	6
200 bytes	PDR_Txcon (%)	100	33.3333	65.4545	92.5926	78.4156	100
1024 bytes		84.6154	33.3333	65.4545	92.5926	74.3833	100
PDR_woTxcon (%)		0	0	0	0	0	0
RSU		**299**	**325**	**368**	**382**	**407**	**430**
Connectivity		8	59	7	39	31	17
200 bytes	PDR_Txcon (%)	39.0625	69.1223	73.4694	78.1955	44.111	74.6606
1024 bytes		39.0625	68.0581	73.4694	75.529	43.3233	74.6606
PDR_woTxcon (%)		0	0	0	0	0	0
RSU		**465**	**467**	**476**	**510**	**544**	**546**
Connectivity		6	34	5	12	50	50
200 bytes	PDR_Txcon (%)	100	28.7926	36	74.0385	60.4232	87.6562
1024 bytes		100	28.7926	36	74.0385	72.9826	83.0729
PDR_woTxcon (%)		0	0	0	0	0	0
RSU		**555**	**560**	**563**	**571**	**582**	**583**
Connectivity		59	8	8	9	11	13
200 bytes	PDR_Txcon (%)	43.3969	51.5625	17.6471	75.2137	29.7521	92.3077
1024 bytes		38.9595	65.625	17.6471	75.2137	29.7521	92.3077
PDR_woTxcon (%)		0	0	0	0	0	0

3.4. Average downlink end-to-end delay

The last parameter evaluated in this study is the average downlink end-to-end delay. **Figure 11** presents the end-to-end downlink delay of RSUs for short packets (see Figure 11(a)) and long packets (see Figure 11(b)). It is seen that the average downlink end-to-end delay is higher when using the proposed model than in the other case. For transmission control, the highest value for the average delay is 1.31ms for short packets (see Figure 11(a)) and 3.97ms for long packets (see Figure 11(b)), whereas, for no transmission control, the highest value of the average delay is 0.36ms for short packets and 1.46ms for long packets. There are some RSUs with an average delay of 0ms. They represent the RSUs with a PDR of 0%. In addition, the average delay is higher in the proposed model because the distance between the RSU and the vehicle has a higher impact on the propagation delay of packets. The effect of distance in the other case is not pronounced because RSU's packets are frequently broadcasted and present in the network. Whereas for the proposed model, the RSU transmission depends on the presence of an oncoming vehicle. Although the average delay is higher for the proposed model, its highest values (1.31ms and 3.97ms) are lower than 20ms. The packet delivery time is extremely short and adequate for the V2I communication network, which has a dynamic network topology.



(a)



(b)

Fig. 11 Average downlink end-to-end delay. (a) 200 bytes packet size. (b) 1024 bytes packet size.

4. Conclusion

One of the biggest challenges the V2I communication system faces is energy consumption. Many research works have been conducted to mitigate this issue in various ways. In this paper, an RSU transmission control has been proposed as a solution to minimize RSU energy consumption in an urban area. The problem was formulated as a BSM message transmission scheduling problem of RSUs based on the traffic flow at intersections. A few tools have been used for the simulation. OSMnx and OpenStreetMap were used to retrieve and model the road network. OSMWebWizard and SUMO were used to generate realistic traffic flow on the map. Then, NS3 was used to simulate the V2I communication network. The simulation was done for packets with 200 bytes and packets with a size of 1024 bytes. The results show that the proposed solution is efficient and minimizes the RSU radio energy consumption for urban deployment. The energy-saving for short packets is 1225.27 Joules in 301 seconds and is estimated to be 351705.41 Joules after 24 hours of simulation. For long packets, the energy saving is 5079.38 Joules in 301 seconds and can be estimated for 24 hours to give 1458001.44 Joules. Also, some RSUs in the simulation obtained good communication parameters in terms of PDR and average downlink end-to-end delay. For short packets, the highest average downlink end-to-end delay for the proposed model is 1.31ms and 3.97ms for long packets. This means that the delay between transmission and reception is extremely short and adequate for the V2I communication network.

Furthermore, the PDR has been improved for some RSUs and can be improved if a collision avoidance technique is combined with the proposed RSU transmission control. The latter can be proposed as future work. Also, it will be convenient to use a metaheuristic algorithm to choose the best positions to deploy RSUs in an urban area to achieve better communication performances.

As the National Transport Safety Authority is doing its best to ensure road safety in the city, the proposed solution can be useful in the nearest future for an urban deployment of RSUs in the city.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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References

[1] World Health Organization, New WHO report highlights insufficient progress to tackle lack of safety on the world's roads, World Health Organization, 2018. https://www.who.int/news/item/07-12-2018-new-who-report-highlights-insufficient-progress-to-tackle-lack-of-safety-on-the-world's-roads (2021).

[2] SAFE-UP, A proactive approach to effectively integrate autonomous vehicles for future road safety, Intelligent Transport, 2021. https://www.intelligenttransport.com/transport-articles/130496/integrate-autonomous-vehicles-road-safety/ (2022).

[3] D. Petrovic, R. Mijailović, and D. Pešić, Traffic Accidents with Autonomous Vehicles: Type of Collisions, Manoeuvres and Errors of Conventional Vehicles' Drivers, in Transportation Research Procedia, 45 (2019) 161–168. doi: 10.1016/j.trpro.2020.03.003.

[4] N. G.Gupta, R. D Thakre, and Y. A. Suryawanshi, Real Time Implementation of Vehicular Ad-hoc Network, Int. J. Eng. Trends Technol., 45(3) (2017) 121–126. doi: 10.14445/22315381/ijett-v45p227.

[5] Tullio Giuffrè, Antonino Canale, Alessandro Severino, and Salvatore Trubia, Automated Vehicles: a Review of Road Safety Implications as a Driver of Change, in 27th CARSP Conference, (2017) 1–16.

[6] J. F. Muhammad Alam, Joaquim Ferreira, Introduction to intelligent transportation systems, in Intelligent Transport Systems Dependable Vehicular Communications for Improved Road Safety, Studies in., Muhammad Alam, Joaquim Ferreira, and J. Fonseca, Eds. Springer, (2016) 1–18.

[7] J. Scholliers, M. Jutila, M. Valta, K. Kauvo, A. Virtanen, and P. Pyykönen, Co-operative Traffic Solutions for Hybrid Communication Environments, in Transportation Research Procedia, 14 (2016) 4542–4551. doi: 10.1016/j.trpro.2016.05.377.

[8] M. Woodard, M. Wisely, and S. S. Sarvestani, A survey of data cleansing techniques for cyber-physical critical infrastructure systems, 1st ed., vol. 102. Elsevier Inc., (2016).

[9] F. A. Teixeira, V. F. e Silva, J. L. Leoni, D. F. Macedo, and J. M. S. Nogueira, Vehicular networks using the IEEE 802.11p standard: An experimental analysis, Veh. Commun.,1(2) (2014) 91–96. doi: 10.1016/j.vehcom.2014.04.001.

[10] F. Perry, K. Raboy, E. Leslie, Z. Huang, and D. Van Duren, Dedicated Short-Range Communications Roadside Unit Specifications, vol. No. FHWA-J. (2017).

[11] Federal Communications Commission, Identification of interstate Transport Regions, (2021).

[12] R Q Malik et al., Mapping and Deep Analysis of Vehicle-to- Infrastructure Communication Systems : Coherent Taxonomy , Datasets , Evaluation and Performance Measurements , Motivations , Open Challenges , Recommendations , and Methodological Aspects, IEEE Access, 7 (2019) 126753–126772 .doi: 10.1109/ACCESS.2019.2927611.

[13] A. Sassi, Y. Elhillali, and F. Charfi, Evaluating Experimental Measurements of the IEEE 802.11p Communication Using ARADA LocoMate OBU Device Compared to the Theoretical Simulation Results, Wirel. Pers. Commun., 97(3) (2017) 3861–3874. doi: 10.1007/s11277-017-4703-4.

[14] P. Gora and I. Rüb, Traffic Models for Self-driving Connected Cars, in Transportation Research Procedia, 14 (2016) 2207–2216. doi: 10.1016/j.trpro.2016.05.236.

[15] Z. Li and M. Shahidehpour, Deployment of cybersecurity for managing traffic efficiency and safety in smart cities, Electr. J., 30(4) (2017) 52–61.doi: 10.1016/j.tej.2017.04.003.

[16] H. Su, C. H. Cho, Y. H. Chu, and W. Y. Chang, A traffic information dissemination mechanism based on DSRC/WAVE and its applications, in 2012 12th International Conference on ITS Telecommunications, ITST 2012, (2012) 635–638, doi: 10.1109/ITST.2012.6425258.

[17] X. Liu, Y. Liu, Y. Chen, and L. Hanzo, Enhancing the Fuel-Economy of V2I-Assisted Autonomous Driving: A Reinforcement Learning Approach, IEEE Trans. Veh. Technol., 69(8) (2020) 8329–8342.doi: 10.1109/TVT.2020.2996187.

[18] A. J. Ghandour, K. Fawaz, H. Artail, M. Di Felice, and L. Bononi, Improving vehicular safety message delivery through the implementation of a cognitive vehicular network, Ad Hoc Networks, 11(8) (2013) 2408–2422. doi: 10.1016/j.adhoc.2013.06.005.
[19] S. Kumar Gupta and S. Khara, Technique to improve the file transfer outcomes between road side unit and vehicles in vehicular ad-hoc networks, in International Conference on Computing, Communication and Automation, ICCCA 2015, (2015) 360–366. doi: 10.1109/CCAA.2015.7148444.
[20] H. Bello-Salau, A. M. Aibinu, Z. Wang, A. J. Onumanyi, E. N. Onwuka, and J. J. Dukiya, An optimized routing algorithm for vehicle ad-hoc networks, Eng. Sci. Technol. an Int. J., 22(3) (2019) 754–766. doi: 10.1016/j.jestch.2019.01.016.
[21] M. Srotyr, T. Zelinka, and Z. Lokaj, Hybrid communication solution for C-ITS and its evaluation, in 2017 Smart Cities Symposium Prague, SCSP 2017 - IEEE Proceedings, (2017) 1–7.doi: 10.1109/SCSP.2017.7973350.
[22] C. Bernardini, M. R. Asghar, and B. Crispo, Security and privacy in vehicular communications: Challenges and opportunities, Veh. Commun., 10 (2017) 13–28.doi: 10.1016/j.vehcom.2017.10.002.
[23] S. Zhang and Y. Shi, Roadside Units Non-full Coverage Optimization Deployment Based on Simulated Annealing Particle Swarm Optimization Algorithm, in 2018 IEEE 4th International Conference on Computer and Communications (ICCC), (2018) 544–549.
[24] C. Tripp-Barba, A. Zaldívar-Colado, L. Urquiza-Aguiar, and J. A. Aguilar-Calderón, Survey on routing protocols for vehicular ad Hoc networks based on multimetrics, Electronics, 8(10) (2019) 1–32.doi: 10.3390/electronics8101177.
[25] P. Qin, Y. Fu, X. Feng, X. Zhao, S. Member, and S. Wang, Energy Efficient Resource Allocation for Parked Cars based Cellular-V2V Heterogeneous Networks, IEEE Internet Things J., (2021) 1–1. doi: 10.1109/JIOT.2021.3094903.
[26] L. Cesarano, A. Croce, L. D. C. Martins, D. Tarchi, and A. A. Juan, A Real-Time Energy-Saving Mechanism in Internet of Vehicles Systems, IEEE Access, 9 (2021) 157842–157858.doi: 10.1109/ACCESS.2021.3130125.
[27] L. Zhang and Y. Wang, An Offline Roadside Unit ON-OFF Scheduling Algorithm for Energy Efficiency of Ad Hoc Networks, IEEE Access, 6(11) (2018) 59742–59751. doi: 10.1109/ACCESS.2018.2872601.
[28] V. Sethi, S. Pal, and A. Vyas, Online energy-efficient scheduling algorithm for renewable energy-powered roadside units in VANETs, in Proceedings - 2020 IEEE 17th International Conference on Mobile Ad Hoc and Smart Systems, MASS 2020, (2020) 506–514. doi: 10.1109/MASS50613.2020.00068.
[29] W. S. Atoui, S. Member, W. Ajib, and S. Member, Offline and Online Scheduling Algorithms for Energy Harvesting RSUs in VANETs, IEEE Trans. Veh. Technol., 67(7) (2018) 6370–6382. doi: 10.1109/TVT.2018.2797002.
[30] U. Demir, C. Toker, and O. Ekici, Energy-Efficient Deployment of UAV in V2X Network Considering Latency and Backhaul (2020). doi: 10.1109/BlackSeaCom48709.2020.9235026.
[31] P. Sun, N. Aljeri, and A. Boukerche, An Energy-Efficient Proactive Handover Scheme for Vehicular Networks Based on Passive RSU Detection, IEEE Trans. Sustain. Comput., 5(1) (2020) 37–47. doi: 10.1109/TSUSC.2018.2878109.
[32] Japan International Cooperation Agency, Republic of Kenya the Project on Detailed Planning of Integrated Transport System and Loop Line in the Nairobi Urban Core, (2018).
[33] Nairobi City County, Explore Nairobi, Explore Nairobi. https://nairobi.go.ke/explore-nairobi. (2021).
[34] Elizabeth Resor, Nairobi Accident map, Nairobi Accident Map, 2015. https://nairobiaccidentmap.com . (2021).
[35] G. Boeing, OSMnx: New methods for acquiring, constructing, analyzing, and visualizing complex street networks, (2017). doi: 10.1016/j.compenvurbsys.2017.05.004.