Priority Signal Transmission for Emergency Vehicles through Optimized Control in Wireless Sensor Network

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***Abstract*—Globally, there is a constant rise in the volume of vehicles on the road, particularly in big cities. Transport experts and policy leaders are now quite concerned about emergency vehicles stuck in traffic. This proposed work presents a new Signal Aggregator with Radio Frequency Sensor Unit based emergency vehicle's information passing technology. Important information including vehicle identification, distance travelled, heading guidance and departure time is properly communicated by the technology. The present study analyses each tracking and identification method based on emergency vehicle parameters, concentrating on its overview. The latest innovation with a lot of promise for use in urgent circumstances is wireless sensor networks. Initially, military uses such as wartime monitoring drove the growth of wireless sensor networks. Wireless sensor networks are, nevertheless, also employed in a wide range of fields, including vehicles, military, business, industry, civil society, health and habitat monitoring. This method's primary goals are to shorten response times and increase the speed of node-to-node communication. To increase the efficiency of the approach, several frequencies are used for the nodes' connection to each other. The results highlight how well the RF sensor performs regarding responsiveness and demonstrate how the priority MAC may minimize end-to-end latency on emergency vehicles.**

***Keywords*—emergency vehicle, wireless sensor network, radio frequency, traffic management, response speed.**

I. INTRODUCTION

Traffic signaling systems can be split into three types: those controlled by people, traditional and sensitive systems such as the traffic officer controlling traffic by hand gestures and periodically making verbal contact as the traffic officer's instincts decide which car should move or stop [1]. The growing popularity of Wireless Sensor Networks (WSNs), which are formed up of nodes, or sensors, has been rendered conceivable by advancements in communications that are wireless. Sensor node devices are inexpensive, compact, low-power gadgets with wireless connectivity, processing, and detecting capabilities. Upon deployment in the wireless network, the sensors automatically set up and establish connections with one another to gather data, which is then transmitted to the base station for processing. Growing amounts of traffic, particularly at times of congestion, are major issues in many nations and are worrying administrators and traffic specialists more and more [2].

Additionally, it interferes with everyday activities; however, it also makes it more difficult for emergency services to operate as intended. An outstanding contender to assist in accomplishing this goal is the use of WSNs. The technology of WSN has been recommended for application in traffic management in numerous studies [3]. To regulate the current status of the traffic light at a junction of roads employing WSN devices, a signal management methodology, and an adaptive vehicle identification approach were presented. WSN is made from nodes, which are groups of connected devices with a processor, broadcasting, power source and a few or several sensors. They analyze data from sensors to provide traffic data, including the quantity, velocity and duration of the vehicles.

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After that, the data is transmitted to the closest junction management station [4]. To further optimize traffic movement, the junction's management agent gathers data gathered by the sensor nodes to examine the traffic situation and decide on suitable steps, which might include modifying the length of the stoplights or communicating signals among other junction officials. The emergency vehicle will be served fast if the administration of the center receives the vehicle's location identification promptly [5]. There's an opportunity to improve emergency vehicle capacity and lower essential automobile crash rates if all automobiles receive emergency vehicle messages. To reduce the amount of time that emergency vehicles spend travelling and queuing on aggregate.

II. Related Works

Many researches were carried out for emergency vehicle signaling system and some of them were discussed here. The current study presents an innovative and adaptive traffic light management technology that depends on WSNs. The device's inexpensive price and ability to achieve wide-scale implementation make it a promising tool for revolutionizing traffic control and monitoring technologies. The idea for the method is made up of two components such as a control system that runs algorithms for control in WSN. The WSN, generally made up of several traffic sensor node networks, is intended to supply the necessary components for traffic transmission and to make the large-scale implementation of traffic surveillance methods [6].

After measuring automobile factors, the vehicle module sends these to the checkpoint stations. The crossroads section receives signals from the roadway unit about the nearby vehicles. After receiving and evaluating data from various parts, the convergence unit sends it into the planning sub-system, which determines the best plan of action based on the predetermined efficiency goal. The junction unit's primary goal is to determine the number of cars within each lane that will arrive at the crossing point before the termination of the stop signal phase with one another. However, there cannot be sufficient talk concerning how the intersecting unit benefits from the data gathered [7].

Emergency Vehicles (EV) traffic control solutions fall into three categories: lane reservation, signal preemption and route optimization. In order to reduce reaction time, EVs can dynamically choose the quickest and shortest route. Traffic lights are adjusted using signal preemption, also known as traffic signal priority, to allow EVs to pass through without interruption. Lane reservation ensures a dedicated and secure lane for EVs by removing and constraining normal vehicles from their path [8]. At the Media Access Control layer, a straightforward split-of-time simultaneous access method is used which consumes less power and lets network devices go into passive modes awaiting they finish their time intervals. The plan reduces the amount of time required to gather information from every node downstream into the base station by implementing a straightforward programming technique. Every single period is allotted to a set of corresponding networks by the technique, to ensure all the information streams are delivered [9].

WSNs are made up of strategically dispersed self-contained sensors that track and relay statistics back to the primary station over the connection about various meteorological and physical parameters like humidity and pressure. The number of disparate nodes with sensor components dispersed throughout a sizable region. A point of entry offers wireless connectivity to these components [10]. The three kinds of communication configurations mentioned earlier are commonly used to arrange nodes in a WSN. Every node within a star configuration has a direct link to an external gateway. The information is transmitted through the bottom node across the hierarchy towards the doorway in a group of tree systems, where every node is connected to every additional node that makes up the tree before reaching the gateway [11]. Mesh networks use components that can link to various networks throughout the framework and transfer information in the most reliable method possible to provide enhanced reliability.

The recommended method for controlling traffic lights operates across both individual and complex junctions. The enhanced variant of the monitoring method suited to the numerous junction scenarios is described in the following part; the specifics of the technique for just one junction scenario are provided here. Under the first scenario, the junction functions independently of adjustments made to adjacent crossovers. It is also possible to employ both preset and adaptable time synchronization [12]. Every single one of the traffic segments has a predetermined period and structure when using a set time administration. One benefit of such a technique is the reality that low-cost, fundamental technology can be used because of the straightforward nature of the control [13].

The range of available methods for sensor monitoring weigh their advantages and disadvantages in terms of setting up, metrics monitored and reliability in adverse climates, changing illumination conditions and shifting traffic patterns. Installing and maintaining over-roadway detectors is made easier by the fact that plenty of them are small and placed either on top or next to the path of traffic [14]. Blocking the highway to regular transport could prove necessary in certain detector setups and repair procedures to protect both the contractor as well as the person operating the vehicle. Every sensor in this list functions both during daylight hours and at night time. There are two general categories for sensors: invasive and non-invasive.

Controllers for Smart Traffic Signals (STS) and Intelligent Traffic Management Systems (ITMS) were proposed [15]. Based on the requirements of future smart cities for justice, shorter commutes, reasonable traffic flow, less traffic congestion and prioritizing emergency vehicles, local traffic management of an intersection is provided. The above method efficiently determines the strain on pathways and overcrowding in the memory buffer of nodes with sensors. In a connected car system built around WSNs takes into account several factors that are input and sends this data to the smart transportation network [16]. To detect rush hour traffic and the presence of emergency vehicles, an Internet of Things (IoT) based RF sensor is put on roadway markings and emergency automobiles. An arduino-based adaptive traffic signal control system was proposed that dynamically adjusts signal timing based on vehicle volume and prioritizes emergency vehicles for immediate passage [17]. This system detects traffic accidents and violations with simple implementations, ensuring faster clearance for rescue vehicles without human intervention with reduced accident rates [18].

Smart Signalization for Emergency Vehicles (SSEV) method was proposed, which uses a specialized mobile application to manage communication while determining a path between an emergency vehicle's current location and its intended location. A specialized mobile application system was created that allows emergency vehicle drivers and traffic lights to communicate, allowing for manual signal management while passing. The software allows traffic signals to return to normal operation when the priority car has passed. Until the emergency vehicle arrives at its location, this procedure is repeated [19]. Efficient traffic management improves vehicle flow, reduces fuel use, minimizes air pollution and enhances road safety. Traditional methods relying on static models and past data are insufficient for modern traffic complexities. Advanced techniques are needed to predict patterns and optimize flow in real time. Machine learning and deep learning leverage traffic sensor and GPS data to analyze, learn and predict conditions more accurately [20]. An automated traffic system using RF modules was proposed which facilitates seamless communication between ambulances and road infrastructure. It incorporates real-time vehicle identification, intelligent traffic management and enhanced safety measures. The system dynamically manages traffic flow and optimizes signal timings for priority passage [21].

Adaptive Traffic Signals System (ATSS) was proposed using machine learning model to speed up emergency response times and increase public safety. In order to detect their arrival and instantly convert traffic lights to green, it makes use of GPS, RFID and sophisticated cameras in emergency vehicles. Furthermore, a real-time map alert system warns surrounding drivers ahead of time, instructing them to yield to emergency vehicles [22]. EV may quickly cross intersections with little impact on other vehicles according to the Emergency Vehicle Management Solution (EVMS). Traffic moves to the shoulder lane to make room for an EV when it comes within communication range [23]. The system gathers and sends EV data to roadside units use IoT sensors, GPS, 5G and cloud computing. This guarantees better emergency management, quicker reaction times and ideal vehicle sequencing [24].

An intelligent traffic signal control system was developed based on Vehicular Ad-hoc Networks (VANETs) and Vehicle-to-Infrastructure (V2I) communication. Using an adaptive control algorithm, the system dynamically modifies signal timings in real time, minimizing disturbances to regular traffic by calculating EV arrival times, adjusting signal phases and maintaining balance. Prioritized EV passage is made possible by using V2I communication to provide traffic controllers with real-time data on EV locations and traffic conditions [25]. Traffic light control is made possible by the application, giving emergency vehicles priority. Signals are normalized once the car passes and the procedure is repeated until the destination is reached. A real-time deep learning system using YOLOv4-tiny is developed for pothole detection and road navigation. Detected potholes are classified by severities such as small, medium or large and navigation directions (left, center, right) are suggested based on severity density. A flask-based web interface allows users to upload images, videos or use live webcam feeds for detection. Pre-processing methods like resizing, normalization and data augmentation were applied to enhance model training [26].

III. Signal Aggregator and Radio Frequency Sensor Unit

The main objective of this paper is to make sure emergency vehicles are managed effectively. A message-passing device with a Signal Aggregator and Radio Frequency Sensor Unit (SA-RFSU) is implemented in this proposed work. To accomplish this goal, the traffic control center's operation is managing the traffic system, methods for determining distance and an approach for routing emergency vehicles according to length are all taken into consideration in this research.

A network that combines sensor innovations, information processing methods, internet connectivity and the latest developments to lessen delays in travel times and energy use and give priority-based communication is known as an Urban Traffic Management System (UTMS) and as shown in Fig. 1.

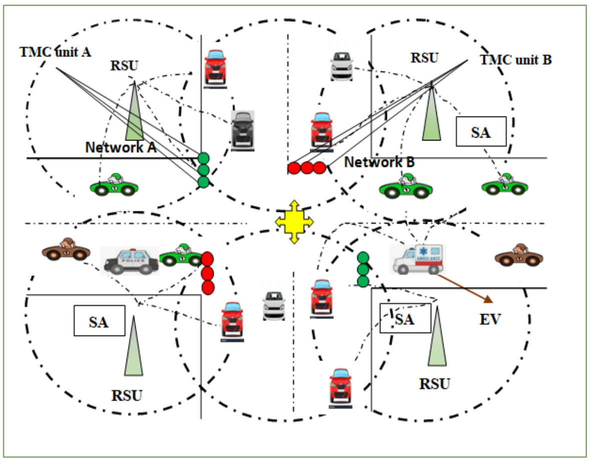

Fig. 1. Traffic management system in urban areas.

The Traffic Management Center Unit (TMCU) uses an appropriate emergency vehicle sending technology to receive data about emergency vehicles by detectors and promptly sends messages to inform the EV. The TMCU of the current junction (TMCU-A) supplies the TMCU of the next intersection (TMCU-B) with the number of vehicles traveling towards intersection B as well as the emergency vehicle's speed. The TMCU-B can predict when the emergency vehicle will arrive at intersection B because it is aware of its speed. Concerning the automobile number count obtained from the TMCU-A and the projected moment of arrival of the emergency vehicle, the TMCU-B establishes the green signal for pattern and period. As a result, emergency vehicles cross junctions quickly or without any delay. The UTMS can manage automobiles and protect both lives and assets by implementing the suggested algorithm.

Every node in the image is a node that collects data and an established protocol defines both the exchange of information and payload structure. The RFSU, an apparatus that makes use of radio frequency waves to send and receive critical automobile data, is installed on each car. The cars and the security officers can communicate with each other without any problems. The supervisors use radio waves for interaction with one another after placing themselves tactically at periodic times along the path of travel.

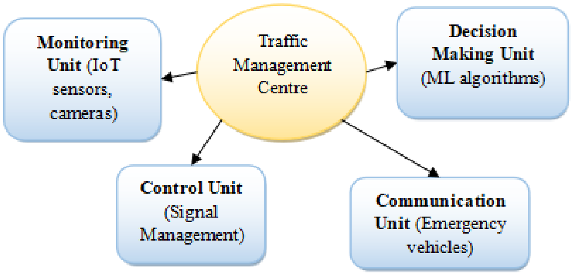

Fig. 2. Traffic management centre.

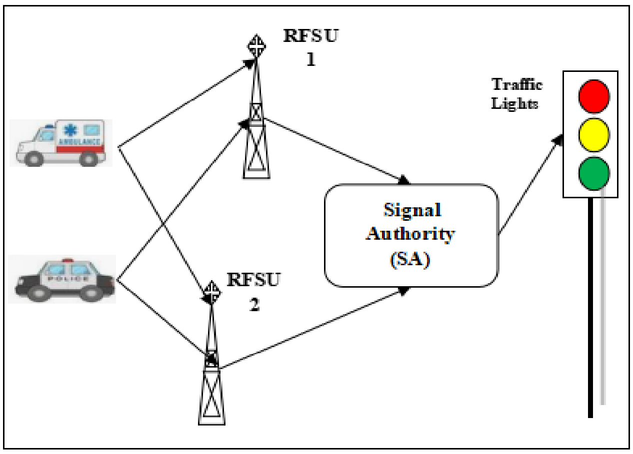

Fig. 3. Interaction between different nodes at different frequencies.

The functions of the Traffic Management Center (TMC) and the responsibilities for every of its sections are explained in the following section. Fig. 2 shows an illustration structure of a standard TMC. According to how they function, traffic signal precedence technologies currently in service can be divided into four categories: optical signals, GPS, radio-controlled and sound sensor technology. When it comes to efficiency and installation expenses, noise sensor-based anticipating techniques operate better than the others. Much effort has gone into developing systems to identify emergency vehicles by their siren frequencies.

In Fig. 3, the interaction paradigm on many frequencies and nodes is shown. An RFSU's transmission bundle structure is shown in Fig. 4, and an example information value is shown in Fig. 5. The Eight parameters of the transmission packet have all of the emergency vehicle's details. The roadway ID or simply the path where the emergency vehicle is headed, is provided in the subsequent column.

Vehicle ID	Path ID	Direction	Time	Distance	Head Light	INT	EOF

Fig. 4. Communication format.

AB045	RD234	→	8.30	15	RED	INT-ON	1

Fig. 5. Sample ccommunication format.

The first parameter contains the ID of the vehicle. The second parameter contains the path ID in the communication format. The emergency vehicle's preferred direction is indicated in the third parameter. The vehicle's time of appearance at the junction is indicated in the fourth parameter. The approximate measurement connecting the emergency vehicle and the junction is provided within the fifth parameter. The traffic instructions receive interruptions and warning signals from the sixth and seventh sections. The packet terminates with the eighth section. The SAs collect the packets generated by the RFSUs and transmit them to the communication center.

Typically, there are three lights on traffic signals: green, red and yellow. The system that is suggested adds violet color lights on both sides of the regular traffic signals to show the approaching and departure routes of the emergency vehicle. Fig. 6 shows the suggested emergency vehicle's information signaling system. To alert the emergency vehicles getting there, the suggested strategy is to turn on the violet signals and sound a constant alert. The emergency vehicle is signaled to commuters by the violet color lights, which also serve as an alert system for cars.

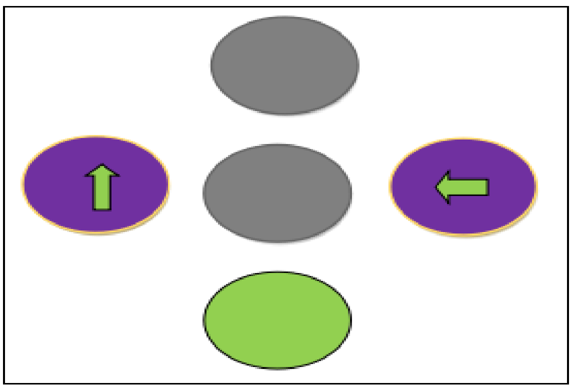

Fig. 6. Emergency vehicle information light.

The emergency vehicle's left violet color signal indicates which way it wishes to travel, while the right violet color light indicates the way it is approaching. As a result, drivers are not confused about the path from where the emergency vehicle is approaching or traveling. As a result, emergency vehicle incidents can be prevented by the suggested strategy. The mishaps can be avoided and rescue lives with comparatively little more technology. The suggested system provides vital details regarding emergency vehicles, including their identifying number, route taken, length of travel and predictable time of getting there.

Every vehicle receives this data via traffic lights and radio frequency waves. The nodes communicate with one another using various wavelengths. One wavelength is used for communication between the sensor units of the emergency automobile as well as the regular automobile, while another is used for communication.

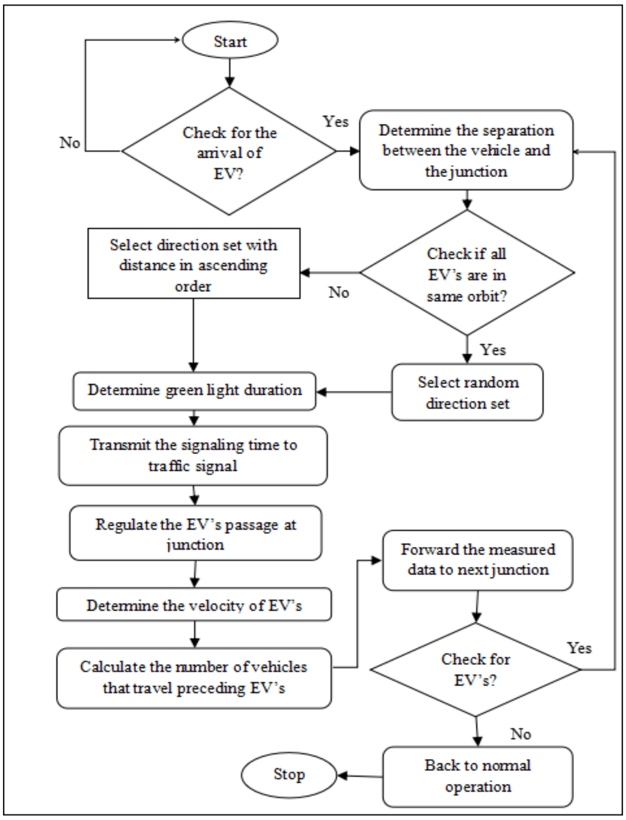

Fig. 7. Proximity dependent EVs distance methodology.

Table I describes about traffic priority given for different vehicle type. Any wireless network of sensors can benefit from increased dependability, velocity, savings on electricity and standard of experience. Emergency vehicles are assigned preference by default according to the MAC. Emergency communications are prioritized via the Priority MAC (PMAC), which also reduces the critical signals' delay from end to end. The details about the emergency vehicle arrived at a traffic signal centre quickly and were processed. This lowers the standard duration of the wait for emergency transport and guarantees that it arrives at its location on schedule. The RFSU begins transmitting the car's signal packet as soon as an emergency vehicle gets on the roadway.

The emergency automobile is given importance by the protocol known as MAC once it has assessed the data packet and determined its level of importance. The signal aggregator then transmits the alerts to the signaling unit. The emergency vehicles receive the all-clear from the traffic control system.

The flow diagram of proximity dependent EV scheduling technique is given in Fig. 7, which accomplish an effective control of traffic signals to allow clearances for any kind of emergency automobile and to reduce its trip time. Every route is considered to have just a single emergency vehicle.

TABLE I. TRAFFIC PRIORITY

Priority	Vehicle Type	Example
Medium Priority	Normal Vehicle	Car, Bus, Container
Higher Priority	Emergency Vehicle	Ambulance, Fire Engine, etc.

The emergency automobiles scheduling method is represented by the EVs in the following schematic. Optical detection techniques are considered to ascertain the length and pattern of green signals. The closest emergency vehicle approaching the junction and the order of events of the green signal are both found using measurement of distance algorithms.

IV. RESULT AND DISCUSSION

The approach suggested is simulated and examined with the Network Simulator 2.35. Device protocols are primarily demonstrated using the Network Simulator, an independent encounter time-driven evaluation platform. The sensing nodes are connected within the setting of the simulation. The total number of nodes considered in this proposed work is 1200 with two ray propagation model. The existing models such as SSEV and ATSS are considered here.

A. Response Time

The nodes' reaction is crucial considering a single latency could trigger a traffic bottleneck or even a traffic collision.

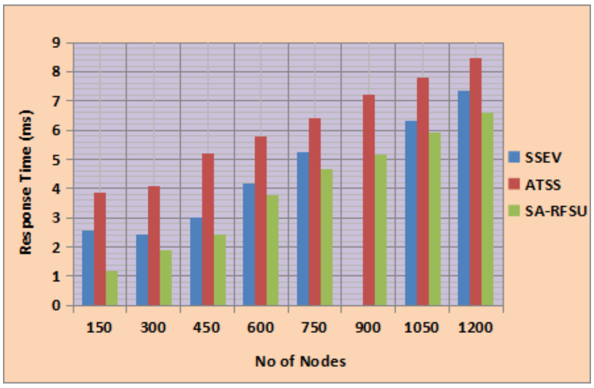

Fig. 8. Response time of proposed and existing models.

Fig. 8 shows the graphical representation of response time as a function of node count obtained for both proposed SA-RFSU and existing models SSEV and ATSS. The nodes' responses determine how quickly information is communicated. When contrasted with the conventional models SSEV and ATSS, the proposed traffic control model SA-RFSU reaction time is extremely short.

B. *Node Separation*

The experiment is run by increasing the node count from 200 to 1200. Proper spacing reduces redundant data transfer, ensuring faster emergency vehicle detection and signal switching. Green signals are given dynamically during emergencies, because well-separated nodes allow the emergency vehicle, traffic lights and control units to communicate continuously. The link between the total amount of nodes and node spacing is seen in Fig. 9.

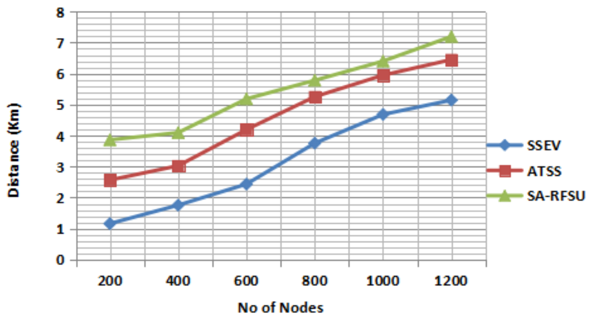

Fig. 9. Node separation in traffic for EV.

The proposed model SA-RFSU provides Optimized node separation which helps in preventing unnecessary re-transmissions.

C. *Packet Delivery Ratio*

The Packet Delivered Rate (PDR) for both the proposed SA-RFSU and conventional models SSEV and ATSS are shown in Fig. 10. PDR is a metric used to quantify the standard service provided for every sensor network, where the proposed method has a PDR of about 99.14%.

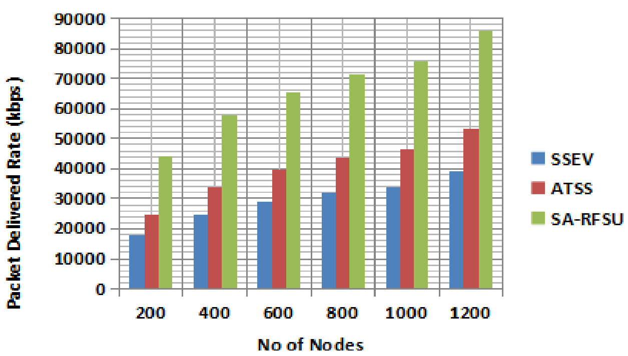

Fig. 10. Packet delivered rate.

SA-RFSU pertains to notifications of emergencies when comparing the standard duration, it takes for information to be transmitted from the starting point to the final endpoint.

D. *Transmission Delay*

The time required for data to be sent and received between two network nodes is referred to as a delay. Fig. 11 describe an experiment in which the network capacity is changed and the consequent delay is calculated.

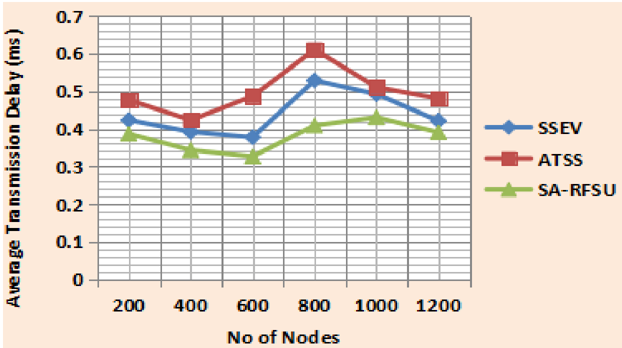

Fig. 11. Transmission delay.

A clear relationship between the system's size and the transmission delay is mentioned. Regarding a greater number of connected nodes, networking interaction, transmission of messages and data transfer amongst the nodes have also risen while taking performance into account. This causes the rate of data transfer to grow effectively and proportionately as the overall number of nodes in the system increases. The proposed model has lower end-to-end transmission delay which includes processing delay, queuing delay and propagation delay than the considered conventional models ATSS and SSEV.

V. Conclusion

The proposed model presents an efficient emergency vehicle control system for cities. Roadside deployment of RF sensor devices is done to keep an eye on passing cars and increase the speed and effectiveness of transmission by minimizing delay. The headlights, color of the license plate and output coming from the SA-RFSU installed in every automobile are used to identify the vehicles. A simulation is used to test the proposed strategy and the outcomes are shown in result section. It is evident from the deliberates and findings that the proposed model SA-RFSU based emergency vehicle control is a superior method when compared with their conventional models. The software detects the order of importance information and assigns a priority based on the MAC protocol configuration.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

S. Balapriya conceptualized the research idea; R. Anto Pravin designed the overall methodology and supervised

the research process; he also contributed the algorithm implementation and its associated tasks; R. Velumani provided domain-specific insights and validated the experimental design; K. Murugan contributed in writing introduction and related works section; S. Vairaprakash supported the validation of results and proofreading of the final manuscript; S. Satish Kumar worked on manuscript drafting, figures and tables preparation; all authors had approved the final version.

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