Reliable and efficient message dissemination by adaptive relay selection in vehicular networks

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Reliable and timely message reception of an emergency event is the prime objective of emergency message dissemination protocols in vehicular networks. Varying vehicle density and road topologies in vehicular networks raise many challenges for efficient message dissemination. This research paper proposes a new multi-hop message dissemination protocol for emergency events in vehicular networks. It employs a dynamically adaptive relay node selection process that depends on current vehicle density and transmission range. Multi-criteria-based dynamic relay node selection reduces redundant transmission and improves the delay performance of the message dissemination process. The efficient selection of relay vehicles makes the protocol scalable for different operating scenarios. We evaluated the protocol with different vehicle densities and network sizes. Simulation output confirms considerable performance improvements over existing distance-dependent protocols. In urban traffic density scenarios, over 20% improvements are achieved in delay performance to the furthest distance-based protocol with increased reliability and scalability in vehicular networks.

Keywords: VANET, ad hoc network, broadcasting, multi-hop, data dissemination, ITS.

1. INTRODUCTION

As reported in Voelcker [2014], total number of vehicles worldwide will become 2 billion by 2035. Due to increased usage of vehicles, traffics and road accidents are rising day by day. Intelligent transportation system (ITS) is an advanced field that aims to reduce road transportation fatalities and provide infotainment services. ITS considers vehicular ad hoc networks (VANET) as a key enabling technology that has the potential to realize the goals Dimitrakopoulos and Demestichas [2010]. In vanet, vehicles equipped with wireless communication capabilities form a network to exchange messages while moving on the road. IEEE 802.11p standards are designed to govern wireless connectivity among moving vehicles. Physical and MAC layer definitions are provided for radio links in these standards and it is known as Dedicated Short Range Communication (DSRC). Along with DSRC, IEEE 1609.x standards provide upper layer definitions for VANET and the whole protocol stack is collectively known as Wireless Access in Vehicular Environments (WAVE).Eze et al. [2016],Karagiannis et al. [2011].

Successful warning message delivery through vanet can reduce road fatalities by giving sufficient time to drivers, to react against it. To deliver a warning message beyond the transmission range of the sender, multi-hop message dissemination is required. In multi-hop message dissemination, nodes receiving warning messages will further re-broadcast the message to provide full coverage in the network Panichpapiboon and Pattara-Atikom [2011]. The rebroadcasting nodes are typically known as forwarding nodes. Poor choice or a large number of forwarding nodes results in poor network performance. It increases packet collisions due to bandwidth saturation and congestion in networks. Opposite to it, the optimum choice of relay nodes and redundant broadcast suppression provides high coverage with acceptable delay and reliability Wu et al. [2017].

It is observed that vanet suffers from broadcast storm problems, frequent disconnections, and mobility-induced varying channel characteristics Tonguz et al. [2010]. In presence of the above characteristics, the task of sufficient coverage and delay-sensitive requirements is challenging work and it is still an open challenge for designers of the applications. This paper focuses on improving delay performance and net reachability for vanet safety applications. We propose a reliable and efficient adaptive dissemination protocol called AMDP – Adaptive multi-hop dissemination protocol. AMDP is a beacon-assisted method that adapts its performance based on the effective transmission range of sending nodes. The proposed work aims to improve delay performance and provide sufficient reachability with less overhead.

The key contributions of this research paper can be listed as:

(i) Adaptive and efficient relay selection mechanism based on the effective communication range and surrounding node density.

(ii) A efficient message suppression mechanism to reduce redundant transmission for avoiding broadcast storm problems in high-density networks.

(iii) Simulations are presented to measure the efficiency of AMDP. AMDP's performance is evaluated through different vehicle densities, vehicle topologies, and results compared with flooding and delay-based broadcast protocols. Results show AMDP improves net delay performance and provides sufficient network coverage.

2. BACKGROUND AND RELATED WORK

In VANET safety-related applications, the warning message is important to all the nodes residing in the networks. Amid rapidly changing topologies and short wireless link lifetime, traditional routing strategies are not suitable for VANET applications da Cunha et al. [2016]. So in vanet, most of the applications follow broadcasting-based message dissemination strategies Vala and Vora [2022].

2.1 Message Dissemination Strategies

Broadcasting-based message dissemination can be classified into two broad types:

a) *Single-hop broadcast:* The sender shares the messages to immediate neighbor vehicles. Receiving vehicles kept this information for their own purposes. Many co-operative driving safety applications such as braking event warning, Blind spot warning, and lane change warning are implemented through Single-hop broadcast methods Pan et al. [2018].

b) *Multi-hop broadcast:* Practical transmission range of 802.11p based wireless link is less than 500 m, so to propagate warning messages at a longer distance multi-hop dissemination schemes are used Rebei et al. [2021]. Plain broadcasting (flooding) of warning messages at multiple hops, results in broadcast storm problems. So selective broadcasting strategies are implemented to eliminate problems of bandwidth wastage, and excessive packet drops and reduces delay in message delivery Wu et al. [2017]

Figure-1 represent VANET architecture in pure Vehicle-to-Vehicle (V2V) communiction scenario. As shown in figure, moving vehicles establish wireless link connectivity among all surrounding vehicles through *Single-hop* and *Multi-hop* communiation.

2.2 Related Work

In the pure flooding method, every received message is rebroadcasted to cover the whole network. This approach results in excessive redundancy and creates broadcast storm problems in the high-density networks Chakroun et al. [2022]. On the other hand, sufficient neighbor nodes are not available to broadcast messages in sparse networks. The issues of scalability, redundancy, and bandwidth wastage is addressed by selectively relay the packets only by fewer nodes Chaqfeh et al. [2014]. Distance-dependent relay node selection is the most widely used scheme. We provide a brief review of past literature closely related to the proposed research work. Comparative finding of relay node selection process, redundancy suppression, traffic topologies and simulation environment presented.

Kim et al. [2008] proposed a simple distance-based broadcast protocol called Distance Based Relay selection (DBRS). Here delay before the broadcast is set inversely proposal to distance from the sender. All other vehicles with higher delays will drop scheduled broadcasts when they receive the same message from a shorter delay forwarder.

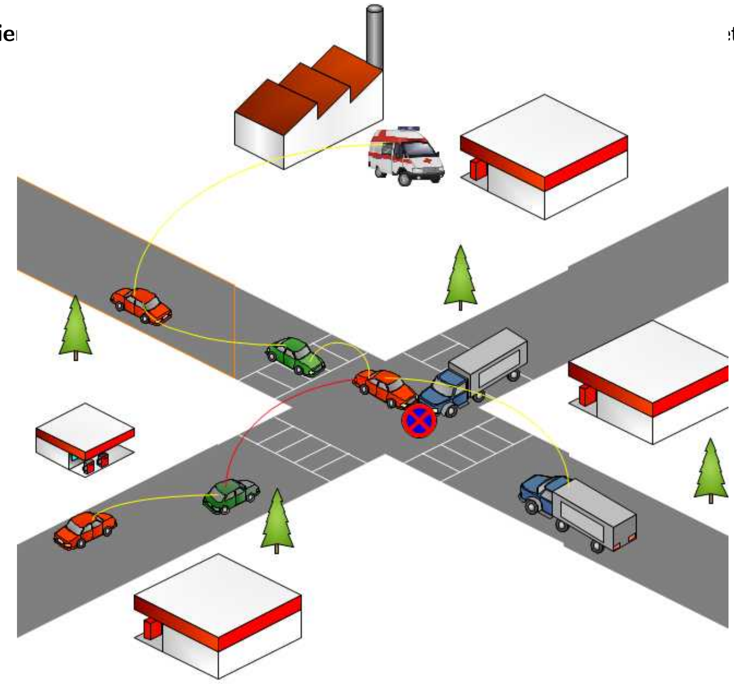


Figure 1. VANET system architecture

In Slavik and Mahgoub [2013], author presented stastical distance based broadcast method. In which author incorporated a thresold factor to reduce redundant broadcast messages. The thresold value is dynamic and adapted to present vehicle density. Simulation is implemented in WiBDAT design tool.

The slotted p-persistence scheme by Wisitpongphan et al. [2007] assign higher probability of forwarding to vehicles located at a longer distance. In this way, it attempts to remove the broadcast storm problem common in simple broadcast networks. The protocol works suitably in highway scenarios only.

In Viriyasitavat et al. [2011] Urban vehicular broadcast is proposed for dense and sparse vehicular density. Here vehicles at the edge of the communication range will utilize a store-carry-forward(SCF) mechanism to deliver messages to every vehicle in the network at the cost of increased overhead. while other inner vehicles will perform broadcast suppression tasks.

Cross Layer broadcast protocol (CLBP) is proposed by Bi et al. [2010] which consider i) The channel condition ii) distance and iii) Speed for selecting forwarding nodes. RTS, CTS based reliable protocol presented that works in highway topology and only in one direction broadcast.

In Voicu et al. [2014], fast and reliable broadcasting protocol is presented which implement independent acknoledgement system of sent messages to increase reliability. author tested the implementation into highway scenario.

In Achour et al. [2016a], the author provided an in-depth comparison between direct delay configuration and slotted delay configuration. It is evident through simulation outcomes that, continuous delay-based protocols induce more delay compared to slot-based schemes. Slotted protocols provide more rooms to customize their delay parameters to make them suitable for traffic safety applications in vehicular networks.

Real-time adaptive dissemination protocol (RTAD) is proposed by Sanguesa et al. [2015], that utilized coverage and received message count to detect channel contention and reliability of the message dissemination process.

In Achour et al. [2016b], the author proposed a simple and efficient dissemination protocol that follows a hybrid strategy for electing relay nodes. In this work, distance-based delay is assigned to every potential relay node. upon timeout, forwarding probability is calculated by using local density and direction. This protocol performs better than simple distance-based protocol, but it still suffers from local synchronization problems. At high density, more vehicles will be available in a single slot with the same local density. This leads to concurrent transmission and packet collision problems.

In Rehman et al. [2016], a bi-directional stable communication (BDSC) based relay node selection process is proposed. Here the author takes into account that transmission range is non-uniform for every vehicle and a single metric can not define the reliable transmission range of different vehicles. so Bi-directional link stability is first verified and priorities assigned to the more stable nodes to relay the message. The evaluation of the performance is provided for only highway scenarios.

Clustering approach is used to provide scalability in data dissemination and vehicle platooning. In Thakur and Ganpati [2021], the author presented a fuzzy logic-based cluster head selection strategy. the node with a high-rank index will be selected as the cluster head and all the message dissemination task toward the cluster is governed by the cluster head.

Adaptive data dissemination protocol (AddP) is proposed by Oliveira et al. [2017], which utilized weighted local density and distance to select optimum relay nodes for alert message dissemination. Along with the relay selection process, the author also highlighted the concept of message aggregation for reducing the number of messages to transmit and reducing channel load. However, the presented simulation outputs are presented for moderate network density only.

In Zhang et al. [2018], author have proposed an Adaptive Link Quality based Safety Message (ALQSM) forwarding scheme for vehicular network. In this, physical channel connectivity probability is calculated first. Based on the probability different scores are assigned to 1-hop candidates. The score oriented priority method will select an optimal forwarder from all available. This method aims to reduce the contention during broadcasting among different vehicles.

Efficient data dissemination protocol (EDDP) is presented by Chaqfeh et al. [2018], which consider traffic flow parameter to derive local traffic condition and adaptively increase the delay time as per high traffic or low traffic conditions. Simulation outputs are presented with urban scenarios. delay is considerably reduced due to less number of slots employed in operation.

Protocol	**Method**	**Objective**	**Topology**	**Simulator**
EWM	Delay-based	Broadcast storm	Highway	-
DADCQ	Delay-based	Broadcast storm	Urban	WiBDAT
S1PD, SPPD	Delay, Probability based	Broadcast storm, reliability	Highway	OPNET
UV-CAST	Delay-based	Disconnected	Grid + Highway	NS-2
CLBP	RTS/CTS	Broadcast storm	Highway (1-way)	NS-2
IFP	Ack decouple	Broadcast storm, reliability	Highway	NS-3
SEAD	hybrid	Redundancy	Highway	NS-3
RTAD	coverage & Count	Broadcasr storm	Urban	NS-2
BDSC	Stable Link	Reliability	Highway	NS-2
AddP	Distance, Density	Broadcast storm	urban, Highway	OMNeT++
ALQSM	Link Stability	Reliability	Highway + Grid	OMNET++
EDDP	Traffic condition	Broadcast storm	Urban	OMNET++

Table I: Data Dissemination approaches

2.3 Comparison of reviewed work

Section-2.2, presents state-of-the-art message dissemination protocols collected through the google scholar search utility. It is observed that many protocols are tested on limited network topologies, while a realistic vehicular network requires scalable protocol. Complex and delay-inducing relay node selection methods are not suitable for safety-related applications due to time-critical operation requirements. Table-I summarise and provides a comparative analysis of referred research papers. It highlights the use of the core method, the objective of the protocol, and used vehicle topology. It also mentions simulation tool details whenever available for easy reference for the readers. With this referred work, we found that scalability and requirements of the time-sensitive dissemination process are rarely discussed in the literature. In section 3, we are presenting an efficient and reliable multi-hop message dissemination protocol that addresses the technical gap and issue of efficient relaying of safety messages.

3. AMDP: ADAPTIVE MULTI-HOP DISSEMINATION PROTOCOL

In this paper, an efficient data dissemination protocol called AMDP - Adaptive multi-hop dissemination protocol is presented for safety application in vehicular networks. During an emergency situation, vehicles generate alert messages and attempt to disseminate the alert in the network. AMDP attempts to disseminate these alerts to all the members of networks with minimum delay. Delay is minimized by carefully avoiding link failure, broadcast storm problems, and excessive redundancy. The proposed protocol utilizes vehicle density and inter-vehicle distance adaptively to elect the next relay vehicles. For proper illustration, we present in section-3.1 the assumptions considered for the proposed work. section-3.2 presents beacon and alert message formats. while the operation of the protocol is presented in section- 3.3.

3.1 Assuptions:

- ✓ We assume that every vehicle is equipped with On board Unit (OBU), Application Unit (AU), and User interface. We also assume that vehicles are equipped with sensors to detect emergency situations.
- ✓ Every vehicle is equipped with Global Positioning System (GPS) to furnish location information.
- ✓ Vehicles exchange Cooperative awareness beacon messages (CAMs), to convey Vehicle ID, Vehicle position, local density, and other information to Single-hop neighbors.

3.2 Message formats:

Beacon and alert messages in the AMDP are defined as per WAVE standards to establish 1-hop and Multi-hop communication in vehicular environments. The fields of Beacon and alert messages are listed into Table II and III respectively.

Field	Description
V_{id}	Vehicle Identifier
M_{id}	Message Identifier
P	Beacon Generator Coordinates

Table II: Beacon Message fields

At reception of every beacon message, neighbour knowledge data-base updated. Receiving vehicle continuously updates its $MaxRange$ parameter through received beacon distance.

Whenever emergency situation detected by vehicle, it generate *Alert Message* with field presented in Table III. Coordinates of alert generator and forwarder conveyed into alert message to identify emergency area. $MaxRange$ value calculated through beacon exchange is also included to efficiently relay the alert in the network. Every time a message is re-broadcasted the hop-count field is incremented in message by relay node.

Field	Description
S_{id}	Alert Generator Identifier
F_{id}	Alert Forwarder Identifier
M_{id}	Message Identifier
P_s	Alert Generator Coordinates
P_f	Alert Forwarder Coordinates
H	Hop-count
MR	Maximum Range

Table III: Alert Message fields

3.3 Message dissemination process in AMDP:

AMDP is a multi-hop adaptive message dissemination protocol that enables multi-directional message relay required for urban vehicular networks. AMDP implements efficient broadcast suppression by utilising current traffic conditions and fewer relay nodes are selected with minimised delay-time. delay-time is the time for which scheduled relaying will wait. Whenever a vehicle detects an emergency situation, it will generate an alert message and send it to all its 1-hop neighbors. All receiving neighbor vehicles calculate the size of the contention window (cw) based on current traffic condition, actual transmission range. Every vehicle then selects their slots from cw and determines delay. The cw based adaptive delay selection process will favour farthest vehicles as relay.

The delay based relaying process utilised in AMDP protocol is presented in Algorithm 1. The overall process can be divided into *Message suppression* and *Message broadcast* parts.

Algorithm 1 Relay Node Selection Algorithm

```
Require: Coordinates of the generator, forwarder, and Range
while Alert message received do
  if Message is Repeated then
    Calculate d_s and d_f
    if d_s > d_f then
      if Message is scheduled for broadcast then
        Re-schedule with new delay
      else
        calculate delay and schedule for broadcast
      end if
    else
      Discard the message
    end if
  else
    Get MaxRange, Get d_f
    Calculate cw, my_slot, and delay
    Schedule forwarding
  end if
end while
```

3.3.1 *Message suppression.* Upon receiving an alert message, the receiving vehicle checks if it's already received before. If a message is repeated, then it will verify if it's already scheduled for broadcast. The receiving vehicle will suppress the scheduled broadcast if distance from receiving to source vehicle (d_s) is less than distance from receiving to forwarder vehicle (d_f) . If $d_s > d_f$ and message is scheduled previously for broadcast then re-scheduling is implemented with new delay calculation.

3.3.2 *Message broadcast.* If a vehicle receives the message for the first time, then it will calculate the Contention Window (cw) and determine its time slots (my_slot) based on current traffic density and Maximum hearing range ($MaxRange$) and distance from the sending node (d_f). Waiting delay is calculated from the assigned slot and message is scheduled for broadcast after delay time. All the vehicles located near the boundaries of Transmission range are assigned with shortest delay and hence favoured as relay nodes. All other vehicles will implement the message suppression process when they listen to the same message backward from farthest vehicles.

3.3.3 *Delay calculation.* Receiving vehicles utilised local traffic conditions through surrounding neighbor density (N_i) and computed adaptive contention window size as per Eq.1. The k is total of average vehicle length plus safest distance between two cars. The constant α and β are used to control the effect of $MaxRange$ and Traffic condition on contention window. Adaptive cw dependant on actual hearing range and local traffic data enable to generate larger cw for higher traffic and lower for light traffic. This feature provides scalable and delay efficient data dissemination in vehicular networks.

$$cw = \alpha(\frac{MaxRange}{k})\beta^{(N_i/N_{th})} \tag{1}$$

Once contention window (cw) is calculated as per existing network and traffic condition, the receiving vehicle then calculates its slot (s_i), based on its geographic location in the transmission range. slot is converted into delay as per equ. 2. Here, w is the waiting time, δ is the minimum delay for 1-hop transmission.

$$w = random(s) \times \delta \tag{2}$$

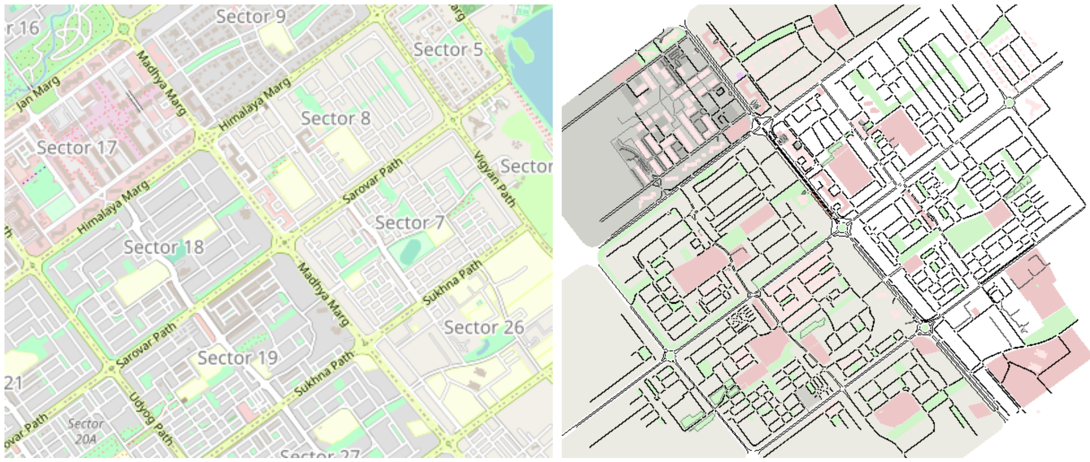
As described above, the farthest vehicle will most likely elect the lower delay and prioritise over vehicles located closer to the sender. This mechanism allows longer distance at every hop with lowest possible delay and redundant broadcasts are suppressed efficiently.

4. PERFORMANCE EVALUATION

The proposed work is evaluated through simulation, by using NS3 as a network simulator and SUMO(Simulation of Urban Mobility) as traffic simulators. Both NS3 and SUMO are open-source simulators widely used in reasearch.Riley and Henderson [2010],Lopez et al. [2018]. SUMO facilitate vehicle modeling on map based road geometry. It has the ability to generate desired vehicular movements with varying speeds and density. For evaluation of AMDP performance, different simulation experiments are performed and the findings are compared with *BFP (Blind Flooding Protocol)*, *S1PD (slotted 1-persistant broadcast)*. In BFP every vehicle forwards every new message in its transmission range. BFP method is native communication method and it is not scalable to varying density of nodes. S1PD is a representative slotted delay based broadcast protocol used widely in literature.In this method, The number of slots are pre-determined and every vehicle is assigned to a fixed slot depending on its distance from the sender. The farthest vehicle is given priority in broadcasting the message.

4.1 Simualtion scenario:

Chandigarh, India *OpenStreetMap* of 2×2.5 km^2 area is imported into SUMO for generating real road networks. Simulation of vehicle traffic and mobility traces are generated by SUMO over that road networks. Figure-2(a) shows the imported *OpenStreetMap* and its corresponding road networks extracted in Figure-2(b) through use of SUMO tools. IEEE 802.11p protocol is integrated into NS3 to simulate vehicular networks. The data rate is set at 6 Mbits/sec at the MAC layer. The transmission power is set to provide roughly 300 meters range. The vehicle density is varied from 100 to 600 into selected area. Figure-3(a) shows generated vehicular movements on real road network. All the parameters used in simulation are mentioned in Table-IV.



(a) (b)

Figure 2. Simulation scenario (a) OpenStreetMap of chandigarh (b) OSM map converted into road network

Parameters	**Value**
Simulation area	$2 \times 2.5\ km^2$
Total Simulation Time	50 sec
Vehicle density	100 - 600
Velocity	5 m/sec - 20 m/sec
Transmission Range	300 m
Packet size	200 bytes
Data Rate	6 Mb/s
MAC layer & Physical layer	802.11p
Propagation model	Two-ray ground

Table IV: Simulation Parameters

4.2 Performance Metrics:

In order to measure the performance of AMDP, three performance metrics *Reachability*, *Mean delay*, *Number of of Hops* are defined as below. These three metrics collectively defined the performance of message dissemination protocols.

Reachability. Reachability metric reveals the alert message coverage in the selected area. The percentage of vehicles out of total available vehicles, that received the alert message is defined by Reachability. Reliable Safety message dissemination protocols must have high reachability.

$$Reachability = \frac{\text{Numberof Vehicles who received warning message}}{\text{Total number of vehicles}}$$

Mean Delay. Alert message broadcasting is time-critical task in safety application, This measurement is done through Mean delay metric. It is the average time a message takes to reach a boundary of AoI

$$\text{Mean delay} = \frac{1}{All\_recv\_n} \sum_{v=1}^{All\_recv\_n} Recv\_time - Msg\_gen\_time$$

(a) (b)

Figure 3. (a) SUMO generated Vehicular Movement(b) Measurement boundary

Number of Hops. There is a trade-off between reliable relay node selection and farthest distance node selection. Aggressive attempts to select the farthest node in the network result in failed transmission and it will increase the delay. The number of hops can be found by measuring the average number of Hops a message needs before it reaches the Measurement point.

$$\text{Num of Hops} = \frac{1}{All\_recv\_n} \sum_{v=1}^{All\_recv\_n} Hop\_count$$

4.3 Simulation Results and Discussions:

This section discuss the performance improvements achieved by proposed AMDP protocol. Validation of improvements is done by comparing the findings with *BFP* protocol and conventional slotted delay based *S1PD* protocol. In the urban scenario, a circular region of 1 km diameter is taken as a reference measurement region. The number of hops and Mean delay parameters is measured around the boundary of that region. Fig-3(b) shows the measurement region over which statistics of *Hops* and *Mean Delay* are calculated.

Fig-4 Presents the average number of hops required to reach the Alert message to reach the boundary. AMDP and S1PD require the same number of hops to reach destinations. While hop-count of *BFP* rises exponentially with vehicle density.

Fig-5 shows the reachability percentage for all three discussed methods. A good alert dissemination protocol must have a high amount of reachability in the network with respect to node topology and node density. The similar reachability of AMDP with S1PD confirms that the delay improvement attempts in AMDP does not penalize the net reachability count in the network.

Fig.-6 presents the plot of Mean delay Vs Node Density. It is apparently visible that AMDP offers optimum delay performance compared to S1PD protocols. At node density 400, AMDP offers 28% reduced delay compared to S1PD respectively. Throughout the evaluation scenario, minimum delay improvement over S1PD is 19%. The measured delay statics confirms the advantage of the adaptive contention window-based delay selection method.

Fig-7 presents total alert messages sent in the network by vehicles with respect to node density. As node density increases within the fixed geographical area, more nodes are reachable with fewer transmissions. The plot confirms that BFP generates high redundancy in the network by forwarding many alert messages in the network. It creates a broadcast storm problem in the network and net reachability gets penalized.

With this, we can conclude that the proposed method offers efficient and reliable emergency

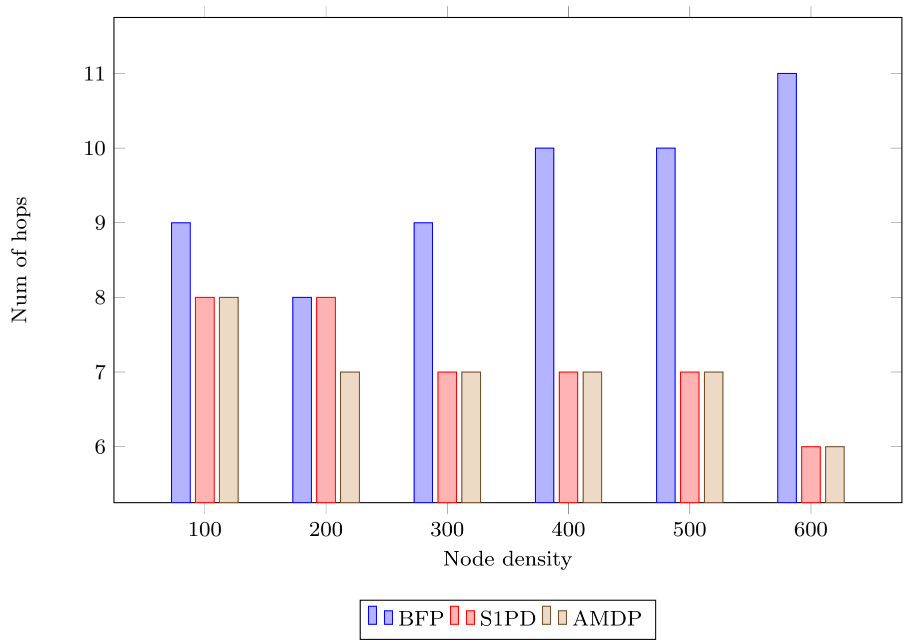


Figure 4. Number of Hops Vs Node Density

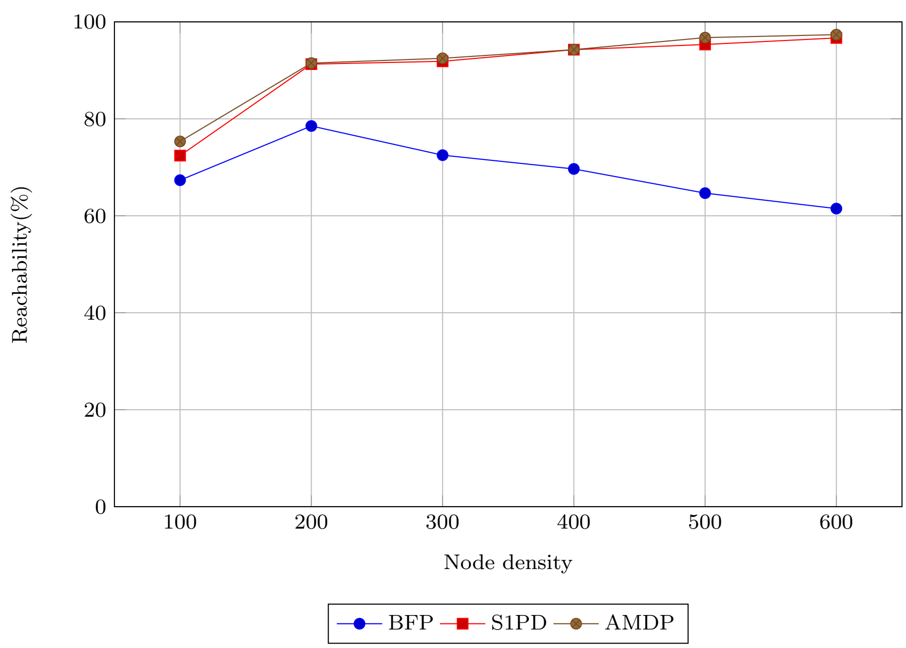


Figure 5. Reachability (%) Vs Node Density

message dissemination. Consistent performance over a wide range of vehicle densities confirms its validity for scalable protocols for practical vehicular network scenarios.

5. CONCLUSION

Multi-hop message dissemination for safety applications is a challenging task due to rapidly changing road topologies, vehicle densities, and short transmission range. This paper presents a

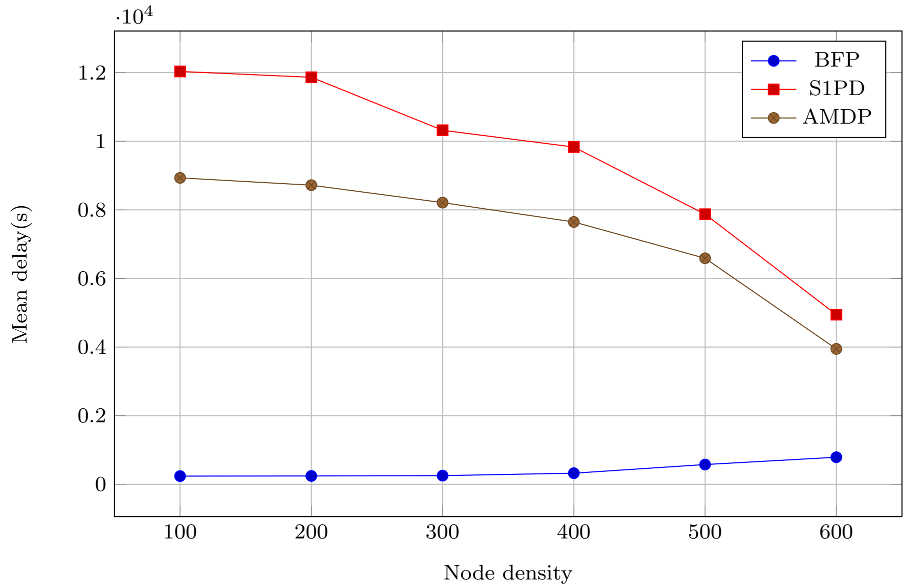


Figure 6. Mean delay time Vs Node Density

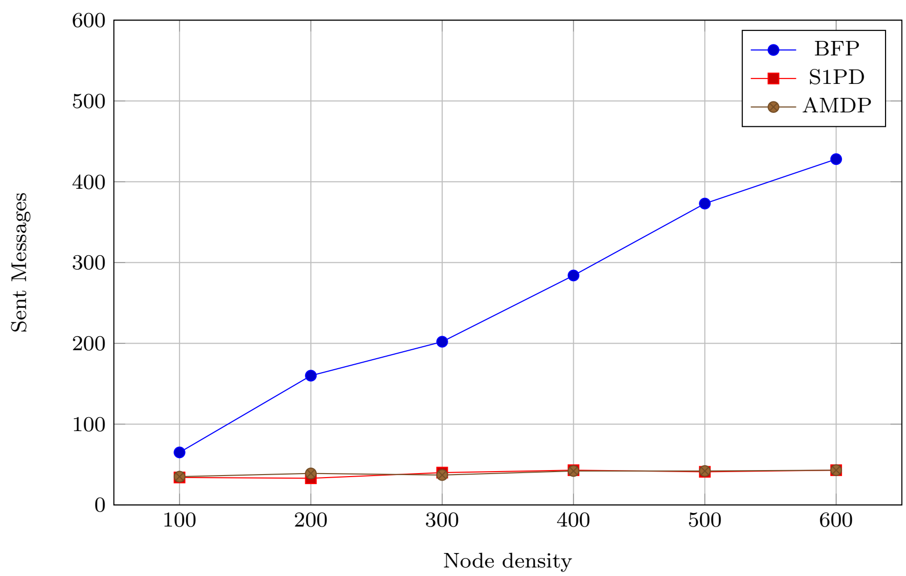


Figure 7. Total Sent Messages Vs Node Density

multi-hop message dissemination protocol (AMDP) that addresses scalability and delay performance without degrading network coverage. AMDP employs efficient relay node selection and redundant message suppression techniques to reduce overhead and delay in message transmission. The use of neighbor vehicle density and transmission range of forwarding nodes results in an effective reduction in delay, increased reliability, and high coverage.

The simulation results show AMDP provides high data delivery and disseminates the messages in the network with a low delay compared to S1PD and Flooding protocols. Therefore, it is suitable to implement fast and reliable traffic safety applications in vehicular networks. AMDP's stable performance in a high-dense urban environment with no infrastructure support makes it a suitable candidate for next-generation Internet of vehicles (IoV) technology.

In future work, priority-based message scheduling to extend AMDP as a non-safety message dissemination scheme can be studied. Another future research direction can be to enhance privacy and security in safety applications.

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