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A Dynamic Congestion Control Scheme for safety applications in vehicular ad hoc networks☆

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ABSTRACT

In recent years, various types of applications have emerged from Vehicular Ad hoc Networks (VANETs) for safety, infotainment, rescue and security purposes. Safety applications have their own strict communication requirements, and they require reliable and timely data communication within networks. Due to a variety of network applications, safety applications have been negatively impacted by communication channel congestion issues. Channel congestion leads to packet loss, delay and unreliability issues, and has a serious impact on vehicular traffic, including road accidents, road jams, and wrong traffic decisions. In addressing these issues, this paper's authors have proposed a Dynamic Congestion Control Scheme (DCCS) as a means of reliable and timely data delivery, in safety applications. The proposed scheme is designed for communication channels, as a means of broadcasting safety messages, and to ensure the reliable and timely delivery of messages to all neighbours in a network. The DCCS scheme is designed for inter-vehicle communication, without fixed infrastructure. Comprehensive simulation is conducted, in order to evaluate the performance of a proposed scheme, and to compare it with other state of the art schemes.

1. Introduction

Vehicular Ad hoc Networks (VANETs) primarily provide data communication among vehicle nodes, without any infrastructure or centralized communication administration. The main aim of these networks is to support traffic monitoring systems, and to maintain network efficiency, through improving data communication processes and the performance of wireless communication channels [1]. Various types of safety and infotainment applications have been designed for VANETs, including emergency alert, accident notification, curve alert, file-sharing, internet, and advertisements. Vehicle nodes generally disseminate two types of information, related to traffic event-driven and traffic management messages [2]. The traffic management messages are hello messages (beacons), which are periodically broadcasted within the network, and contain vehicle nodes position, speed and direction information. On the other hand, event-driven or safety messages are broadcasted in the case of emergencies, such as collisions, accident and road surface collapse. Safety applications have gained popularity due to recent dense and sparse traffic con-

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ditions. Event-driven messages in the network require reliable and timely data transmission, in order to distribute emergency notification messages [3]. If these messages are not delivered to the network in a timely way, this might result in serious impacts, including accidents, traffic jams, and wrong traffic decisions. In VANETs, a large number of vehicle nodes transmit safety messages, multiple times, over a high frequency. In dense situations, this multiple broadcasting of safety messages builds congestion in communication channels, causing network overhead, packet loss and delay issues. For in-time data delivery, the load of safety messages on communication channels should be precisely monitored, in order to fulfill all communication requirements.

In VANETs, the traffic situation frequently changes between alternately sparse and dense conditions, resulting in dynamic, unpredictable, and highly-mobile vehicle nodes, degrading application performance. Most safety applications have been affected by channel congestion issues, especially in dense traffic situations where several vehicle nodes disseminate safety messages to other vehicles. In order to address channel congestion issues, various congestion control schemes have been proposed [4–6]. In these schemes, a different method has been adopted for the purpose of detecting and controlling congestion. The development of an optimal congestion control scheme has faced many challenges, because of dynamic and frequently-changing topologies, and a high-mobility of vehicle nodes [7]. Most existing schemes cannot be directly adapted to event-driven or safety applications, due to stringent requirements regarding data reliability. Some schemes focus only on one type of event-driven messages, such as the application of the emergency brake light while forwarding [8]. However, the requirements of various safety applications are different from each-other, such as pre-crash sensing, traffic signal violation, and lane-changing warning messages. It is difficult to meet all safety applications requirements.

In order to address aforementioned congestion issues, this paper's authors propose a Dynamic Congestion Control Scheme (DCCS) for safety application in VANETs. The main aim of a congestion-control scheme is to control communication channels when these channels are overloaded. The proposed scheme detects congestion and control, by exploiting existing network resources for road traffic safety and cum security. In summary, the main objectives of this research can be generalized as seeking to determine whether:

1. If when monitoring the communication channel load, a congestion detection scheme will reduce congestion by using realistic weighting factors.
2. If after congestion detection, a congestion control scheme can control congestion through message originated-based queue freezing, and through adaptive congestion control methods.

The remainder of this paper is organized in the following way: Section 2 presents related works within the field. Section 3 introduces a proposed congestion scheme, based on congestion detection and control methods. The simulation results, and corresponding performance evaluations, are discussed in Section 4. Section 5 concludes the paper, by suggesting future research directions.

2. Related work

A congestion control mechanism has not been well established in VANETs, when compared to wired and stationary networks. Therefore, various congestion control schemes have some limitations within these networks. These schemes face difficulties in handling self-organized and distributed networks. In the following section, the researchers discuss work related to the field of congestion controlling in VANETs.

According to Hannák [9], congestion control schemes can be divided into two main categories, namely reactive and proactive. The reactive type of control scheme reduces the network load, by obtaining feedback from the network. These schemes can control first-order feedback about channel state, and react on values instead of predefined thresholds. One main drawback of reactive schemes, is that they only act after congestion is detected, resulting in a consequential switch to the recovery phase – this results in delay in the network. The second type is proactive, preventing congestion from happening in the first place. In addition, proactive schemes are based on built-in systems. These schemes can estimate traffic in next-time instances. These schemes are highly dependent on the accuracy built-in system model's accuracy, and its prediction of future traffic.

Congestion control schemes are based on different approaches, including measurement-based detection, queue freezing, transmit power control, and MAC blocking. The measurement-based detection refers to a scheme which detects and monitors congestion in the communication channel, by periodically sensing the channel, based on a predefined threshold. The threshold measures packet queue length, channel usage, channel occupancy time, and event validation.

In queue freezing schemes, every vehicle node determines brute force queue freezing for transmission, instead of high-priority messages for safety applications. For instance, if a vehicle node detects an event-driven message, it will freeze all beacon safety messages in the Control Channel (CCH). The queue freezing schemes of VANETs have been extensively studied by Mughal and Wagan [10], and by Bouassida and Shawky [11]. These schemes have some serious impacts on the performance of safety applications, due to queues stopping, after detecting event-driven safety messages.

Transmitting power control provides point-to-point communication, and minimizes energy consumption. Basically a higher data rate usually needs higher transmission from the sender side, which may cause high interference in the network. The transmit power control-based detection schemes in VANETs have been extensively studied by Le and Baldessari [12], and by Bratko and Michalski [13]. A Media Access Control (MAC) layer blocking method in congestion control, is used for the immediate and aggressive control of beacon message transmission, as a means of mitigating congestion. He and Chen [4] present a method for the congestion control of Dedicated Short-Range Communication (DSRC). The MAC blocking method provides very high data transfer rates, when latency is minimized through wireless channels.

Some other congestion control schemes are single-rate, multi-rate, rate-based and window-based. Window-based schemes, involves the use of a congestion window at both the sender and receiver sides, and the size of window increases or decreases, based on congestion state. On the other hand, rate-based schemes utilize transmission rates, based on feedback algorithms. In addition, unicast protocols have used single-rate schemes. Therefore, the sending rate should be accepted, based on the receiver side only. The last multi-layer category adopted a layered multicast approach [14].

Another Distributed-Fair Power Adjustment scheme for VANETs (D-FPAV) was proposed by [15]. This scheme has a dynamic control strategy, through which it controlled the congestion transmission range, especially for the safety applications of VANETs. The short beacon messages are periodically broadcasted, and this updated information relates to vehicle speed, direction, and position information, among vehicle nodes. The safety application messages are initiated, based on network events. Whenever this scheme faces congestion, beacon messages are shrunk along its transmission range. In order to avoid communication overhead, vehicle density is used to evaluate transmission range value. However, if this scheme has one main drawback, it is the reduced probability of receiving beacon messages, especially from a long distance, because the transmission range is decreased. On the other hand, high traffic density, and greater beaconing, consumes more bandwidth through a communications channel. This issue leads to the degraded performance of safety applications, which are not able to handle unique VANETs characteristics.

Zang and Stibor [16] have proposed Congestion Control for Vehicular Safety Applications (CC-VSA). Within this scheme, two concrete congestion control approaches have been introduced through manipulating the MAC transmission queues. This scheme has two types of congestion detection methods, including measurement and event-driven detection. Within event-driven detection, the safety applications control congestion, when a device detects safety messages that are either generated independently, or are received from other devices, and launched congestion control. On the other hand, in terms of measurement-based congestion detection, each device periodically senses channel usage levels, and detects congestion whenever the measured channel usage level exceeds a predefined threshold. After congestion detection, the scheme initiates congestion control through Media Access Control (MAC) queue manipulation. Upon the detection of safety messages, the scheme applies brute force queue freezing for all the MAC transmission queue, except in terms of the safety messages queue. In addition, the origin of a message with a time stamp is not considered to be congestion detection, which can lead to inappropriate congestion detection within the scheme. Moreover, through channel usage measurement, the weightage of parameters including channel busy period, a back-off period, and the Arbitration Inter-Frame Space (AIFS), are all not utilized. Therefore, equal weightage has to be considered. However, these parameters have significantly-differing impacts on channel usage [17].

CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) is used in VANETs. This standard was redefined by IEEE 802.11p/WAVE [18]. This scheme is used as a default strategy for congestion control, and is based on the exponential back-off method for controlling congestion. However, the exponential back-off method is not appropriate for disseminating beacon messages within the network. This scheme does not work well when the message generation is set to a high frequency within the network. In addition, whenever beacon messages time-out in the network, this leads to packets dropping before data transmission. Various schemes designed for VANETs are based on adjusting transmission frequency and range. However, sometimes the congestion occurs because of a malfunctioning CSMA in the MAC layer, especially in a high-traffic density situation.

Baldessari, et al. [19] proposed another congestion scheme, based on transmission rate adjustment. This scheme aims to fairly assign vehicle nodes resources within a network. In this scheme, the channel busy time is used as a counting metric for estimating traffic density, and the numbers of vehicle nodes in surrounding areas. In addition, the transmission rate is adjusted to a predefined threshold, or to the estimated traffic density within a network. However, this scheme does not provide for fair and safe channel usage, because it does not utilize channel bandwidth.

A Street Broadcast Reduction Scheme (SBR) was proposed by [20], as a means of addressing broadcast storm issues in VANETs. In SBR, the source vehicle broadcasts the message *‘m’* to all its neighbors, indicating that the message has been sent, or received by each vehicle node. If any vehicle receives *m* for the first time, that vehicle rebroadcasts it to its neighbors only when the distance between the source and the destination is greater, or has been received in a different street. SBR combines with the location base scheme, and rebroadcasts the warning messages only if they appear on a different street. However, the VANETs topologies are dynamic and highly mobile. These types of rebroadcasting schemes have suffered due to network overhead, especially on the MAC layer.

Huang, et al. [21] proposed the vehicle oriented congestion control algorithm (AVOCA). This scheme is optimized through a network, resolving the congestion issue at the transport layer. However, controlling the congestion at a transport layer leads to connectivity failure between vehicle nodes in a coverage zone. This scheme has its performance threshold at the transport layer, which controls packet transmissions. The performance threshold increases whenever the vehicle nodes enter the coverage zone. Following this, the parameters of congestion control are reset and the packet transmission is consequently initiated. The performance threshold decreases whenever the vehicle node exits the coverage zone. This situation causes the termination of the data transmission, and also the freezing of other parameters of congestion control. Although this scheme has better throughput, the delay is upwards of 60 microseconds. The higher rate of a beacon message in the network leads to congestion, especially within dense situations.

A three-phase congestion control scheme was proposed by [6]. This scheme prioritized beacon messages, and detected channel congestion, and then tuned the transmission rate. This scheme prioritizes messages through a number of hops during message traveling. After this, the scheme detects congestion by determining average collision rate, waiting time, and beacon reception rate metrics. Transmission power is adjusted, as based on previous phases. This helps utilize channel bandwidth in a better way. The scheme ensures the data delivery and reliability of VANETs. However, delay is higher in this scheme due to its transmission range adjustment.

Uni-Objective Tabu Search (UOTabu) was proposed by [22] for VANETs. This scheme adopts a measuring method for controlling a communication channel's congestion, by calculating channel usage level and transmission range, and the rate is consequently tuned by minimizing the delay function. This method is used in the Tabu list, as short-term memory for the Tabu search algorithm. This scheme is a uni-objective scheme, which considers delay to be an objective function. The authors compared the scheme with the CSMA/CA, UOTabu and D-FPAV schemes. After comparison, it can be determined that UOTabu decreases delay and packet loss, and increases throughput. However, this scheme suffers from computational complexities, through the Tabu search algorithm.

Context Awareness Beacon Scheduling (CABS) has been proposed in [23], as a means of addressing the congestion issue in VANETs. This scheme adopted a unique distributed method for scheduling beacon messages. CABS uses spatial context information, for dynamically scheduling beacon messages, in terms of vehicle speed, position, and nodes direction. Then, the vehicle node possesses a time slot, in terms of TDMA-like transmission. In this scheme, the channel access delay and packet reception rates are improved, and channel congestion is addressed through tuning the beacon frequency. This scheme does not use the interworking of the MAC layer, as a means of adjusting the time slot for different data transmissions. Table 1 presents a comparison of all aforementioned congestion schemes.

2.1. A comparison and discussion of congestion control schemes

A number of schemes have suggested through literature focusing on congestion control, within a vehicular environment. These schemes utilized different congestion control methods, such as transmission power control, contention window adaptation, and control rate adaptation. D-FPAV [15], Combined Transmit Power and Rate Control Algorithm [19], SBR [20], UOTabu [22] and CABS [23], all utilize transmission power control and rate adaptation as a means of controlling congestion by increasing or decreasing transmit power. Increasing broadcast power leads to an increase in wireless channels, reducing the performance of communication systems. On the other hand, small transmit power leads result in direct impacts on selecting the next hop, due to dynamically-changing topologies, especially in sparse areas. These techniques result in isolating vehicle nodes in dense situations, due to frequently-changing topologies, and the high mobility of nodes in networks. However, these schemes have suffered various issues such as transmission delay, communication overhead, and inefficient bandwidth utilization [5,24].

Some schemes have utilized contention windows to overcome congestion. In Zang and Stibor [16], the origin of a message with a time stamp is not considered an example of congestion detection, which may lead to inappropriate congestion detection. Moreover, in a channel usage measurement, the weightage of parameters including channel busy period, back-off period, and Arbitration Inter-Frame Space (AIFS), are not utilized. Consequently, equal weightage is considered. However, these parameters have differing impacts on channel usage. The main objective of VANETs application is to provide convenient comfort to travelers and drivers. In order to achieve this objective, disseminating safety messages without creating network delays presents a challenge. This challenge is a result of dynamic topologies, high traffic density and the number of beacon messages, all of which cause congestion in control communication channels. Therefore, the performance of safety applications is degraded due to the delay or failure of beacon messages. Therefore, communication channels should be free from congestion, and should thereby ensure the timely delivery of messages in the network [25,26]. Contention-based MAC schemes are more robust, in terms of changing the network, and they require less configuration time than contention-free schemes [27]. However, these schemes still

Table 1
Comparison of congestion control schemes for VANET.

VANET Congestion Control Schemes	Transmission power control	Contention window adaptation	Beacon rate adaptation	Periodic beacon messages	Safety messages	Urban environment
D-FPAV [15]	√	×	×	√	√	×
CC-VSA [16]	×	√	×	×	√	×
Carrier sense multiple access with collision avoidance [18]	×	√	×	√	×	×
Combined transmit power and rate control algorithm [19]	√	×	√	√	√	×
SBR [20]	√	×	×	×	√	√
AVOCA [21]	×	√	√	√	×	×
Robust congestion control scheme [6]	√	×	√	×	√	×
UOTabu [22]	√	√	√	√	√	×
CABS [23]	√	×	√	√	√	√

have some limitations behind handling the exclusive characteristics of VANETs, such as high mobility conditions, dynamic network topologies, and extreme multipath environments. In order to address congestion issues, the following section discusses the proposed scheme in detail.

3. A dynamic congestion control scheme

Various types of different applications have been adapted, as a means of providing safety and comfort in VANETs. Safety applications are based on critical information, including accident detection and emergency messages, and accordingly they receive great priority within networks. A number of safety messages are sent from roadside units, access points or from neighbouring vehicles, thereby causing communication channel congestion. Due to the broadcasting of different application messages, the timely delivery of safety application messages remains a challenge to VANETs. The communication channels are become more congested, and cause network overhead, packet loss, and delay issues in the network. In order to solve the issue of congestion in networks, this research proposes a Dynamic Congestion Control Scheme (DCCS) as a means of improving safety message delivery. Fig. 1 shows the physical model of a DCCS congestion scheme.

In Fig. 1, vehicle node A detects self-originated event-based congestion, as caused by accidents, and launches congestion control through queue freezing and adaptive congestion control methods. On the other hand, vehicle B shows neighbor-originated event-based detection, and congestion control launch through time stamp-based queue freezing, and adaptive congestion control methods. Fig. 2 shows the complete flowchart of the DCCS scheme. Self-originated event-based congestion helps control critical situation in the network, through the queue freezing and adaptive congestion control method. In these methods, the DCCS monitors safety messages and applies congestion control, whenever safety messages originated from itself. As shows in the above Fig. 1, when a vehicle detects safety messages generated through its own application layer, this immediately launches congestion control, due to predictable traffic congestion. On the other hand, through the neighbour-originated event-based method, DCCS monitors safety messages received from neighbour nodes, and launches congestion control for safety messages. As shown in Fig. 1, when a vehicle receives different safety messages from neighbour nodes, it launches congestion control through the time stamp values of received messages.

Safety applications utilize beacon messages, as a means of broadcasting safety messages through control channels at the MAC layer. The MAC layer assigns these messages to different levels, based on message priority and importance [28]. When a number of safety messages are broadcasted in the network, the Control Channels (CCHs) are congested, and network performance decreases accordingly. In addition, during the transmission of these messages the resource demand exceeds available capacity, resulting in congestion. The details of congestion detection and controlling in DCCS is discussed in detail within the following sub-section.

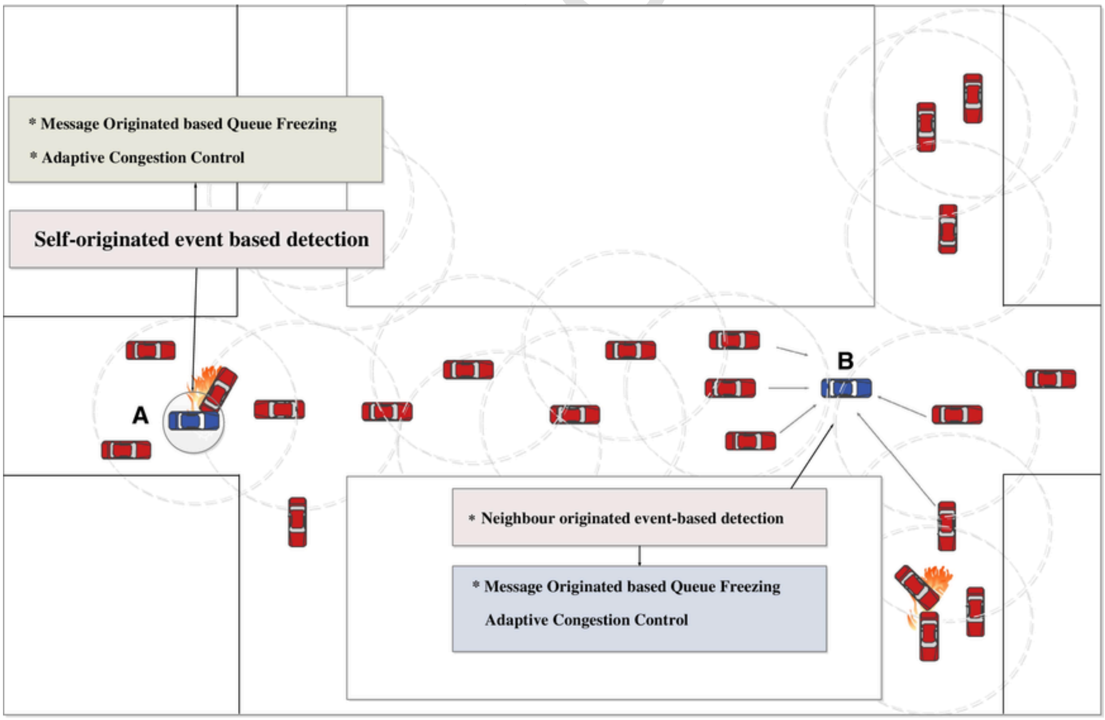


Fig. 1. Physical example of DCSS scheme.

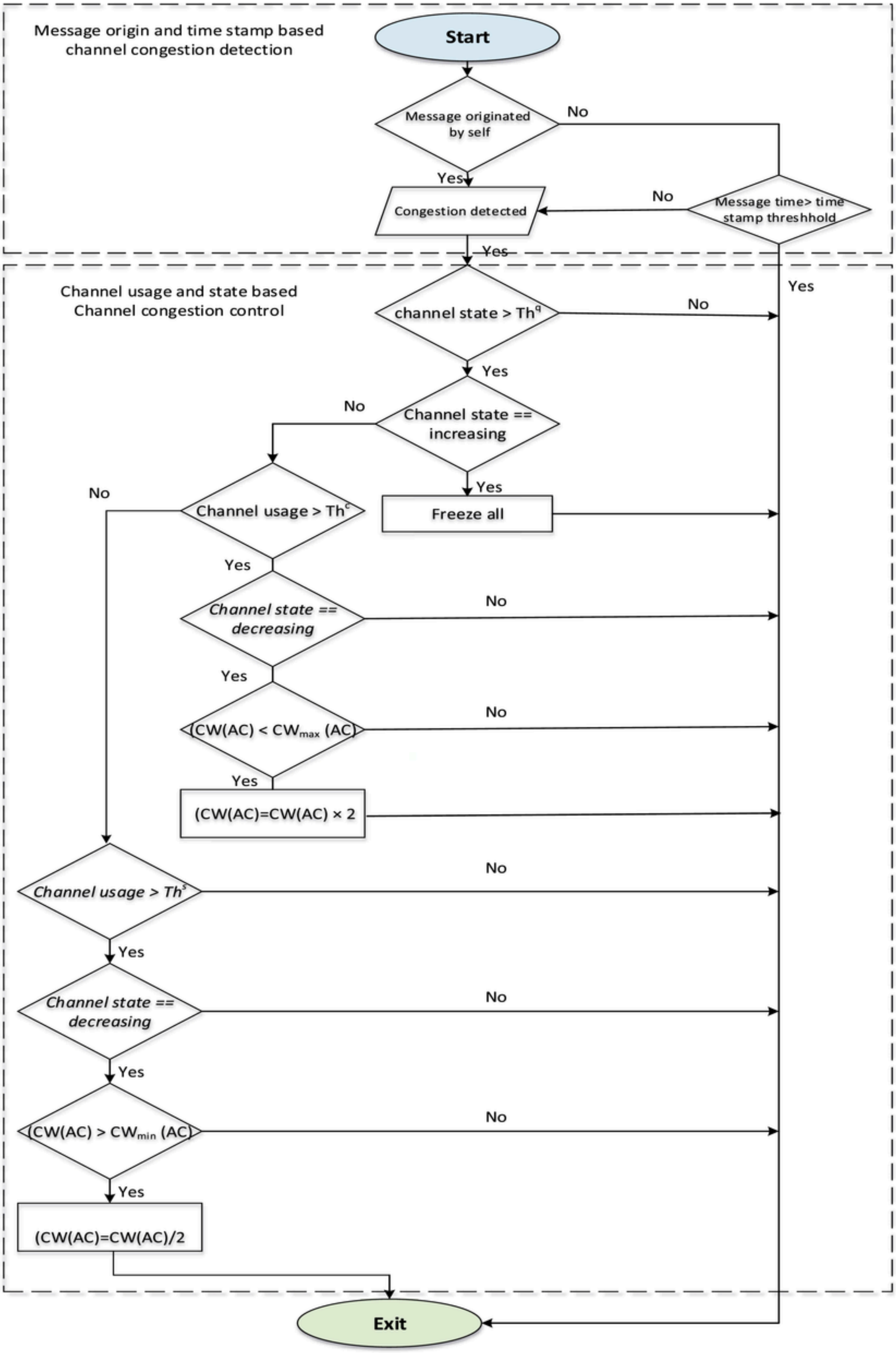

Message origin and time stamp based channel congestion detection
Start
Message originated by self
No
Yes
Congestion detected
No
Message time> time stamp threshhold
Yes
Yes
Channel usage and state based Channel congestion control
channel state > Th^q
No
Yes
No
Channel state == increasing
Yes
No
Channel usage > Th^c
Freeze all
Yes
Channel state == decreasing
No
Yes
(CW(AC) < CW_max (AC)
No
Yes
(CW(AC)=CW(AC) × 2
Channel usage > Th^s
No
Yes
Channel state == decreasing
No
Yes
(CW(AC) > CW_min (AC)
No
Yes
(CW(AC)=CW(AC)/2
Exit

Fig. 2. Flow chart of DCCS scheme.

3.1. Congestion detection

In this section, the congestion detection methods discussed include self-originated event-based detection, and neighbour-originated event-based detection. Therefore, a channel evaluation is undertaken based on its usage, introduced with the consideration of realistic weighting factors.

(i) **Self-originated event-based detection:** The self-originated event-based detection method monitors safety messages and consequently applies congestion control, whenever safety messages are originated from themselves. For example, when a vehicle detects safety messages generated from its own application layer, it immediately launches congestion control, due to predictable congestion.
(ii) **Neighbour-originated event-based detection:** The neighbour-originated event-based detection method monitors safety messages received from neighbour nodes, and launches congestion control for safety messages. For example, when a vehicle receives different safety messages from neighbour nodes, it launches congestion control through the time stamp values of the received messages.

After the verification of the above two methods, channel usage is examined based on measurement. For the purposes of channel usage measurement, each vehicle periodically senses the channel usage level, and makes a decision about congestion should the channel usage level exceed the predefined threshold, or should the channel increase its traffic state. The communication channels are measured by message queues, channel occupancy, and usage level. The DCCS scheme measures medium busy time and channel usage levels. The average medium busy time refers to the time when the wireless medium is busy, due to transmission from nearby vehicles in the network. In addition, this metric also shows the vehicle density and the packet exchange rate among vehicles. After determining the average waiting time, the scheme computes channel usage levels through channel busy duration, and mean back-off duration.

The channel usage level is calculated through every control channel interval, through Eq. (1).

$$\text{Channel usage} = \frac{\sum\left(wt_{busy} \times D_{busy} + wt_{backoff} \times D_{backoff} + wt_{AIFS} \times D_{AIFS}\right)}{D_{CCH}} \times 100\% \tag{1}$$

The $\sum$ numerator denotes the estimated overall channel busy time of n messages, as sensed by one Control Channel (CCH) interval. $wt_{?busy}$ denotes the weighting factor of the channel busy time, and $D_{?busy}$ denotes the channel busy duration for every sensed message. $wt_{?backoff}$ denotes the weighting factor of the mean back-off duration of safety messages, and $D_{?backoff}$ denotes the mean back-off duration of the messages. The last factor, $wt_{?AIFS}$, denotes the weighting factor of message length, and $D_{?AIFS}$ denotes the safety message length. $D_{?CCH}$ denotes the duration of one control channel interval. The three weighting factors $wt_{?busy}$, $wt_{?backoff}$ and $wt_{?AIFS}$ are assigned comparative weightage between 0 and 1. The sum of all three weight values is always 1. The comparative weightage is assigned using Algorithm 1.

The weighting factors are assigned to values, according to the realistic impact of corresponding parameters regarding channel usage or business. After computing the medium busy time and channel usage level values, these values are compared with a predefined threshold. According to Zang and Stibor [16], the channel usage is equal to or less than 70% (≤70%), which for communication channels is considered to be a normal state, while a channel usage of more than 70% (>70%) is considered to be a congested state. In this proposed work, the above-fixed usage level is modified. The three usage levels are considered to include 30%, 70%, and 90%, with the state of the channel either increasing or decreasing (±5%). The weighting factors are calculated, considering the increased significance of a busy channel situation, within a dense vehicular traffic environment. In the case where the current back-off duration is greater than the average back off duration, the increasing weighting factors are considered

Algorithm 1
Weighting factors assignment.

if $(D^{max}_{backoff} - D_{backoff} > \left(\frac{D^{max}_{backoff}}{2}\right))$ *then*
 $wt_{?busy} = 0.5$
 $wt_{?backoff} = 0.35$
 $wt_{?AIFS} = 0.15$
else
 $wt_{?busy} = 0.5$
 $wt_{?backoff} = 0.25$
 $wt_{?AIFS} = 0.25$

to be AISF, back-off and busy weights. Otherwise, AISF and back-off weights are considered equal, but the busy weight is still greater. This is explained within the next congestion control section.

3.2. Congestion control

The congestion control phase allows for congestion-free channels for safety messages. The two methods are used for congestion control within DCCS, including message originated based queue freezing, and adaptive congestion control methods. These two methods are also explored by Zang and Stibor [16] in Congestion Control for Vehicular Safety Applications (CC-VSA,) but both these methods are quite different in this paper's proposed DCCS scheme, operationally, which enabled it to control congestion better than the schemes presented in literature, particularly CC-VSA. In queue freezing, DCCS incorporates message time stamp, enabling better congestion prediction than the CC-VSA time stamp. In adaptive congestion control, DCCS utilizes three channel levels, which include 30%, 70% and 90%. For channel level determination, which is quite better than the fix one level, there is a 70% determination of CC-VSA. Both these techniques are discussed in detail within the following sub-sections.

(i) **Message originated based queue freezing:** In DCCS, in message-originated queue freezing based congestion control, MAC queues are frozen based on the message origin point. The origin point of the message is either itself, or a neighbor. The neighbor-originated message requires time stamp verification. Meanwhile, the complete process of queue freezing is provided in Algorithm 2.

(ii) **Adaptive congestion control:** The adaptive congestion control method provides a dynamic reservation fraction of bandwidth for safety applications. In this method, two types of strategies are used, specifically level based and channel usage state based strategies. In the level based form, three separate levels are defined, which include 30%, 70% and 90%, where a channel may fall. After determining a channel's level, the channel usage state is identified by monitoring the channel for the specific time calculation. The $\pm 5\%$ channel usage within this duration determines the channel state. The channel is considered to be in an increasing state if it registers traffic higher than 5%, and to be in a decreasing state, if traffic is reduced by 5%. The process of adaptive congestion control is presented in Algorithm 3.

The main purpose of the DCCS scheme is to detect and control congestion, and to give priority to safety packets, in order to determine which packet is to be transmitted first. The scheme is helpful for delivering safety messages, without any delay in the network, and for reducing congestion on communication channels.

4. Simulation results

This section presents the simulation set-up, used to evaluate the DCCS scheme. The MOVE is used for mobility generation, based on SUMO, as an open source simulation package for VANETs. The simulation parameters include the following:

- **Physical layer:** For the physical layer, the Nakagami propagation model is used.
- **Mobility and traffic model:** The total selected area is 2000 m × 2000 m, and the map is extracted from the open street map in an osm.eml format from the TIGER (Topologically Integrated Geographic Encoding and Referencing) database, for the U.S. Census Bureau as presented in Fig. 3 [29]. The speed of the vehicle nodes is set at 30–100 km/h in the presence of 150, 250 and 350, vehicle nodes.
- **Network and media access control layers:** The contention window size is 15–1023, and the data rate is set at 3 Mb/s for packet broadcasting. Lower data rates are feasible against interference and noises in the network, and most of the authors were preferred for safety messages [30]. The transmission range has been set at 300 m. The standard IEEE 802.11p is used for the MAC layer, with a 10 MHz channel bandwidth [30].
- **Simulation time:** The total simulation time is 450 s for one round, where the settling time is 50 s from the beginning, in order to remove the impact of transient behavior from results. The total 25 simulations are running with 95% confidence intervals.

Algorithm 2
Queue Freezing.

```
if      (A safety message is self-generated)
    Freeze all MAC queues immediately for all other messages except for the safety queue;
else if     (Safety message received from neighbours)
    If (message-time stamp > threshold – time stamp)
    Continue; || message is old therefore no need queue freezing
    else
    freeze all MAC queues immediately for all other messages except for safety messages;
    end if
End if
```

Algorithm 3
Adaptive congestion control.

Notations:
Increasing state: ± 5%
Decreasing state: – 5%
$Th^{?q:}$ Threshold queue freezing (90%)
$Th^{?c:}$ Threshold congestion (70%)
$Th^{?s:}$ Threshold sparse (30%)
CW: Contention window
AC: Access category
if (channel state > $Th^{?q}$)
  If (Channel state == increasing)
  Freeze all;
  else if (Channel usage > $Th^{?c}$)
   If (Channel state == decreasing)
   if (CW(AC) < $CW_{?max}$ (AC)
   (CW(AC) = CW(AC) × 2
   end if
  end if
  else if (Channel usage > $Th^{?s}$)
   If (Channel state == decreasing)
   if (CW(AC) > $CW_{?min}$ (AC)
   (CW(AC) = CW(AC)/2
    end if
  end if
 end if
end
If

Fig. 3. Fragmented city map for simulation in SUMO [29].

DCCS is compared with three existing schemes, namely Street Broadcast Reduction (SBR) [20], Context Awareness Beacon Scheduling (CABS) [23], and Congestion Control for Vehicular Safety Applications (CC-VSA), as proposed by [16]. The simulation results are based on performance metrics, including packet average delay, packet loss ratio, and average throughput (Mbps), with different parameters including numbers of vehicles and simulation time. The performance metrics details include the following:

- **Packet average delay:** The average delay refers to the time required to deliver data packets from source to destination.
- **Packet loss ratio:** Packet loss occurs when data packets fail to reach destination, especially in congested situations. Through packet loss ratio, this paper's authors measured the total number of loss data packets as a means of estimating network performance.
- **Average throughput:** The average throughput is used to evaluate the average value of computed transmitted messages, over a communication channel, at the MAC layer.

To test these performance metrics, this study conducted various experiments, with different parameters including different vehicle densities and velocities within an urban environment.

4.1. Traffic density analysis

In this section, DCCS performance is investigated through different traffic densities. In a dense network, vehicle nodes are in high numbers, and their transmission range is available for communicating with each other. In a sparse network the situation is the opposite, due to the distance between vehicles. Fig. 4 shows the packet loss ratio, between average delay and throughput, and the number of vehicles, in order to check the effectiveness and performance of a DCCS scheme (together with the network's existing schemes).

In addition, the SBR rebroadcasts safety messages through location services, and uses a computational overhead. Moreover the graph also indicates that by increasing the number of vehicles in the network, the packet loss ratio likewise increases. However, when compared to the existing scheme, the ratio of the DCCS scheme is less, and at it shows better performance within an urban environment, and improves safety applications' services in VANETs.

The second experiment is with the number of vehicles, used to evaluate the average delay. Fig. 4(b) depicts the average delay with a number of DCCS vehicles, compared with the existing SBR and CABS schemes. When the number of vehicles increases by up to 100 or 150, the delay increases in all schemes. However, DCCS performance is better when compared to two other existing schemes. In addition, the CABS delay is less than that of SBR, due to beacon scheduling and the tuning of beacon frequency, instead of rebroadcasting. The average delay in the presence of 150 nodes, as faced by DCCS, CC-VSA, SBR and CABS, is 0.352 seconds, 0.425 seconds, 0.505 seconds and 0.558 seconds, respectively. This means the DCCS is more effective in terms of its delay, by factors of 17.17%, 30.29% and 36.9%, for CC-VSA, SBR and CABS, respectively.

The impact of the average throughput, with the number of vehicles in Fig. 4(c), depicts the performance of DCCS when compared with existing SBR and CABS schemes. The results show that throughput increases, through increases in the number of vehicles in the network, because increasing the numbers causes an increase in the number of delivered packets. The performance of the DCCS is more desirable, when compared to existing schemes. CABS is slightly better than SBR, because of the tuning of beacon messages. The average throughput achieved by DCCS, CC-VSA, SBR and CABS, is 12.96 Mbps, 12.15 Mbps, 9.81 Mbps, and 11.34 Mbps, respectively. This means that the average throughput achieved by DCCS is 2.52% greater than CC-VSA, 32.11% greater than SBR, and 14.2% greater than CABS.

The proposed and existing congestion control schemes for VANETs have been evaluated through a number of vehicles, in terms of packet loss, packet delay, and throughput. The results have revealed that the DCCS scheme outperforms, when compared to existing schemes.

4.2. Simulation with time analysis

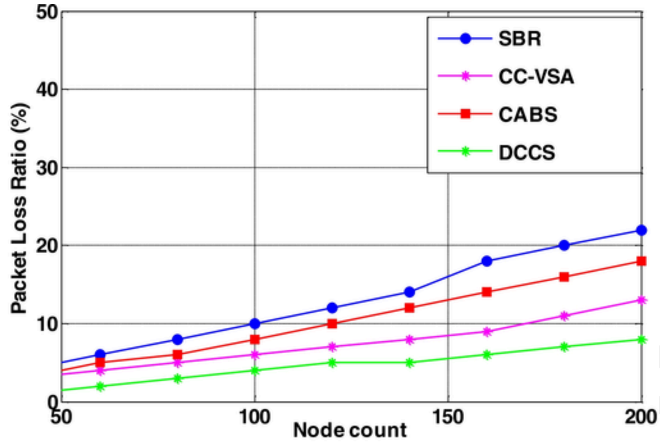
The performance of DCCS and existing schemes, have been investigated for the urban environment, in terms of simulation time. In Fig. 5(a), the average delay with the simulation time involves four levels of time, specifically 50, 100, 150 and 200. The results show that with the advancement of time, the delay of the data packets is decreased for all schemes. However, the DCCS has the lowest delay, when compared with the two existing CABS and SBR schemes. This delay is high at the beginning of simulation, due to greater collisions in transmission. The average delay in the presence of 200 nodes, as faced by DCCS, CC-VSA, SBR and CABS, is 0.728 seconds, 0.784 seconds, 0.973 seconds, and 0.882 seconds, respectively. This means the that DCCS is more effective, with a delay factor that is 5.6% greater than CC-VSA, 25.17% greater than SBR, and 17.46% greater than CABS.

The variation of average throughput, as presented in Fig. 5(b), indicates simulation time. DCCS has a larger throughput when compared to CABS and SBR, in terms of simulation time. In addition, less packet loss and increased packet delivery, automatically makes for a more efficient throughput within the network. The average throughput achieved by DCCS, CC-VSA, SBR and CABS, is 5.22 Mbps, 3.83 Mbps, 4.56 Mbps and 4.76 Mbps respectively. This means that the average throughput achieved by DCCS is 36% greater than CC-VSA, 14.47% greater than SBR, and 9.66% greater than CABS.

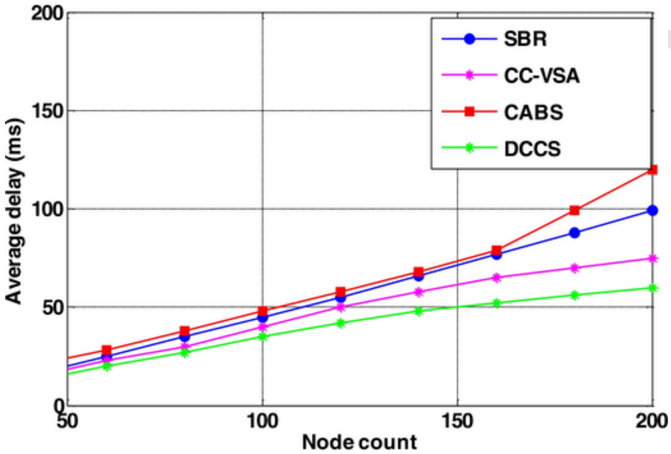
The simulation time results, in regards to average delay and throughput, are depicted through the greater performance of DCCS when compared to existing schemes. The average delay for SBR is greater than that of CABS, due to its rebroadcasting strategy, and the computational complexities faced within an urban environment. The CABS delay is better than SBR, due to beacon frequency tuning. On the other hand, with less delay, CABS is also superior to SBR in terms of throughput. Nonetheless, the DCCS is better in terms of all results, and is considered to be an efficient solution for VANETs, especially in regards to safety applications, and for time data delivery.

4.3. Comparison analysis for proposed and existing schemes

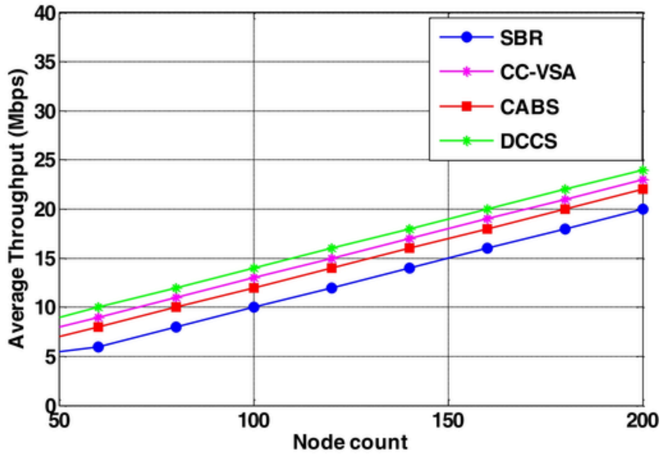
In this section, the simulation results are tabulated for identifying DCCS benefits, within a map-based scenario (see Table 2). In this comparison analysis, this paper's authors considered three evaluation parameters which include maximum, minimum and average values. It can be clearly observed that DCCS has a better performance, when compared to SBR, CC-VSA and CABS. In the case of traffic density, DCCS achieved a high level, performance, and has a reduced packet drop ratio when compared to state of the art schemes. In terms of average delay, again DCCS achieved better results, and this resulted in less delay time when



(a) Packet loss ratio with number of vehicle nodes



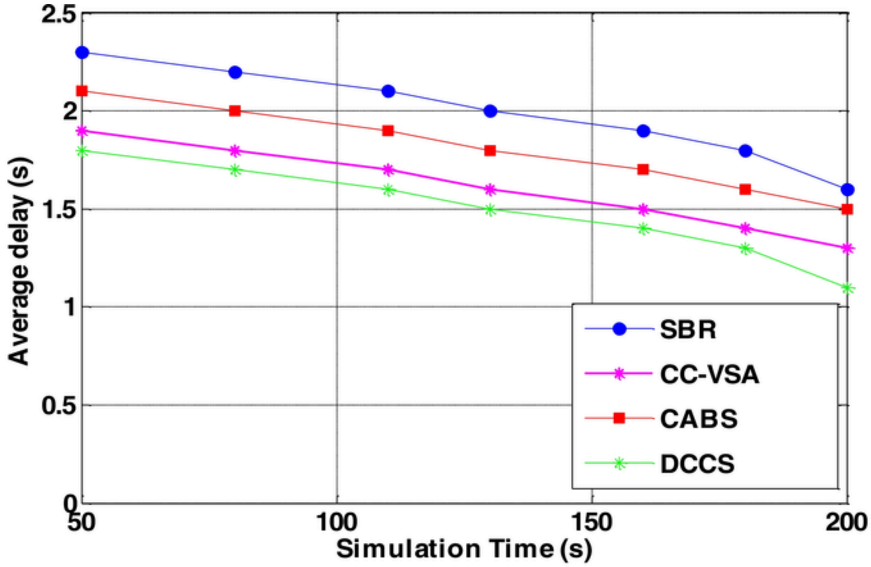
(b) Average delay with 200 vehicle nodes



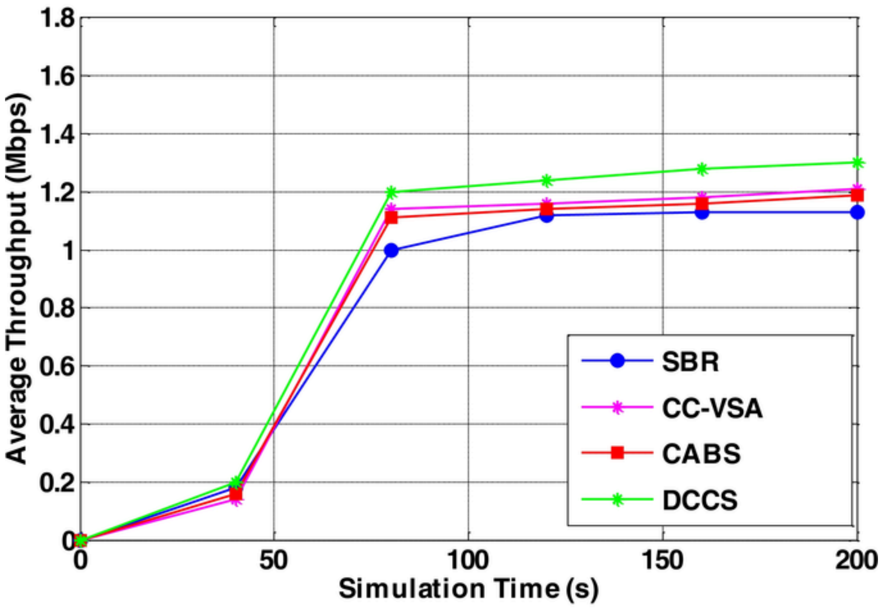
(c) Average Throughput with the number of vehicles

Fig. 4. (a) depicts a ratio between the number of packet losses and the number of vehicles. The graph clearly shows the degree of packet loss for the SBR, CC-VSA and CABS schemes, and the better performance of the DCCS scheme. Such improvement was obtained through DCCS congestion detection and controlling approaches, where the scheme monitors a self-originated event detection or neighbour-originated event-based detection, and then measures of the detection and launch congestion control mechanism used to broadcast safety messages. On the other hand, CABS schedules beacon messages by direction, position, and

speed metrics, and assign a time slot in order to solve the congestion issue by tuning the beacon frequency. However, the CABS scheme does not consider a mechanism used to adjust time slots for different transmissions. The average packet loss ratios achieved by DCCS, CC-VSA, SBR and CABS, are 3.69%, 5.95%, 10.26% and 8.28%, respectively. This means that the performance of the packet loss ratio as achieved by DCCS, with 200 nodes, is 37% less than CC-VSA, 64% less than SBR, and 55% less than CABS.



(a) Average delay with simulation time



(b) Average throughput with simulation time

Fig. 5. Simulation time analysis.

compared to SBR, CC-VSA and CABS. In addition, DCCS has a higher throughput when compared to other schemes. The second type of experiment generated results based on time analysis, in terms of average delay and average throughput. The average delay of DCCS is less, when compared to other schemes, which is a good sign for safety-based applications within the network. On the other hand, the average throughput of DCCS is greater when compared to SBR, CC-VSA and CABS. Table 2 shows the complete results of the proposed and existing schemes.

Table 2
Results comparison table.

Traffic scenario metrics	Performance metrics		SBR	CC-VCA	CABS	DCCS
Traffic density analysis	Packet loss ratio	Minimum	0	0	0	0
		Maximum	22	13	18	8
		Average	13	7	10	4
	Average delay	Minimum	0	0	0	0
		Maximum	99	75	120	60
		Average	58	48	63	40
	Average throughput	Minimum	0	0	0	0
		Maximum	20	23	22	24
		Average	12	14	14	16
Time analysis	Average delay	Minimum	0	0	0	0
		Maximum	2.1	2.1	1.7	1.6
		Average	1.175	0.9375	1.0625	0.8625
	Average throughput	Minimum	0	0	0	0
		Maximum	1.13	1.21	1.19	1.3
		Average	0.5475	0.46125	0.575	0.6275

5. Conclusion

This research work proposed a Dynamic Congestion Control Scheme (DCCS), based on congestion detection and controlling strategies. The main focus of this scheme is to improve the performance of VANETs safety applications, by monitoring the control channels at the MAC layer. The control channels are dedicated for safety messages, and due to the number of these messages, the channels are congested and consequently network performance is lowered. Most existing congestion controlling schemes are based on the tuning transmission frequency, or the increasing and decreasing broadcasting frequencies. Due to high mobility and interference in the network, these schemes have suffered from delay, and from packet dropping issues, and this has caused serious issues in VANETs. DCCS shows greater performance, in terms of data delivery, delay and data throughput in network. The simulation results reveal performance improvement achieved through DCCS, specifically in regards to number of vehicles, and simulation time. The performance of packet loss ratio with traffic density analysis, as achieved by DCCS, is 37% less than CC-VSA, 64% less than SBR, and 55% less than CABS. In regards to delay, the DCCS is more effective than CC-VSA, SBR and CABS, by 17.17%, 30.29% and 36.9% in terms of traffic density analysis, and 5.6%, 25.17% and 17.46% in terms of simulation time analysis, respectively. Lastly, the average throughput achieved by DCCS is 36% greater than CC-VSA, 14.47% greater than SBR, and 9.66% greater than CABS. In the future, this paper's authors will explore probabilistic traffic prediction techniques, considering the dynamic network environments in the vehicular scenario. Heuristic-based channel estimation, considering constraints in vehicular traffic environments, will also be researched.

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