ARTICLE IN PRESS
JID: COMCOM [m5G;April 22, 2016;11:59]

Computer Communications 000 (2016) 1–15

Contents lists available at ScienceDirect

Computer Communications

journal homepage: www.elsevier.com/locate/comcom

# An adaptive relay nodes selection scheme for multi-hop broadcast in VANETs

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ARTICLE INFO

*Article history:*
Received 27 February 2015
Revised 3 January 2016
Accepted 14 April 2016
Available online xxx

*Keywords:*
VANETs
Link quality
Multi-hop
Packet delivery ratio
End-to-end delay

ABSTRACT

Vehicular ad hoc networks (VANETs) have potential applications for improving on-road driving experiences including preemptive road safety measures and provision for infotainment services. This paper proposes a Bi-directional Stable Communication (BDSC) relay nodes selection scheme designed for multi-hop broadcasting protocols over a platoon of vehicles. Relay nodes selection is based on quantitative representation of link qualities for single-hop neighboring nodes by using a proposed link quality estimation algorithm. The BDSC scheme aims to improve packet delivery ratio while maintaining low end-to-end communication delays over a densely populated network with nodes distributed over a large coverage area. To achieve this, the proposed scheme attempts to adaptively balance between the estimated link qualities and the distance between the source broadcaster and the potential forwarders when selecting the next hop nodes for relaying the broadcast messages. Our results from extensive simulation analysis reveal that the proposed BDSC scheme outperforms existing multi-hop broadcasting schemes in terms of packet delivery ratio when evaluated over a densely populated VANETs.



## 1. Introduction

Many academic as well as industrial experts expect vehicular ad hoc networks (VANETs) to become the de-facto enabling technology for communication among vehicles on the road [1–5]. The scale of research projects, road tests and government investments in VANETs has intensified over the past few years [6–10]. This has been fuelled by the fact that VANETs can play a key role in improving traffic safety and efficiency by enhancing drivers' awareness of immediate and far distant traffic situations [11–13]. In addition, a variety of comfort and infotainment services is plausible to deploy over VANETs to further enhance on-road experience [13–16].

Large physical areas can be covered in a platoon of communication technology-enabled vehicles using a multi-hop propagation scheme, where assistance from intermediate relay nodes is used for forwarding messages to their final destination. In addition, multi-hop propagation provides a controlled broadcasting over a shared wireless medium instead of using a high power long transmission range configurations, which in-turn expands the collision domain of messages [17,18]. A proper selection of relay nodes is crucial in the design of multi-hop broadcast messaging protocols which highly governs the delivery ratio of the broadcasted messages, especially over densely populated networks [12,19–21]. Conversely, a poor selection of relay nodes could lead to the drop of message reception rates, hence significantly limiting the delivery of messages over far distanced nodes. For the case of critical-in-nature safety alert messages, reliable and timely reception of these messages is a prime design objective when developing VANETs-based multi-hop safety messaging protocols [22,23]. In accordance with the safety messaging design requirements, a proper selection of relay nodes in multi-hop alert messages broadcast is an important aspect that requires in-depth investigation.

This paper introduces a new Bi-Directional Stable Communication (BDSC) relay nodes selection scheme for multi-hop messages broadcasting which can be used for different broadcast based applications in VANETs, such as safety alert messaging, route discovery and on-road information advertisement. The proposed scheme is incorporated with a sender-oriented messaging protocol in which the potential relay nodes are explicitly selected at the sender side. The BDSC scheme takes into consideration the quantitative estimations of link qualities for the forward links between each pair of nodes. The proposed scheme aims to improve multi-hop packet delivery ratio over densely populated network and at far distanced nodes. To reduce the loss of messages at the relays, the proposed scheme aims to adaptively improve the relay selection process by focusing not only on the distance from source but also on the link quality ratio.

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http://dx.doi.org/10.1016/j.comcom.2016.04.007
0140-3664/

Please cite this article as: O. Rehman et al., An adaptive relay nodes selection scheme for multi-hop broadcast in VANETs, Computer Communications (2016), http://dx.doi.org/10.1016/j.comcom.2016.04.007

The rest of the paper is organized as follows. Section 2 provides an overview on broadcasting techniques in VANETs and also discusses the relevant research work. Section 3 describes the multi-hop broadcasting scheme using the proposed BDSC scheme along with the link quality estimation and link selection criteria algorithms. Section 4 describes the simulation scenario over a varying speed mobility profile. Section 5 presents and analyzes the obtained simulation results and Section 6 concludes the work alongside with suggestions for further system performance improvement.

## 2. Broadcasting in VANETs

### 2.1. Single- and Multi-hop broadcast in VANETs

Broadcast is considered as the most suitable form of information dissemination in VANETs, especially for safety related messages, due to nodes' high mobility and the rapid topological changes [3]. Both periodic exchange of *HELLO* packets as well as the event-driven messages is propagated over a platoon of vehicles using the broadcasting technique. Based on application's design requirements, the broadcasted information can be disseminated using single-hop or multi-hop propagation technique. The broadcasted packets or messages can incorporate information that can further assist in performing localized processing at the receiver or to re-broadcasting the received information further upstream. In the reminder of this paper, the terms "packet" will be used while referring to the single-hop *HELLO* packets, while the term "message" will be fit along with multi-hop application specific messages broadcast.

Periodic single-hop broadcasts are mainly used in VANETs to exchange neighboring nodes information, commonly known as beacons, heartbeats or *HELLO* packets [12]. Assuming that all vehicles are equipped with transceivers for inter-vehicular communication, the exchanged information is required to acquaint vehicles about their surrounding conditions of nearby vehicles. Single-hop broadcasts usually contain basic information about the broadcasting node, such as positioning coordinates, mobility speed, node's and packet's IDs [24,25]. Information exchanged through *HELLO* packets act as a fundamental building block for distributed routing protocols. Three parameters can affect the single-hop packet delivery ratio over an IEEE 802.11-based wireless ad hoc network, and these are the nodes density, transmission range and transmission rate [26,27]. In a saturated traffic condition, the packet delivery ratio drops significantly with the increase in node density [27].

Communication protocols in VANETs are mostly designed with the adoption of multi-hop message propagation within a platoon of vehicles [3,7,15,28]. Multi-hop messaging is a fundamental communication model for many of VANETs based applications, including safety related messages dissemination. Primarily, two performance metrics are pursued when devising a multi-hop messaging scheme and these are the end-to-end communication delays and messages reception reliability [12,13,20]. Messages reception is usually measured either through packet delivery ratio or messages reachability [20,21]. The rise and fall in the packet delivery ratio of multi-hop broadcasting depend on the capabilities of relay nodes to forward the received messages. Fig. 1 provides a depiction of both single-hop and multi-hop broadcasting in VANETs along with their coverage domain. For the multi-hop example in Fig. 1, a relaying path represented by *A, F, J, M, R, U* is established for broadcasting the messages throughout the platoon within a targeted coverage area.

The selection of relay nodes can be based on "localized" or "distributed" information. A localized process does not gather neighboring nodes information for the relaying to occur, whereas a distributed process requires frequent updates of neighboring nodes that is usually gathered through periodic *HELLO* packets. Various multi-hop messaging protocols have been proposed while considering localized and distributed relay nodes schemes [12,13]. Furthermore, relay nodes selection is categorized as either *sender-oriented* or *receiver-oriented* [28]. In the sender-oriented relay selection, the source broadcaster explicitly selects the next potential nodes for becoming the next relays. Hence, only those nodes that receive the broadcast message and are listed as potential relays contend for becoming the next hop relays [12,21,22,29]. At the explicitly selected relays, once one of the potential relays forwards the message, all other contending nodes stop their waiting process upon hearing the rebroadcast. Conversely in the receiver-oriented relay selection, all nodes receiving the broadcast contend for becoming relays [13,17,30]. In the receiver-oriented relays selection, large amount of redundant broadcasts is inevitable leading towards poor bandwidth utilization. In contrast, the sender-oriented relay nodes selection controls the relaying process by initially limiting the contending nodes and then assigning the selected nodes with relaying priorities, which in-turn results in efficient channel bandwidth utilization.

### 2.2. Related work

Most existing research on VANETs have emphasized on the reduction of end-to-end communication delays over a platoon of vehicles by selecting relays falling furthest in distance from the source [10,12,13,31]. In the furthest distance scheme, nodes falling further from the source are assigned with less waiting time while contending for becoming the next relay. As a consequence, farther nodes have higher priority in forwarding the messages as compared to nearer ones. In [10,12], asymmetric transmission ranges among single-hop neighboring nodes is considered, where intermediate nodes are used to convey *HELLO* packets between any pair of nodes of which one of the nodes is not able to hear the other directly. A message broadcasting technique referred to as PIVCA has been proposed for the reduction of end-to-end communication delays [13,31]. The mechanism focuses on reducing the delay by estimating the transmission range of each node and utilizing the estimated range for optimizing relay nodes' waiting time before forwarding the received messages.

Variants of a *p-persistence* broadcasting scheme have been proposed in [17,30] which promote nodes located farther away from the broadcaster to become the next relay by assigning those nodes higher broadcasting probabilities as compared to nearer ones. Segmentation of the broadcast coverage area as a physical road segment has been suggested in [23], where a fast forwarding mechanism is achieved by providing smaller waiting time to nodes residing in segments that are further away from the source. However, all nodes within the same segment are assigned similar waiting time which may results in redundancy and broadcast collisions, and hence an increase in overall communication delays. An opportunistic and sender-oriented broadcasting protocol has been introduced in [21] to improve the speed of messages transmission by assigning dynamic waiting time to sender-oriented relays. An expected transmission speed (ETS) metric was proposed to evaluate the performance of broadcast transmission speed and evaluate the impact of selected relay candidates on ETS. A path diversity mechanism was proposed in [22], where two nodes are selected in each broadcast; one as a relay and the other as an auxiliary supporting node. The relay node performs multiple functions by rebroadcasting the received messages, selecting the next relay and selecting an auxiliary node. The auxiliary node only augments the relay nodes' broadcasts by only rebroadcasting the message without performing any relay nodes selection.

A link metric, known as the expected progress distance (EPD), has been introduced in [32] to assess transmission link quality. The EPD scheme measures the packets error rate for both forward

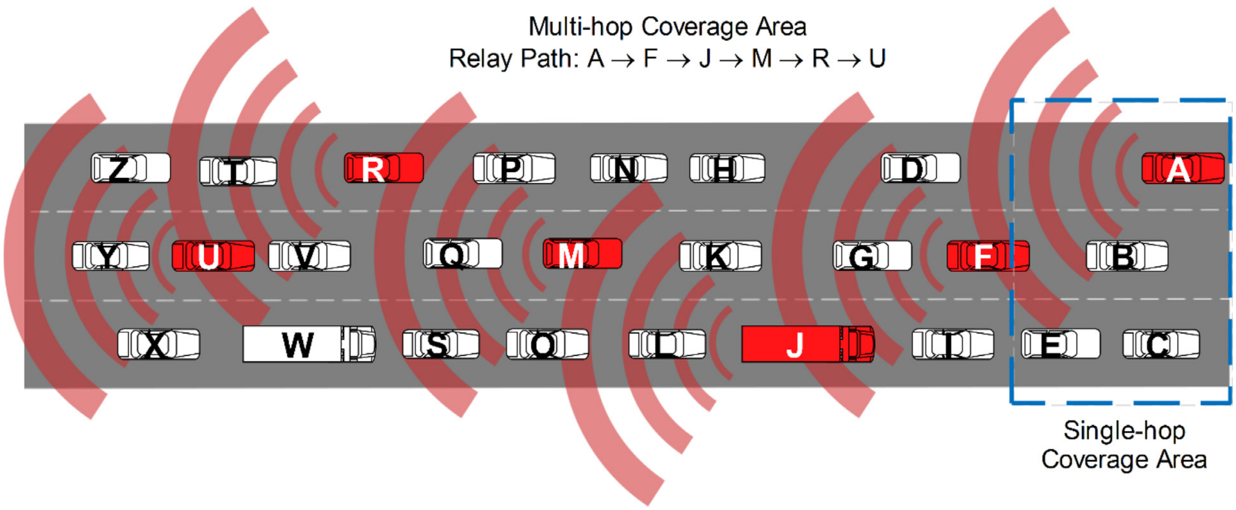



**Fig. 1.** Single-hop and multi-hop broadcast coverage area in VANETs.

and reverse links. The forward link's error rate is reported by the neighboring nodes, whereas the reverse link's error rate is measured locally at each node. However, loss of the occasional packets that report the forward link's error rate could lead towards faulty estimations of link qualities, hence faulty selections of relay nodes. In addition, the computation of the EPD metric is dependent on both the forward and reverse link qualities, where poor reverse links' performance may overshadow the good performance of forward links, resulting in neglecting those potential forward links. Moreover, piggy-bagging the delivery ratio of the received packets from different senders is required in each *HELLO* packet broadcast which limits the amount of data that can be sent within a defined *HELLO* packets size.

In a relatively high node density and in the presence of high data traffic transmission rate, the packet delivery ratio drops at the receiver as a function of distance from the source due to collision of packets [27]. Combining the effects of an increase in data traffic density and distance from the source, more packets loss is expected when selecting nodes falling farther in distance as relays [27,33]. Most of the above discussed schemes select relay nodes based on the distance parameter without considering quality of the link between the source and the selected nodes. Therefore, a sole reliance on furthest in distance as the decisive criteria for relay nodes selection can result in frequent losses of broadcasted messages.

## 3. The proposed relay selection scheme

Our proposed relay nodes selection scheme, referred to hereafter as Bi-directional Stable Communication (BDSC), is a *distributed* and *sender-oriented* multi-hop broadcasting scheme. The BDSC scheme is mainly composed of three components that are responsible for the establishment/exchanges of the periodic *HELLO* packets, estimation of forward link qualities and adaptive selection of the available relay nodes. A detailed description of the above mentioned components are in the subsequent sections.

### *3.1.* HELLO *packets establishment and exchange*

Periodic single-hop *HELLO* packet broadcast is exploited to exchange information with neighboring nodes. The information embedded inside each *HELLO* packet contains the broadcaster ID, positioning coordinates and an updated list of directly connected vehicles, referred to as the active communication nodes list (ACNL). The broadcaster ID can be represented by the MAC address of the Wi-Fi transceiver and the positioning coordinates can be taken with assistance of satellite system based receivers, such as those for the Global Positioning System (GPS) or Global Navigation Satellite System (GNSS). Fig. 2 shows the contents of a typical *HELLO* packet broadcasted by each node.

Periodic *HELLO* packets are sent by each node for updating their single-hop neighboring nodes about its presence and positioning coordinates. Additionally, the exchanged single-hop information assists in establishing the ACNL locally at each node. The ACNL is built by using the nodes IDs extracted from the received *HELLO* packets. Considering an example of nodes *A* and *B*, when a *HELLO* packet from node *A* is received at node *B*, node *B* updates its ACNL(B) by putting an entry of node *A*'s ID as being currently active in single-hop communication. In similar way, node A updates its ACNL(A) based on the *HELLO* packets received from node *B*. Conversely, the loss of a *HELLO* packets that originated from node *A* will result in the absence of node *A*'s entry in the ACNL(B).

At each node in VANET, the ACNL is updated frequently within the time period between consecutive *HELLO* packets exchange. After each *HELLO* packet broadcast, the ACNL is reset in order to be updated again. The frequent reset is considered to ensure that ACNL entries are recent and do not contain entries of nodes that are not active in communication any longer. As a consequence, two consecutively transmitted *HELLO* packets from the same source may not enlist similar ACNL entries. The established ACNL is forwarded to single-hop neighboring nodes by appending it with the periodically broadcasted *HELLO* packets. Fig. 3 provides an illustration of the exchanged ACNLs among single-hop neighboring nodes. Each received ACNL from neighboring nodes is utilized for a correlation process which is further used for the link quality estimation, as will be described in Section 3.2.

Considering the example of node *B* in Fig. 3, the received ACNLs at its side are ACNL(A), ACNL(C), ACNL(D) and ACNL(F) that are encompassed inside the *HELLO* packets originating from nodes *A, C, D* and *F*, respectively. In addition, the sender IDs encompassed inside those same *HELLO* packets are used to establish ACNL(B). However, the *HELLO* packets that are generated by node *E* are not able to reach node *B*, which can be due different effects, such as large separation distance and channel fading. As a result, node *E*'s ID is not inserted inside ACNL(B) and additionally, node *B* is not aware of the contents in ACNL(E). Based on the above discussed communication scenario, the resulting ACNL at node *B* is represented by ACNL(B) = {*A, C, D, F*}. In similar ways, the ACNLs of the

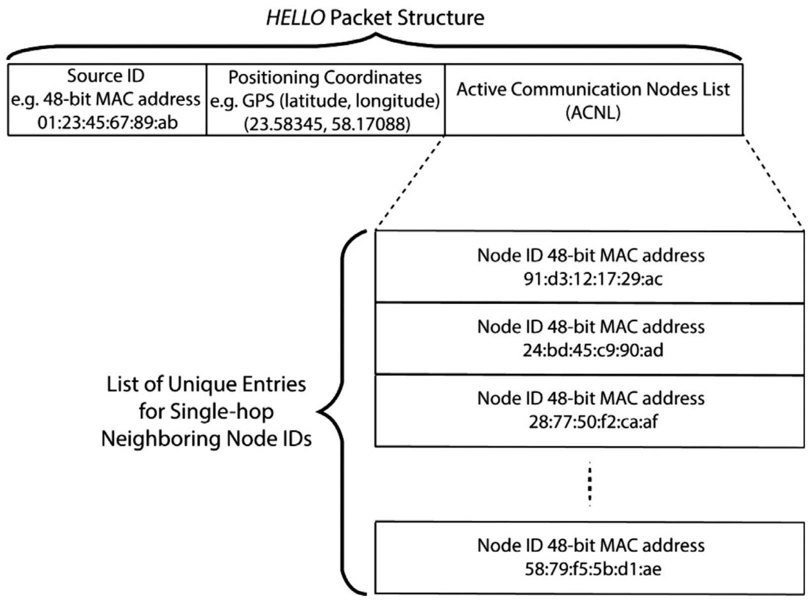



**Fig. 2.** The contents of *HELLO* packets.

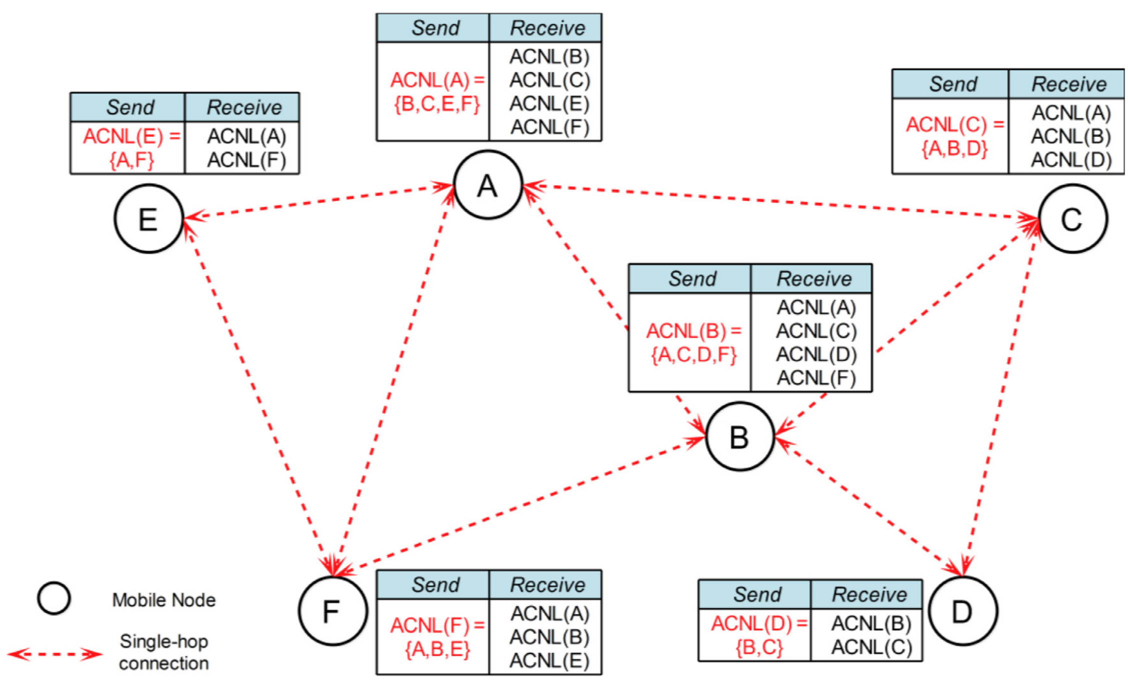



**Fig. 3.** ACNL distribution through single-hop *HELLO* packets broadcast.

remaining nodes in Fig. 3 are established and further exchanged to their single-hop neighboring nodes. The time interval over which each node receives the *HELLO* packets is denoted by $T_h$, which also represent the time interval between the broadcast of consecutive *HELLO* packets. At the end of each $T_h$, each node broadcasts its *HELLO* packet along with the last established ACNL, which is followed by emptying the entries inside the current ACNL. A pseudo-code representing the establishment, exchange and reset of ACNL is provided in Fig. 4.

### *3.2. The link quality estimation algorithm*

Between a given pair of nodes, each node has two communication links with the other, known as the forward and reverse links [19]. The forward link represents the communication link over which a node sends its data, such as the *HELLO* packets. In contrast, the reverse link is the communication link over which the same node receives data. The proposed link quality estimation algorithm provides quantitative representations for the quality of single-hop forward links between each pair of nodes. The algorithm takes into account the number of *HELLO* packets that have been successfully received over a pre-defined duration $T_{BDSC}$ and over the forward links. The computation of the number of successful receptions of *HELLO* packets over a given duration can assist in predicting the communication stability of the evaluated link, as have already been shown in the study of [32,34], which in-turn can be further used for the broadcast of application specific messages, such as alert messages dissemination at the time of an accident. In-fact, *HELLO* packets reception and loss that is evaluated over a given time duration captures a given link's behavior as the

**ACNL Establishment, Exchange and Reset Algorithm**

```
receiving HELLO packets within periodic time interval T_h
{
  extract transmitters' IDs from received HELLO packets ;
  make entry of extracted transmitters' IDs in ACNL_Receiver ;
  IF (time interval T_h ends) THEN
      put established ACNL_Receiver inside HELLO packet ;
      broadcast HELLO packet ;
      reset ACNL_Receiver by emptying all entries ;
}
```

**Fig. 4.** The ACNL establishment, exchange and resetting algorithm.

distance between the two nodes and the surrounding node density changes. In the proposed BDSC scheme, quantitative representations for link quality estimates are given as ratio ranging from 0 to 1, where higher scales indicate better link quality.

Each node locally runs the link quality estimation algorithm by which quantitative values are obtained representing the forward link qualities with the neighboring nodes. The estimation process is periodic and takes place after the end of each time period $T_{BDSC}$. Within the duration $T_{BDSC}$, an acceptance or rejection of the received *HELLO* packets is carried based on a defined condition. After each estimation cycle, the previous quantitative value is updated by the current one. The periodic update captures the latest changes in a given node's links with its neighboring nodes, such as the impact of dynamically changing nodes densities on communication links in a specific broadcast area. Since for any given link, the time gap between the currently estimated link quality ratio and the next estimated value is $T_{BDSC}$, hence the duration of $T_{BDSC}$ should be configured appropriately for a node in order to be able to timely capture the changes in quality over that communication link. Assigning a large time duration for the $T_{BDSC}$ can lead to an outdated representations for the link qualities when used by the upper layer applications in VANETs. On the other hand, assigning a small duration for the $T_{BDSC}$ can prove as ineffective since a little or no change in physical surroundings, hence the link quality, is expected to occur within that small duration. In this research, a system configuration of $T_{BDSC} = 5$ sec has been considered, which proved to exhibit promising results, as shown in Section 5, and is also similar to those adopted in other relevant research [32]. Since the link quality estimation over the time period $T_{BDSC}$ is directly dependent on the received *HELLO* packets over that duration, hence the duration $T_{BDSC}$ should also be large enough for a node to be able to capture appropriate number of *HELLO* packets to ensure a good estimation for the link quality.

In a typical vehicular communication scenario, the broadcasting source cannot be aware of the number of *HELLO* packets that have been successfully received at the other neighboring nodes, unless acknowledged by the receiving nodes. However, explicitly acknowledging the reception of the broadcast packets can easily lead to the well-known broadcast storm problem [35]. Our proposed BDSC scheme introduces an implicit acknowledgement mechanism for the successfully received *HELLO* packets by taking assistance of the ACNLs received inside the *HELLO* packets. At each *HELLO* packet reception, the ACNL encompassed inside the *HELLO* packet is examined by the receiver for its own ID. In case the receiver finds its ID within the received ACNL, then the receiver realizes that its last sent *HELLO* packet was heard by this sender, which is in-turn is an implicit acknowledgment for reception of the last broadcasted *HELLO* packet.

While focusing only on the ACNLs received at node *A*, Fig. 5 illustrates the successfully received *HELLO* packets acceptance and rejection for estimating the link quality ratios. Node *A* broadcasts a *HELLO* packet and is received by nodes *B* but lost before reaching node *C*, which can be due an adverse effect in communication, such as packet collision or channel fading. The constructed ACNLs at node *B* and *C* are incorporated into their corresponding *HELLO* packets and broadcasted with their next scheduled *HELLO* packet broadcast. As node *A* receives the *HELLO* packets broadcasts by node *B* and *C*, it starts scanning the received ACNLs for its own ID. In the plotted scenario, node *A* finds its entry at ACNL(B) but the same is not true with ACNL(C). As a consequence, node *A* is implicitly acknowledged for its *HELLO* packet broadcast to node *B*, while no implicit acknowledgment is resulted for its broadcast to node *C*. Once node *A* knows that received ACNL(B) contains its ID, an implicit acknowledgement is satisfied and the received *HELLO* packet is considered at node *A* for link quality estimation by increasing the implicit acknowledgement count (IAC) by one.

At a given node *A*, if the reception of a packet satisfies an implicit acknowledgement from another node *B*, a bi-directional communication (BDC) relation is established at node *A* with *B*. Once the BDC relation is established, a BDC_flag that signifies the underlying relation between the pair of nodes is triggered from its default status of *false* to a *true* status. The BDC_flag remains in *true* status as long as node *A* keeps on receiving *HELLO* packets from node *B*. If node *A* continuously stops receiving *HELLO* packets from node *B* for a time duration of $T_{idle}$ sec, then node *A* is no longer in BDC relation with node *B* and the BDC_flag status at node *A* is turned to *false*. For a BDC_flag to become *false* means that a node in a pair is assumed to be out of communication range and the BDC relation needs to be established again with that node. In a given pair of nodes, once the BDC_flag is triggered *false* in the leading node, the trailing node is removed from the list of potential relay for the leading node. For this work, a configuration of $T_{idle} = 2$ sec is considered based on the commonly adopted values in relevant works [32,33]. A pseudo-code of the link quality estimation algorithm is represented by Fig. 6.

For a given node in VANETs, a set of $n$ single-hop trailing nodes can be represented by $N = \{N_1, N_2, \ldots, N_n\}$. In correspondence, the distance between that given node and its trailing nodes can be represented by $D = \{d_1, d_2, \ldots, d_n\}$, where the Euclidean distance is considered for distance representation between nodes. The current broadcaster estimates the link quality ratio for each single-hop trailing nodes $n$. For the considered $n$ trailing nodes, the estimated forward link quality is given by $\widetilde{LQ} = \{LQ_1, LQ_2, \ldots, LQ_n\}$. The link quality ratios in the BDSC scheme are estimated as function of those *HELLO* packets that satisfy the above described BDC relation within the time duration $T_{BDSC}$. For a given time interval between the broadcast of consecutive *HELLO* packets, denoted by $T_h$, the expected number of *HELLO* packets within the time duration $T_{BDSC}$ is $\{T_{BDSC} \times (1/T_h)\}$. Higher counts of *HELLO* packets satisfying the BDC relation indicate higher estimated link quality ratios. The *LQ* for the forward link of a given node and to any of the following nodes is given by Eq. (1).

$$LQ = \frac{IAC}{\{T_{BDSC} \times (1/T_h)\}} \tag{1}$$

### 3.3. The link selection algorithm

The proposed link selection algorithm prioritizes the forwarding links, hence the relay nodes, based on the specified adaptive criterion. The link selection process is dependent on the feedback received by the link quality estimation algorithm, where the dynamic updates of link qualities occurring every time $T_{BDSC}$ have

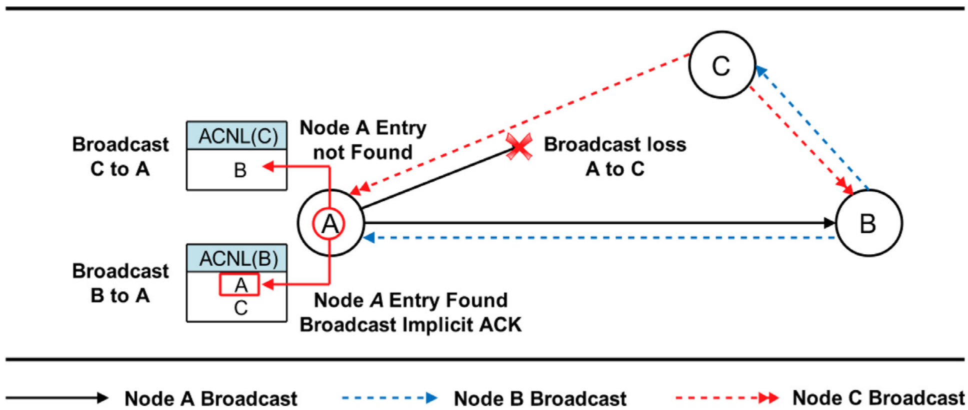



**Fig. 5.** Acceptance and rejection of *HELLO* packets satisfying the BDC condition.

**Algorithm 1: Link Quality Estimation**

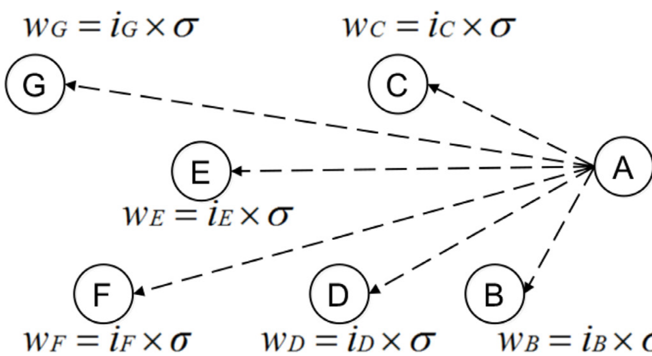
```
set IAC = 0 ;
upon receiving a HELLO packet containing ACNL(Transmitter)
{
 make entry of transmitter's ID in ACNL(Receiver) ;
 IF ( receiver ID is listed in ACNL(Transmitter) ) THEN
      "BDC_flag" = TRUE ;
      accept HELLO packet for link quality estimation ;
      set IAC ++ ;
 ELSE
      reject HELLO packet for link quality estimation ;
 END IF
 IF ( (T_Current - T_Initial) ≥ T_BDSC ) THEN
      compute LQ (IAC / expected number of HELLO packets within T_BDSC) ;
      update HELLO packets listening timer T_Initial = T_Current ;
      reset IAC = 0 ;
 END IF
}
```

**Fig. 6.** The proposed link quality estimation algorithm.

a direct impact on the set of selected nodes at the time of message broadcast. The suggested adaptive link selection criterion attempts to consider both the estimated link qualities $LQ$ and the distance $d$ of the potential relays from the current source broadcaster, and it is given by $LQ \times d$. In the proposed algorithm, the distance $d$ of potential relay nodes from the source must satisfy the condition $d \leq \bar{d}$, where $\bar{d}$ is the mean distance from current source to all single-hop potential relay nodes and is given by $\bar{d} = (d_1 + d_2 + \ldots + d_n)/n$. Hence, all nodes having a distance $d \leq \bar{d}$ are qualified by becoming a relay node, while the rest are neglected. The mean distance condition is considered to avoid the selection of those nodes that fall furthest in distance from the source, hence limiting the selection of relay nodes within a specific region of interest, computed dynamically by distance $\bar{d}$.

The product of all available link qualities with their corresponding distances from the source produces new quantitative values. The new product value provides a balance in the selection of links that satisfy both acceptable message forwarding capabilities and higher per-hop coverage distances from source that lead towards low number of hop counts till reaching the targeted destination. Based on the obtained product values, of $LQ_j$ with their corresponding distances $d_j$, higher relaying priority is given to those links with larger $LQ_j \times d_j$ product values, where $j = 1, 2, \ldots, n$. Based on the new product values, the $n$ trailing nodes are sorted in descending order. From the sorted set, a limited number of node IDs are selected defined by the cardinality $C$ of the relay nodes set. The cardinality value is a pre-defined system parameter, which is considered as $C = 12$ for this study. The relay nodes cardinality defines a limits on how many of the trailing nodes can be selected as relays, hence limiting the number of nodes that would contend for becoming the next-hop relay and hence controlling redundancy. The final selected set of relay nodes is given by $R = \{R_1, R_2, \ldots, R_C\}$.

Based on the above defined link selection criterion, the broadcasting node adaptively selects a set of $C = 12$ links representing potential relay nodes and includes their IDs in an “ordered” list, referred to in this research as the “relay priority list”. To obtain a rebroadcast prioritization among the $C$ potential relay nodes, the entries inside the “relay priority list” are assigned with rebroadcast priority indexes, referred to as the “relay priority index”. A given node with highest rebroadcast priority is assigned with lowest index value, and vice versa is correct. The “relay priority index”, $i$, ranges from $0$ *to* $C - 1$. For case of $C = 12$ potential relay nodes, the indexing sequence would range from 0 to 11. Once the list of $R$ possible relay nodes is determined, the list is incorporated inside the application message and then broadcasted further upstream. If the ID of a receiving node is among the broadcasted “relay




| Priority Index (*i*) | Nodes ID | Link Quality (LQ) | Distance (d) | LQ x d |
|---|---|---|---|---|
| 0 | E | 0.7 | 175 | 122.5 |
| 1 | F | 0.5 | 188 | 94 |
| 2 | G | 0.2 | 193 | 38.6 |
| 3 | D | 0.7 | 45 | 31.5 |
| 4 | B | 0.9 | 13 | 11.7 |
| 5 | C | 0.8 | 14 | 11.2 |

**Fig. 7.** Priority mechanism of sender-oriented relay nodes selection using the $LQ \times d$ link selection criteria.

priority list", the receiving node sets it's "relay waiting time" before rebroadcasting the message. The "relay waiting time" at each contending relay node is proportional to its "relay priority index" with the received "relay priority list". Hence, the "relay waiting time" for a contending node is given by $w_i = i \times \sigma$, where $\sigma$ represents a predefined waiting time slot duration of $\sigma = 10ms$. Hence, the first node in the list has a zero waiting time, whereas the rest have a waiting time in the order of $\sigma$.

The delay in a message rebroadcast and till it reaches the next-hop relay is usually represented by four delay contributing factors, which are the processing delay $T_{proc}$, transmission delay $T_{trans}$, channel access delay $T_{ca}$ and propagation delay $T_{prop}$. In the case of this study, another delay influencing factor is added at each relay node which is defined as the "relay waiting time" delay at each contending relay node. As a consequence, the delay at each relay is given by Eq. (2) while the total end-to-end delay is represented by Eq. (3), where $H$ is the total hop counts required for an end-to-end communication to occur.

$$T_{relay} = T_{proc} + T_{trans} + T_{ca} + T_{prop} + (\sigma \times i) \quad (2)$$

$$T_{EtoE} = \sum_{k=1}^{H} T_{relay}(k) \quad (3)$$

By setting up the appropriate "relay waiting time" at each contending relay node, a rebroadcasting priority scheme is inherently obtained. This would reduce redundant rebroadcasts of the messages leading to reduced collisions. Fig. 7 provides an illustration of the waiting process among the contending relay nodes while employing the $LQ \times d$ link selection criterion. The $LQ \times d$ column in the extreme right of the table in Fig. 7 represents the values as an outcome from the product. Conversely, the extreme left column presents the resulting "relay priority indexing" of the nodes based on the highest product values achieved in the $LQ \times d$ column. A pseudo-code representing the adaptive link selection criterion is given in Fig. 8.

### *3.4. Overhead in the BDSC scheme*

In the proposed BDSC scheme, the overhead due to the total number of *HELLO* packets generated from each node in a VANET can be determined by means of Eq. (4), where $T_h$ is the time interval between consecutive broadcasts of *HELLO* packets, $T$ is the duration over which the transmission overhead is measured and $P_{size}$ is the considered size for the *HELLO* packets in Bytes.

$$\bar{O} = \frac{1}{T_h} \times T \times P_{size} \quad (4)$$

On the other hand, the overhead due to the total *HELLO* packets received at a given node having $M$ neighboring nodes is given by Eq. (5). Considering a single lane road segment, the number of neighboring nodes $M$ can be given by Eq. (6), where $N$ is the total node in the VANET, $R$ is the transmission range and $R_{len}$ is the considered road segment length.

$$\bar{\bar{O}} = \frac{M}{T_h} \times T \times P_{size} \quad (5)$$

$$M = 2 \times \left\lfloor \frac{N \times R}{R_{len}} \right\rfloor \quad (6)$$

As can be noted from Eq. (4), the governing factor in the overhead introduced by the BDSC scheme is the frequency of the *HELLO* packet exchange, where higher frequency of these packets, i.e. smaller values of $T_h$, would lead towards larger overheads. On the other hand, both *HELLO* packets frequency and number of neighboring nodes $M$ play a dominating role when measuring the overhead at a given receiving node, as presented by Eq. (5), where either the increases in *HELLO* packets frequency or number of surrounding nodes, i.e. $M$ would increase the overhead at a given receiver.

In this work, a *HELLO* packet frequency of 2 packets/sec is adopted, i.e. $T_h = 500$ *msec*, where the BDSC scheme exhibits promising performance over existing solutions (discussed in Section 5). For $T = 1$ sec, the overhead due to the *HELLO* packets generated by each node is only $2 \times P_{size}$. On the other hand, the overhead due to the received *HELLO* packets at a given node in VANET would vary in time since the number of neighboring nodes $M$ for that node can vary over time. In contrast to the proposed BDSC scheme, a number of existing solutions have shown to exhibit higher frequency for the *HELLO* packets broadcast, such as having 10 *HELLO* packets/sec [12,13,22].

## 4. Simulation setup

The proposed BDSC scheme is compared against two others existing schemes, which are the furthest distance (FD) [12,13,31] and expected progress distance (EPD) [32] schemes. To the best of our knowledge, the FD based multi-hop broadcast is to-date the most commonly researched scheme in the development of relay nodes selection techniques for VANETs. On the other hand, the EPD scheme reflects a recent development in link quality-based multi-hop messages broadcast. The EPD is configured to obtain the maximum throughput with a weight value of $\alpha = 6$, as recommended in [32]. As is the case with the proposed BDSC scheme, the FD and the EPD schemes are implemented as sender-oriented messaging schemes.

The packet delivery ratio, end-to-end delays and saved rebroadcasts are the main performance measurement metrics considered for evaluating the proposed BDSC scheme. The considered three metrics represent the assessment of "reliability", "timeliness" and "bandwidth utilization" for the proposed relay selection

Please cite this article as: O. Rehman et al., An adaptive relay nodes selection scheme for multi-hop broadcast in VANETs, Computer Communications (2016), http://dx.doi.org/10.1016/j.comcom.2016.04.007

**Adaptive Link Selection Algorithm**

```
when relaying an Application/Event-Driven MESSAGE
{
  FOR all active-in-communication single-hop nodes
       compute the product ( LQ X d ) for each active node ;
  sort achieved product values in ascending order ;
  select a list of node IDs having the highest C = 12 product values ;
  incorporate the selected list inside the MESSAGE ;
  broadcast the MESSAGE ;
}
```

**Fig. 8.** Adaptive link selection criterion algorithm.

scheme. The packet delivery ratio is measured as a function of both network density and distance from the initial broadcasting source, hence providing a much comprehensive assessment of broadcasting scheme's reliability. The end-to-end delay is measured between two reference nodes, each residing at one of the two ends of the platoon [12,13]. Based on that, the end-to-end delay is the total time required for the broadcasted message initiated by a reference node at beginning of the platoon to reach the other reference node using multi-hop propagation.

Each vehicle is assumed to be equipped with a wireless transceiver adhering to the IEEE 802.11p standard [12,13] and configured for one of the recommended transmission ranges by the standard of 300 meters [18], alongside a GPS positioning device and a data processing unit. Initially the vehicles are uniformly distributed over an approximately 4 km highway segment containing four lanes, where each lane is 3.7 meters in width. All vehicles move towards the same direction while having different mobility speeds ranging from 80-120 km/h, where each node is randomly assigned with a mobility speed within the above specified speed range. The selected range represents a large relative speed difference among the nodes and it also covers most of the speed limits of high speed roads around the globe [36]. Furthermore, mobility scenarios having large relative speed difference represents a more challenging communication environment as compared with small relative speed difference, since nodes tend to have smaller link life duration in the earlier scenario as compared to the later [37].

A platoon of varying node densities ranging from 100 to 800 nodes is considered, with an increment of 100 nodes per simulation scenario. The considered range of node densities represent a spectrum that covers both sparse and dense VANETs scenarios over a four lane highway segment, inspired by similar conditions adopted in [12–14]. For characterizing the wireless propagation channel among nodes in VANETs, the Nakagami fading channel model is adopted in this research study with a fading intensity of $m = 1.5$, as recommended by the studies of [22,38]. The underlying channel model reflects several aspects of a realistic wireless channel in VANETs, such as multi-path fading effects, which is not considered by other models, such as the widely used Two-Ray Ground channel model.

For the purpose of this study, three types of broadcast messages are considered, and these include the *HELLO* packets broadcast which is used for the estimation of link qualities, the application messages which are used for evaluating the proposed BDSC scheme, and finally some additional background traffic used to evaluate the BDSC scheme over varying loads of network traffic. A simulation time of 130 sec is set for each run in which the *HELLO* packets are periodically generated with a frequency of 2 packets/sec. In case of this work, a frequency of 2 *HELLO* packets/sec is found to be sufficient for obtaining adequate assessment of link quality over the duration $T_{BDSC} = 5$ sec. Though the application messages size and frequency are mostly dependent on the application requirements, a frequency of 10 messages/sec is adopted in order to strain the loading conditions on the VANET while evaluating the BDSC scheme. The transmission of the application messages is initiated from a given source node as being the first node in the platoon and after a warm-up time of 30 sec. Addition network traffic load is exerted on the VANET in the form of background traffic that is generated with a frequency of 10 messages/sec. However, to evaluate the BDSC scheme over a varying network traffic density, three simulation scenarios are considered over which 10%, 50% and 100% of the total nodes in the VANET participate in broadcasting the background traffic. A size of 512, 256 and 256 bytes are chosen for the broadcasted *HELLO* packets, application messages and background traffic, respectively. In addition, the obtained results are averaged over 100 simulation runs.

**Table 1**
Simulation parameters for broadcasting in VANETs.

| Parameter | Value |
|---|---|
| Frequency | 5.9 GHz |
| Channel bandwidth | 10 MHz |
| Data rate | 6 Mbps |
| CW slot time ($\sigma$) | 16 µsecs |
| SIFS time | 32 µsecs |
| Preamble length | 32 µsecs |
| PLCP header length | 8 µsecs |
| CW minimum size | 32 slots |
| CW maximum size | 1024 slots |

The ns-2.35 network simulator [39] is used as the simulation platform, where built-in ns-2 modules for IEEE 802.11 are used for the physical and MAC layers. The main modifications include the usage of carrier frequency of 5.9 GHz and a control channel bandwidth of 10 MHz. The proposed broadcast messaging approach is designed to work while utilizing the control channel band as envisioned by the IEEE 802.11p standard for different applications, such as safety messaging services. The main system parameters which have been used in our simulation experiments are summarized in Table 1.

## 5. Results and analysis

In this section, performance results of the proposed BDSC scheme in terms of end-to-end delays, packet delivery ratios and saved re-broadcast percentages are presented and compared with those obtained for the existing competing solutions. In each con-

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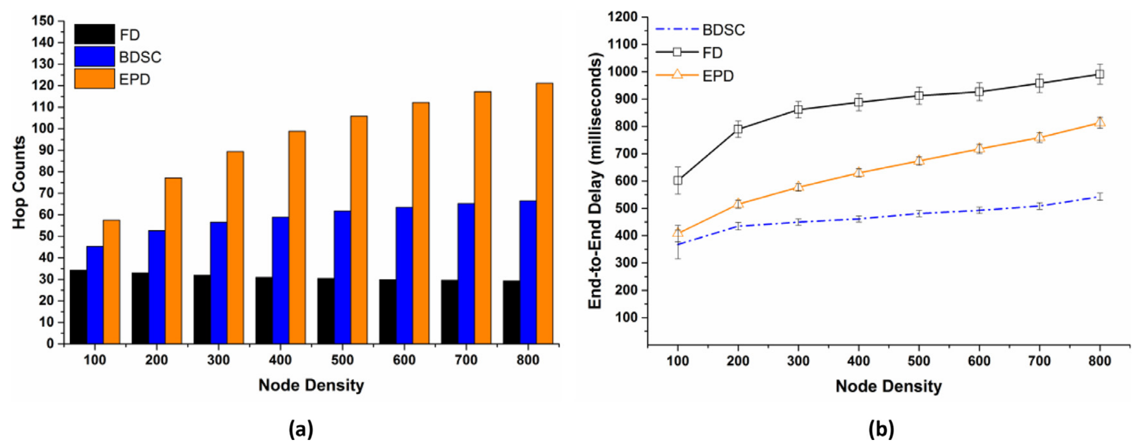


**Fig. 9.** Multi-hop messages propagation requirements with 10% of nodes generating background traffic (a) Hop Counts (b) End-to-end delay.

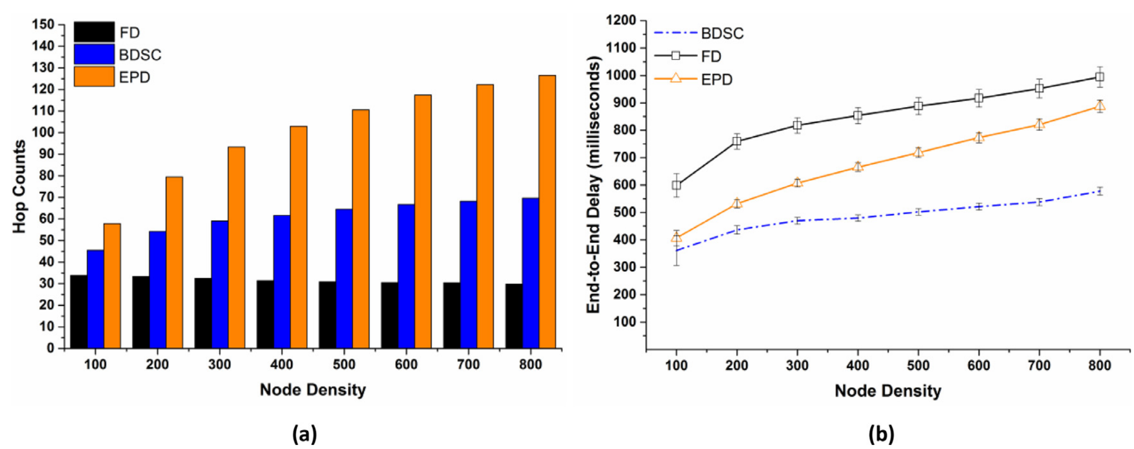


**Fig. 10.** Multi-hop messages propagation requirements with 50% of nodes generating background traffic (a) Hop Counts (b) End-to-end delay.

sidered performance measurement metrics, results are exhibited for the three considered background traffic scenarios in which 10%, 50% and 100% of nodes participation in generating the background traffic. This actually assists in exploring the performance of the proposed BDSC scheme over varying network traffic densities.

### *5.1. End-to-end delays*

Along with the end-to-end delay performance results, this section presents the results for other considered metrics that assists in justifying the end-to-end delay behavior exhibited by the proposed BDSC scheme and the other existing solutions. The hop counts required for the disseminated message to propagate from the source node and till it reaches the last node in the platoon is highly governed by the way the broadcasting scheme selects the relay nodes, which in-turn has a direct impact on the obtained end-to-end delay. The hop counts and end-to-end delays required for the application messages are presented by Figs. 9–11, for the considered three background traffic scenarios. As can be seen in Figs. 9–11, comparable performance patterns are exhibited by the BDSC scheme over all three considered background traffic scenarios. The proposed BDSC scheme has the lowest end-to-end delays over all considered node densities and persists in remaining the lowest as the background traffic increases. In addition, the delays obtained by the BDSC scheme tend to increase marginally over high node density networks as the background traffic increases. In comparison, the EPD presents higher end-to-end delay requirements, while being more prominent over high node density networks. In contrast to the proposed BDSC scheme, the EPD delay requirements tend to increase noticeably over high node density networks as the background traffic increases. The high end-to-end delay exhibited of the EPD scheme is influenced by the large hop counts requirements of the scheme for reaching the destination node, as shown in Figs. 9–11. The EPD scheme tends to select those relays that have high throughputs, which results in selection of those nodes falling close to the current broadcaster and hence increasing overall hop counts.

The FD scheme is well known for its low hop counts [12,13], and is indeed the case in the results depicted in Figs. 9–11 where the hop counts required by the FD scheme is the lowest compared to the BDSC and EPD schemes. In contrast, the FD scheme exhibits the highest end-to-end delay over all node density networks and in all background traffic scenarios. The high end-to-end delay exhibited by the FD scheme is not due to the influence of the hop counts, as is the case with the BDSC and EPD schemes, but due to the delay factor introduced by the “relay waiting time” in the adopted *sender-oriented* multi-hop relay selection approach.

The impact of “relay waiting time” at each message rebroadcast can be realized by studying the relaying contribution of each $C = 12$ contending relay nodes in rebroadcasting the received message. This is obtained by counting the number of cases for each contending relay in rebroadcasting the message out of the total hop counts required for that message to reach the targeted destination. The above described analysis is referred to in this work as the “Relay Selection Optimality”, which measures the optimality of the investigated scheme in successfully selecting relay nodes with less “relay waiting time” which in-turn leads towards obtaining

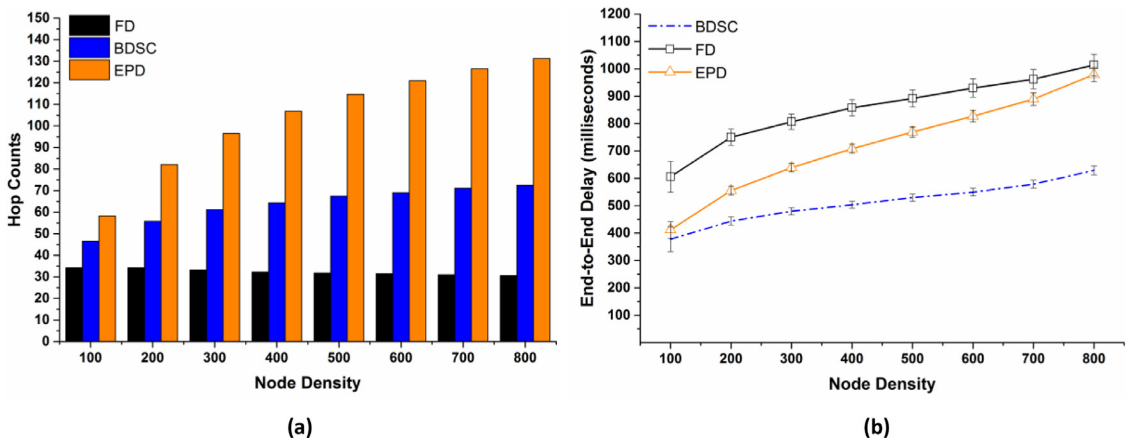


**Fig. 11.** Multi-hop messages propagation requirements with 100% of nodes generating background traffic (a) Hop Counts (b) End-to-end delay.

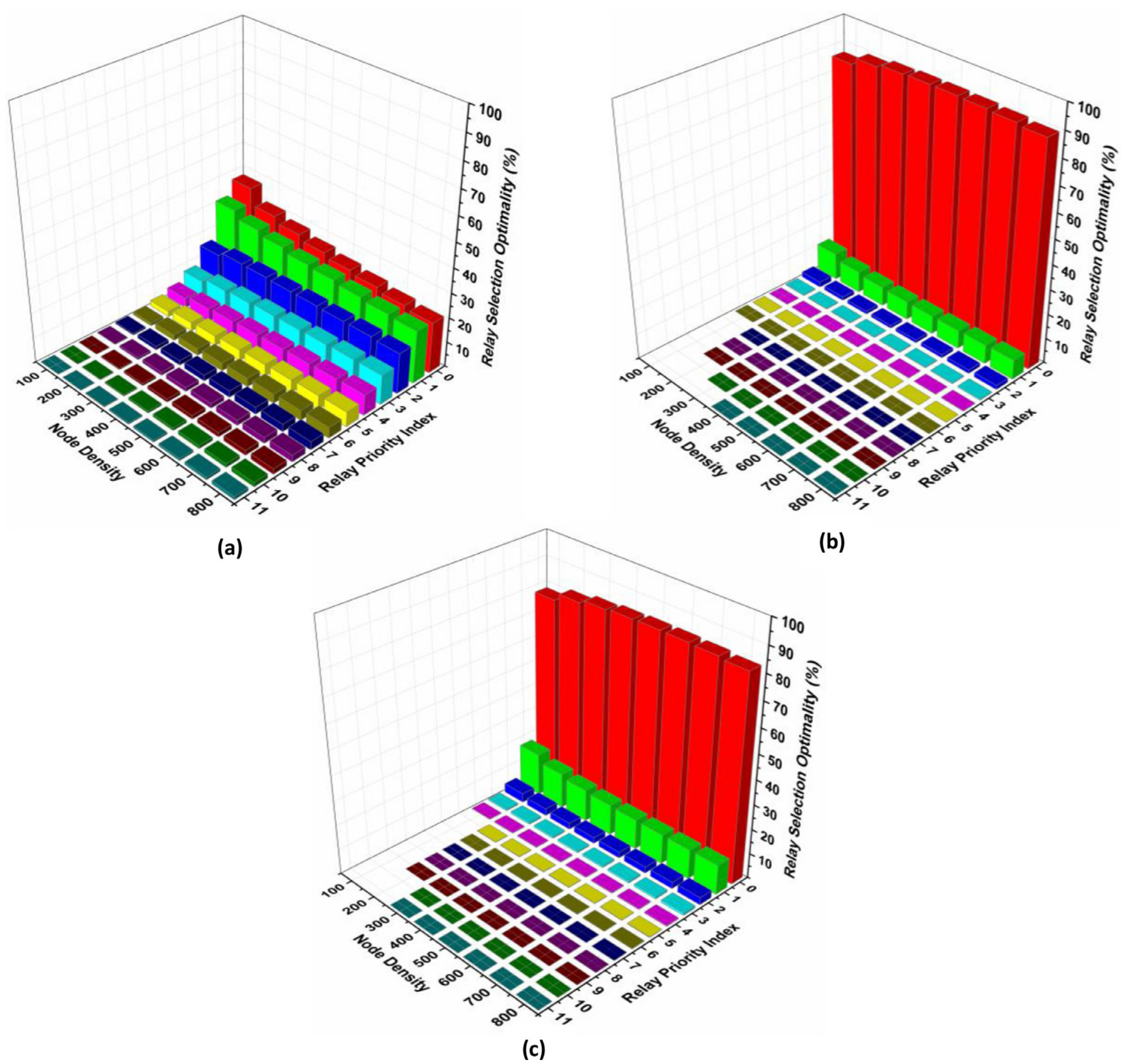


**Fig. 12.** Relaying contribution of C = 12 contending relays as a function of node density by (a) FD (b) EPD (c) BDSC.

lower end-to-end delays. The message broadcasting schemes that present higher successful selection of relay nodes having the “relay priority index” $i = 0$, i.e. zero “relay waiting time”, those schemes are expected to exhibit lower end-to-end delays, and the opposite is correct.

For brevity and without loss of generality, Fig. 12 present the “Relay Selection Optimality” of the BDSC, EPD and FD schemes for the case of 100% background traffic scenario, where similar patterns can be speculated for the 10% and 50% background traffic scenarios. As presented in Fig. 12(a), the FD scheme exhibit poor “Relay Selection Optimality” where most of the relaying is performed by those contending relays that have “relay priority indexes” $i > 0$. As a consequence, the FD scheme exhibits high end-to-end delays even while showing the lowest hop counts.

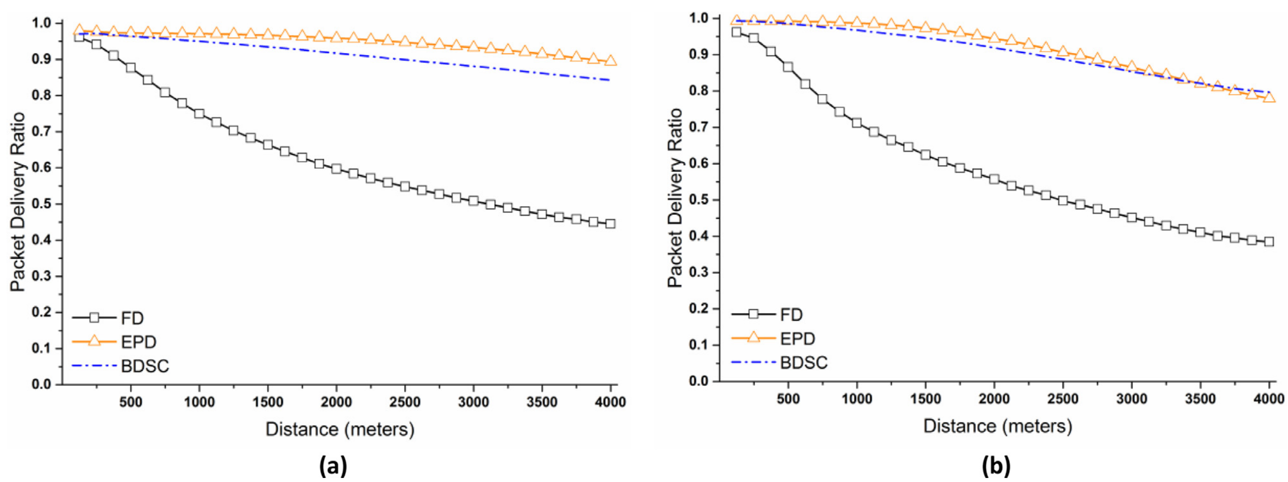


**Fig. 13.** The packet delivery ratio as distance from source increases with 10% of nodes generating background traffic (a) 400 nodes (b) 800 nodes.

**Table 2**
The end-to-end delays in milliseconds compared over 800 node density VANETs.

| | Total Nodes Generating Background Traffic out of 800 Nodes | | |
|---|---|---|---|
| | 10% | 50% | 100% |
| FD | 991 | 995 | 1014 |
| EPD | 813 | 887 | 979 |
| BDSC | 543 | 578 | 629 |

Failure of the FD scheme in having high relaying contribution by relay nodes with small “relay priority indexes” is due to the low probability of successful messages reception at nodes falling furthest in distance from the source over the adopted wireless fading channel, which aggravates further as the surrounding node density increases. In contrast to the FD scheme, most of the relaying contribution over the EPD and BDSC schemes are performed by relays with “relay priority index” $i = 0$, as shown in Fig. 12(b) and (c), respectively. The EPD scheme exhibits large end-to-end delays due to its large hop counts. The BDSC collectively exhibiting promising performance in terms of both hop counts and “Relay Selection Optimality”, hence having the lowest end-to-end delays when compared to FD and EPD schemes.

A comparative analysis for the investigated broadcasting schemes is provided in Table 2 in terms of their end-to-end delays (measured in milliseconds) with focus over the highest considered node density VANETs of 800 nodes. As can be observed in Table 2, a rise in the end-to-end delay is experienced as the background traffic increases which is due to the increase in contention over the shared wireless channel. By analyzing Table 2, a reduction by up to 45% is observed by the proposed BDSC scheme in terms of the required end-to-end delay. In addition, the most rapid increase in the end-to-end delay is observed for the EPD scheme as the background traffic generating nodes increases. Based on the readings displayed in Table 2, it can be speculated that the end-to-end delay resulting from the usage of the EPD scheme may even surpass the delay requirements of the FD scheme if evaluated over node densities higher than 800 nodes. In contrast, the BDSC scheme exhibits small increment in the end-to-end delays as the nodes contributing in generating the background traffic increases.

### *5.2. Packet delivery ratio*

Performance of the proposed BDSC scheme in terms of packet delivery ratio is presented in this section, where two different representations are considered that highlight the performance impact of both distance from source and the increasing node densities. As shown in Figs. 13–15, each figure presents the packet delivery ratio obtained by the BDSC scheme for two considered node density cases of 400 and 800 nodes, while being different from the other figures in the number of background traffic generating nodes. Based on the obtained results, the BDSC scheme improves performance by up to 40% over that obtained by the FD scheme, where the large improvements in performance are noticeable over both 400 and 800 node density scenarios and over the three considered background traffic scenarios.

The EPD scheme exhibits competitive performance compared to that obtained by the BDSC scheme. However, as the distance from the source, the node density and the background traffic increases, the proposed BDSC scheme outperform the EPD scheme in terms of the packet delivery ratio. This behavior can be clearly observed in part (b) of Figs. 13–15, depicting the results for 800 nodes density VANETs. The BDSC scheme exhibits better performance over EPD since it tends to maintain low hop counts to reach far-distant destinations as the node density and the background traffic increases. In contrast, the EPD suffers from having large hop count requirements over similar conditions, as presented by Figs. 9–11, where the probability of packets loss increases as the hop counts increases for reaching the destination. As a consequence, the BDSC scheme presents better performance over EPD over high node density networks having high traffic generation rates.

The other depictions of the packet delivery ratio obtained by the FD, EPD and BDSC schemes are shown through Figs. 16–18 as a function of all considered node densities and distance from the broadcasting source, with each figure depicting the impact of different adopted background traffic scenarios. The FD scheme shows a rapid fall in performance as the separation distance between the receiver and the source increases. In comparison to the FD scheme, the EPD and BDSC schemes exhibit promising packet delivery ratios over large coverage distances. In-fact, the proposed BDSC scheme shows more robustness to packet loss compared to the EPD scheme when evaluated over high node density VANETs along with high traffic generation rates. For each investigated scheme, an indication of the lowest obtained packet delivery ratio is highlighted in Figs. 16–18, which are obtained over the highest considered node density networks, i.e. 800 nodes, and at a distance of 4000 m from the broadcasting source node. Over all considered background traffic scenarios, the proposed BDSC scheme exhibits the highest packet delivery ratio over the above described scenario.

For all considered broadcasting schemes, a fall in packet delivery ratio is noticed at low node density networks, as depicted

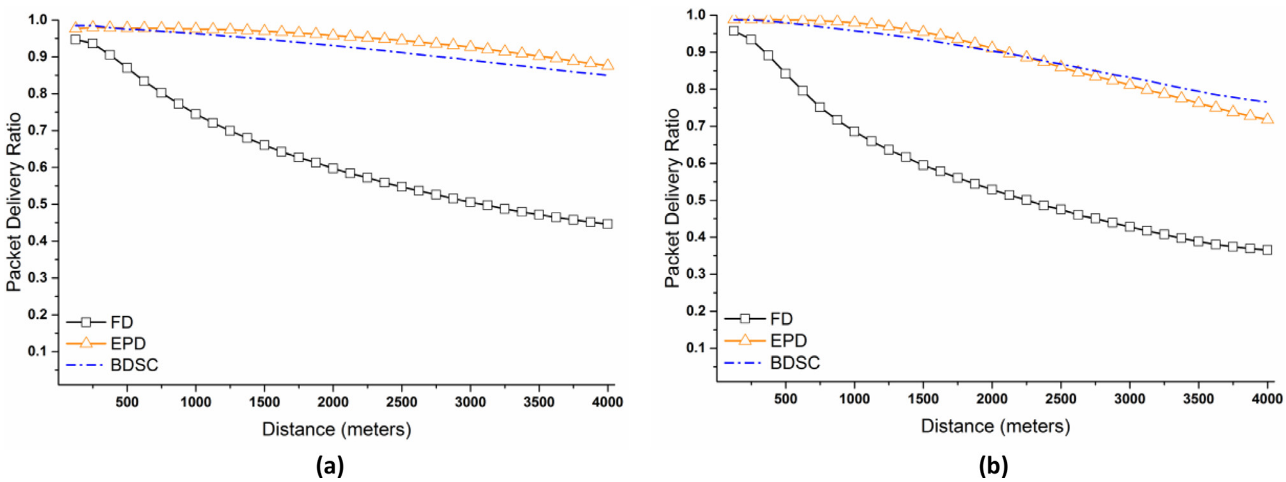


**Fig. 14.** The packet delivery ratio as distance from source increases with 50% of nodes generating background traffic (a) 400 nodes (b) 800 nodes.

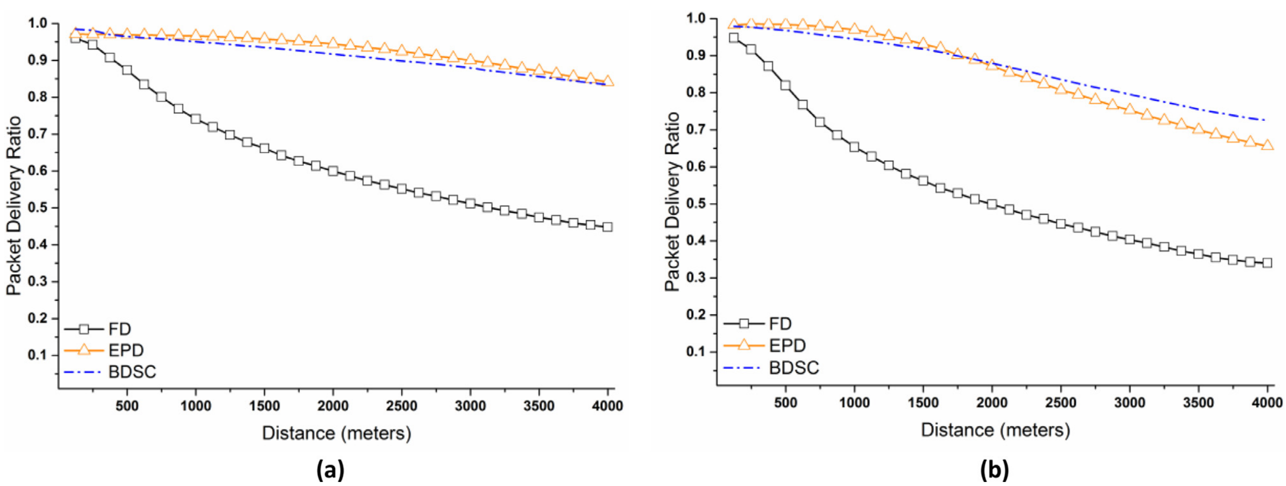


**Fig. 15.** The packet delivery ratio as distance from source increases with 100% of nodes generating background traffic (a) 400 nodes (b) 800 nodes.

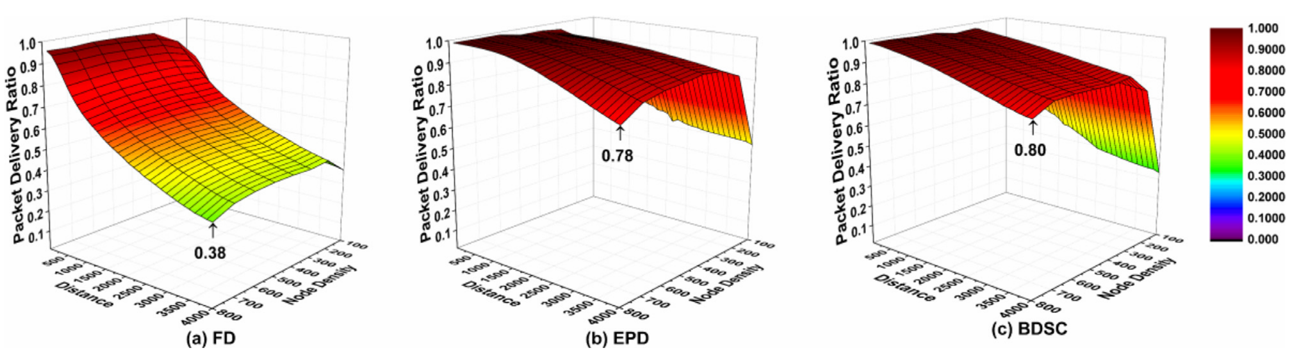


**Fig. 16.** The packet delivery ratio over varying node densities and distances from source with 10% of nodes generating background traffic (a) FD (b) EPD (c) BDSC.

by Figs. 16–18. This phenomenon is due to the sparse network effects which lead to network disconnectivity at different parts of the road segment, while being more prominent for nodes falling at far distances from the source. The performance impact of receiving nodes' separation distance from the broadcasting source is presented quantitatively through Tables 3–5. In these tables, a comparative analysis of the packet delivery ratio obtained by the investigated schemes over different background traffic generation scenarios is provided for the case of highest considered node density VANETs of 800 nodes.

### *5.3. Saved Re-broadcasts*

The investigated broadcasting schemes are evaluated for their efficiency in bandwidth utilization which is represented in Fig. 19 in the form of saved-rebroadcasts percentage. The hop counts directly influence the saved-rebroadcast, where high hop counts lead towards having low saved-rebroadcast. As a result, the FD scheme has the highest saved-rebroadcast since it requires the lowest hop counts to reach the targeted destination. However, the FD scheme also exhibits large end-to-end delays along with having high loss of packets over dense network scenarios, presented previously in

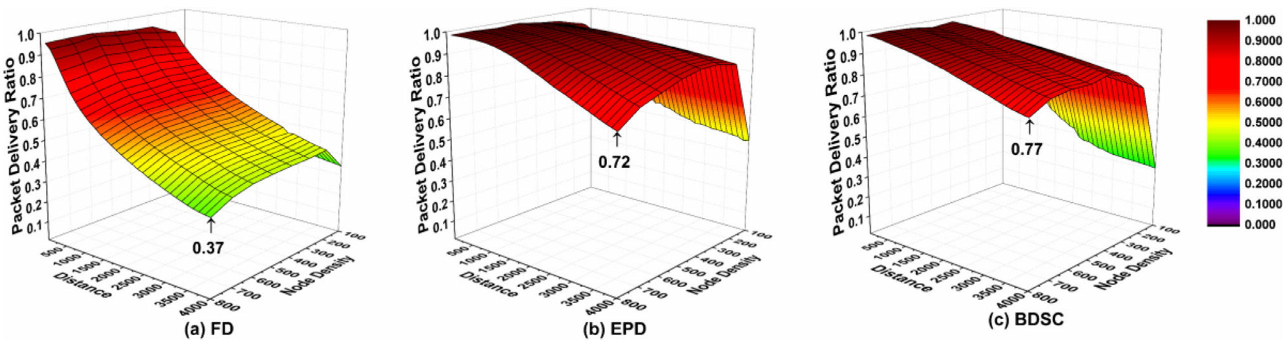


**Fig. 17.** The packet delivery ratio over varying node densities and distances from source with 50% of nodes generating background traffic (a) FD (b) EPD (c) BDSC.

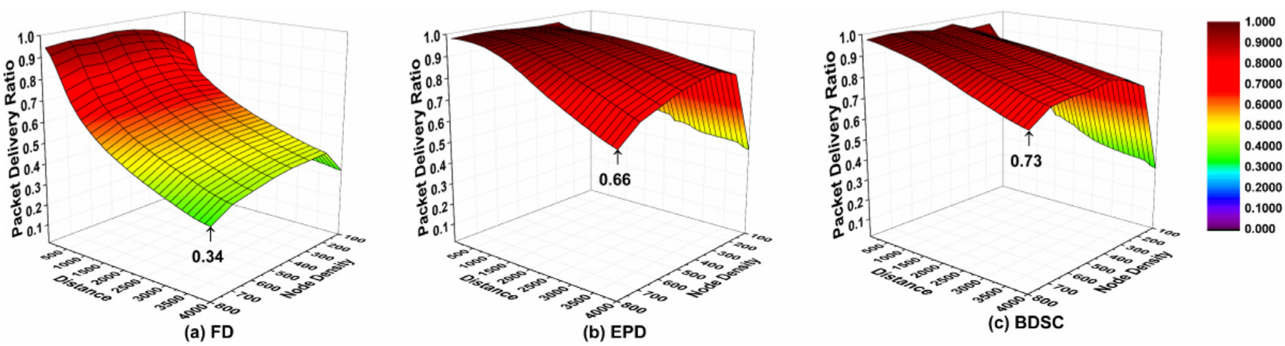


**Fig. 18.** The packet delivery ratio over varying node densities and distances from source with 100% of nodes generating background traffic (a) FD (b) EPD (c) BDSC.

Sections 5.1 and 5.2, respectively. In comparison, the BDSC scheme also exhibits high percentage of saved re-broadcasts while falling slightly shorter than that exhibited by FD. The EPD scheme has relatively lower saved rebroadcasts when compared to both FD and BDSC schemes which is mainly due to the large hop counts required for the broadcasted messages to reach the targeted destination. The above described performance observed for the three investigated schemes is generally noticed for the three considered background traffic scenarios, as can be seen in Fig. 19. As presented in Table 6 while focusing on 800 node density VANETs, the impact of increasing background traffic over the saved-rebroadcast percentage is marginal for all three investigated schemes. This is due to the fact that increasing background traffic has a marginal effect on the hop counts requirements by the investigated schemes, as seen in Section 5.1, hence marginal difference is also observed over the saved-rebroadcast performance.

**Table 3**
The packet delivery ratio over 800 nodes VANETs along with 10% of nodes generating background traffic.

| | Packet delivery ratio at distance (m) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 500 | 1000 | 1500 | 2000 | 2500 | 3000 | 3500 | 4000 |
| FD | 0.87 | 0.71 | 0.62 | 0.56 | 0.50 | 0.45 | 0.41 | 0.38 |
| EPD | 0.99 | 0.98 | 0.97 | 0.94 | 0.91 | 0.87 | 0.82 | 0.78 |
| BDSC | 0.99 | 0.97 | 0.95 | 0.92 | 0.89 | 0.85 | 0.82 | 0.80 |

**Table 4**
The packet delivery ratio over 800 nodes VANETs along with 50% of nodes generating background traffic.

| | Packet delivery ratio at distance (m) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 500 | 1000 | 1500 | 2000 | 2500 | 3000 | 3500 | 4000 |
| FD | 0.84 | 0.69 | 0.59 | 0.53 | 0.48 | 0.43 | 0.39 | 0.37 |
| EPD | 0.99 | 0.98 | 0.95 | 0.91 | 0.86 | 0.81 | 0.76 | 0.72 |
| BDSC | 0.98 | 0.96 | 0.93 | 0.90 | 0.87 | 0.83 | 0.79 | 0.77 |

**Table 5**
The packet delivery ratio over 800 nodes VANETs along with 100% of nodes generating background traffic.

| | Packet delivery ratio at distance (m) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 500 | 1000 | 1500 | 2000 | 2500 | 3000 | 3500 | 4000 |
| FD | 0.82 | 0.65 | 0.56 | 0.50 | 0.46 | 0.40 | 0.36 | 0.34 |
| EPD | 0.98 | 0.97 | 0.93 | 0.87 | 0.81 | 0.75 | 0.70 | 0.66 |
| BDSC | 0.97 | 0.94 | 0.92 | 0.88 | 0.84 | 0.80 | 0.76 | 0.73 |

**Table 6**
The saved-rebroadcast percentage compared over 800 node density VANETs.

| | Total Nodes Generating Background Traffic out of 800 Nodes | | |
|---|---|---|---|
| | 10% | 50% | 100% |
| FD | 92.27 | 91.68 | 90.87 |
| EPD | 81.22 | 80.30 | 79.26 |
| BDSC | 86.33 | 85.55 | 84.62 |

## 6. Conclusions

This paper has proposed a new multi-hop message broadcasting scheme over a platoon of vehicles forming a VANET. The scheme, referred to as Bi-Directional Stable Communication (BDSC), aims to improve the packet delivery ratio over densely populated VANETs and at nodes positioned at far distances from the broadcasting source. The BDSC scheme utilizes a forward link quality estimation algorithm that periodically provides quantitative representations of the link qualities between the current broadcasting source and the set of potential relay nodes. A link selection criterion is devised within the proposed BDSC scheme that attempts to take into consideration the estimated link qualities of potential relay nodes and their corresponding distances from the current broadcaster when

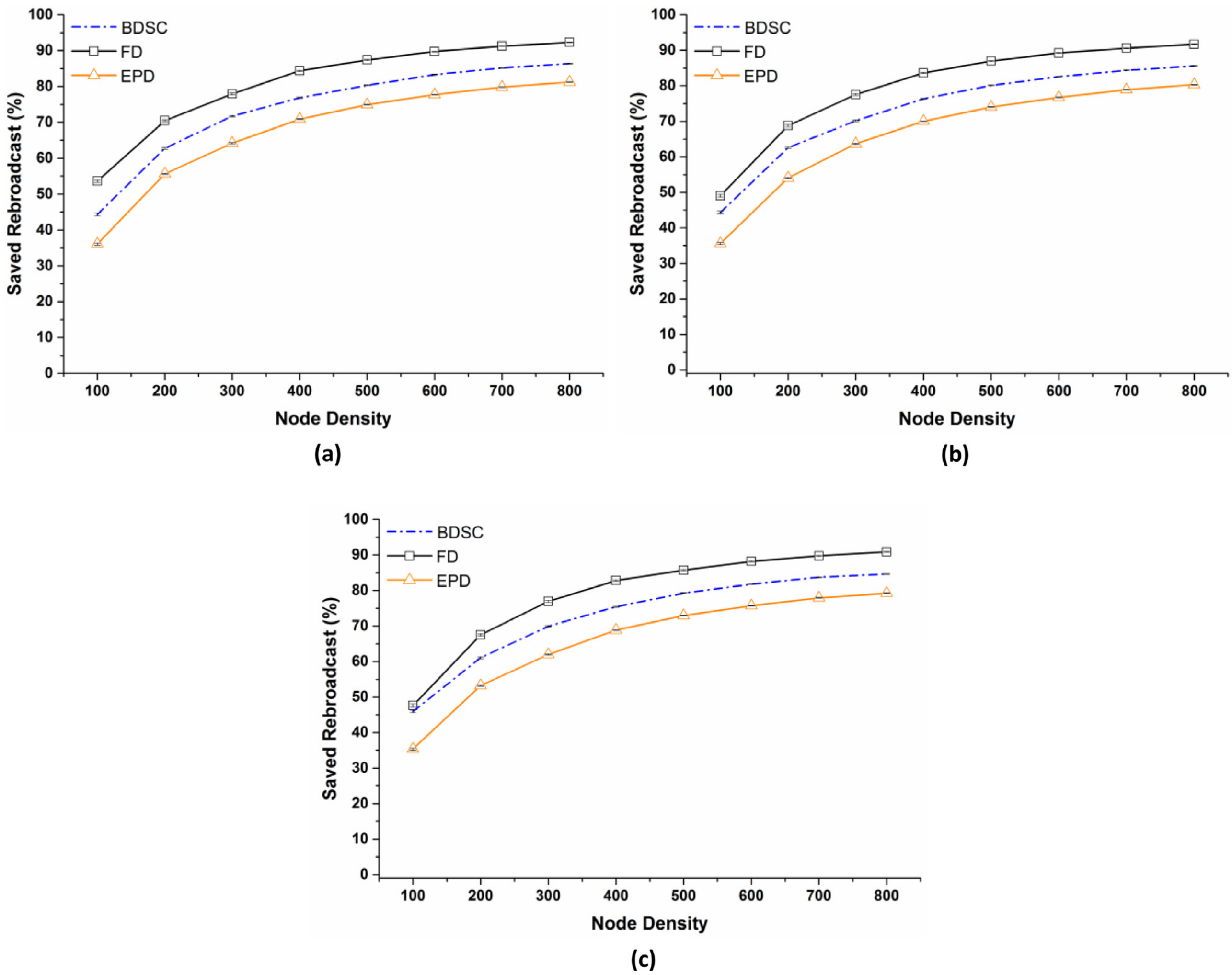


**Fig. 19.** The saved re-broadcast percentage over varying node density VANETs and evaluated with different number of sources for generating background traffic (a) 10% (b) 50% (c) 100%.

selecting the next relay forwarding node. In addition to improving the packet delivery ratio, the suggested BDSC scheme also attempts to obtain low end-to-end delays and high saved-rebroadcasts over densely populated VANETs.

The performance of the proposed BDSC scheme has been evaluated over both low and high node density VANETs. In order to study the impact of varying data traffic, three different background traffic scenarios have been adopted in which 10%, 50% and 100% of the total nodes participate in generating the background traffic. Our results have demonstrated that the BDSC scheme outperforms existing similar solutions in terms of packet delivery ratio at high node density networks and increased background traffic. Furthermore, the BDSC scheme exhibits the lowest end-to-end delays over all considered background traffic scenarios. The superior performance characteristics exhibited by the BDSC scheme, in terms of packet delivery ratio and end-to-end delay, are obtained while maintaining comparable saved-rebroadcasts to that obtained by the existing furthest distance scheme. A trend of higher resilience to messages loss, as reflected by the achieved high packet delivery ratios, is observed by the proposed BDSC scheme. The BDSC scheme can serve as an important building block for multi-hop message dissemination protocol for many applications in VANETs, such for safety-related alert messages and traffic management services.

As future continuation of this research, we would suggest to investigate the performance of the BDSC scheme over variants of street topographies [14,24,40] along with suitable obstacle models [25], such as with those streets found in urban environments [24,25]. In addition, we would suggest to including a messages retransmission technique in the event of messages loss to further improve the packet delivery ratio over high node density VANETs.

## Acknowledgements

The authors would like to acknowledge the support of The Research Council (TRC) Oman, (www.trc.gov.om), for supporting this work under Grant No: ORG/ICT/12/002. This research has used resources of the Free & Open Source Software (FOSS) Lab under the Communication & Information Research Center (CIRC) at Sultan Qaboos University (SQU) - Oman, (www.squ.edu.om/circ). The authors would also like to acknowledge the support of the Information Technology Authority (ITA) - Oman, (www.ita.gov.om), for the support in establishing the FOSS Lab at SQU.

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Please cite this article as: O. Rehman et al., An adaptive relay nodes selection scheme for multi-hop broadcast in VANETs, Computer Communications (2016), http://dx.doi.org/10.1016/j.comcom.2016.04.007