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RELIABLE RECOVERY STRATEGY FOR CONTENTION-BASED FORWARDING IN VEHICULAR AD HOC NETWORK STREETS

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ABSTRACT

Recent research studies prove that contention-based forwarding (CBF) algorithms are preferable in highly-dynamic vehicular environments. CBF algorithms are beaconless, whereas position-based algorithms rely on periodic beacon information to make forwarding decisions. Considering the store-carry-forward paradigm of delay-tolerant networks, which relies on mobility of vehicles to deliver packets when next forwarding vehicle is unreachable, we proposed a new recovery strategy and enhanced the CBF algorithm to tackle the network disconnection problem that frequently occurs in vehicular wireless networks. This enhanced CBF with a store-carry-forward capability is referred to as CBF-SCF algorithm. The algorithm was simulated, and the results indicate that CBF-SCF outperforms normal CBF in terms of packet delivery ratio and routing overhead.

Keywords: contention-based, beaconless, store-carry-forward, position-based, VANET.

INTRODUCTION

Vehicular ad hoc networks (VANETs), also referred to as cooperative vehicular networks, are a rising class of mobile ad hoc networks (MANETs) that offer new vehicular wireless applications to improve public safety and traffic management, as well as providing road condition information, local information, advertisements and entertainment for drivers and passengers [1, 2]. These cooperative networks require vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications to exchange information between moving vehicles and/or between vehicles and roadside equipment to provide such applications [2]. In 1999, the United States Federal Communications Commission (FCC) allocated the 75 MHz of spectrum in a band of 5.9 GHz (5.850-5.925 GHz), especially for VANET communications. In 2003, the FCC then enacted the dedicated short range communications (DSRC) service for VANET [3]. IEEE supports DSRC. IEEE 802.11p is an amendment to the IEEE 802.11 standard, and it is utilized for DSRC-based vehicular communications.

Few safety applications such as lane-change assistance rely on single-hop DSRC communications, whereas most VANET applications are between distant vehicles and/or roadside equipment (long-range communications) and require multi-hop routing. Cooperative road traffic monitoring, road condition warnings, and Internet connectivity are example applications of long-range communications with multi-hop routing [2, 4]. Due to the special characteristics of vehicular environments, designing an efficient routing protocol is a challenging task in VANET. High mobility, frequent partitioning (disconnections) and variations in network density and vehicle velocities are key challenging characteristics of a VANET which result in significant loss rates and very short communication times. Various routing protocols have been proposed in the literature to cope with such issues in vehicular networks. There are three main types of VANET routing protocols: topology-based routing, position-based forwarding, and contention-based beaconless forwarding. As we discuss in the next section, contention-based forwarding (CBF) is more suitable for VANETs.

The CBF algorithm proposed in [5] has three different beaconless forwarding methods called basic, area-based and active selection. Among them, only active selection method thatis based on a RTS/CTS/DATA process prevents packet duplication in forwarding path [5]. Hence, it is more proper to be applied in VANET. CBF with an active selection method (from now on called CBF) is the base for some other VANET beaconless forwarding protocols such as IB protocol [6]. This paper is an enhancement to the CBF, based on the store-carry-forward (SCF) paradigm of delay-tolerant networks (DTNs). The aim of our proposed protocol, which is called CBF-SCF, is to efficiently tackle the network partitioning problem in vehicular environments. CBF-SCF is a complete solution that includes a greedy mode for forwarding in connected partitions and a SCF mode for forwarding in disconnected partitions.

The remainder of this paper is organized as follows: In the second section we review related work. The third section describes the CBF-SCF algorithm. In the fourth section the algorithm is simulated and performance results are discussed. Finally, the last section concludes the paper and presents our future work.

BACKGROUND AND RELATED WORK

Topological routing

Traditional topology-based MANET routing protocols, e.g., AODV [7] and OLSR [8], are less suitable for vehicular communications due to the unique challenges presented by VANETs. Traditional protocols consider the whole network topology (nodes and wireless links) to create data packet routes either in a proactive or reactive approach.

In proactive or table-driven protocols, e.g., DSDV [9] and OLSR, all nodes periodically send routing control packets to create and update routing tables, even if there is no data to transmit. Therefore, proactive topology-based routing protocols have an excessive amount of control packets and consequently the overhead and bandwidth consumption is high. In contrast, reactive or on-demand topology-based routing protocols, such as DSR [10] and AODV, discover and create routes only when they want to send data to the destination. In these protocols, a flooding method is applied to route discovery. Therefore, on-demand protocols incur a delay when determining routes before starting to send data.

Both topology-based approaches are inefficient in highly-mobile vehicular networks, because as the network dynamics increases, route construction and maintenance overhead rise dramatically. This problem degrades network performance and limits the scalability of such routing protocols [2]. Although several topological protocols have been adapted to improve the performance of these protocols in vehicular networks, they are not able to eliminate the main issues challenging such protocols. For example, Fast OLSR [11] which is an enhancement to the OLSR protocol, as a proactive approach tries to adapt the frequency of periodic control messages to tolerate the network dynamic, and in a reactive approach proposed in [12], geographical information was added to AODV route request packets to improve the quality of discovered routes.

Geographical position-based routing

Geographical position-based algorithms are another type of MANET routing algorithms, which do not establish the route between source and destination. The forwarding (relaying) decision is made on-the-fly based on the positions of neighbors and the position of the destination. Information about the position of a destination can be obtained from a location service. It can also be obtained simply by flooding messages in the destination area to find the destination and receive its reply. Information related to next-hop neighbors is obtained from small control messages called beacons (or hello messages) which are periodically broadcast from every node (vehicle) in the network to inform one-hop neighbors of its existence and position [2]. Nodes also obtain their position through a positioning system like Global Positioning System (GPS) or Galileo. Since GPS devices will be available in future vehicles, more position-based forwarding algorithms have been proposed for VANETs. GPCR [13], VADD [14] and ACAR [15]are examples of these algorithms.

In a position-based forwarding scheme, each node has a neighbor table that stores a list of one-hop neighbors and their positions. The table is updated with information received from the beacons. When a data packet needs to be forwarded, the next relaying hop is chosen from the table in a way that the forwarding progress is maximized (e.g., typically, this is the neighbor closest to the destination).Such forwarding is called greedy forwarding. This process continues until the packet reaches the destination. Hence, it is essential for each node in the forwarding path to keep precise neighbor information to successfully choose the next-hop. When network dynamics increase, determining the position of neighbors becomes unstable. If position information is not accurate, the chosen next-hop may not be the best next-hop, or even worse, it can be a node that is already out of the transmission range. Both cases lead to inefficient or inaccurate forwarding decisions. Obtaining more up-to-date neighbor information requires more frequent beacon broadcasting (beaconing). However, this results in large communication overhead (bandwidth waste) and can also increase the probability of network congestion and packet collisions at the link layer, especially in dense vehicular networks [16].

Geographical beaconless forwarding

Beaconless forwarding, which is basically an on-demand (reactive) position-based forwarding approach, is another type of geographical forwarding algorithm that has been proposed to avoid periodic beacon transmissions. In a beaconless forwarding approach, the next-hop selection operation is performed in a distributed manner without having knowledge about other neighbors and thus eliminating the neighbor table and the required information in the beacons. CBF, BLR [17], BGR [18], BOSS [19], Coop Geo [20], IB, TOPOCBF [21] and CBF with ACK [22] are examples of such a forwarding approach.

According to Sanchez *et al*. in [23], beaconless forwarding algorithms are comprised of four separate mechanisms:

1) Data transmission announcement: The node holding the data packet starts the transmission process by broadcasting a message to all neighbors. The current positions of the forwarder (relaying node) and the destination are stored in the message headerto enable the message receivers to calculate their progress toward the destination. The broadcasted message is either a small control packet or the data packet itself. In the CBF and IB protocols, a control packet is applied to start the transmission, whereas in the other mentioned beaconless protocols, the data packet itself is broadcast.

2) Calculation of contention timer value for the neighbors located in forwarding area: Contention timers are employed to defer responses to the broadcasted message. Neighbors respond to the announced data transmission immediately upon the expiration of their contention timer. Each neighbor has a timer, and the timer is typically set in a way that the closest node to the destination responds first (greedy forwarding). To avoid multiple responses, during the deferring time each node that holds the broadcasted message listens to the wireless channel; if it overhears another node answering the message, it cancels its timer and drops its copy of the message as well.In addition, to ensure the detection of the responses by all the neighbor nodes, among the neighbors that successfully received the announcement message, only the ones located in the predefined forwarding area (within the transmission coverage area of the forwarder) are eligible to contend and answer the message, while others have to drop it. Indeed, the nodes located in the forwarding area become candidates for next-hop forwarding. Different forwarding areas are defined in the literature. The larger the forwarding area, the higher the probability of having more candidate nodes, but also the higher the likelihood of not receiving the responses from all the candidates. Therefore, there has to be a trade-off between these two issues when defining the forwarding area.

3) Next-hop selection in contention: In some protocols such as CBF, BOSS, CoopGeo, and IB, selecting the next-hop forwarder is done by the current forwarder based on the responses received from the candidates. In general, the candidate that responds first will be the selected node as the next-hop. Such protocols need to send an extra control message to the selected candidate to perform next-hop selection and also to inform other candidates about this selection. In other protocols, candidates perform a self-election process; the best candidate responds by reforwarding the data packet while others that overhear this retransmission, drop their copy.

4) Recovery operation: When a data packet gets stuck in a forwarding node with no neighbor closer to the destination than itself, a recovery strategy must be applied; otherwise the packet has to be dropped. This situation is referred to as local maximum. Figure-1 is an illustrative example of the situation. In this figure, forwarding area (darker region), that is the intersection of the circle delineating the transmission range of the forwarding node F and the circle around the destination D with radius equal to distance between F and D, is empty of neighbors. N1 and N2 are outside the forwarding area, and they are further from D, so they are not candidate nodes. In this situation although paths (F → N1 → N3 → D) and (F → N2 → N4 → D) exist to D, N1 and N2 will not respond to the announcement message and F will not forward data packets to them in greedy forwarding. That means that the network is partitioned (disconnected). Therefore, another forwarding strategy must be used in these situations to avoid packet drops. This strategy is called recovery strategy.

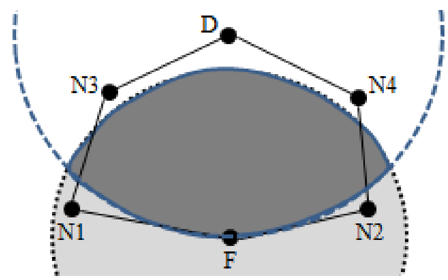

Figure-1. Forwarding node F is a local maximum with respect to destination D [24].

Related work

In the majority of proposed beaconless routing protocols, the recovery strategy is left as an open issue, especially in VANET beaconless forwarding protocols. For example, TOPOCBF, IB protocol, CBF with ACK, and road-based beaconless routing protocol proposed in [25] are designed for VANETs. However, their authors assumed that paths between sources and destinations are highly connected, whereas it is rare to establish fully connected paths in practice. Few have considered use of a so-called perimeter mode (also called face routing) strategy to escape from local maximum. In the perimeter mode, the forwarder first needs to discover all its neighbors to construct a planar subgraph, i.e., a graph that can be drawn with no intersecting links. Then the face routing algorithm is used to route the packets by applying the right-hand rule on the faces of the local planar subgraph [26]. This recovery strategy first was designed for ad hoc networks and is widely used in MANET position-based routing protocols (e.g., GPSR [24]).

There has been some exploitation of this approach in VANET position-based protocols such as GPCR. In beaconless protocols, for example, BLR protocol uses beaconing to discover neighbors and applies face routing as a recovery strategy. It is designed for wireless ad hoc networks, and it is not adapted for highly-mobile vehicular networks. A similar recovery strategy is also used in the BOSS routing protocol, which it is introduced for wireless sensor networks. However, all the existing recovery proposals need to have full or partial knowledge of one-hop neighbors to construct the planar subgraph. Also, a decision for selecting the next-hop (in perimeter mode) is taken by the forwarder according to the information received from neighbors. This kind of recovery results in the main issues challenging position-based routing protocols in vehicular environments, as

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ARPN Journal of Engineering and Applied Sciences

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previously discussed, which can still appear with such a recovery method. Moreover, as depicted in Figure-1, there have to be some neighbor nodes within the transmission range of the forwarder and the nearby area outside of the forwarding area (N1 and N2) to construct a temporary alternative path using the perimeter operation.

However, with respect to the ratio between the width of a street (or a highway) which is normally tens of meters and the wireless transmission range of vehicles which is based on the IEEE 802.11p standard and, depending on the application can vary from 100 m to 1000 m, it is highly unlikely that proper neighbors can be found around the forwarder to construct the planar subgraph unless the width of the street is greater than the transmission range (this is very rare). This situation is depicted in Figure-2. In this Figure, it is assumed that wireless transmission range is five times the width of street while the value may be much higher in actual VANET. In the figure, the darker shaded area is the forwarding area that is empty. For constructing the planar subgraph, other vehicles must be located in the lighter shaded area. However, the intersection of this area and the street is negligible, and it is very unlikely that other vehicles located in it. This means that each time a vehicle faces local maximum, partitioning happens in the network and communications disconnect. Hence, it is necessary to consider an efficient recovery strategy in forwarding algorithms for VANETs. Otherwise, each partitioning leads to packet drops in the network.

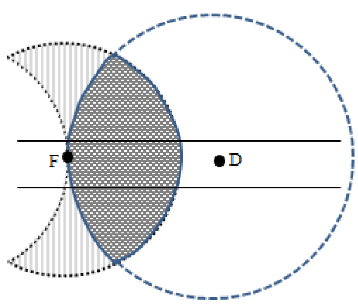

Figure-2. Relation between the width of the street and the wireless transmission range of vehicles.

THE PROPOSED CBF-SCF ALGORITHM

The SCF approach has been employed as a recovery strategy in some position-based routing protocols such as VADD in VANET. However, in the following we adapt the CBF as a beaconless protocol to tolerate frequent network partitioning using the SCF approach.

Overview of CBF-SCF protocol

CBF-SCF is an integrated protocol to combine both beaconless forwarding for connected partitions and the SCF mechanism of delay tolerant networks for forwarding between partitions. Based on this, the protocol includes two operational modes, the greedy mode and the SCF mode. In the greedy mode, CBF-SCF follows exactly the CBF algorithm and operates as truly contention-based, without an explicit selection of the next forwarder by the forwarding node. In each hop, a packet is greedily forwarded toward the destination in a way that the candidate neighbor that provides the most progress to the destination wins the contention and acts as the next forwarder. However, as stated earlier, due to the high mobility in a VANET, partitioning or disconnection frequently occurs in the network, especially in sparse networks. In this case, the CBF-SCF protocol switches to SCF mode and relies on mobility to deliver packets. In the SCF mode, the moving vehicle stores packets in a buffer until a new neighbor with positive progress appears in the network. When such a neighbor shows up the protocol switches back to greedy mode to forward packets to that neighbor.

Figure-3 illustrates an example of CBF-SCF operation in a two-way road segment. In this figure, data packets are transmitted from left to right towards a destination located at right-end of the road. At time t1, the vehicle N3 that receives data from N1 cannot find any vehicles in the target direction and has to store and convey the data in SCF mode until N4 enters the N3 transmission range, at time t2. Upon detection of N4, N3 transmits these data to it, and N4 relays them to N6, N8 and N9 in greedy mode. In this way, data packets are eventually transferred toward the destination.

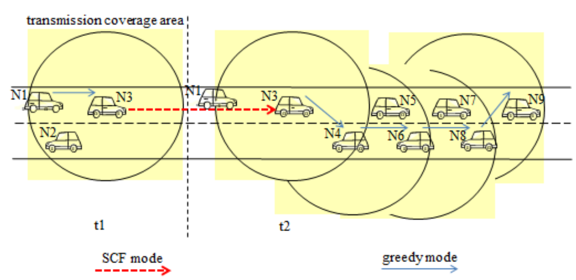

Figure-3. An illustrative example of CBF-SCF operation with respect to neighbors of the vehicleN3at different times t1 and t2.

Thus, unlike the common belief that the mobility of vehicles is a problematic behavior in VANET routing, in our approach we develop a way to utilize mobility to improve routing performance.

Algorithm

Figure-4 provides a flowchart of the CBF-SCF protocol. The normal boxes depict greedy mode and the bold boxes depict SCF mode. The flowchart entry “Packet Received (P)” is a point at which the network layer receives a packet P either from the upper layer at the source of the packet (Data packet only) or from the link

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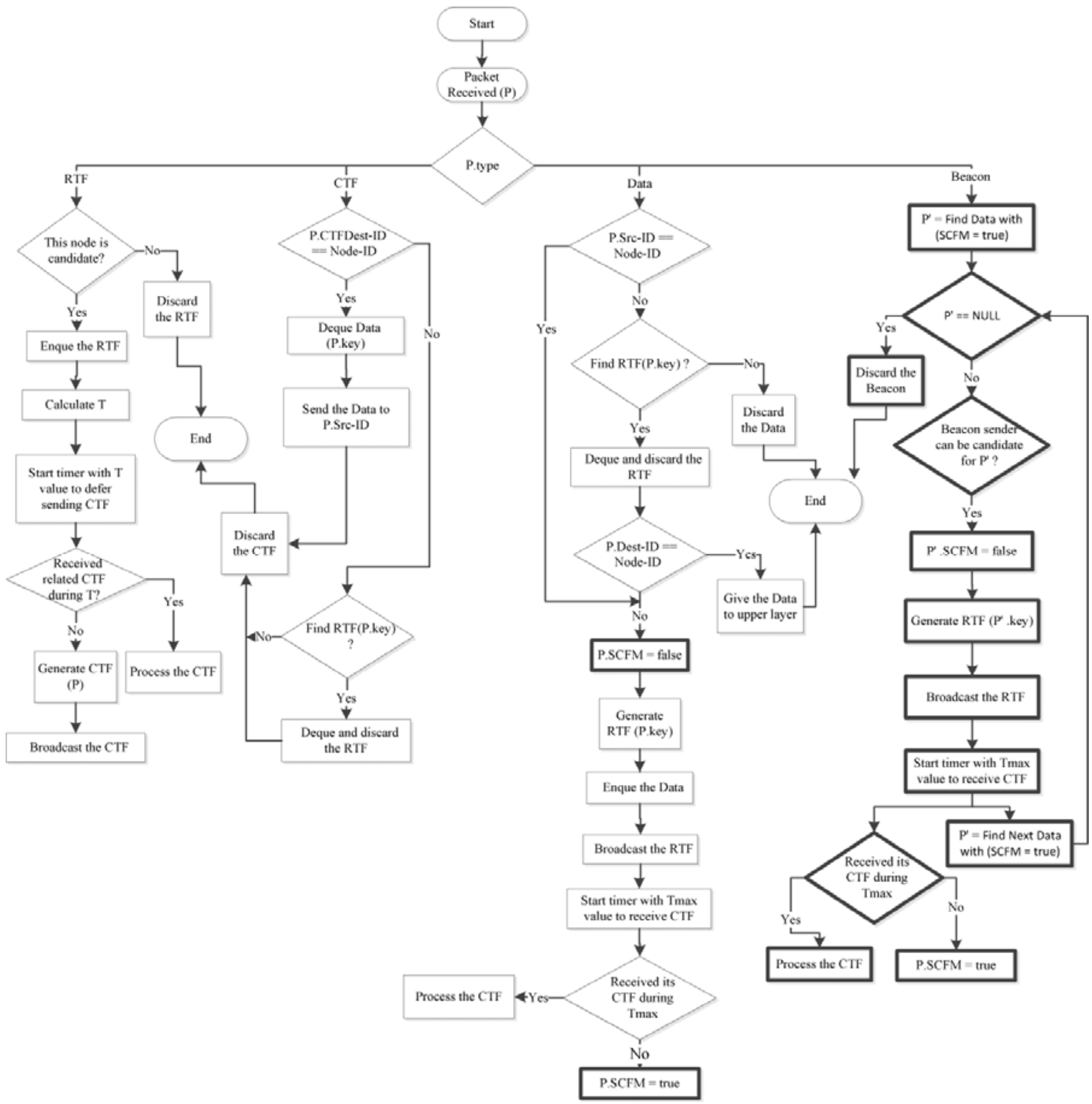

Figure-4. Flow chart of CBF-SCF protocol with relation between greedy mode (normal boxes) and SCF mode (bold boxes).

layer at intermediate nodes. Four packet types are used in the forwarding process: request to forward (RTF) control packet, clear to forward (CTF) control packet, Data, and Beacon. Beacons are generated by the IEEE 802.11p MAC protocol. Thus, they are not routing layer packets. We only use their information in SCF mode to know whether or not a neighbor with positive progress has entered the transmission range of the current forwarder. The Data packet includes a bit in its header to indicate the operational mode currently being used (greedy or SCF). This bit is called SCF Mode bit (SCFM). When a Data packet receives, the SCFM is set to false by default. Given that multiple data flows from different pair of sources and destinations may exist in the network, it is essential for each Data packet to clearly identify as belonging to which data flow. Therefore, in addition to other required packet header fields, a key field which is a combination of data source identifier, data sequence number and destination identifier (Dest-ID) also needs to be included in the routing packet headers.

The protocol works as follows: The forwarding node that holds a Data packet announces the transmission by broadcasting a RTF packet. The RTF contains the current position of the forwarder, the position of the

ARPN Journal of Engineering and Applied Sciences

destination and the key. Every neighbor that receives the RTF checks whether it provides positive progress for the Data packet specified by the RTF (i.e., can be a candidate or not). Progress *P* is defined as [5]:

$$P(f,d,n) = \max\left\{0, \frac{dist(f,d) - dist(n,d)}{r}\right\} \quad (1)$$

where f is the position of the forwarder, d the position of the destination and n the position of the neighbor. dist represents the Euclidian distance between two nodes and r is the nominal transmission range. Forwarding area covers the complete greedy area and it is defined as the intersection of the circle delineating the transmission range of the forwarder and the circle centered at the destination with radius of dist(f,d) (darker region in Figure-1). The progress P ranges from 0 to 1, where 0 indicates that the neighbor node is located out of the forwarding area, and it is unsuitable for consideration as a candidate node, while 1 belongs to an optimal candidate that provides the most progress. Candidates hold the received RTF while unsuitable nodes have to drop it. Then candidates contend for sending a CTF packet as an answer to the broadcasted RTF.

The winner of the contention broadcasts the CTF, but it is clear that it answers to which forwarding node and for which data packet by including a CTF destination identifier (CTFDest-ID) and the key fields in the CTF header. During the contentions, each node that overhears the CTF cancels its contention timer and drops its copy of the corresponding RTF.

The contention timer T function is [5]:

$$T=(1-P)T_{max} \quad (2)$$

where T_{max} is the maximum time that the forwarder waits to receive a CTF for each Data packet. If it receives the CTF, it sends the Data to the CTF sender and allows that node to act as a new forwarder, otherwise the forwarder knows that the network has been disconnected, so it has to set the SCFM bit to true, holding and carrying the Data until a new neighbor with positive progress appears in the network.

As position-based protocols goes one step back and use topology-based routing for their recovery strategy (planar subgraph and face routing), in SCF mode, we also go back to position-based protocols and use periodic beacons to determine the existence of potential next-hop candidates.Whenever a beacon receives, the forwarder checks its buffer to determine whether there is any Data packet being carried on SCF mode or not. If there is, for each Data packet, it checks whether the beacon sender can be a next-hop candidate. Then for every Data packet that has a potential next-hop candidate, the operational mode switches back to greedy, and a corresponding RTF packet will be rebroadcast.

Note that in the CBF-SCF algorithm, while in the SCF mode operation, the forwarder discovers candidate neighbors just by receiving their periodic beacons that exist in IEEE 802.11p, but unlike position-based routing protocols, the beacon information does not have any effect on forwarding decision-making. Here, the forwarding process is always in a contention-based beaconless manner.

PERFORMANCE EVALUATION

To assess the performance of the proposed CBF-SCF we conducted a series of simulations for both CBF-SCF and CBF algorithms in various highway scenarios and then compared results. In the following subsections, we explain the simulation setups and discuss the obtained results.

Simulation setup

The algorithms were implemented in ns-2 (version 2.35) [27] running under Ubuntu Linux. The MObility model generator for VEhicular networks (MOVE) tool (version 2.91) [28], which incorporates vehicular mobility and wireless network models,was employed to generate the simulation scenarios. MOVE uses Simulation for Urban Mobility (SUMO) simulator (version 0.12.3) [29] for creating a layout (map) of the scenarios and vehicular traffic patterns as well as for generating movement trace files. MOVE offers the movement trace files as input to the ns-2 and generates ns-2 scenario scripts thatare needed for the simulations.

Table-1 shows mobility model, data traffic and wireless model parameters and their values. The scenario layout was an 8 km two-way highway with three lanes in each direction. Vehicles travel in both directions with a maximum road speed of 60, 90 and 120 km/h. The number of travelling vehicles range from 50 to 500.

For all simulations, there are four data sources, two mobile nodes (vehicles) and 2 fixed nodes. Each fixed node is located at one end of the road. Data sources send 512 bytes CBR data packets with a data sending rate of 4 kb/s (1 packet/s) to 2 fixed destinations located at the other end of the road. To obtain more accurate vehicular movement, the most stable 300 seconds of the SUMO trace file with the maximum number of vehicles was considered in the simulation and the other parts were discarded. CBR traffic duration was 250 seconds, and the simulation was terminated 50 seconds after stopping of the last data traffic.

Physical and MAC layer configurations were according to predefined IEEE 802.11p parameter values in ns-2 with only an altering of transmission power to provide a maximum transmission range of 250 m. A two-ray-ground model was used as the wireless signal propagation model.

VOL. 10, NO 20, NOVEMBER, 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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Table-1. Simulation environment.

Mobility model		Data traffic		Wireless model	
Parameter	**Value**	**Parameter**	**Value**	**Parameter**	**Value**
Simulation area	8 km highway	Traffic model	CBR,four sources	PHY and MAC layers standard	IEEE 802.11p
Number of lanes and directions	Three lanes, two directions	Traffic duration	250 s	Propagation model	Two-ray-ground
Max. road speed	60, 90, 120 km/h	Data Packet size	512 bytes	Transmission power	-37.2 dBm
Number of vehicles	50-500	Packet rate	Onepkt/s	Transmission range	250 m

In the simulations, to reduce the negative effect of beacons on network performance, the beacons were generated on demand. That means that only when a forwarder has a Data packet to send and the network is disconnected, will it initiate broadcast of a beacon request packet and request neighbors to send their beacons.

Metrics

The performance of CBF-SCF and CBF was evaluated by varying the network density and the maximum speed of the highway. The performance metrics for the algorithms are as follows:

Packet delivery ratio (PDR): This metric is defined as the number of unique data packets delivered to the destinations per number of sent data packets.

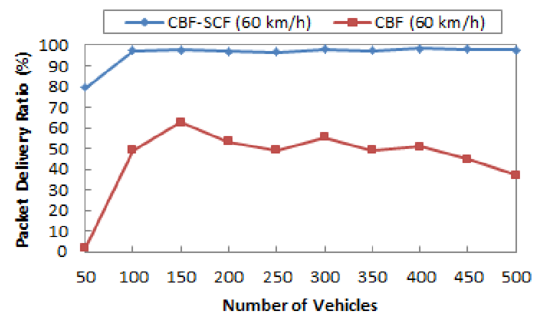
Average end-to-end delay: This metric is defined as the average end-to-end delay for the successfully received packets.

Average hop count: This metric is the average number of intermediate vehicles that act as relay nodes to forward a data packet from a source to a destination (average path length).

Routing overhead: This metric is defined as the number of routing control packets per number of unique data packets delivered to the destination.

Simulation results

Figure-5 shows the PDR of the network when vehicle density varies from sparse to very dense, with three different maximum road speeds. For a sparse network with 50 vehicles on the road, in CBF there is no delivery when vehicles speeds are high (90 and 120 km/h) and only about 2.18% of sent packets were delivered to the destinations at a lower speed, while this amount increased to at least 60% in CBF-SCF. The figure also shows that for other vehicle densities, CBF-SCF outperforms CBF by as much as an approximate 45% PDR increase. In most cases, we observed a decrease in the PDR of the CBF as node density increased while CBF-SCF obtaining a delivery ratio of around 97% for all the evaluated densities



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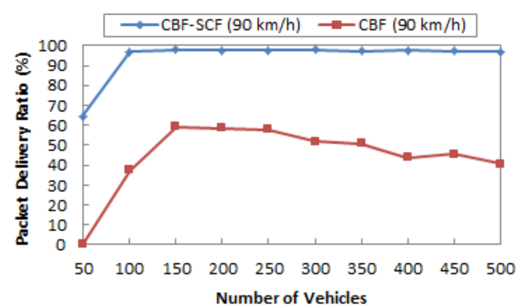

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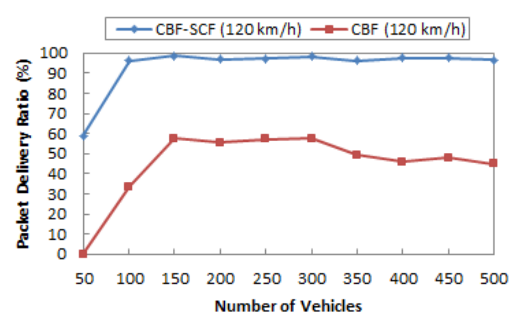

(c)

Figure-5. Packet delivery ratio with different node speeds. (a) 60 km/h. (b) 90 km/h. (c) 120 km/h.

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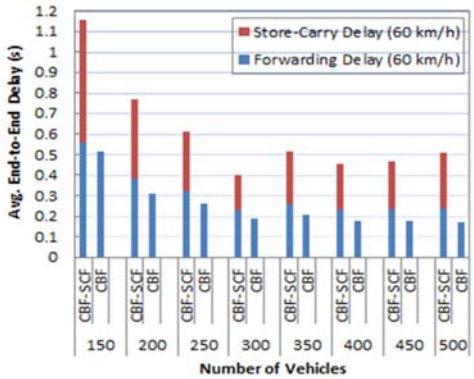
and speeds, which means that the proposed algorithm can cope with the offered mobility. Network disconnections and the lack of a recovery mechanism prevent the CBF from achieving a high delivery ratio.



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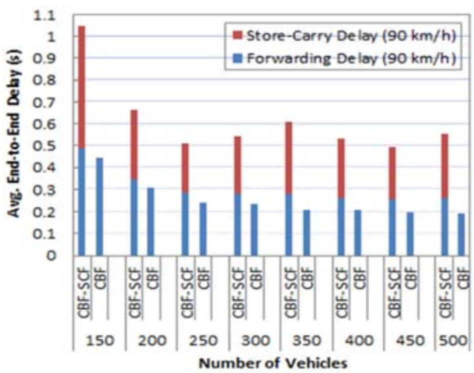

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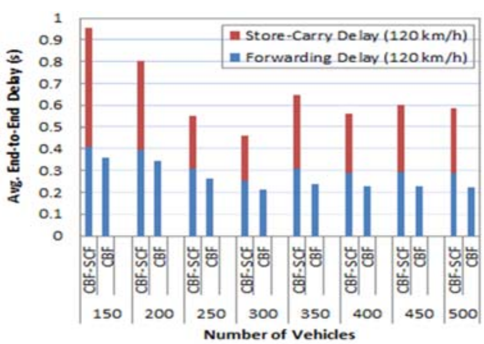
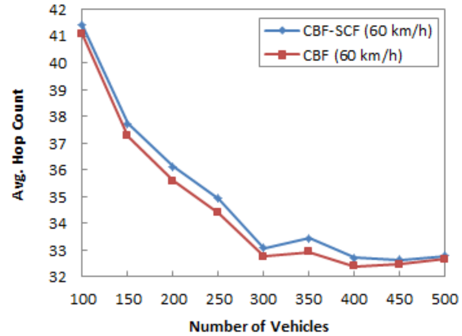


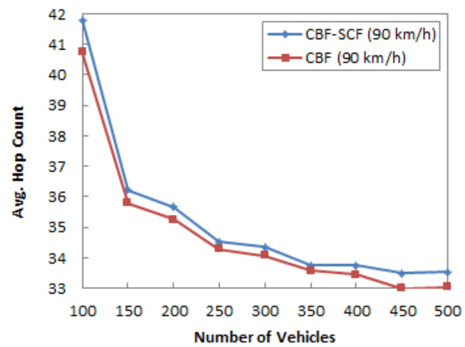
(c)

Figure-6. Average end-to-end delay with different node speeds. (a) 60 km/h. (b) 90 km/h. (c) 120 km/h.

Figure-6 shows the average end-to-end delay. For CBF-SCF, this metric is represented as the total amount of average buffering delay (store-carry delay) and average transmission delay (forwarding delay) of all successfully delivered packets (Note: values of average delay for sparse



(a)



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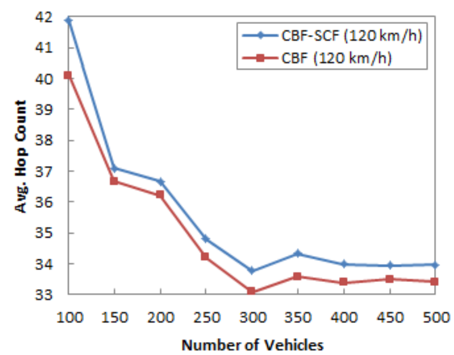

(c)

Figure-7. Average hop count with different node speeds. 60 km/h. (b) 90 km/h. (c) 120 km/h.

network with 50 and 100 vehicles are more than 60.56 and 2.02 second respectively. So, these values cannot be scaled to the figure size to show.).CBF-SCF that uses a buffer to tackle the temporary network partitions present additional delay compared with CBF. Nevertheless, it can deliver packets to the destinations in scenarios with frequent disconnections in which CBF failed. As shown in Figure-6, as the network density increased, the network topology becomes more connected, and, therefore, the average delay decreases. The other point is that, in general, with rising vehicle speed the average transmission delay (the

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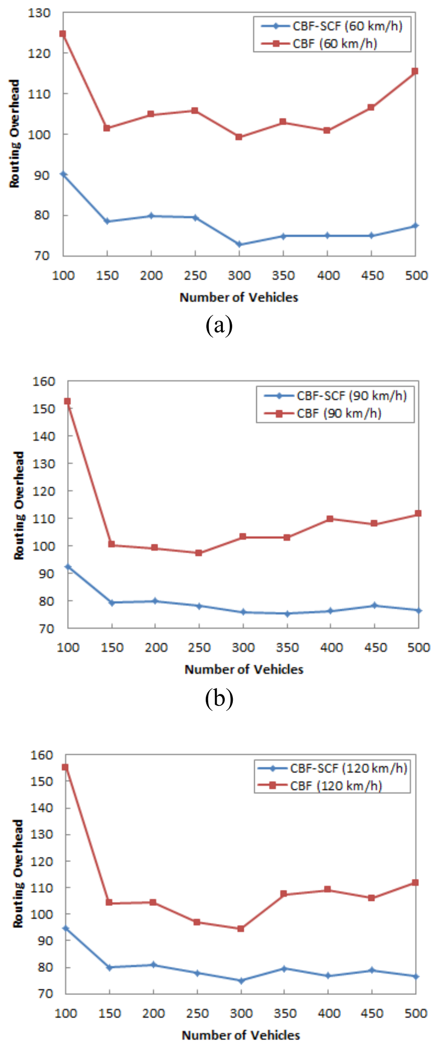
ARPN Journal of Engineering and Applied Sciences



(c)

Figure-8. Routing overhead with different node speeds. (a) 60 km/h. (b) 90 km/h. (c) 120 km/h.

blue part in Figure-6) goes up. The reason is that with increasing vehicle speed, the wireless link connectivity of the vehicles decreases, which leads to a rise in failure to deliver the data packets to the next-hop. The IEEE 802.11p MAC protocol tries to cope with such failures by retransmitting the unicast packets up to the predefined number of times (set to 7 in ns-2) which leads to more overhead and traffic congestion at the link layer.

Figure-7 plots the average hop count of the delivered packets. The comparison between CBF-SCF and CBF in this figure indicates that variation of the average hop count is similar for both, but our proposed algorithm has a slightly longer average path length than other. This is due to the SCF mode that is triggered when network disconnection occurs. In fact, when a packet faces network partitioning and has to be buffered, it can be forwarded again upon detecting a neighbor node with positive progress toward the destination, but this neighbor may not necessarily be a neighbor with the largest possible progress. As depicted in Figure-7, the denser network a better neighbor that can be selected which results in a smaller hop count. However, the results do not imply that because of selecting worse intermediate nodes, our algorithm leads to worse performance. This algorithm offers better performance in terms of packet delivery ratio and routing overhead.

Figure-8 represent the routing overhead of the network. Based on the definition of this metric, a decrease in delivery ratio is causing an increase in routing overhead. Obtained results in Figure-8 prove the issue. When a data packet is sent to a destination, for each hop that the packet travels, at least two control packets (RTF and CTF) impose as routing overhead on the network. In CBF, for the lack of recovery strategy, each network partitioning leads to one or more packet drops which it means that there were overhead without delivering the packets. As presented in the figure, routing overhead of CBF-SCF is much less than CBF in all evaluated network densities and speeds. Note that beaconing overhead is not considered in Figure-8 as beacons belong to the MAC layer, not to the network layer.

CONCLUSIONS

In this paper, we have briefly reviewed existing forwarding algorithms and their shortcomings in VANET. We gave more attention to contention-based beaconless forwarding algorithms and focused on the frequent network partitioning problem in vehicular networks. CBF-SCF protocol as an enhancement to the well-known CBF beaconless forwarding protocol was proposed. This protocol employs a store-carry-forward mechanism as a recovery strategy to efficiently tackle the network partitioning problem. The protocol detects network partitions and the SCF operation is integrated with the normal contention-based beaconless greedy operation. We conducted ns-2 simulations on a highway scenario, and the results show that CBF-SCF can be reliably applied in both sparse and dense vehicular environments.

In our ongoing and future work, we will improve our algorithm to make it fully beaconless without requiring beacons for its neighbor detection mechanism in SCF mode. In addition, we will derive and formulate a new weighted contention-timer (delay timer) function that incorporates two criteria to self-elect the best next hop, selecting the shortest path and reducing communications over lossy links.

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