Forwarding Methods in Data Dissemination and Routing Protocols for Vehicular Ad Hoc Networks

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Abstract

Intermittent connectivity, abrupt changes in network topology and low reception rate are the most important properties that distinguish VANET (vehicular ad hoc networks) from other types of ad hoc networks. To optimize reliability and time criticality metrics in data communication protocols for VANET, novel ideas are needed. In this article, we present a tutorial on methods (at the network layer), encountered in recent literature, for small and large scale routing protocols, and geocasting (broadcasting, data dissemination, and warning delivery) protocols.

VANETs are distributed, self-organized and potentially highly mobile networks of vehicles communicating via wireless media. They are a form of Mobile Ad hoc Network (MANET) where movement of each node (vehicle) is restricted by road direction, encompassing traffic and traffic regulations.

The communication among vehicles in VANETs may be performed by means of the Dedicated Short-Range Communication (DSRC) standard that employs the IEEE 802.11p for wireless communication. The DSRC is a Medium Access Control (MAC) protocol that operates at 5.9 GHz. It mandates all vehicles periodically (every 300ms) exchange beacons which contain vehicle geographic locations (available via GPS) enabling each vehicle to know the position of neighboring vehicles.

VANET scenarios differ from others in three main aspects, which, taken together, pose enormous challenges for the design of timely and reliable data dissemination protocols: low packet reception rate, intermittent connectivity, and abrupt changes in (and potentially high) neighbor density.

Vehicular communication channels suffer from reflections and signal scattering, which degrade signal strength and quality. Also, vehicular mobility adds more dynamic fading conditions combined with spatially correlated shadow fading effects. Strong ground reflections also produce deep faded outage areas between transmitters and receivers.

Vehicles on the road may be neighbors for only a few seconds. The whole platoon of vehicles can be temporarily disconnected from other platoons. Network dynamics is also characterized by sudden changes in speed and frequent static and dense configurations in congested areas, at traffic lights or in parking places. These aspects have impact on designing VANET protocols for different applications.

VANET Applications may require a high percentage of reception by intended receivers, defined as reliability here. Protocols should have good trade-off between reliability and latency. Further, time critical applications such as warning delivery dissemination require that messages should be received with minimum latency, at the cost of lower reliability.

Data communication protocols designed for ad hoc wireless networks, including reactive on demand routing and proactive route maintenance, have the implicit assumption of network connectivity. They work poorly when applied to VANETs since they do not consider disconnection and do not react to the discovery of new neighbors [1]. Data communication protocols should seamlessly adapt their behavior from static, to moderate, and to highly dynamic scenarios, to abrupt changes in network conditions and to scenarios with different mobility patterns in different parts of the network at the same time.

There is no consistent naming for data communication problem statements that are solved in VANET. For instance, many solutions described as 'broadcasting' protocols by their authors (including some reviewed here) are instead small scale routing tasks because there is no attempt to deliver messages to all recipients (e.g. those located between the last two senders); instead, the idea is to advance the message in a certain direction. We describe solutions to the two main problem statements (elaborated in [2]) that are *geocasting* and *routing*. Geocasting is one-to-all communication in a specific region; it is also called broadcasting, data dissemination, and warning delivery. Routing is one-to-one communication. *Small scale routing* deals with routing on a single road segment between two intersections, and with vehicles located in several lanes and possibly moving in opposite directions. *Large scale routing* deals with routing between different road segments and decisions of choosing the next forwarder are made at intersections.

The goal of this article is to review novel algorithmic paradigms specifically designed for VANETs as opposed to other types of wireless ad hoc network. A plethora of proposed solutions exist. We do not review transport layer issues (e.g. message priority), one-hop warning protocols, protocols assuming always connected vehicles, centralized algorithms assuming availability of full network knowledge to solve the

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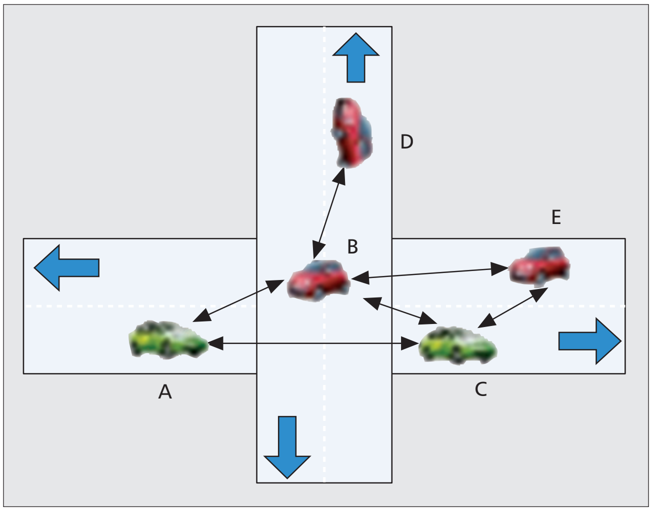

Figure 1. *Sender and receiver oriented forwarding:* A *forwards to* C *overlooking* D *due to lack of local knowledge at receiver* B.

corresponding optimization problem, and protocols applying network coding. We select representative new ideas for the design of VANET data communication protocols, and give a tutorial on how they work. A detailed survey is given in [2]. Described protocols can incorporate the use of road side units as a special static 'super-vehicle' for wireless communication, possibly with wired links among them and additional processing and storage.

Small Scale Routing Protocols

This category includes **sender oriented** and **receiver oriented** forwarding algorithms. We use the term *sender* for the node, including the source, that has just transmitted a message and its task is to identify *forwarding* nodes for further message propagation. TRADE and DDT [3] are two routing algorithms for cars located in parallel lanes on a road. TRADE is sender oriented; a car that retransmits the message will piggyback the ID of the furthest neighbor (in the direction of message broadcasting). That neighbor, upon receiving the message, will be the next to retransmit it. For example, in Fig. 1, A selects its furthest neighbor *C* to retransmit. However, the intended neighbor may be disconnected at the time of message transmission, since the connectivity was established earlier, or may not receive the request. This would stop the flooding process prematurely. Another issue occurs if we want to disseminate messages in two dimensions. In the same example, *A* is not aware of vehicle *D* which is covered by its neighbor *B* because *B* is not selected for forwarding.

Beacons can be lost due to the probabilistic nature of reception, which causes vehicles to inaccurately estimate existing neighbors and their positions. DDT [3] is a beaconless receiver oriented next hop selection strategy. A transmitting vehicle appends its location with the message. Receiving vehicles defer retransmitting for a back-off time that is inversely proportional to their distances from the transmitting vehicle. Candidate neighbors set timer values proportional to $1-d/R$, where d is the distance from the sender, and R is the transmission range (assumed to be the same for all vehicles). Therefore, the farthest receiver retransmits first. That retransmission will normally block other neighbors. However, neighbors that do not hear it may continue competing using the same timer value which causes additional retransmissions.

Increasing the beacon frequency has limited impact on the performance of the back-off timer approach. It is more useful for vehicles to update their positions and neighbors' positions dynamically by calculating velocity and orientation using consecutive GPS locations and time between them.

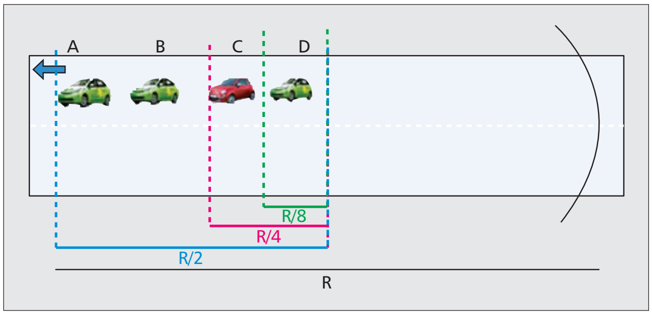

Figure 2. BPAB *forwarding;* D *wins after binary partition based competition.*

VDEB [4] is a receiver oriented protocol where possible forwarders are partitioned into several rings. The ring width is inversely proportional to vehicle density (the number of neighboring vehicles detected via periodic beacon messages). It is included in the message, and each ring is assigned a waiting time. Vehicles in the outermost ring have the shortest waiting time so they retransmit first. If the retransmission fails, vehicles in the next ring retransmit. Packet collisions in the same ring are resolved by the 802.11 back-off mechanism (used by other protocols described here). VDEB corresponds to the sequential search, while BPAB, presented next, has its analogy in the binary search.

BPAB (Binary Partition Assisted Broadcasting) [5] is also a receiver oriented protocol for reducing the delay of emergency messages. It is based on iterative binary partitioning to find the furthest segment containing possible forwarders. Initially, the coverage range R is divided in two halves (inner and outer). The black burst is used to determine which half is the input for the next iteration. If the number of iterations reaches a parameter value N, iterations terminate and the remaining competing cars apply random back-offs in a contention window.

An example of BPAB is shown in Fig. 2. After A transmits RTS, the transmission range of *A* is divided in the first iteration into two equal segments of length $R/2$. In this example, the outer $R/2$ segment does not contain any vehicle, so the inner segment will become the input for the next iteration. The inner $R/2$ segment is divided into two equal segments ($R/4$). Since vehicle *B* in the inner segment detects the black burst transmitted by vehicles *C* and *D* in the outer segment, *B* exits the competition and the outer segment becomes the input for the next iteration. The outer $R/4$ segment is divided into two R/8 segments, both containing vehicles (*C* and *D*). Vehicle *D* wins the black burst competition and becomes the forwarder because it is in the outer R/8 segment. It then sends CTS to *A* which broadcasts the message attaching the address of the next forwarder (*D*). Overhearing can be used as passive acknowledgment by A to recognize RTS from the next forwarder.

The main drawback of BPAB is the delay due to the lack of vehicles in certain intervals. If all possible forwarders are near the sender, there is a delay until iterations eliminate spaces with no vehicles.

TO-GO [6] discusses the small scale routing as part of the large scale one. To maintain connectivity, greedy advance is made toward the next intersection on the selected route, instead of using actual destination (not necessarily located on the same road segment) as the target destination. Forwarding targets the node with possible advance and having the largest number of neighbors estimated based on beacons. Candidate receivers apply a delay function that favors nodes which are near the selected target node (an ellipse around the targeted

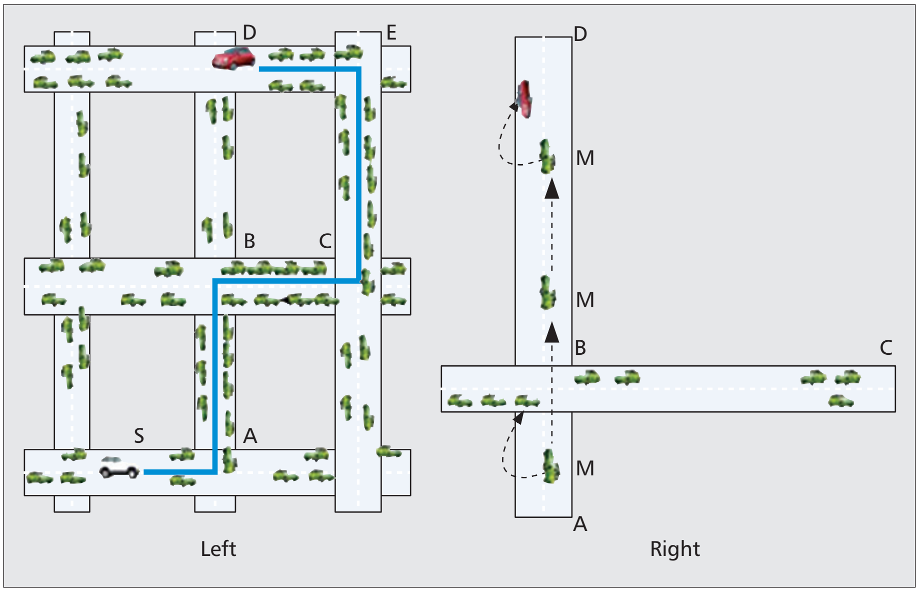

Figure 3. CAR-*path construction and anchor points illustration.*

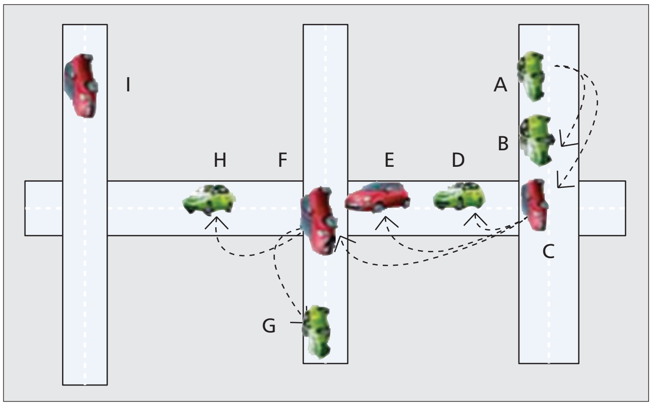

Figure 4. *ackBSM broadcasting: source* A *and retransmissions by backbone cars* C *and* F *and later* H *when it meets* I.

node is applied to show the limits), and the one with the smallest delay will respond first offering to forward the message.

Large Scale Routing Protocols

Several protocols were proposed to propagate messages in a large scale road network. These protocols aim to overcome vehicle disconnection for reducing time delay. In epidemic routing [7], each receiving car forwards the packet (at most once) if it is closer to the destination than the source. If a vehicle is disconnected, it acts as a new source, stores the message and waits for a new neighbor that is closer to the destination.

Connectivity-Aware Routing (CAR) [8] targets urban areas. Beaconing is adaptive: the fewer neighbors, the more frequent beacons. Data packets also carry beacon equivalent reports. The algorithm first performs flooding from a source *S* to discover a destination *D*, with the delay recorded on the path; the best path is selected at the destination and reported back to the source. Routing from *S* to *D* then proceeds along the constructed path and therefore decisions at each road intersections (called anchors, e.g. *A*, *B*, *C*, and *E*, Fig. 3) are predetermined. Anchor points are included in packets for considering possible road changes. To propagate packets between anchors points, greedy forwarding is used, where current vehicle transmits the message to the closest neighbor to the next anchor point.

If a disconnection occurs, intermediate vehicles may carry the message for a limited time until advancement to another vehicle is possible. If a vehicle carrying a message continues driving along a road which is not on the predetermined path, it waits until a vehicle driving in the opposite direction (toward the anchor point) is able to take over the routing task. That vehicle will recursively have the same task at the anchor point. Therefore the message is kept around an anchor point until a vehicle carrying the message continues driving on the predetermined path. In Fig. 3 (left), the routing path is constructed between *S* and *D* using the anchor points *A*, *B*, *C*, and *E*. A Preprocessing flooding step favors this path over the *ABD* shortcut because of the intermittent disconnectivity at segment *BD*. Fig. 3 (right) shows the vehicle *M* driving from *A* towards *D*. If none of receiving vehicles around *B* continues driving along *BC* then *M* mules the message until it meets a vehicle *N* driving back toward *B*.

When the destination moves, a one hop route extension is possible. If the message is not delivered in certain time, new location discovery is initiated. It starts at an intermediate node, with flooding of half hop count of the original path.

A **trajectory-based** data forwarding algorithm [9] focuses on data delivery from a vehicle to an access point (RSU) in light traffic with minimum time delay. A road map, vehicle arrival rates and speed of each road are available to vehicles in the area. Vehicles also know their own planned movement trajectory but do not know plans of other vehicles. A vehicle at an intersection needs to determine whether to forward a message to another vehicle or carry it to avoid disconnection. So, each vehicle calculates the EDD (expected delivery delay) to the closest RSU, and adds it to its periodic beacon to inform neighbors. To establish forwarding priority, the algorithm sorts roads at intermediate intersections by the geographically shortest paths. Thus, a message is forwarded to a vehicle whose EDD is minimum. Instead of returning the message to anchor points as in [8], the advance in [9] is attempted at the next intersection.

The protocol uses simple broadcasting to exchange the EDD with neighbors causing a broadcast storm which increases communication delay and network overhead. Another problem is relying on unstable information such as speed, trajectory and direction to predict the time delay.

Reliability in Geocasting Protocols

To increase the reliability of transmission, **repetitions** are often applied, for the same step in the forwarding process. Consider a simple warning delivery service protocol, every time a vehicle receives a new warning message, it decides with probability *p* to act as a relay and forwards the message. There are a few broadcasting cycles, which start at regular intervals every *D* seconds (selection of a vehicle that initiates a broadcast cycle is nontrivial). A vehicle may unnecessarily send too many messages after all vehicles already have the message. In other scenarios, it may send too few messages, because there is no mechanism to restart flooding immediately after the discovery of new neighbors. Also, reception of message is uncertain.

In [10], once a vehicle transmitted a first cycle emergency packet, one or more neighboring nodes that have successfully received the packet will be selected to repeat the message. This process continues until a specified number of repetitions (*Nc*) has been issued in the one-hop range. A new timer is set by each neighbor that received the message based on its distance and transmission range. The timer value is presumably set in the previous transmission round since no mechanism is given to trigger new timers at the remaining neighbors. The senders are informed if the previous broadcasts are successful or not via the repetitions of the message by the receivers. Each message copy has a sequence number, so a counter can be maintained at nodes even if some message copies were not received. However, the same sequence numbers can be repeated by different forwarders. If the sender vehicle hears sufficient number of copies before the deadline, it will resume periodic beacon messages. Otherwise it will issue one more round of emergency message broadcast.

In [10], safety messages are further propagated (beyond the first hop) similarly, with some differences. Instead of using the geographic distance to decide the timer value, the directional distance is used, which is the projection of geographic distance onto the road trajectory. The number of repetitions by forwarders is set to $Nc = 2$. Also, emergency messages can be transmitted with two-hop busy tone that blocks all nodes within the sender's two-hop transmission range from attempting to send beacon messages afterwards [10].

VANET communication protocols provide solutions for vehicle disconnection using strategies such as the **store-carry-forward**. A transmitting vehicle stores the message at disconnection and carries it along the road until it finds a destination or a potential forwarder. The store-carry-forward strategy seems to be the basic function for protocols addressing the intermittent connectivity, including even safety critical applications. For example, fast moving vehicles tend to be disconnected. Warning delivery message about collision or road conditions could halt until newly arriving vehicles connect. Messages are kept alive and reach such vehicles following their "hello" beacons.

Acknowledgment based reliable broadcasting strategy (ackBSM) is proposed in [11]. It targets different traffic scenarios, from static to mobile. AckBSM only employs local information acquired via periodic beacon messages. Beacons include a sender's position and acknowledgements of circulated broadcast messages. Based on received beacons, each vehicle decides whether it is part of backbone or not. The backbone concept only gives higher priorities (shorter waiting period) for retransmitting messages to certain well located vehicles, within the same main algorithm. In dense scenarios, such as cars waiting at traffic lights, retransmissions by only backbone vehicles minimizes packet collisions and increases reliability [11]

In ackBSM, every node has two lists: *R* (neighbors believed to have received the message) and N (other neighbors). After receiving any copy of the same message, a receiving car discards neighbors (move them to its R lists) covered in the same transmission (based on their estimated location at the time of transmission), and it starts a waiting period before potential retransmission. The waiting period formula may include the number of nodes in *N* (e.g., $T = 1/($number of nodes in $N))$, and the distance from previous senders. One of the basic ingredients is the **neighbor elimination** algorithm [11]. At the end of the back-off time, a car will retransmit the message only if it has a neighbor who did not acknowledge message reception within the last circulated beacon (*N* is then nonempty). Afterwards, all neighbors are added to the *R* list and the retransmitting node waits for another time period to receive acknowledgments from neighbors. If a neighbor does not acknowledge the reception, this neighbor will be deleted from *R* and moved to *N*. Also, as new neighbors appear, the timer can be restarted. In this solution, road structures and mobility information are not used, and it is therefore applicable to arbitrary vehicle locations.

The protocol makes use of the store-carry-forward concept to overcome the intermittent connectivity problem. Fig. 4 shows an example of ackBSM protocol. All nodes exchange one-hop information. Nodes *C*, *E*, *F* and *I* (red color) are in backbone. Vehicle *A* is the source and transmits to *B* and *C* (in its range) which are activated since their neighbor *D* is likely not covered. *C* retransmits while *B* (longer timer because it is not in the backbone) cancels its transmission upon receiving the message from *C*. Vehicles *D*, *E* and *F* receive the message. *F* retransmits first because it is in the backbone and is farther than *E* from the sender *C*. *D* and *E* cancel their transmissions upon receiving message from *F*. Reliability is guaranteed by mandating each receiver to send an acknowledgment. If *B* drives towards *G*, *B* will overtake *C*–*F*. *B* will not retransmit to *D*–*G* if they acknowledged the reception with their beacons to *B*. When *H* meets *I*, since *I* doesn't acknowledge the message in its beacon, *H* will retransmits the message to *I*. Therefore ackBSM protocol has the ability to work in an intermittent connectivity scenarios. The main drawback of the protocol is the overhead resulted from acknowledgment piggybacking in beacon messages. The time delay function also needs to be better specified for time critical applications.

Time Criticality in Geocasting Protocols

We discuss here only part of solutions dealing with time criticality, while the full description should also incorporate some mechanisms to deal with intermittent connectivity.

Zero-Coordination Opportunistic Routing (ZCOR) algorithm [12] delivers mission-critical life safety messages over limited target geocasting regions. ZCOR relies on **slot reservation** mechanism. Specifically, ZCOR employs the R-ALOHA style channel reservation method, where a slot reserved by one of source nodes remains reserved until they are idle again. Differently from R-ALOHA, however, the reservation of slots is spatially extended over multi-hop. That is, retransmitting vehicles use the same reserved slot, which requires time synchronization (by road side units or GPS) and extension of carrier sensing range to guarantee the reception of packets at possible next hop relay locations. *L* transmission slots are periodically repeated. One such slot (tailored to the size of data packet) fits $2K$ access back-off minislots and data packet; *K* minislots for emergency messages followed by *K* minislots for non-emergency messages. A sender considers its transmission successful only if it overhears the same packet *L* slots later again. Otherwise it switches to another slot and retransmits again. Overall the latency for h hops is hL slots (assuming no failures) although the ideal latency is approximately *h* slots.

ZCOR exploits neighbor knowledge for coordination free opportunistic packet relay [12]. Each forwarder designates an area for implicit coordination, which is called Circle-of-Trust (CoT), to enable opportunistic relay. Nodes in CoT are ranked by their distances to the center of CoT, such that the highest ranked one that actually received the packet will retransmit it starting from the corresponding minislot. Nodes simply convert their distance rank into channel access priority.

Protocol	Problem Statement	Strategy	Neighbor knowledge	Acknowledgment in beacon?	Intermittent Connectivity Addressed?	Metric	Reference
TRADE	Routing: Small scale	Sender oriented	Positional	No	No	Delivery ratio and bandwidth utilization	[3]
DDT	Routing: Small scale	Receiver oriented	Positional	No	No	Delivery ratio and bandwidth utilization	[3]
VDEB	Routing: Small scale	Receiver oriented	Positional	Yes	No	Delay and overhead	[4]
BPAB	Routing: Small scale	Receiver oriented	Not required	Passive acknowledgment	Yes	Delay	[5]
TO-GO	Routing: Small scale	Receiver oriented	Positional	Yes	Yes	Delay	[6]
DAER	Routing: Large-scale	Epidemic routing	Positional	Yes	No	Delay and delivery ratio	[7]
CAR	Routing: Large-scale	Connectivity awareness	Positional	Yes	Yes	Delay, delivery ratio and overhead	[8]
LD-CROP	Routing: Large-scale	Trajectory knowledge	Positional	Yes	Yes	Delay and delivery ratio	[9]
MHEB	Geocasting: Reliability	Repetition	Positional	Yes	No	Delay and delivery ratio	[10]
Ack-BSM	Geocasting: Reliability	Acknowledgment + CDS	Positional	Yes	Yes	Delay, delivery ratio and overhead	[11]
ZCOR	Geocasting: Time criticality	Slot reservation and Circle-of-Trust	Positional	Yes	No	Delay and delivery ratio	[12]
ReC	Geocasting: Time criticality	Receiver consensus	Positional	Yes	Yes	Delay and delivery ratio	[13]

Table 1. *A summary of the reviewed protocols.*

ZCOR is extended to multi CoTs to overcome spatially correlated shadowing effects. It constructs several circles and ranks them. What remains is to decide how many circles M there will be, what will be their centers, and their radii R. R, M, and K (the maximum number of competing neighbors in all CoTs) are the design parameters, and an algorithm is given to select approximately K/M nodes in each circle.

In **receiver consensus** algorithm [13], active nodes start the forwarder selection by ranking neighbors according to their distance to ideal forwarding locations. The ideal location is the centroid C of neighbors that need the message. A node X is passive if there are no such neighbors. Neighbors who could possibly have a copy of the message, based on local information, are sorted by their distance to C. The closest node obtains rank 1. A node X calculates its rank, e.g. r, and it will retransmit in the upcoming r-th slot if all higher ranked neighbors remained silent in previous slots (when they were expected to forward).

In 1D case (cars lined up on a road), assuming a unit disk graph model, all such neighbors are beyond the transmission range of the last sender. The ideal location is the farthest node from the sender and the closest to the centroid. Therefore, the algorithm corresponds to the solution in [3]. It is in fact an improvement because the closest node to the centroid retransmits immediately in the next time slot, instead of using a back-off timer, as in [3]. If the "winning" neighbor is silent then the next ranked node will retransmit in the second slot. Therefore the delay to select a forwarder is avoided.

Summary and Future Work

The reviewed protocols are summarized in Table 1. The main limitation of many protocols is the long time delay caused by the long waiting time before each retransmission. The time delay also increases when vehicles drive away from the desired path or when messages are kept around an intersection hoping to find a vehicle driving toward the destination.

This article has attempted to bring forward main ideas for data dissemination in vehicular networks. A general framework for broadcasting in static to highly mobile wireless networks was given in [14, 15] for VANETs and others. This framework could be extended to incorporate more ideas and scenarios, and could serve as a platform for a unique design that will automatically adapt to any particular vehicular scenario while preserving the optimal performance.

More work is needed to generalize algorithms for vehicles with heterogeneous transmission ranges. Receiver consensus algorithm is upgraded as in [13]. Candidate neighbors are ranked using d-r instead of d, where d is the distance to the ideal forwarding location and r is the communication range of a node. Beacon frequency and transmission powers are automatically adjusted using vehicle velocity and density, which motivates to design appropriate flexible data dissemination algorithms making use of this heterogeneity.

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Biographies

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