# Multi-hop Communication in Vehicular Ad Hoc Networks: A Survey

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*Abstract*— **Vehicular flow is not always optimal when traffic is dense due to time-of-day, population, vehicular accidents, and differing speeds between vehicles. Congestion, increased travel time, and increased risks of accidents due to these variables can be reduced by having vehicles inform other vehicles of upcoming emergency situations or slow downs where better routes might be an option. As vehicular communication standards have emerged, transmission power must be limited in order to prevent the limited spectrum from being over saturated. The range of this communication is typically 400 meters, so multi-hop communications must be utilized in order for the messaging to reach useful distances. This paper is a survey of papers concerning multi-hop communication in vehicular ad hoc networks.**

## I. Introduction

Vehicular traffic continues to rise as populations grow and the number of vehicles per capita increases. Figure 1 shows a steady increase in the number of registered vehicles in the United States over the past 50 years. Similar increases have been observed in other countries around the world.

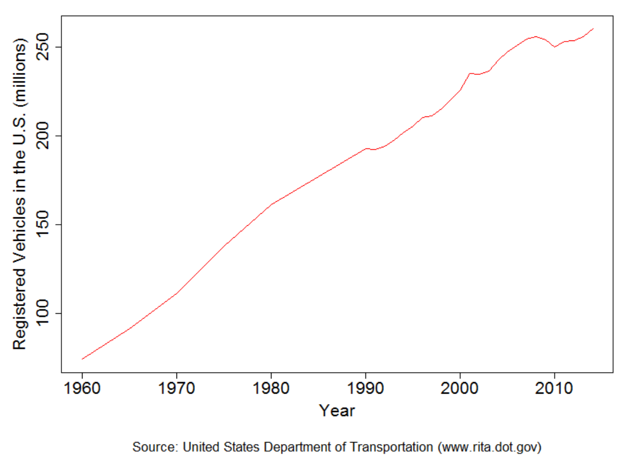


Fig. 1. Registered U.S. Vehicles over Time

Driving becomes more time-consuming as traffic becomes more congested. Traffic accidents and road construction can slow the flow of traffic considerably. Also driving becomes much more risky when dangerous conditions exist such as fog, smoke, or ice on the roadway.

When a vehicle slows or stops due to congestion or hazardous roadway conditions, this information could be useful to other vehicles traveling on the roadway. In particular, if this information could be transmitted to other vehicles a mile or more behind the vehicle that is slowing (or ahead to vehicles traveling in the opposite direction), the other vehicles would have time to take appropriate action by perhaps slowing down or finding an alternative route.

How can this information including location, velocity, and direction of travel be passed from vehicle to vehicle? The vehicles can form a wireless ad hoc network. Vehicular ad hoc networks are referred to as VANETs in industry and literature.

With a typical wireless transmission range of 400 meters, multi-hop communications must be utilized in order for the messages to reach distances that are beneficial to traffic flow. Numerous papers have been written concerning multi-hop VANET communications. In this paper, we present a survey of 11 of those papers.

One protocol, Irresponsible Forwarding (IF), stands out as offering excellent performance with relatively low overhead. We offer a suggested improvement to the IF protocol that we call Self-Limiting Irresponsible Forwarding (SLIF).

In this survey, we give some background information about VANETs and the various types of protocols developed for that environment. We discuss our motivation behind comparing the protocols we have researched and why we chose to focus on multi-hop broadcast protocols rather than clustering protocols. We then present the protocols that we researched as well as their limitations, propose our Self-Limiting Irresponsible Forwarding protocol to address the limitations of the Irresponsible Forwarding protocol, give a descriptive and clear comparison of all the protocols discussed, and then end with some concluding remarks and our intended future work.

## II. Background

### A. VANETs

In October 1999, the United States Federal Communications Commission (FCC) allocated 75 MHz in the 5.9 GHz band to be used for vehicular communications. The Dedicated Short-Range Communications (DSRC) standards were formed to utilize this 5.9 GHz band for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications.

The DSRC physical layer and MAC sublayer are defined by the IEEE 802.11p standard which adds wireless access in vehicular environments (WAVE) to the 802.11 standard.

At the Network and Transport layers, either WAVE Short Message Protocol (WSMP) or TCP/IPv6 are typically used. WSMP is used for bandwidth-reduced short messaging where as TCP/IPv6 is used for Internet access.

For maximum bandwidth conservation, a communication mode called "Outside the Context of a BSS" (OCB) is used where the Basic Service Set (BSS) is as defined in the IEEE 802.11p specification. In OCB communications, there are no beacon messages, synchronization, or MAC layer setup. Therefore OCB communications offers light-weight low-overhead rapid messaging between vehicles.

Vehicular ad hoc networks (VANETs) are a concept of creating a network of communicating vehicles for a specific need or situation [20]. Each vehicle in the network is a node that sends and receives messages from surrounding nodes.

Communications may be channeled through mobile DSRC onboard units (OBU) or stationary roadside units (RSU). These communications are typically Basic Safety Messages that include vehicle location, velocity, and direction of travel or location-based service messages advertising a service localized to a particular area.

Connections to the Internet may be accomplished though a cellular network or multiple RSUs depending on the location and network congestion at any given moment [21].

With the invention of automated vehicles, developing an efficient and meaningful way for these vehicles to communicate in order to maintain safe traffic flow on the roadway is of utmost importance.

### B. Routing Protocols for VANETs

A number of different routing protocols are used in VANET communications as outlined in a survey by Li and Wang [17]. These routing protocols may be classified as Ad Hoc Routing, Position-Based Routing, Cluster-Based Routing, Broadcast Routing, and Geocast Routing. Ad hoc routing protocols such as Ad-hoc On-demand Distance Vector (AODV) and Dynamic Source Routing (DSR), Position-Based Routing that use geographic maps, and Cluster-Based Routing all suffer from the highly dynamic nature of vehicle node mobility.

At first glance, Cluster-Based Routing seems to make sense as messaging is confined to either intra-cluster communications between a cluster head and the other vehicles in the cluster, or inter-cluster communications between cluster heads. However, upon deeper investigation, it appears that Cluster-Based Routing protocols are best suited to slow-moving high-density traffic environments where cluster changes are infrequent. In higher speed traffic, cluster changes occur frequently and the overhead of setting up the clusters outweighs the benefits of reduced messaging. Furthermore, vehicle clustering does not scale well due to dynamic vehicle densities which necessitates changing cluster sizes.

Therefore, the papers we survey here fall mainly into the Broadcast Routing classification. We also consider one Geocast Routing protocol.

## III. Motivation

Vehicles in the future may be equipped with DSRC radios that can communicate with nearby vehicles via a single hop and with far away vehicles via multi-hop communications in order to extend drivers' range of awareness to beyond what they can see.

The primary motivating factor of this communication is increased safety and a reduction in traffic accidents, injuries, and fatalities. In addition to emergency warning messages, drivers can be made aware of traffic congestion ahead so that they may look for alternative less-congested routes to their destinations. Finally, commercial businesses may broadcast location-based services (such as information concerning a refueling station) via stationary road-side unit (RSU) radios.

We feel that there is a need for propagating messages in all directions: forward, backward, and laterally. Consider the following scenarios.

### A. Forward

A refueling station broadcasts a location-based service message to nearby vehicles. These vehicles rebroadcast the message forward in their direction of travel (see Figure 2). The message is also broadcast laterally into the opposing lanes of travel and backward to vehicles behind them. All vehicles are alerted to the presence of the refueling station.

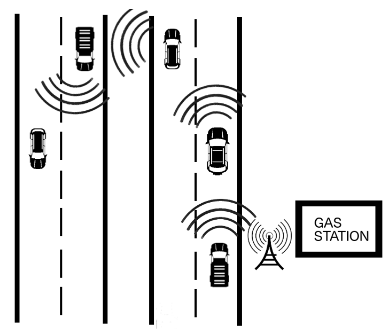


Fig. 2. Forward Broadcasting

### B. Backward

A large truck is blocking both lanes of travel in the forward direction. As vehicles slow and stop due to this blockage, messages are sent backward to vehicles behind so that they may also slow down or consider alternative routes (see Figure 3).

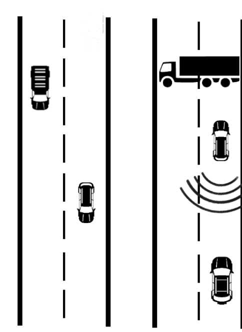

Fig. 3. Backward Broadcasting

### C. Lateral

Two vehicles are approaching the same intersection at right angles and are alerted to each other's presence by receiving each other's Basic Safety Message that includes location, velocity, and direction of travel (see Figure 4).

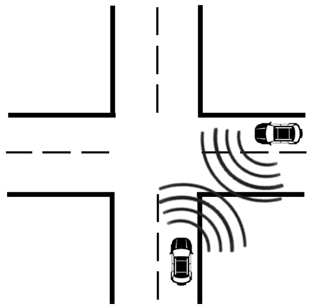

Fig. 4. Lateral Broadcasting

Multi-hop broadcast communications in VANETs can be accomplished by forwarding messages from node to node without having a preset route. The naive pure flooding scheme results in many redundant rebroadcasts of each message. Channel bandwidth is wasted and packet collisions are frequent when vehicle density is high (this is known as a *broadcast storm*).

In this survey, we consider a number of papers and corresponding protocols or algorithms for multi-hop broadcast communications in VANETs that try to flood messages to all relevant nodes while mitigating broadcast storms.

## IV. Efficient and Reliable Abiding Geocast Based on Carrier Sets for Vehicular Ad hoc Networks (AG-CS)

The Abiding Geocast paper [1] presents a method for sending abiding geocast messages which are persistent messages localized to a particular area. These messages are usually warning messages for an area or location-based service messages.

The abiding geocast process can be divided into two phases: the routing phase where the message is propagated from the source to the destination area and the persistence phase where the information is maintained in the destination area. The Abiding Geocast paper focuses on the persistence phase.

Carrier sets (which are essentially backbones) identify vehicles that carry the messages for a particular location and send them via a single hop to uncovered vehicles. Carrier set vehicles are essentially cluster heads. The carrier set vehicles detect uncovered vehicles by listening to beacon messages.

In the AG-CS algorithm, a vehicle selects a neighbor to receive the message using a Stability Estimation Index. The Stability Estimation Index is based on both Link Connectivity and Link Duration. Link Connectivity considers signal fading, channel contention and interference, and link availability. Link Duration is a function of distance, speed, and direction.

After selection of a vehicle using the Stability Estimation Index, an abiding message is broadcast that contains the ID of the selected vehicle. If the selected vehicle successfully receives the message, it repeats the selection process and rebroadcasts the message. If the originating vehicle does not receive this message back within a waiting period (this is sometimes referred to as an *implicit acknowledgement* mechanism), it means that the chosen neighbor did not receive the message. In that case, a new vehicle is chosen using an updated Stability Estimation Index and the process is repeated.

Reliability is noted as increased by way of an uncovered vehicle being able to receive a message by more than one carrier set vehicle.

### A. Limitations

The first limitation of the AG-CS protocol is that it is only used for messages that are persistent in a particular area such as location-based service messages.

Secondly, in order to calculate a Stability Estimation Index, this algorithm gathers information from beacon messages. Therefore, this algorithm does not function in Outside the Context of BSS (OCB) mode.

## V. Multi-hop Vehicular Broadcast (MHVB)

The VANET broadcast protocol presented by Osafune, et al. [2] is designed to disseminate vehicular information to other vehicles in what is known as V2V communication. In order to achieve the required coverage within the communication range, MHVB is comprised of two algorithms.

The first algorithm presented is called the Backfire Algorithm. Figure 5 illustrates how the backfire algorithm works. A is trying to send a message to D. Since D is outside A's transmission range, a multi-hop transmission is required. Both B and C will calculate their distance from A since they are within A's transmission range. C will not send anything, thereby saving bandwidth.

The second algorithm in MHVB is the Traffic Congestion Detection Algorithm. On board short-range sensors will detect whether or not a vehicle is in congested traffic. If it is determined that the vehicle is in heavy congestion, its waiting time for retransmission is increased due to the high volume of messages exchanged between vehicles. This will also help reduce the network bandwidth to avoid a broadcast storm.

The results from this paper showed low bandwidth and highly successful packet delivery in networks where the number of nodes was less than 30 and the distance between nodes was 200 m or less.

### A. Limitations

While the proposed MHVB protocol did successfully reduce bandwidth in smaller, more tightly-knit networks, the improvement in large, more spread out networks was only marginal over a naive broadcast/flooding approach. To be more specific, networks comprised of 30 or more nodes will see a collision rate of packets of at least 60% and networks with a vehicle separation of 250 m or more will see approximately a 40% decrease in the successful packet delivery ratio depending on the size of the network. Lastly, this protocol requires short range sensors that are specialized

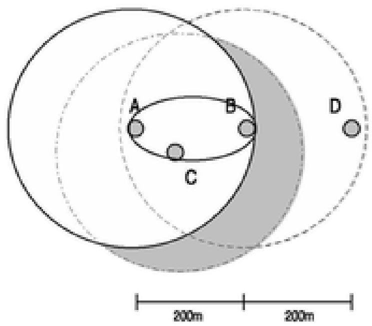


Fig. 5. Backfire Algorithm

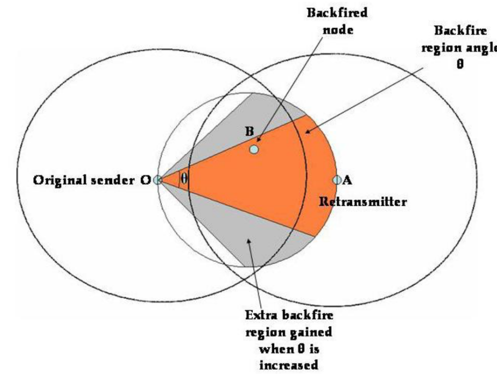


Fig. 6. Sectoral Backfire Algorithm

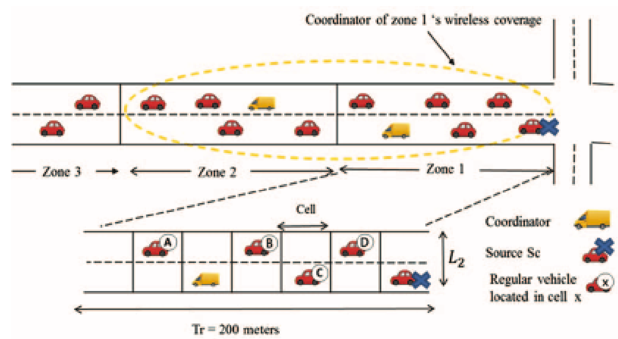


Fig. 7. Cell Division in M-HRB

hardware in order to use the traffic congestion detection algorithm.

## VI. Enhanced Multi-Hop Vehicular Broadcast (MHVB) for Active Safety Applications (E-MHVB)

The designers behind MHVB decided to enhance their solution in [3] in order to further reduce network bandwidth and increase successful packet delivery. Additional parameters and characteristics were added to the two existing algorithms as well as introducing dynamic scheduling.

The first enhancement made was the addition of a sectoral angle parameter to the existing backfire algorithm. This modified algorithm is illustrated in Figure 6 where the orange region is the backfire zone determined by the angle parameter ($\Theta$). $\Theta$ can be adjusted to include the shaded region as well. Any nodes outside of the backfire zone are disregarded, making the calculation to determine the node that will retransmit much faster. This adjustment allows for the direction in which to propagate information customizable.

The second enhancement the authors made to the MHVB protocol was the introduction of dynamic scheduling. The wait time until retransmission for each node is determined by its distance from the source node. Nodes that are more than 200 m from the source node will retransmit sooner than the closer nodes, resulting in the closer nodes being backfired and saving network resources. This scheduling scheme allows emergency messages to have priority and travel farther and faster than other messages.

### A. Limitations

The results of the simulations run by the authors showed 100% success rate in networks with the distance between vehicles of 400 m or less. Outside of the radio range, success rates saw a 15-20% improvement in success rate over MHVB. However, the conditions under which these simulations were run were not realistic to the nature of vehicular networks. The first scenario was a single lane set up where the vehicles were stationary and equidistant from one another. The second scenario was a way point environment in which vehicles could move in any direction at any speed rather than constricted to the road network. The third scenario was a highway scenario with intersections. While this is the most realistic scenario of the three, it is still very controlled as the vehicles are not randomly dispersed and the speeds are predetermined. Because of the scenarios in which they chose to test their protocol, it is very likely that the improvement values they saw were falsely inflated.

## VII. Multi-Hop Reliability for Broadcast-based VANET in City Environments (M-HRB)

The multi-hop reliability scheme proposed in [4] claims to provide better reliability and lower bandwidth than existing solutions. M-HRB estimates the wireless link quality within a defined target area by dividing the transmission range into grid-like cells. These cells are further divided into smaller cells consisting of either 1 or no vehicles as seen in Figure 7. Within these cells, data is collected by a chosen coordinator vehicle known as the Data Collection phase (DCP). The data collected from the vehicles within the zone includes information such as location, speed, successful transmission ratio, etc. The coordinator will then use this information to decide which vehicle will forward a packet known as the Local State Processing phase (LSPP) and the Forwarder Selection Phase (FSP) as illustrated in Figure 8. M-HRB will stop selecting forwarders once the reliability of the next hop is equal to the reliability of the current hop.

### A. Limitations

While the results from the simulations showed high packet delivery ratio and lower bandwidth usage along with a high

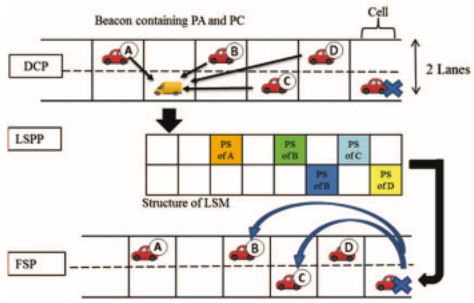


Fig. 8. Cell Division in M-HRB

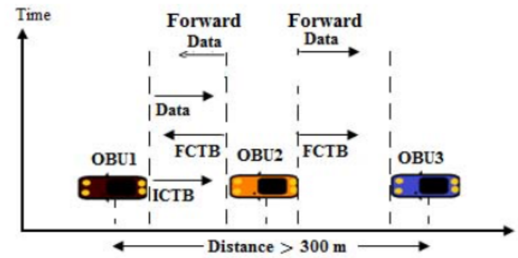


Fig. 9. Cell Division in M-HRB

network density, there still exists some limitations with the M-HRB protocol.

The first limitation is that the protocol itself is a complicated process involving a significant amount of computation in order to divide the roadway into zones and decide which vehicle is going to be the forwarder. Because of all the required computation, a larger retransmission delay may incur. This means that emergency safety messages may take longer to propagate through the network. This increase in delay was seen in their simulations against the Oppcast and ABSM protocols.

The second limitation is that M-HRB showed only a marginal decrease in network load compared to other protocols in a network density of 120 vehicles/km. We believe this to be because of all the computational power required by the protocol. Lastly, M-HRB has optimal performance in city environments where intersections divide the roads naturally into nearly equal segments. It was not tested in highway environments and therefore its behavior in that situation is unknown.

## VIII. Highway Multihop Broadcast Protocols for Vehicular Networks (HMB)

The Vehicular Multi-hop Broadcast protocol proposed in [5] called the Highway Multihop Broadcast, was designed to lower the probability of a broadcast storm, address the Hidden Terminal problem, and increase the reliability of multi-hop packet delivery. It consists of four rounds: Initial Clear-To-Broadcast (ICTB), Forwarded-Clear-To-Broadcast (FCTB), sending data, and forwarding data. These four rounds of HBM are illustrated in Figure 9. Because IEEE 802.11p does not support RTS/CTS messages to help eliminate the Hidden Terminal problem, ICTB and FCTB in HBM take on the handshake roles similar to RTS/CTS messages as a work-around to this restriction. Similar to the other presented multi-hop broadcast protocols, forwarding of a packet will occur on vehicles furthest away from the source vehicle while remaining within the radio transmission range. However, HMB differs from other protocols in that the forwarding vehicle's relative speed to the source vehicle is also taken into account. This is done by categorizing the vehicles into four states: Master Repeater, Repeater Ready, Repeater, and Ordinary Vehicle. Master Repeaters have the most relative speed to the source vehicle and will therefore be the first category of vehicles to retransmit. Ordinary Vehicles are vehicles that are close to the source vehicles, outside the transmission range of the source vehicles, or have a speed not relative to the source vehicle. Repeater Ready and Repeater vehicles take second and third retransmission priorities respectively.

### A. Limitations

The limitations of HBM are trade-offs for eliminating the Hidden Terminal problem, reducing the probability of a broadcast storm, and improving the reliability of packet delivery. By using the ICTB and FCTB handshake mechanism, the chance of redundancy or collision of packets due to a hidden node is reduced and even almost eliminated by evidence of their test results. The handshake approach also increases the successful packet delivery ratio by providing acknowledgements for successful packets, allowing lost packets to be sent again.

However, the handshake takes additional time that results in an increase of time between the transmission of packets. Message overhead is increased because of the added handshaking mechanism. Also, by passively selecting a vehicle to forward a packet, the probability of a broadcast storm and the overall bandwidth usage is reduced. However, this comes at a cost of actively keeping record of which state each vehicle within the transmission range is in. This information is likely to be changing frequently with the highly dynamic environment of VANETs. Lastly, this protocol is optimal in highway scenarios. It has not been tested in urban environments involving intersections and rapidly changing speeds. Its performance in such an environment is therefore unknown.

## IX. Dominating Sets and Neighbor Elimination-Based Broadcasting Algorithms in Wireless Networks (DS)

The Dominating Sets algorithm depicted in [6] tries to solve the broadcast storm problem that occurs during message flooding. Clustering the vehicles and creating an algorithm based on clustering was an idea to solve such a problem. But many studies have shown that maintaining the clustering structure in a highly mobile environment incurs a tremendous amount of overhead [18] [19]. In light of these studies, researchers have started to produce new solutions and the Dominating Set algorithm is one of them. This algorithm essentially employs graph theory which is

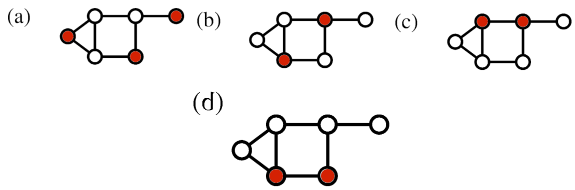


Fig. 10. Dominating Set Examples

a subsection of discrete mathematics. According to the algorithm, there would be a dominating set that consists of a couple of vehicles called *internal nodes* and only these nodes rebroadcast the received message. A node is in the dominating set when:

- Either all nodes are in the set, or
- Any node adjacent to that node is in the set

Fig. 10 illustrates a few examples of dominating sets as shown in (a), (b) and (c). However, (d) is not a dominating set because the node in the top right corner doesn't have a neighboring node in the dominating set.

Since, running the DS algorithm limits the number of nodes that are rebroadcasting, a broadcasting storm is prevented.

### A. Limitations

Although the algorithm seems like a good solution for existing problems, it has couple of shortcomings.

First, it doesn't differ much from clustering. Sets can be thought of as clusters and internal nodes as cluster heads. Therefore, in highly dynamic environments, maintaining the the infrastructure will cause overhead and congestion on the control channel which leads to a waste of resources and eventual decrease in QoS.

Second, experiments show that in high density environments, it doesn't perform as well as the Irresponsible Forwarding (IF) algorithm which we will review in the next section of this paper. Luong, et al. [7] clearly prove that when the transmission range (Tx) and density (vehicles/km) increases, the number of rebroadcasting nodes jumps dramatically in the DS algorithm. In fact, the IF algorithm performs almost three times better in those environmental settings. In other words, the DS algorithm is not a scalable solution.

## X. Irresponsible Forwarding (IF)

The Irresponsible Forwarding (IF) algorithm focuses on solving the broadcast storm issue once and for all. The authors' aim is to limit the number of rebroadcasting nodes by assigning each node a rebroadcasting probability not only according to its distance between the source node and the node itself but also according to the density of the network. This algorithm is called Irresponsible Forwarding because once the vehicle receives the initial broadcast message, it evaluates the presence of other vehicles in its surroundings. If there are other vehicles, it "Irresponsibly" decides not to broadcast and precludes a broadcast storm [8].

The IF algorithm suggests that the farther the node gets from the source, the probability of rebroadcasting should increase. The idea behind this is the farther a node gets from the source, the greater the potential coverage area. So by assigning a higher probability, it's encouraged to cover more ground.

| DS | | | | |
|---|---|---|---|---|
| Density | $T_x$ = 100 | $T_x$ = 130 | $T_x$ = 150 | $T_x$ = 200 |
| 25 | 1.99 | 2.57 | 2.82 | 3.53 |
| 40 | 3.25 | 4.01 | 4.76 | 6.1 |
| 75 | 6.47 | 8.83 | 9.88 | 12.07 |
| 130 | 13.35 | 17.72 | 23.16 | 33.83 |
| IF | | | | |
| Density | $T_x$ = 100 | $T_x$ = 130 | $T_x$ = 150 | $T_x$ = 200 |
| 25 | 4.14 | 5.14 | 5.68 | 6.88 |
| 40 | 6.14 | 7.21 | 7.91 | 9.16 |
| 75 | 9.49 | 10.72 | 11.38 | 11.85 |
| 130 | 13.79 | 13.69 | 13.40 | 12.38 |

Fig. 11. Comparison Between DS and IF in Different Environment Settings in Terms of Number of Rebroadcasting Nodes (Density is in Vehicles/km and Transmission Range, $T_x$, is in meters)

On the other hand, since in denser networks there are more vehicles, the possibility of a broadcast storm occurrence is higher. Thus, the denser the network gets, the probability assigned to each node should be as low as possible in order to avoid a broadcast storm. The probability of rebroadcasting is calculated with the following equation:

$$p = e^{\frac{-\rho_s(T_x - d)}{c}} \tag{1}$$

where $\rho_s$ represents the density in vehicles/km, $T_x$ is the transmission range in meters, d is the distance between the source node and the receiver node and $c \geq 1$ is the coefficient used to shape the probability value. The higher the value of $c$, the higher the probability of rebroadcasting.

According to the experiments [7], IF performs consistently better across all environments. Luong, et al. prove that by considering both density and transmission range, the number of rebroadcasts can be limited efficiently and broadcast storms can be avoided.[7]

### A. Limitations

Due to its low complexity and its perspective of being very thorough, this algorithm stands out among the other algorithms. It has very few limitations, but there is one thing that can be and should be considered. The algorithm assigns probabilities based on network density and distance between the node and the source, but it never considers how far the message should disseminate throughout the vehicles on the road. The authors do not attempt to explain the area-of-interest and how far the message should proceed. They did not specify any limitations regarding message dissemination. The reasoning behind this consideration is that if a message disseminates too far, it would waste resources when taking locality into consideration.

## XI. How Do You Quickly Choreograph Inter-Vehicular Communications? A Fast Vehicle-to-Vehicle Multi-Hop Broadcast Algorithm, Explained (FB)

The Fast Broadcast (FB) algorithm [9] is an algorithm that tries to solve or eliminate the delay problem as much as possible in vehicular networks. Since many algorithms prioritize the packages to be sent, a massive amount of delay is introduced during the process. By introducing the two-step Fast Broadcast algorithm, the authors' goal is that the delay would be minimized by active listening. According to the algorithm, there are two phases:

1) Estimation Phase
2) Broadcast Phase

In the Estimation Phase, vehicles continuously try to estimate their transmission range by sending out what the authors call *hello messages*. Since vehicles are aware of the transmission range at any given time, they can exploit it during the Broadcast Phase.

To be able to calculate the transmission range in the Estimation Phase, time is divided into turns and information collected during each turn is stored in two variables named *Current-turn Maximum Forward Range (CMFR)* and *Current-turn Maximum Back Range (CMBR)*. They are kept for that particular turn and the next one. Then they are discarded. Once the turn has expired, the value on each variable in CMFR and CMBR are stored in *Latest-turn Maximum Front Range (LMFR)* and *Latest-turn Maximum Back Range (LMBR)*. Thus the protocol maintains the latest and current values to guarantee the communication.

When a vehicle receives a hello message, it checks to see if it has been received from in front or behind and decides if it's either CMFR or CMBR. If the received maximum range is higher than its calculated transmission range, it updates the CMFR or CMBR value that it stores.

In the Broadcast Phase, another parameter is introduced which is called *MaxRange*. MaxRange is calculated by comparing and taking the maximum value of LMBR, CMBR or LMFR, and CMFR. It is used for determining which node will rebroadcast the message on the next hop. To minimize the number of hops and consequently propagation delay, the algorithm assigns the farthest vehicle from the source the highest probability to transmit.

In addition, vehicles are also prioritized to forward the broadcast message by assigning different *contention window* values. These contention window values are calculated and assigned depending on the distance from the source. The longer the distance, the lower the contention window value.

### A. Limitations

The authors' aim was to try to solve delay problems in vehicular networks by introducing active listening and storing current and latest back and forward transmission ranges and try to create an adaptive protocol for forwarding messages. Although their aim was to eliminate delay, we are highly doubtful that it's a good solution for eliminating delay due to its complexity. Since the vehicular network environment is highly mobile, calculations need to be made extremely quickly. Introducing lots of parameters and calculating them in real time is a challenge and we believe it won't help much. In their simulation, they compare the FB algorithm with a static transmission range algorithm and didn't mention anything about delays which was mildly suspicious.

## XII. An Effective Multi-Hop Broadcast Control Mechanism for Emergency Alert Message in VANET (BCU)

A Broadcast Control Unit (BCU) is a newly introduced layer that works on top of IEEE's 1609.3 WSM Protocol and also an algorithm proposed in [11] that aims to again minimize the number of rebroadcasting nodes at the same time by assigning priorities to each node so that broadcast storms can be avoided. According to the algorithm, each node will have a back-off value based on the distance between the source and themselves. Each node will have a unique back-off value to rebroadcast the message. The algorithm differentiates the old messages from new messages by including IDs in the packets. If an event's ID is received for the first time by a specific node, it bypasses the back-off step and transmits it immediately. If there is another node that detected the same event and therefore the same event ID and received it from another vehicle, it discards the message and decides not to rebroadcast the same message.

### A. Limitations

The algorithm's main purpose is to minimize simultaneous rebroadcasting nodes while, at the same time, not limiting the number of nodes rebroadcasting. While it essentially eliminates the broadcast storm, it introduces another problem – delay. By assigning a unique back-off timer to each node, it is almost guaranteed that no node will use the bandwidth at the same time. Almost all messages will be cached for a period of time in all nodes and maybe even queued leading to large amounts of delay on the network for any message. In extremely dense networks, the delay could be so large that not receiving the message in the intended time frame could cause loss of interest for that specific package. Eventually, this leads to a waste of resources.

## XIII. Vehicle Density Based Forwarding Protocol for Safety Message Broadcast in VANET (VDF)

Whereas many multi-hop broadcast protocols select the farthest node in the broadcast range as the forwarder, the Vehicle Density Based Forwarding protocol [12] chooses the forwarder based on vehicle density. The authors argue that the farthest forwarder may experience a large number of collisions, so their adaptable protocol obtains a balance between contention delay and forwarding hops.

The VDF protocol uses the beacon messages from neighboring vehicles to determine the vehicle density. VDF prioritizes the best relaying vehicle by giving it a smaller contention window in the IEEE 802.11p MAC layer.

### A. Limitations

This algorithm gathers information from beacon messages. Therefore, it does not function in Outside the Context of BSS (OCB) mode.

This protocol focuses on reducing broadcast delays which is most useful for time-critical safety applications. While this is primary motivation for VANETs, there may be other applications that will not benefit from this protocol.

## XIV. Reliable Multihop Broadcast with a Low-Overhead Link Quality Assessment for ITS Based on VANETs in Highway Scenarios(RLMB)

The Reliable Multihop Broadcast Protocol paper [13] discusses a protocol that attempts to balance overhead and reliability. The protocol utilizes beacon information along with an implicit acknowledgment mechanism and a position prediction algorithm.

This protocol includes the farthest neighbor in each message direction in the relay set. The farthest neighbor is calculated based on the received signal strength indicator (RSSI) and maintained in a neighbor table.

An implicit acknowledgment mechanism is employed by this protocol. If the sender does not overhear the rebroadcast packet after a period of time, the sender retransmits the original packet.

### A. Limitations

This algorithm gathers information from beacon messages. Therefore, it does not function in Outside the Context of BSS (OCB) mode.

Also, this algorithm maintains a table of neighbor information which must be updated frequently in a dynamic VANET environment.

Finally, the RLMB protocol is tuned for use on highways. Since it was not tested in other environments, its performance in non-highway settings is unknown.

## XV. Self-Limiting Irresponsible Forwarding (SLIF)

From our research among the multi-hop broadcast protocols for VANETs that we have just discussed, we propose a protocol we call the Self-Limiting Irresponsible Forwarding protocol (SLIF). Irresponsible Forwarding (IF) is an algorithm that stands out among the other protocols due to its exceptional performance in reducing the probability of a broadcast storm with relatively low bandwidth along with high reliability of successful packet delivery.

Our SLIF protocol is comprised of the following features:

1) Basic Safety Messages and location-based service messages will be rebroadcast using the Irresponsible Forwarding protocol discussed earlier.
2) A counter known as the Time-To-Live (TTL) counter will decrement by one for every rebroadcast until the counter reaches zero and the rebroadcast is halted. The value of the TTL is determined by the message type as well as its priority. Higher priority requires a higher TTL to ensure that sufficient flooding occurs.
3) Along with the TTL, each message will contain an expiration time. Once the expiration time is reached, the message is no longer rebroadcast. The expiration time differs from the TTL in that the expiration time denotes how long the message is important and useful whereas the TTL denotes the distance the message needs to travel to reach all affected vehicles.

### A. Hypothesized Impact

We expect our Self-Limiting Irresponsible Forwarding protocol to provide a three fold improvement over the other protocols discussed in this survey.

1) Achieve effective multi-hop dissemination of messages while reducing the probability of a broadcast storm and thereby reducing overall bandwidth usage.
2) Propagate messages forwards, backwards, and laterally to inform oncoming, following, and intersection traffic of information such as Basic Safety Messages and location-based service information that affect all lanes of the roadway.
3) The messages will not propagate indefinitely. With proper tuning, all impacted vehicles and only those vehicles for a specific message will be informed by using the Time-To-Live counter. Messages which no longer carry timely information will no longer be rebroadcast.

### B. Limitations

While SLIF addresses some of the shortcomings and limitations of the discussed protocols, certain limitations remain.

The first limitation is that it may be a challenge to accurately calculate all the vehicles that may be impacted by a particular vehicular event.

The second limitation is that some vehicles beyond a location-based service may receive its information only to forward it on to other traffic. This will increase the message overhead by a small amount.

Lastly, the expiration time of a message is predetermined before it is broadcast which may result in the time being too short in which not all the impacted vehicles will receive the message in the case where a vehicular accident took longer than expected to clear off of the roadway. On the other hand, if the expiration time is too long, the message may travel farther than it needs to which wastes bandwidth and network resources.

## XVI. Analysis and Comparison

The multi-hop broadcast protocols for VANETs that we have discussed all have a unique perspective in solving the vehicular communication problem while mitigating the chances of a broadcast storm. We will now give a detailed comparison and clear picture of the differences between all of the protocols discussed in this survey.

Table I is a comparison of the features each protocol offers. Table II is a comparison of how each protocol performed during testing. Our SLIF protocol has not yet been tested and

TABLE I
FEATURE COMPARISON

| Protocol | Type | OCB | Message Type | Message Persistence | ACK | Forwarding Mechanism |
|---|---|---|---|---|---|---|
| AG-CS | Geocast | No | LBS | Forever | iACK | Stability Estimation Index used to choose carrier vehicles |
| MHVB | Broadcast | Yes | BSM | Forever | No | Backfire & Congestion Detection |
| E-MHVB | Broadcast | Yes | BSM | Priority & Wait Time | No | Sectoral Backfire & Dynamic Scheduling |
| M-HRB | Broadcast | Yes | BSM & EVAM | Reliability Equivalence | No | Zone Coordinator selects forwarder based on collected data |
| HMB | Broadcast | No | BSM, ICTB, & FCTB | Forever | Yes | Passive forwarder selection based on vehicle state |
| DS | Broadcast | N/A | BSM | Forever | No | Broadcasting via internal nodes |
| IF | Broadcast | Yes | BSM & LBS | Forever | No | Rebroadcasting Utilizing Distance & Density |
| FB | Broadcast | Yes | BSM & LBS | Forever | No | Rebroadcasting Utilizing Distance & Contention Window |
| BCU | Broadcast | Yes | EVAM | Forever | Yes | Rebroadcasting Utilizing Back-Off Mechanism |
| VDF | Broadcast | No | BSM & EVAM | Forever | None | Contention window adaptation |
| RLMB | Broadcast | No | BSM & LBS | Forever | iACK | Uses neighborhood table constructed from RSSI values |
| SLIF | Broadcast | Yes | BSM & LBS | Hops & Time Limit | No | Same as IF plus TTL and Expiration Timer |

Notes: LBS = Location-Based Service message, BSM = Basic Safety Message, EVAM = Emergency Vehicle Alert Message, ICTB = Initial-Clear-To-Broadcast, FCTB = Forwarded-Clear-To-Broadcast, iACK = Implicit Acknowledgement

TABLE II
PERFORMANCE COMPARISON

| Protocol | Overhead | Increase PDR | Environment | Decrease Hidden Terminal Problem | Scalable |
|---|---|---|---|---|---|
| AG-CS | High | Yes | Urban | N/A | Yes |
| MHVB | High | Yes | All | Yes with Backfire | No |
| E-MHVB | Low | Yes | All | Yes with Sectoral Backfire | Yes |
| M-HRB | Low | Yes | Urban | No | Yes |
| HMB | High | Yes | Highway | Yes with handshaking | Yes |
| DS | Low | Yes | Not Designed For VANET | No | No |
| IF | Low | Yes | All | N/A | Yes |
| FB | Low | Yes | Highway | N/A | Yes |
| BCU | High | N/A | Highway | N/A | No |
| VDF | High | No | All | N/A | Yes |
| RLMB | High | Yes | Highway | N/A | Yes |
| SLIF | Low | Yes | All | N/A | Yes |

TABLE III
TESTING COMPARISON

| Protocol | Compared With | Network Simulator | Simulator Scenario |
|---|---|---|---|
| AG-CS | LINGER | NS-2 | Urban environment with 12 intersections and 17 two-way streets |
| MHVB | Naive Broadcast | NS-2 | Simple 2-lane Highway 600X300m |
| E-MHVB | MHVB | NS-2 | Random waypoint, single lane, & simple highway with intersections |
| M-HRB | Oppcast & ABSM | Omnet++, Sumo, & Veins 2.0 | 4km fragment of real map street |
| HMB | HMB priorities & 802.11p | Own | 400X100m highway up to 400 nodes |
| DS | 802.11 & Neighbor Elimination | Own, Written in C | 100 fixed nodes with transmission range of 500m |
| IF | IF with different “c” constants | Matlab | 10km road, various number of nodes to test density |
| FB | FB with fixed transmission range | N/A | 8km stip-shaped road, 500 - 1000 nodes, vehicle velocity 72 - 144km/h |
| BCU | PBCC, Position Based, Flow, BPAB | NS-2 | 3-lane highway, vehicle velocity 90 - 120 km/s, vehicle distance 10m - 100m |
| VDF | ReC | NS-2 | Four unidirectional 5 km lanes |
| RLMB | FUZZBR | OPNET Modeler simulator | Two 3km lanes in each direction, velocity max 40 m/s |
| SLIF | IF | TBD | TBD (To be determined) |

Notes: PBCC = Prioritized Broadcast Contention Control, BPAB = Binary Partition Assisted Broadcast

therefore the values are an estimate. Table III is a comparison of how each protocol was tested, what protocols they were compared to in their experiments, and what environments they were tested in. Again, our SLIF protocol has yet to be tested.

Most of the protocols rely on beacon messages as part of their rebroadcast decision-making process. The use of beacon messages precludes the use of the low overhead OCB mode as seen in the OCB column of Table I.

Some of the protocols use explicit acknowledgment messages to determine if a message needs to be retransmitted. An implicit acknowledgement mechanism is employed by a few protocols where a node listens for a rebroadcast of its latest message and, if the rebroadcast is not heard, the message is retransmitted.

Direct head-to-head comparisons of the performance of the surveyed protocols is difficult as evidenced by Table III. All of these protocols are compared to different baseline protocols and the test environments vary widely.

## XVII. Conclusion

This paper presents a survey of several other papers concerned with multi-hop broadcast communications in vehicular ad hoc networks.

Some of the protocols operate effectively in only certain environments while others perform well in diverse settings.

Most of the protocols surveyed use beacon messages for determining how close a node is to its neighbors. The use of beacon messages precludes the use of OCB (Outside the Context of BSS) communications. Since Basic Safety Messages are generally encapsulated in a WAVE Short Message and broadcast via OCB, most of the protocols surveyed are not useful for Basic Safety Messages.

The main thrust of our survey was to identify protocols that would be useful for Basic Safety Messages and location-based service messages. The Irresponsible Forwarding (IF) protocol works in OCB mode and appears to offer excellent performance and the low overhead of operating in OCB mode.

The main limitation that we noted regarding the IF protocol was the lack of a mechanism to stop the eternal rebroadcast of a particular message. Our proposed Self-Limiting Irresponsible Forwarding (SLIF) protocol layers Time-To-Live counters and Expiration Timers onto the IF protocol to ensure that messages don't propagate indefinitely.

## XVIII. Future Work

As a future work, we hope to implement our protocol in a controlled simulation environment and determine the key parameters that define the protocol efficiency. We also hope to compare our results with other protocols to see if there is any improvement and to determine the most superior protocol among the ones that we have inspected.

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