Performance Analysis of Metrics of Broadcasting Protocols in VANET

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Abstract—VANETs (vehicular ad hoc networks) 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 different challenges in VANET such as intermittent connectivity, abrupt changes in network topology and low reception rate distinguish it from other types of ad hoc networks. This paper covers different performance metrics encountered in recent literature, for small and large scale broadcasting protocols. Novel ideas are needed to optimize reliability and time criticality metrics in data communication protocols for VANET. The reason for analyzing the broadcasting protocols is that, in most of the emergency situations, there is less time to make a handshake with other nodes in the networks, as the emergency message is to be delivered fast and efficient. Therefore broadcast based routing protocol plays a major role in almost all the safety applications. A detailed understanding of the existing protocol is needed before contributing new protocol for the upcoming research field.

Index Terms-VANET, Broadcasting, emergency messages

I. INTRODUCTION

With fast development in ad hoc wireless communications and vehicular technology, it is foreseeable that, in the near future, there will be a paradigm shift in traffic information systems. In particular, real-time traffic data will be collected and disseminated by distributed mobile probes, instead of fixed sensors used in the current infrastructure based systems. A distributed network of vehicles such as a vehicular ad hoc network (VANET) can easily turn into an infrastructure-less self-organizing traffic information system, where any vehicle can become a mobile sensor, participating in collecting and disseminating useful traffic information such as section travel time, flow rate, and density. Disseminating traffic information in a VANET is a unique problem. In contrast to the unicast data typically transmitted in a network such as the Internet, the traffic information generally has a broadcast-oriented nature. In other words, the traffic information is of public interest, and it usually benefits a group of users rather than a specific individual. Consequently, it is more appropriate to use a broadcasting scheme rather than a unicast routing scheme in disseminating the traffic information. The main advantage of a broadcasting scheme is that a vehicle does not need to know a destination address and a route to a specific destination. This eliminates the complexity of route discovery, address resolution, and topology management, which are difficulties in dynamic networks such as VANETs. In this paper, we will mainly focus our attention on broadcasting protocols for VANETs. However, they can generally be divided into two main categories:

Single-hop Broadcasting: In single-hop broadcasting, information packets are not flooded by vehicles. Instead, when a packet is received by a vehicle, information is kept in the vehicle's on-board database. Periodically, every vehicle selects some of the records stored in its database to broadcast. Hence, in single-hop broadcasting, each vehicle carries the traffic information with itself as it travels, and this information is transferred to all other vehicles in its one-hop neighborhood in the next broadcast cycles. Ultimately, vehicle's mobility is involved in spreading the information in single-hop broadcasting protocol.[4]

Multi-hop Broadcasting: On the other hand, in multi-hop broadcasting strategy, a packet is spread in a network by the way of flooding. In general, when a sender vehicle broadcasts an information packet, a number of vehicles within the vicinity of the sender will become the next relay vehicles by rebroadcasting the packet further in the network. Similarly, after a relay vehicle (node) rebroadcasts the packet, some of the vehicles in its vicinity will become the next relay nodes and perform the task of forwarding the packet further. As a result, the information packet is able to propagate from the sender to the other distant vehicles.[5]

II. SINGLE HOP BROADCASTING PROTOCOLS

In single hop broadcasting, vehicle periodically disseminates some of the information in its database to the other vehicles in the network. Broadcast interval and information are the two choices that need to be considered while designing the broadcast protocol for VANET. To keep the most up-to-date information without redundancy, the broadcast interval must be set appropriately. It should not be too long and not too short. Apart from this, important and relevant information should only be selected to broadcast. Single-hop broadcasting protocols can be further divided into following two categories: which are the **Fixed Broadcast Interval Protocols** and the **Adaptive Broadcast Interval Protocols**. While the main focus of the fixed broadcast interval protocols such as TrafficInfo[6] and TrafficView which are based only on the selection and aggregation of information, whereas in adaptive broadcast interval protocols, an adjustment of broadcast intervals is also taken into consideration.

Segment-oriented Data Abstraction and Dissemination (SODAD) protocol [7] also uses adaptive broadcast interval in which roads are divided into segments of predefined length. Each vehicle collects the data by sensing the information itself and from the reports of other vehicles. Each vehicle adaptively adjusts its broadcast interval to reduce the redundancy. Information received from other vehicles is characterized in two ways (i) provocation and (ii) mollification. A provocation event is an event that reduces the time until next broadcast, whereas a mollification event is defined as an event that increases the time until next broadcast. When a vehicle receives a packet, it determines whether it is a provocation or a mollification event by assigning a weight to the received packet. A weight is calculated from the discrepancy between the received data and those in the vehicle's knowledge database. The weight will be high if the received information is newer than the stored information. Based on the packet weight, node determines whether a provocation or mollification event has occurred by comparing it with a threshold. The time for next rebroadcast is increased or decreased depending on the weight. The single hop broadcasting protocols suffer from many limitations such as Packet dissemination speed may be slow, not suitable for delay-sensitive applications and may require large storage space to keep un broadcast information.

III. MULTI HOP BROADCASTING PROTOCOLS

As mentioned earlier, in multi-hop broadcasting [5-6], flooding is used for packet propagation in the network. However, a pure flooding is inefficient because it lacks scalability and there is lot of packet collision. Redundancy increases as the network becomes denser and wastes the channel bandwidth which in turn reduces the network scalability. In addition, packet collision is another critical problem because multiple vehicles in the same region may rebroadcast the packet at the same time. This is called as a broadcast storm problem [9]. Multi-hop broadcasting can be further divided into following three categories:

Delay Based Multi Hop Broadcasting Protocols: In a delay-based multi-hop broadcasting scheme, different waiting time before rebroadcasting the packet is assigned to each receiving vehicle. Fundamentally, the vehicle having a shortest waiting time gets the highest priority to rebroadcast the packet. In addition, redundancy is avoided by the other vehicles by aborting their waiting process once they know that the packet has already been rebroadcasted. While different delays are assigned to each vehicle in delay-based broadcasting protocols, a different rebroadcast probability is assigned to each vehicle in a probabilistic-based protocol.

Reliable Broadcasting of Life Safety Messages (RBLSM) [14] is also a class of delay based multi-hop broadcasting in which as soon as a node receives a packet from source, it determines the waiting time for rebroadcasting the packet. In contrast to the other conventional strategies where the rebroadcast priority is given to the farthest vehicle, in RBLSM the priority is given to the vehicle nearest to the transmitter. The reason behind choosing the nearest vehicle as the next rebroadcasted is that, it is considered to be more reliable than the other vehicles that are at far away distance from the transmitter. It is assumed that nearer vehicle has better received signal strength. This protocol also uses the concept of RTB and CTB control packets. Performance evaluation is done via simulation with only single hop latency. Link-based Distributed Multi-hop Broadcast (LDMB) is a similar protocol which assigns the waiting delay based on a link quality as proposed in [5].

Probability Based Multi Hop Broadcasting Protocols: In probabilistic-based broadcasting approach, each vehicle rebroadcasts a packet according to the assigned probability. Since only few vehicles will rebroadcast the packet, redundancy and packet collisions are reduced. In Weighted p-Persistence protocol [8] a vehicle that receives a packet for the first time computes its own rebroadcasting probability based on its distance from the transmitter. The distance can be computed by comparing its current position with the position of the transmitter specified in the packet. In particular, the rebroadcast probability is computed from the following equation: $P_{ij}= D_{ij}/R$ where *Dij* represents the distance between transmitter *i* and vehicle *j*, and *R* is the transmission range of transmitter *i*. On the basis of above equation, vehicles that are farther away from the transmitter will get higher rebroadcast probabilities. However, vehicle density is not taken into consideration in this probability assignment function. Hence, in the dense network, the number of rebroadcast packets can still be large. There is another protocol named Optimized Adaptive Probabilistic Broadcast (OAPB) protocol [9], in which number of neighbors' i.e. local vehicle density is also taken into consideration while determining the forwarding probability. Each vehicle exchanges HELLO packets periodically to select an appropriate forwarding probability. In particular, when a vehicle receives a packet, it computes its own forwarding probability based on the following equation: $= P1+P2+P3/ 3 where *P1*, *P2*,and *P3* are functions of the number of one-hop neighbors, the number of two-hop neighbors, and a set of two hop neighbors that can only be reached through a particular one-hop neighbor [10].

Network Coding Based Multi Hop Broadcasting Protocols: Network coding is a new way of information dissemination which can be applied to a deterministic broadcast approaches, resulting in significant reductions in the number of transmissions in the network and hence yields a much higher throughput than the traditional way of transmission. CODEB relies on opportunistic coding, in which coding opportunities to transmit coded packets is determined. In addition, each node periodically broadcasts the list of its one-hop neighbors. This allows all nodes to build a list of its two-hop neighbors, which will further be used to construct a broadcasting backbone. Moreover, CODEB also pointed out that opportunistic coding for broadcast is somewhat different from coding for unicast. In broadcasting all the neighbors of the node must receive the packet where as in uni casting, only the intended next hop node receives a given packet. Hence broadcasting increases the level of complexity as all nodes that receives packet must be able to decode.

Efficient Broadcasting Using Network Coding and Directional Antennas (EBCD) is a network coding-based broadcasting protocol which gains the benefit of both network coding and directional antennas [7]. EBCD similar to CODEB also determines a subset of neighbouring nodes that can perform forwarding task deterministically. Although, Dynamic Directional Connected Dominating Set (DDCDS) algorithm is used by EBCD. As a result, a directional virtual network backbone is constructed by DDCDS where each node determines both its forwarding status as well as the outgoing edges (antenna sectors) in which the packets can be transmitted. EBCD and CODEB also have one more difference that, in EBCD, network coding is applied in each sector of the directional antennas around the node whereas in CODEB, network coding is applied in omni-directional. EBCD shows significant improvement with directional antennas and network coding in terms of number of transmissions, over to other schemes.

IV. PERFORMANCE METRICS

The main parameters which need to be analyzed in broadcasting protocols in VANETs are: (i) how frequently the information packets are duplicated, (ii) how far the information packets can propagate, and (iii) how fast the information can be spread. The existing metrics commonly used in the literature are listed in Table I. The first column of Table I indicate the domain where each metric belongs. In our perspective, these metrics can be classified into four domains, namely frequency, space, time, and mixed. The metrics in the frequency domain are those related to frequency counting (e.g., counting of packets or the number of vehicles). The metrics in the space domain involve the measurements of distance whereas those in the time domain involve the measurements of time. The metrics in the mixed domain are those created from a combination of metrics in more than one domain. The second column indicates the ID that we assign to each metric, which will later be used for referencing purpose. The third column of Table II lists the metric names. It can be observed that some of the metrics are very similar although they are called differently. The fourth column describes how each metric is computed while the fifth column describes what each metric is designed to measure. The sixth column specifies the unit of each metric. Finally, the last column suggests the favorable value for each metric (i.e., indicating whether a low value or a high value of the considered metric is desirable).

In the frequency domain, the following three attributes of broadcasting protocols are usually of interest, and the metrics in this domain are designed to quantify them.

• **Redundancy**—Redundancy is a key performance indication of a broadcasting protocol. A good protocol should be able to disseminate information with the least amount of redundancy or overheads. The metrics used for quantifying the redundancy are redundancy rate, load generated per broadcast packet, forward node ratio, link load, and broadcast overhead. Generally, these metrics measure the number of duplicate packets or the number of duplicate bits used in disseminating one information packet.

• **Reach ability**—An information should be disseminated in such a way that it reaches all the reachable nodes in the target area. Keeping the redundancy low while maintaining high reachability is one of the main challenges in designing a broadcasting protocol. The metrics used for quantifying the reach ability are delivery ratio and reception rate. As observed from Table I, these two metrics are defined a bit differently. Basically, the delivery ratio is derived from the total number of vehicles in the network whereas the reception rate is derived from the number of reachable nodes. In other words, the reception rate measures the proportion of “connected nodes” that receives the broadcast packet.

• **Failure rate**—If the rebroadcast mechanism of a broadcasting protocol is not designed carefully, there could be a lot of packet collisions since many vehicles in the same vicinity may rebroadcast the packets at the same time. This is usually referred to as the broadcast storm problem [15]. Obviously, the failure rate should be kept at minimal. The metric commonly used in quantifying the failure rate is collision ratio or packet loss ratio.

The metrics in the space domain typically measure how far a packet can propagate. Propagation distance measures a distance that a packet can propagate from the point where it is originated in unit of meters whereas the number of hops propagated measures how far a packet can traverse in terms of the number of hops. Sustainable number of hops, on the other hand, measures the number of hops that a packet can traverse while maintaining a desired quality of service (QoS), for example, in terms of bit error rate [56]. In addition to the total propagation distance, a progress made at each hop is also an important quantity, and this is typically measured by forward progress. Basically, the forward progress measures the distance gained beyond the current transmitter if a particular vehicle was selected as a next rebroadcast node. Normally, a vehicle with the largest forward progress will be selected.

In the time domain, propagation time measures a time it takes a packet to traverse from a source to the other point in the network. This includes the “air time,” which is the delay incurred from passing a packet from one vehicle to the other via the wireless communication channel, and the “ground time,” which is the delay incurred while a vehicle is carrying the packet before rebroadcasting it to the other vehicles. Rebroadcast latency measures a time until the packet is received successfully by the next vehicle

Finally, the metrics in the mixed domain are those created from a combination of the metrics in the frequency, space, and time domains. Based on our survey, the only metric in the mixed domain currently defined in the literature is propagation speed or dissemination speed. Basically, it measures the distance at which a packet can traverse the network per unit time.

TABLE I. EXISTING PERFORMANCE METRICS FOR EVALUATION OF BROADCASTING PROTOCOLS

Domain	ID	Metric Name	Mathematical Definition	Description	Unit
Frequency	1	Redundancy rate	$\frac{\text{no. of duplicate packets}}{\text{no. of source packets}}$	Measure the number of duplicate packets per one source packet	unit-less
	2	Load generated per broadcast packet	$\frac{\text{no. of bits transmitted}}{\text{no. of source packets}}$	Measure the total number of bits used in broadcasting one source packet	bit/pkt
	3	Forward node ratio	$\frac{\text{no. of vehicles forwarding the packet}}{\text{no. of vehicles in the network}}$	Measure the proportion of vehicles in the network that rebroadcast the source packet	unit-less
	4	Link load	$\frac{\text{no. of broadcast bits received by a vehicle}}{\text{observation period}}$	Measure amount of broadcast traffic received at each vehicle over unit time	bit/s
	5	Broadcast overhead	$\frac{\text{no. of duplicate packets received by a vehicle}}{\text{no. of vehicles in a defined zone}}$	Measure the number of packets collectively duplicated in a defined area	pkt/veh
	6	Delivery ratio, Success ratio	$\frac{\text{no. of vehicles successfully receiving packets}}{\text{no. of vehicles in the network}}$	Measure the proportion of vehicles that successfully receive the broadcast packets	unit-less
	7	Reception rate, Reachability	$\frac{\text{no. vehicles receiving the broadcast packets}}{\text{no. of vehicles reachable by pure flooding}}$	Compare the reachabiltiy of a broadcasting protocol to that of the pure flooding protocol	unit-less
	8	Saved rebroadcast	$\frac{\text{no. receiving host - no. transmitting hosts}}{\text{no. hosts receiving packet}}$	Measure the number of saved rebroadcast packets	unit-less
	9	Collision ratio, Packet loss ratio	$\frac{\text{no. of collision packets}}{\text{no. of transmitted packets}}$	Measure the rate at which the collision occurs	unit-less
Space	10	Propagation distance	| Packet last position - Packet initial position |	Measure the distance between the origin of the packet and the point where it is last received	m
	11	Forward progress, One-hop progress	| Position of next rebroadcast vehicle - Position of current transmitter |	Measure the additional distance covered by the packet when it is rebroadcasted	m
	12	Number of hop propagated	Last hop the packet is received - Packet origin	Measure the number of hops that the packet can traverse	hops
	13	Sustainable number of hops	Last hop the packet is received with required QoS - Packet origin	Measure the number of hops that the packet can traverse with the desired quality	hops
Time	14	Propagation time, End to end delay	The instant the packet is received at a specific point - The instant the packet is originated	Measure the time it takes a packet to traverse from a source to a specific point in the network	s
	15	Rebroadcast latency	The instant the packet is received by the next vehicle - The instant the packet is broadcasted by current vehicle	Measure the time until the packet is received successfully by the next vehicle	s
Mixed	16	Propagation speed, Dissemination speed	$\frac{\text{Packet propagation distance}}{\text{Propagation delay}}$	Measure the rate at which the packet can propagate per unit time	m/s

TABLE II. BROADCASTING PROTOCOLS IN VANETS AND THE METRIC DOMAINS USED FOR EVALUATION

S. No.	Name of Protocol	Hoping Level	Basis	Simulation Platform Used	Metrics Used for Evaluation
1.	TrafficInfo	Single-Hop	Fixed Broadcast Interval	STRAW / SWANS	Packet Delivery Ratio
2.	TrafficView	Single-Hop	Fixed Broadcast Interval	NS-2	Propagation Distance
3	Segment-Oriented Data Abstraction and Dissemination (SODAD)	Single-Hop	Adaptive Broadcast Interval	NS-2	Packet Drop Ratio, End to End Delay
4.	Reliable Broadcasting of Life Safety Messages (RBLSM)	Multi-Hop	Delay	MATLAB	Dissemination Speed
5.	Link Based Distributed Multi-hop Broadcast (LDMB)	Multi-Hop	Delay	Not Specified	Packet Delivery Ratio, End to End Delay
6.	Weighted p-Persistence	Multi-Hop	Probabilistic	OPNET	Link Load, Reception Rate, Packet Drop Ratio, No. of Hop Propagated, End to End Delay
7.	Optimized Adaptive Probabilistic Broadcast (OAPB)	Multi-Hop	Probabilistic	NS-2	Broadcast Overhead, Packet Delivery Ratio, End to End Delay
8.	CODEB	Multi-Hop	Network Coding	NS-2	Packet Delivery Ratio
9.	Efficient Broadcasting Using Network Coding and Directional Antennas (EBCD)	Multi-Hop	Network Coding	NS-2	Redundancy Rate, Packet Delivery Ratio

V. CONCLUSION

Broadcasting of messages in VANETs is still an open research challenge and needs some efforts to reach an optimum solution. The common focus in designing these protocols is in suppressing the excessive rebroadcast packets. In multi-hop broadcasting protocols, the reduction of redundant rebroadcast packets is typically done through the delay and probability assignment functions, which adjust the waiting delay and the rebroadcast probability based on the vehicle location and the physical characteristics of the network such as the vehicle density. The number of packet transmissions can also be reduced by using a network coding approach. In single-hop broadcasting protocols, where each vehicle rebroadcasts the packet periodically, the suppression of excessive rebroadcast packets is usually done by letting each vehicle adjust its rebroadcast interval dynamically. We hope that this concise work will help in better understanding of broadcasting protocols in VANETs and pave their way to develop a new protocol which are more reliable and cover the realistic scenarios and other traffic considerations into a new broadcasting protocol that works for both rural and urban traffic conditions.

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