Opportunistic Broadcast in VANETs (OB-VAN) Using Active Signaling for Relays Selection

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***Abstract*: A Vehicular Ad hoc NETwork (VANET) is often formed by a large group of vehicles communicating with each other without the use of any infrastructure. A key challenge in such a scenario is to design an efficient broadcast strategy that quickly disseminates the packets in the VANET. While several protocols have been proposed, most of them are based on the proactive and reactive routing schemes of general MANETs and do not satisfy the tight time constraints and high delivery ratio required by VANET safety applications. Therefore, we present an opportunistic routing protocol that uses a modified 802.11 MAC layer using active signaling to select the best relay from all the vehicles that have correctly received the packet. This technique allows for quick and efficient relay selection. The analysis of the ns-2 simulation results show that it is highly suited for VANET safety applications.**

***Index Terms*— Opportunistic Routing Protocols, VANETs, Broadcast, Flooding, MAC Layer Optimization, Cross Layer Design, Generalized CSMA, Relay self selection**

I. Introduction

Mobile ad hoc networks (MANETs) enable mobile nodes to communicate with each other without the need for pre-existing infrastructure. Since the radio range of each node is limited, multi-hop routing protocols are needed to allow communication between nodes that are not within range of each other. For these protocols all nodes act both as routers and as normal nodes. VANETs are a very important example of MANETs because they can allow vehicle-to-vehicle and vehicle-to-infrastructure communication on the road. That is why many government organizations and car manufacturers are carrying out extensive research to enhance safety on the road using VANETs. Most are involved in projects, consortia and standardization activities focusing on Intelligent Transportation System (ITS) e.g. Network On Wheels (NOW) [1], Car2Car consortium [2], ETSI, Partners for Advanced Transit and Highways (PATH) [3] etc. They are likely to revolutionize our traveling habits by increasing safety on the road while simultaneously providing value added services.

The key issue to enhance safety on the road is to build efficient systems to exchange information between cars in a reliable fashion. This has been greatly eased by the tremendous progress in wireless communications. Two kinds of traffic can be exchanged in a VANET. The first one is broadcast or multicast oriented that will be useful for safety applications, e.g. emergency messages transmitted after a car crash to warn other vehicles in the vicinity. This kind of traffic may also be used to disseminate other kinds of important information in the VANET e.g. fog and rain updates. The second kind of traffic is point-to-point traffic. This will be useful for value added services such as entertainment, news, advertisements, Internet access, etc.

In this paper we focus on the first category of traffic exchange in a VANET i.e. broadcast oriented traffic. We employ a recent routing strategy, called opportunistic routing (see [4], [5]) that has usually been used for point-to-point communication in MANETs. We show how an opportunistic routing protocol can be used to efficiently and quickly disseminate a broadcast packet in a linear VANET network.The **O**pportunistic **B**roadcast in **VAN**ETs (OB-VAN) protocol uses a slightly modified 802.11 DCF MAC protocol to select the best relay among the nodes that have received the packet correctly. The active signaling used for OB-VAN is fast and efficient. We compare and analyze the performance of this new broadcast technique with the simple flooding scheme through extensive simulations, highlight the advantages and possible drawbacks and outline future work.

This paper is organized as follows. Section II provides an introduction to VANET routing protocols specifically focusing on previously proposed opportunistic protocols. Section III explains how OB-VAN can be used to broadcast a packet in a VANET. Section IV describes the simulation environment and scenarios. Section V presents and analyzes the simulation results of the classical flooding protocol with OB-VAN. Section VI outlines future work that we plan to undertake, and our conclusions are set out in Section VII.

II. Related Work

Two types of routing protocols are essential to maintain connectivity in a VANET: Unicast protocols for point-to-point communication and Broadcast and Multicast protocols for point-to-multipoint communication. IETF, through its MANET working group, has designed and standardized several routing protocols for MANETs e.g. OLSR [6], AODV [7] and DSR [8]. There have also been several other protocols proposed for use in MANETs, e.g. GPSR [9], IGF [10], etc. These protocols form the basis of VANET routing protocol research and can be divided into two broad categories.

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Topology-based protocols include all proactive and reactive routing protocols whereas position-based routing protocols include geographic and opportunistic routing protocols. These will be discussed more thoroughly in the following subsections.

A. Proactive and Reactive Routing Protocols

Proactive protocols maintain a correct routing table at all times by sending periodic control messages. Reactive protocols do not maintain the routing table but discover the route when there is data to be sent. This is usually done by flooding a control message from the source at that time. Reactive and proactive protocols have been designed for unicast communication but most of them have multicast extensions e.g. MOLSR [11], MAODV [12]. However, these protocols have several drawbacks and cannot be used in VANETs. Proactive protocols have too high overhead due to their periodic control messages. Reactive protocols consume less bandwidth than proactive protocol because routes are only built on demand. Unfortunately, due to the high mobility of vehicles in VANETs, their performance, in terms of delay, is unacceptable.

B. Geographic Routing Protocols

Geographic routing protocols use the knowledge of nodes' geographic positions to forward packets towards their destination. This approach reduces the complexity because, instead of running an algorithm over the entire network to find globally optimal routes, each successive hop is constructed incrementally. Geographic routing protocols reduce the routing state of each node dramatically compared with topology based routing protocols and are hence much more scalable. They have to know the position of the destination. Location services are usually used to determine the destination node's position. They also let a node know the positions of all the one-hop neighbors. Periodic control beacons, containing their geographic location, are exchanged between one hop neighbors for this information. GPSR [9] and face-2 [13] are examples of geographic routing protocols.

C. Opportunistic Routing Protocols

Opportunistic routing protocols are essentially geographical routing protocols in the sense that the positions of the nodes are used to route the packets. The main difference with geographic routing lies in the fact that opportunistic routing selects relays dynamically from all the nodes that have received the packet correctly. The exact criterion for selection of the *best relay* depends on the algorithm. In simple terms, it is often defined as the relay with the least remaining distance to the destination, but the goal always is to reach the destination as efficiently and quickly as possible.

In traditional MANET networks, the benefits of opportunistic routing are intuitive since there are numerous paths close to the shortest path. This make it fast, efficient and robust because it adapts with every hop to current network conditions. Dropped packets and retransmissions that occur in deterministic routing due to mobility, fading, collision, etc. are reduced dramatically. In [4] a systematic comparison between opportunistic and conventional routing is performed and shows that opportunistic routing greatly outperforms its rival.

Until recently, most research in opportunistic routing has focused on point-to-point communication. Examples of such opportunistic routing protocols include [10], [14], [15]. They can be sub-divided into two broad categories:

1) Timer-based protocols: CBF [16], BLR [17] and BGR[18] propose a timer-based contention process, which allows the most-suitable node to forward the packet and to suppress other potential forwarders. The principle is to assign shorter retransmission timers to better relays. Hence, the best relay's retransmission timer will expire before all other possible relays and it will retransmit the packet. This retransmission will be heard by the other potential relays which will stop the retransmission timers and give up retransmission. This process will continue until the destination has been reached.

2) MAC-based protocols: Other protocols utilize the same basic idea but implement it inside the MAC scheme. IGF [10] modifies the RTS/CTS mechanism of the IEEE 802.11 DCF MAC. Before the transmission of the data packet, the transmitter sends an "Open RTS" (ORTS). A potential relay will respond with a CTS after a certain time interval. The better the relay, the shorter this time interval will be. Thus the best relay will respond with a CTS and complete the handshake before other potential relays. ExOR [15], on the other hand, sends the list of possible relays in the packet header. The potential relays use a timer-based approach before sending a modified MAC layer ACK. These acknowledgements enable the source to select the best relay towards the destination and to prevent the other nodes from retransmitting the packet. SDF [19] uses a similar approach. OAR [20],GeRaF [21], ROMER [22], OPRAH [23] are also opportunistic protocols using variations of the above-mentioned methods.

In [24] a new signaling scheme is used in the acknowledgement to select the best relays towards the destination. In this technique, derived from the access scheme of HiPERLAN type 1 [25], the potential relays compete using the acknowledgement. The best relay can then be selected.

Opportunistic routing protocols have mostly been proposed for point-to-point communication but there have been a few proposals for point-to-multipoint communication [26], [27], [28], [29], [30], [31], [32]. These proposals are modified unicast opportunistic protocols that do not offer the high performance required for time-critical applications in VANETs. We have designed an opportunistic broadcast protocol that meets these rigorous requirements. It uses the active signaling technique first presented in [24]. The precise description of this opportunistic broadcast routing protocol and its comparison to classical flooding is the main contribution of this paper.

III. Algorithm and Explanation

VANETs are deployed on roads or highways which have most often a linear topology. Thus it can be understood that

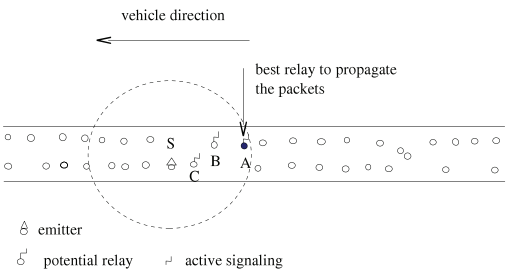

Fig. 1. A Linear VANET. The circle around the transmitter depicts nodes that received the packet.The broadcast packet can be forwarded in two directions. In this example we only consider broadcast in the direction opposite to the movement of the vehicles.

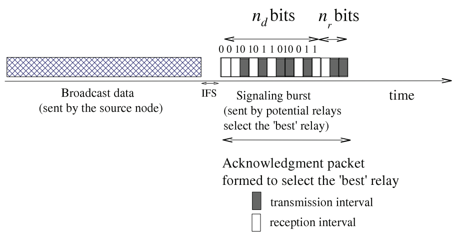

Fig. 2. Structure of the acknowledgment packet to select the 'best relay' towards the destination.

opportunistic routing can easily be adapted for broadcast dissemination even though there is no specific destination for the packet. The area of dissemination is usually defined by a source-specified criterion, e.g. distance from the source, number of hops etc. The protocol selects the relays which offer the best progression for the packets to disseminate them in the targeted area. All the intermediate vehicles receive the packets due the genuine broadcast nature of radio transmission. An example of such a linear VANET is depicted in Figure 1. The source vehicle S wants to broadcast a packet. It transmits the packet and all the vehicles inside the capture area around S receive it. We assume, S wants to propagate the packet unidirectionally in the opposite direction of the vehicles' movement. Thus only vehicles behind S compete to be selected as relays by invoking the relay self selection algorithm. In a linear VANET, we can envision unidirectional broadcast or bidirectional broadcast.

Existing opportunistic broadcast protocols use a timer-based scheme to perform the selection of the relays; the larger the distance between the source and the relay, the smaller the backoff. On the other hand, OB-VAN uses a logarithmic selection (i.e., the discrimination between potential relays is done *on the logarithmic scale* for the distance between source and the relay) taking advantage of signaling bursts [33] to select the best relays. This active signaling technique was first introduced for the HiPERLAN type 1 standard [25]. To implement OB-VAN we use the acknowledgement scheme to perform the selection among the potential relays. The nodes that have captured the packet must transmit a short acknowledgment made up of signaling bursts just after the end of the reception of the broadcast packet. The goal of this acknowledgment is twofold. First it allows the sender to know that the packet has been received by potential relays. Second, this acknowledgment allows the best relay to be selected. This burst consists of a sequence of intervals of the same length in which a given receiver can either transmit or listen (see Figure 2). During this active signaling phase, each receiver applies the following rule: if it detects a signal during any of its listening intervals, it quits the selection process (i.e. it stops transmitting during the entire remaining part of the active signaling phase). It does this because, the detection of a transmission during a listening interval, implies that a better relay has also captured the broadcast data sent in the first part of the slot. The previous scheme can be interpreted as a generalized CSMA; the back-off technique usually used to compete is replaced here by the active signaling scheme.

These signaling bursts can best be represented by a binary sequence, where 0 denotes a listening interval and 1 denotes a transmission interval. This binary sequence can be computed by each reception node as follows: the first n_d bits are computed by the receiver as a function of the criterion that we wish to optimize for our 'best' relay. These n_d bits may simply code this criterion in base 2. The criterion must only satisfy the following rule: the 'better' the relay is, the larger the criterion is.

For instance, $n_d = 10$ will allow distances up to 1 km to be coded with a precision of 1 meter. It can be easily checked that the selection mechanism will always select the relay with the highest parameter since there will always be an interval in which another relay with a smaller parameter listens while the relay with the largest parameter emits. Additionally we add n_r bits selected at random to discriminate between nodes offering the same progress. The last bit of the n_r bits is set to 1. This forces the receiver which remains active after the selection process, to provide evidence of its activity.

In Figure 3 we represent the selection process for the scenario described in Figure 3. Node A which offers a better progression on the road in the opposite direction of the traffic than nodes B and C wins the selection process. To cope with possible interference on the signaling bursts, these bursts are sent using a CDMA spreading code. The code that must be used by the potential relays is selected at random by the transmitting node and is mentioned in the broadcast packet. Thus the potential relays know these codes. In the case of a bidirectional broadcast in the a linear road topology, two different codes must be used for the two different directions. The relay forwarding in the direction of vehicles' movement will thus use first spreading code. The relay forwarding in the opposite direction of the vehicle movement will use the second code.

The broadcast packet must include the position of the initial source node, the position of the intermediate relay and a sequence number. The position of the initial source is used to stop the broadcast of the packet when the targeted diffusion area is reached. The sequence number and the position of the intermediate relay allows one to get rid of the duplicate packet. A duplicate list is used in each node to keep track of the already forwarded packets. A complete

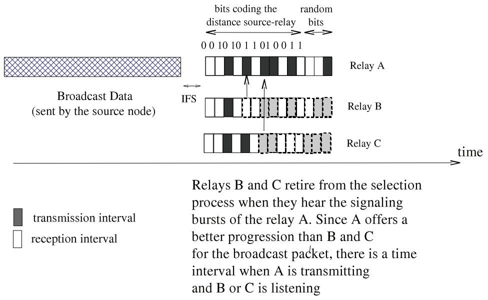

Fig. 3. The process of relay selection.

description of our opportunistic broadcast routing protocol in pseudo code is fairly simple but is not given here due to limitations of space. For the same reason, we have not presented in this paper, how OB-VAN can be adapted for opportunistic broadcast in non linear VANETs.

IV. Simulations

The VANET topology simulates a 1 kilometer long stretch of straight road, consisting of two lanes. The mean distance between two vehicles in the same lane is 50 meters.

All our simulations were done in ns-2 [34], using the integrated CMU wireless extensions. This simulation environment was chosen because it offers high fidelity, since it includes a full implementation of the IEEE 802.11 physical and MAC layers. The default parameters are detailed in the table below:

Parameter	Value
Transmission range (Tr)	250m
Carrier sense range (Cs)	550m
Data rate	11Mbps
Basic rate	2Mbps
Preamble length	72
RTS/CTS	disabled
Queue length	50

Each single simulation run lasts 30 seconds. The background traffic is started randomly in the first 10 seconds. This traffic consists of a CBR source started at each node. The CBR packets are destined for only one immediate neighbor i.e. there is no multihop background traffic. Each background traffic data packet has a size of one kilobyte. A lightly loaded network is simulated by a packet generation rate of 10 packets per second. In a heavily loaded network this rate goes up to 20 packets per second.

10 seconds into the simulation, the vehicle S (see Figure 1) starts transmitting the broadcast packet. The broadcast packet size is 100 bytes and generation rate is 10 packets per second. In the remaining 20 seconds a total of 200 individual packets are transmitted by the source.

We have implemented a slightly improved classical flooding as the benchmark protocol against which we compare the opportunistic protocol. In this implementation of flooding, each node that receives a broadcast packet, retransmits the packet. To avoid a broadcast storm, each node maintains a database of rebroadcast packets so that no duplication retransmission occurs. The implementation of the opportunistic protocol has already been explained in Section III.

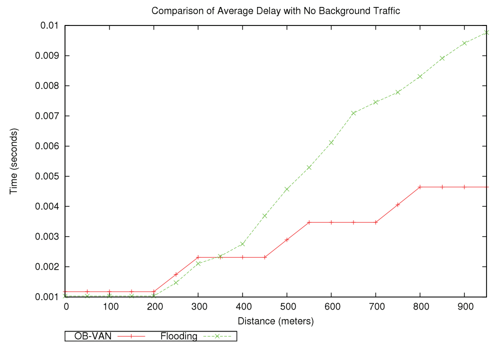

Fig. 4. Comparison of the average delay with no background traffic

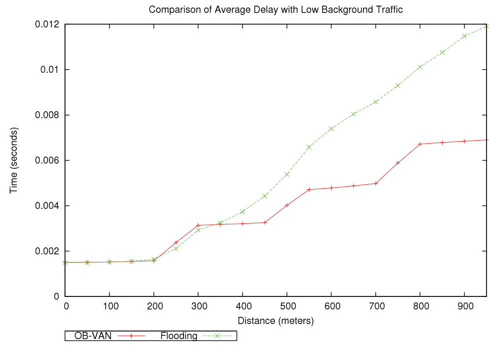

Fig. 5. Comparison of the average delay in a lightly loaded network

V. Results

In this section we present the results of the simulations and discuss their implications.

A. Effect of Background Traffic

Figures 4, 5 and 6 show the average delay of the broadcast packets as they traversed the VANET. The opportunistic broadcast protocol performs very well compared with flooding, especially as the distance from the source increases. This advantage decreases as the background traffic increases. This is explained by the fact that an increase in background traffic increases the possibility of collisions. The best nodes lose more broadcast packets, because they have more collisions since they are so far away from the source. Hence, less than optimum nodes are chosen to relay the broadcast packets resulting in an increase in the average delay. Even so, the opportunistic protocol is able to maintain better a delay than flooding.

B. Effect of Noise

Figure 6 shows the average delay of both flooding and opportunistic broadcasting in a heavily loaded network but with practically no external noise. Figure 7 shows the same network but with 10% of the broadcast packets lost due to external noise. A comparison shows the ability of OB-VAN

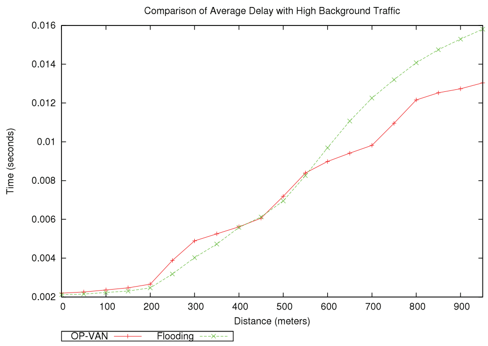

Fig. 6. Comparison of the average delay in a heavily loaded network

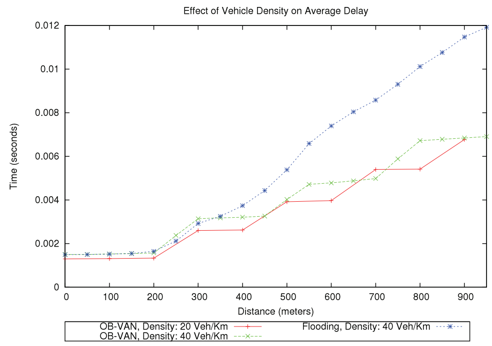

Fig. 8. Comparison of the average delay with increasing vehicle density

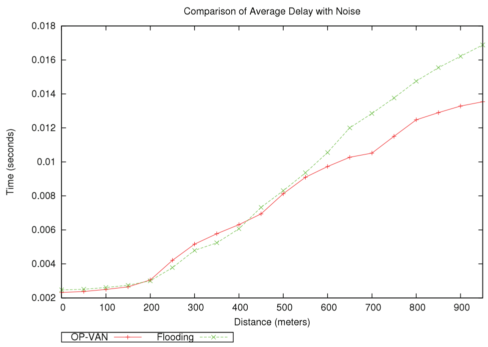

Fig. 7. Comparison of the average delay, with random errors

Fig. 9. Comparison of the average delivery ratio in a network with medium background traffic

to handle random errors due to noise in the VANET very well. Even though the average delay is increased for OB-VAN, it is still able to maintain a better performance than flooding. Flooding's own performance is adversely affected by the noise-induced errors.

C. Effect of Network Density

Figure 8 highlights the suitability of OB-VAN protocol for high density VANET scenarios. Doubling the vehicle density from 20 vehicles per km to 40 vehicles per km has no noticeable affect on the average delay. When the density is doubled again, we see an increase in the delay. However this increase is caused by the increased background traffic in the network and the consequent network congestion and collisions.

D. Delivery Ratio vs Packets Transmitted

Figure 9 shows the comparison of delivery ratio of broadcast packets under medium load conditions. Flooding has a 97% delivery ratio while OB-VAN is at 95% but Figure 10 shows the cost of that slight advantage. The opportunistic protocol keeps the number of transmissions close the theoretical ideal of 100 transmissions in a 1 km stretch of road. On the other hand, flooding transmits approximately eight times the number of packets. These extra packets can quickly saturate the wireless network and this is extremely undesirable for critical situations e.g. accidents.

VI. Future Work

The simulation results show that this protocol has properties which will be useful in VANETs. However, further work needs to be done including simulations of a more complex road structure e.g. a city area. It is also important to measure the protocol's performance in scenarios with high, relative vehicle mobility . More comparisons also need to be made with other geographic and opportunistic broadcast protocols. We are currently in the process of developing a realistic model for errors, introduced by noise and fading in VANETs. This will enable an indepth evaluation of this protocol.

VII. Conclusion

Vehicle Ad-hoc Networks need a mechanism to broadcast important safety related information to all the participating vehicles. This mechanism has to be fast and bandwidth efficient. In this paper we presented an opportunistic broadcast protocol for VANETs (OB-VANET) that can meet these requirements. This protocol selects the vehicle that offers the best progression for the packet to act as a relayer. It uses active signaling bursts to make this logarithmic selection. Simulations in ns2 show that it offers a significant decrease in the average delay for the broadcast packets compared with optimized flooding. It is also robust to random errors and works satisfactorily in high density networks. Its delivery ratio is slightly lower but this is offset by the small load imposed on the network. We feel that the logarithmic selection used by OB-VAN will aslo provide better performance than

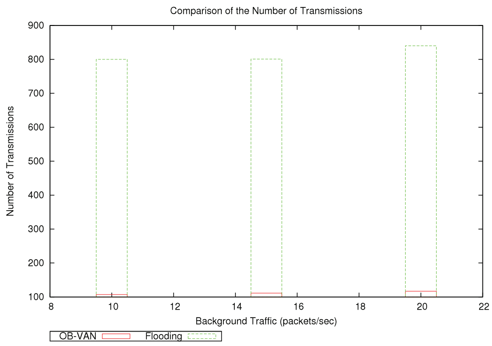

Fig. 10. Comparison of the of the number of packets transmitted

the backoff technique used by other opportunistic protocols. We conclude that this OB-VAN merits further study and propose that further comparisons with other geographic and opportunistic broadcasts protocols should be carried out.

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