Introduction to Vehicular Ad Hoc Networks and the Broadcast Storm Problem

Nathan Balon

Intro

The recent adoption of the various 802.11 wireless standards has caused a dramatic increase in the number of wireless data networks. Today, wireless LANs are highly deployed and the cost for wireless equipment is continuing to drop in price. Currently, an 802.11 adapter or access point (AP) can be purchased for next to nothing. As a result of the high acceptance of the 802.11 standards, academia and the commercial sector are looking for other applicable solutions for these wireless technologies. Mobile ad hoc networks (MANET) are one area that has recently received considerable attention. One promising application of mobile ad hoc networks is the development of vehicular ad hoc networks (VANET).

A MANET is a self forming network, which can function without the need of any centralized control. Each node in an ad hoc network acts as both a data terminal and a router. The nodes in the network then use the wireless medium to communicate with other nodes in their radio range. A VANET is effectively a subset of MANETs. The benefit of using ad hoc networks is it is possible to deploy these networks in areas where it isn't feasible to install the needed infrastructure. It would be expensive and unrealistic to install 802.11 access points to cover all of the roads in the United States. Another benefit of ad hoc networks is they can be quickly deployed with no administrator involvement. The administration of a large scale vehicular network would be a difficult task. These reasons contribute to the ad hoc networks being applied to vehicular environments.

Traffic fatalities are one of the leading causes of death in the United States. The Federal Communications Commission (FCC), realizing the problem of traffic fatalities in the US dedicated 75 MHz of the frequency spectrum in the range 5.850 to 5.925 GHz to be used for vehicle-to-vehicle and vehicle-to-roadside communication. The 5.9 GHz spectrum was termed Dedicated Short Range Communication (DSRC) and is based on a variant of 802.11a. Seven channels of 10 MHz each make up DSRC, with six of the channels being used for services and one channel for control. The goal of the project is to enable the driver of a vehicle to receive information about their surrounding environment. The control channel is used to broadcast safety messages e.g. to alert the driver of potentially hazardous road conditions. The control channel is also used to announce the services that are available. If vehicle finds a service of interest on the control channel, it then switches to one of the service channels to use the service. A number of additional value added features are to be provided by the service channels such as the announcement of places of interest in the driver’s locations e.g. restaurants in the area or gas prices.

The creation of Vehicular Ad Hoc Networks (VANET) has also spawn much interest in the rest of the world, in German there is the FleetNet project and in Japan the ITS project. Vehicular ad hoc networks are also known under a number of different terms such as inter-vehicle communication (IVC), Dedicated Short Range Communication (DSRC) or WAVE. The goal of most of these projects is to create new network algorithms or modify the existing for use in a vehicular environment. In the future vehicular ad hoc networks will assists the drivers of vehicles and help to create safer roads by reducing the number of automobile accidents.

Challenges Creating Ad Hoc Networks

There are many challenges that need to be addressed when creating a vehicular ad hoc network. One of the challenges facing ad hoc networks is the topology of the network changes rapidly. Vehicles in a VANET have a high degree of mobility. The average length of time that two vehicles are in direct communication range with each other is approximately one minute. Another obstacle restricting the wide spread adoption of ad hoc networks is many of the protocols used for 802.11 are centralized and new distributed algorithms must be developed. Many of the algorithms that were acceptable for 802.11 relied on the fact that there was a centralized controller, the AP. The 802.11 standard provides a limited ad hoc mode with the independent basic service set (IBSS) configuration, but it is not sufficient for vehicular ad hoc networks. Furthermore, wireless communication is unreliable. The error rate in wireless networks is much higher than on an Ethernet. All of these issues make implementing a VANET difficult.

Media Access Control

To create wide-scale vehicular ad hoc networks, changes need to be made to the media access control (MAC) layer. The objective of media access control layer is to arbitrate the access to the shared medium, which in this case is the wireless channel. If no method is used to coordinate the transmission of data, than a large number of collisions would occur and the data sent would be lost. The ideal scenario is a MAC that prevents nodes within transmission range of each other from transmitting at the same time and no collision occur.

The 802.11 family of protocols use CSMA/CD with acknowledgments to restrict the number of collisions and to reliably transmit packets. The 802.11 standard defines two MAC protocols the Distributed Coordination Function (DCF) and the Point Coordination Function (PCF). The Distributed Coordination Function is a contention based access protocol. In a contention based protocol all nodes that have data to send contend for the channel. Contention based protocols are the easiest to implement but the problem with them is they offer no quality of service (QoS) guarantees. Contention free protocols are achieved by scheduling when a node can transmit. Contention free protocols enable the use of real-time services. The Point Coordination Function is a contention free protocol but is not applicable to ad hoc networks because it relies on central node to support the real-time delivery of packets.

One of the main problems effecting the reliability of the DCF is the problem know as the hidden terminal problem. The hidden terminal problem is the main cause of collisions in a wireless network. The hidden terminal problem occurs when there are two nodes that are outside the transmission range of each other but will each transmit to a node that is shared between them. In figure 1 below, nodes S1 and S2 can not sense each others transmissions. If both S1 and S2 were to transmit to R1 at the same time a collision would occur.

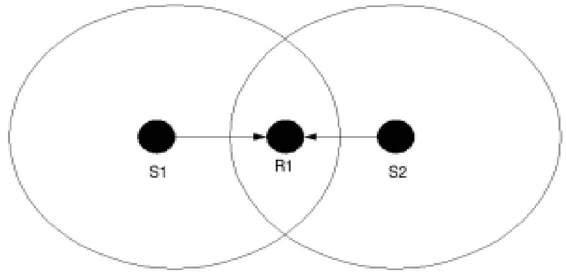

Figure 1. Hidden Terminal Problem

The 802.11 protocol address this problem by adding an optional RTS/CTS transmission before the actual data is transferred. Figure 2 below shows the RTS/CTS exchange before the transmission of data. The hidden node problem is elevated when S2 hears the CTS coming from R1. The CTS received at S2 will cause S2 to defer its transmission till the exchange between S1 and R1 is complete.

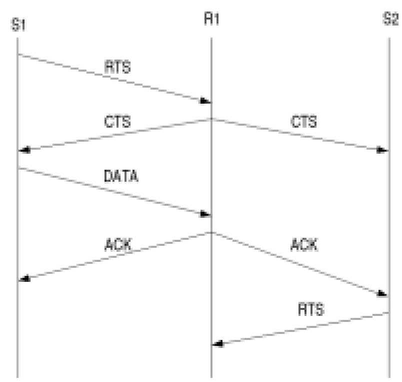

Figure 2. RTS/CTS Exchange

The wireless bandwidth is a scarce resource, so the MAC should make efficient use of it. MAC protocols can be contention based or contention free. The RTS/CTS helps to eliminate the problem of hidden terminals and in turn making a better use of the bandwidth. While this solves the problem for unicast message, the problem still remains for broadcast messages.

Broadcast Messages

A number of challenges exist in providing reliable broadcasts. In vehicular ad hoc networks a majority of the messages that are transmitted will be periodic broadcast messages that announce the state of a vehicle to it neighbors. It is likely that there will be more broadcast messages than unicast messages in vehicular networks. Broadcast messages can not use the RTS/CTS exchange, because it would flood the network with traffic. As a result of not using the RTS/CTS exchange, the network exhibits the hidden terminal problem as discussed above. Also, it isn't practical to receive acknowledgments from all of the nodes that receive a broadcast message. Without receiving an ACK the sender of the broadcast has no way of determining if the broadcast was successfully received by its neighbors.

A number of different approaches can be taken to broadcast a message to each node in an ad hoc network.

- Flooding
- Probabilistic Broadcast
- Counter-Based Broadcast
- Location-Based Broadcast
- Cluster-Based Broadcast

Flooding is the easiest method to implement, but also suffers from the most problems. The flooding algorithm works by each node in the network that receives a broadcast message for the first time then rebroadcasts the message. A message sent to n nodes will result in the message being rebroadcast n times. The use of flooding results in the "broadcast storm problem". The problem can be characterized by redundant rebroadcasts, contention, and collisions. First, when each node rebroadcast a message it is highly likely that the neighboring nodes have already received the broadcast, which results in the flooding algorithm creating a large number of redundant messages. Second, since all nodes in the area are trying to rebroadcast the message at approximately the same time there will be a significant number of nodes contending for access to the wireless channel. Third, a high number of collisions will occur without the use of the RTS/CTS exchange, because the hidden terminal problem will still exist.

Conclusion

As a result of the "broadcast storm problem" more efficient methods of broadcasting need to be used. In the paper, "The Broadcast Storm Problem in a Mobile Ad Hoc Network" the authors describe five possible solutions to provide more efficient broadcasts in an ad hoc network. A number of other papers have built on the ideas discussed in this paper. Providing reliable broadcasts in an ad hoc network is still an open issue of research.

References

H. Alshear and E. Horlait. "An Optimized Adaptive Broadcast Scheme for Inter-Vehicle Communication," in Proc. IEEE Vehicular Technology Conference (IEEE VTC2005-Spring), Stockholm, Sweden, May 2005.

J. Blum, A. Eskandarian, and L. Hoffman. "Challenges of Intervehicle Ad Hoc Networks," IEEE Transactions of Intelligent Transportation Systems, Vol. 5, No, 4, December 2004.

S-Y. Ni, Y-C. Tseng, Y-S. Chen, and J-P. Sheu. "The Broadcast Storm Problem in a Mobile Ad Hoc Network," in Proc. ACM/IEEE MobiComm, 1999.

M. Torrent-Moreno, M. Killat, and H. Hartenstein. "The Challenges of Robust Inter-Vehicle Communications," in Proc. 62nd IEEE Semiannual Vehicular Technology Conference, Dallas, Texas, September 2005.

Q. Xu, T. Mak, and R. Sengupta. "Vehicle-to-Vehicle Saftey Messaging in DSRC," in Proc. ACM VANET, Philadelphia, October 2004.