GPS-Based Message Broadcasting for Inter-vehicle Communication

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Abstract

Intelligent Transportation Systems (ITS) have become a focus for many countries. To achieve ITS, Inter Vehicle Communication (IVC) is required for the exchange and distribution of data such as congestion or emergency information. If this communication can be done without fixed infrastructure, the systems can be deployed quickly and on a larger scale. Ad hoc networking technologies are one such technology to achieve IVC. However, if generic ad hoc network solutions are applied directly to IVC, performance can degrade quickly as the system scales particularly for broadcast type messages. In this paper, we propose two new broadcast protocols that reduce bandwidth required for broadcast communication by taking advantage of a vehicle's highly directional movement and Global Positioning Information. To show the performance of our new protocols, we compare our approach with generic ad hoc broadcasting techniques. Our results show that it is possible to achieve several hundred percent improvement of bandwidth utilization with very slight sacrifice of reachability.

1 Introduction

The Intelligent Transportation Systems (ITS) is an effort to design safer and more efficient transportation system for the next millennium ITS includes many different applications, such as advanced traffic management and information systems, advanced vehicle control systems and advanced public transportation systems. Many papers [8, 10] have appeared in the literature on this subject and some projects, such as the Vehicle Information and Communication System (VICS) in Japan [11], ERTICO in Europe [2], and the Model Deployment Initiative in the US [9], have already been implemented. Large scale deployment of these services, however, can not be realized without the aid of efficient message communications. Message communication in ITS is normally achieved by installing a radio transmitter and receiver in each vehicle allowing wireless communications. In early 1997, the Unlicensed National Information Infrastructure (U-NII) spectrum became available and the middle band of the U-NII makes wireless communications for ITS feasible [4]. Depending on the type of ITS services, a variety of message communications can be implemented. A simple approach to implementing IVC is to provide a direct communication link between each vehicle and a pre-installed infrastructure. VICS is one example of such an approach. In VICS, each vehicle receives road information from the VICS center through the infrastructure. The advantage of this approach is that since all the local information is collected by a centralized station either from all the vehicles or another infrastructure, it is easier for the system to deduce the global road information. The disadvantage of this approach is that since the infrastructure needs to be available along the road, the wide-scale installation of such an infrastructure is, in general, time-consuming and expensive. Also, for some real-time applications, the nearby vehicles need to communicate quickly (e.g., warning messages between nearby vehicles to avoid traffic accident), where communication without an intermediary is required.

Another type of communication is Inter-Vehicle Communications (IVC), which has attracted the interest of many automobile manufacturers, including Honda [1, 5, 7]. In inter-vehicle communications, no permanent infrastructure is required for communications between vehicles. The vehicles form a dynamic, ad hoc network, in which each vehicle is a node capable of sending/receiving/relaying messages to/from/to neighboring vehicles via wireless media. Although IVC can be regarded as a type of ad hoc net-

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work, it significantly differs from ad hoc networks in several ways. First, the difference is that the nodes in traditional ad hoc networks are generally assumed to move much slower than the vehicles in IVC. This implies the links between vehicles in IVC can be very unstable. The second difference is that the nodes in traditional ad hoc networks are assumed to move freely in any direction while each node in IVC can only move along the paved road. This difference brings two important properties: (1) Most of the road structures are narrow and long comparing to the radio transmission radius. In order to relay messages to the neighboring vehicles efficiently, message propagation should follow the road as well. This reduces two-dimensional message propagation into one-dimension. (2) Even though most of the vehicles are moving in high speed, if two vehicles are moving on the same direction along the same road, the wireless link between them is considerably more stable compared with other links. To avoid message transmission failure, the protocol should pick up the stable links if available. Traditional ad hoc network protocols, because of these differences, perform poorly for IVC. A good IVC protocol design should take these differences into consideration.

In some ITS applications, message broadcasting may be required (such as emergency information or road congestion information). Traditional broadcast protocols for ad hoc networks can be used for such a purpose, however, because of its flooding nature, it will perform poorly in terms of bandwidth utilization. To save precious wireless bandwidth, the number of the rebroadcasting needs to be cut down. To achieve this, some ideas can be borrowed from another single-cast protocol, called Zone Routing Protocol (ZRP) [3]. This protocol basically defines a zone for each node. When a message is generated for destination outside the zone, the sender tries to pick up the vehicles at the border to re-send the query to save the bandwidth for route discovery requests. Inside the zone, this protocol uses table-driven routing protocol such as distance vector or link state protocol to handle routing. However, in IVC, there might be hundreds of vehicles in a hop and topology is continuously changed. If table-driven protocol is used on this kind of environment, it will waste bandwidth to maintain the routing table. Also, because ZRP is designed for general two-dimensinal ad hoc network and single-cast communication, it does not consider the difference of the ad hoc network and IVC. If ZRP is directly ported to IVC for broadcast service, it reduces into the traditional broadcast protocol.

In this paper, we propose two broadcast protocols suitable for highway IVC that improve the bandwidth utilization. The key to our approach is that only a small sbset of neighboring vehicles is selected to rebroadcast the message, (instead of everyone as in traditional broadcast). For fast deployment of the system, we assume no infrastructure is required on the highways. However, for the vehicles to deduce the road information for our protocols, we assume each vehicle is equipped with Global Positioning System (GPS) device which can deduce its current position by radio from satellite. Since GPS chips are becoming commodity parts, it is likely that GPS will become standard equipment for all vehicles in the future [6]. Our first approach, called Vector-based TRAcking DEtection (V-TRADE) protocol, makes use of the vehicle movement and position vectors for such a purpose. Our second protocol History-enhanced V-TRADE (HV-TRADE), uses the vehicle history positions to help vehicles determine whether they are travelling along the same road. The simulation results shows both protocols improve the bandwidth utilization by several times compared to the traditional broadcast protocol without suffering reachability failure.

The rest of the paper is organized into five sections: the second section describes the traditional ad hoc broadcast protocol; the third section contains the detailed explanation and algorithms of the V-TRADE and HV-TRADE protocols; the fourth section describes the simulation model; the fifth section outlines the simulation results and our analysis; The last section is the conclusion and further research topics.

2 Traditional Broadcast Protocol

Broadcast service is important for all kinds of networks. When a message needs to be sent to all nodes across the network or if the destination location is unknown when the message is sent, a broadcast is necessary. For some specific types of single-cast routing protocols (e.g., route discovery), broadcast service is also used as the means to find an efficient route to the destination.

The simplest way to implement a broadcast service is to have each node rebroadcast messages to all of its neighbors except the one it got this message from. This method is called flooding. Flooding guarantees the message will eventually reach all nodes in the network. It is also terribly inefficient and wastes significant bandwidth (particularly for wireless media). When the number of nodes in the network increases, the bandwidth required for one broadcast message transmission can increase exponentially. Broadcast implementations typically include a time_ to_ live field and employ a message identifier to limit the number of duplicate messages in the network.

Applying traditional broadcast protocols for wireless ad hoc network has several advantages. First, the protocols are simple and easy to implement. Second, to support the broadcast service, each node does not need to send any extra signaling when no broadcast message is generated. Third, in traditional broadcast protocols, each broadcast message will take all possible ways to reach other nodes. If some nodes fail during message broadcasting, most of the nodes will still be able to receive the message. However, traditional broadcast protocol has one main disadvantage. If the transmission radius is large (e.g., UNII for IVC) or if the density of the nodes is high, the transmission area of any node will cover many nodes. Assume node B is in the middle of node A and C and both node B and C are able to hear from node A. If node A broadcasts a message, node B and C will both receive the same broadcast message. If the transmission radius is the same for all the nodes, since the transmission areas of node A and C cover the transmission area of node

B, it would be a waste of wireless bandwidth for node B to broadcast the message. In IVC, the number of neighboring vehicles for one vehicle can range from tens to hundreds depending on what area this vehicle is located. (e.g., rural or urban areas) If the traditional ad hoc broadcast protocol were used for IVC, many unnecessary message transmissions similar to above case would happen. Therefore, the traditional broadcast protocol may not perform well in IVC.

3 Proposed Broadcast Protocols

In this section, we propose a new broadcast protocol IVC on on highways. For example, The protocol can be used to broadcast a message to

- all vehicles on all roads in an area
- all vehicles on the same road as the source vehicle in both direction
- all vehicles on the same road as the source vehicle which are headed in the same direction as the source vehicle
- all vehicles on the same road as the source vehicle which are headed in the oppositedirection direction as the source vehicle

The goal is to improve bandwidth utilization while maintaining the same level of reachability as the traditional broadcast protocol. To achieve that goal, the proposed protocol takes advantage of vehicle position information which is available through GPS.

3.1 Basic Protocol

The basic idea of the proposed protocol is described in the following.

Algorithm Basic_Protocol

1. When a vehicle A has one or more messages to (re)broadcast, it transmits a message to request for position information. It then waits for a prespecified period of time for the vehicles in its neighborhood to reply.
2. Each vehicle B that receives A's request replies with a position report that contains information about B's position (and possibly other additional information).
3. Based on the position reports received, vehicle A classifies each vehicle that has responded into one of five classes
    - Same_Road_Same_Direction_Ahead(A)
    - Same_Road_Same_Direction_Behind(A)
    - Same_Road_Opposite_Direction_Ahead(A)
    - Same_Road_Opposite_Direction_Behind(A)
    - Different_Road(A)

    We note that GPS by itself does not contain road information. Rather it just knows the global position. Further data such as a DVD navigation system clearly having information simplifies the selection process at the expense of more road information required for vehicle. For now we assume the general case of not having a full glown navigation system (i.e., only GPS).
4. Select zero or more vehicles from each of the above five classes. /* The selected vehicles are called *border vehicles*. */
5. For each message x that A wants to (re)broadcast, A transmits the message together with the ID's of the border vehicles (as well as some other necessary control information).
6. When a vehicle B receives the broadcast message, it determines whether it is responsible for rebroadcasting the message. If the answer is yes, it rebroadcasts the message using this same protocol. If the answer is no, it does not rebroadcast the message.

    /* Each message carries a message ID and a "time_to_live." B is responsible for rebroadcasting a received message if the following condit ions are all satisfied: (a) the message's time_to_live is still positive, (b) B is one of the border vehicles as specified in the message, and (c) B has not seen this message before. */

There are two major design issues: how to classify the vehicles into different classes (step 3), and how to select border vehicles from each class (step 4)? The strategies employed to resolve the two issues will affect the protocol's performance.

In subsequent sections, we propose two schemes for classifying vehicles and discuss how to select border vehicles. The two classification schemes are named Vector based TRAck DEtection Protocol (V-TRADE) and History enhanced Vector TRAck DEtection Protocol (HV-TRADE).

3.2 Vector based TRAck DEtection Protocol (V-TRADE)

Suppose that vehicle A wishes to classify the vehicles in its neighborhood. Let B be any vehicle in A's neighborhood. The V-TRADE method makes use of three vectors to classify B. The three vectors are:

- $\overrightarrow{A'A}$: the vector from A's previous position to its current position.
- $\overrightarrow{B'B}$: the vector from B's previous position to its current position.
- $\overrightarrow{AB}$: the vector from A's current position to B's current position.

In the above, we use A to denote vehicle A's current position; and A', its previous position. The same for vehicle B.

The angle between $\overrightarrow{A'A}$ and $\overrightarrow{B'B}$, denoted by $\angle(\overrightarrow{A'A}, \overrightarrow{B'B})$, is used to determine whether the two vehicles are on the same road. If $\angle(\overrightarrow{A'A}, \overrightarrow{B'B})$ is close to 0° or close to 180°, they are regarded as being on the same road. Otherwise, they are regarded as being on different roads. If vehicle A and B are determined to be on the same road, the angle between $\overrightarrow{A'A}$ and $\overrightarrow{AB}$ is used to further determine whether B is in front of A or is behind A. B is regarded as being ahead of A if $\angle(\overrightarrow{A'A}, \overrightarrow{AB})$ is close to 0°; and is regarded as being behind A if $\angle(\overrightarrow{A'A}, \overrightarrow{AB})$ is close to 180°.

The V-TRADE protocol classifies the vehicles into five groups based on the above ideas. It is more precisely specified in the following.

Algorithm V-TRADE

1. A sends out a message to request for position information.
2. On receiving A's request, vehicle B replies with a position report that contains B's current position and previous position.
3. Based on the position reports received, vehicle A classifies neighboring vehicles that have responded as following:

```
for each vehicle B that has sent in a position report do
  if |∠(A'A→, B'B→)| < δ for some threshold δ
  /* same road, same direction */
    if |∠(A'A→, AB→)| ≤ 90° /* B in front of A */
      add B to Same_Road_Same_Direction_Ahead(A)
    else /* B behind A */
      add B to Same_Road_Same_Direction_Behind(A)
  elseif |∠(A'A→, B'B→) − 180°| < δ
  /* same road, opposite direction */
    if |∠(A'A→, AB→)| ≤ 90° /* B in front of A */
      add B to Same_Road_Opposite_Direction_Ahead(A)
    else /* B behind A */
      add B to Same_Road_Opposite_Direction_Behind(A)
  else /* on a different road */
    add B to Different_Road(A)
```

The above scheme is a heuristic approach. There are road structures where V-TRADE may incorrectly classify vehicles. For instance, if A and B are on the same highway and one of them happens to be on a big curve, V-TRADE may place B in Different_Road(A). Fortunately, as it will be seen, most misclassifications are harmless for our purpose.

The next section describes a strategy to enhance the V-TRADE protocol that allows the neighboring vehicles to be classified more accurately. The enhanced protocol, called History enhanced Vector TRAck DEtection Protocol (HV-TRADE), makes use of certain "position history information" in addition to the vectors used by V-TRADE.

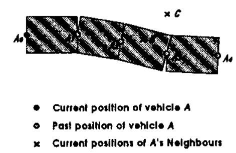

Figure 1. B is in the position history and C is not.

3.3 History enhanced Vector TRAck DEtection Protocol (HV-TRADE)

In HV-TRADE, each vehicle maintains a *position history* that indicates the vehicle's previous positions within the transmission range. Given a position history, $H = (A_0, A_1, \ldots, A_k)$, and a position B, B is said to be in H, denoted as $B \in H$, if position B is in the retangulars defined by the position history (i.e., the shaded area as illustrated in Figure 1).

For any pair of vehicles A and B, given their position histories, $H(A)$ and $H(B)$, and their current positions, A and B, we can determine their relative positions as following:

- $A \in H(B)$ and $B \notin H(B)$: B is in front of A and they are headed the same direction on the same road.
- $A \notin H(B)$ and $B \in H(A)$: B is behind A and they are headed the same direction on the same road.
- $A \in H(B)$ and $B \in H(A)$: A and B are getting away from each other, headed in opposite directions on the same road.
- $A \notin H(B)$ and $B \notin H(A)$: A and B are getting close to each other, headed opposite directions, may or may not on the same road.

Incorporating the above ideas into V-TRADE, we obtain the following History enhanced Vector TRAck DEtection Protocol (HV-TRADE).

Algorithm HV-TRADE

1. A sends out a message to request for position information. The request include A's current position.
2. Each vehicle B that receives A's information request replies with a position report that contains B's current position (B), its previous position (B'), and a single bit, called D-bit, that indicates whether or not $A \in H(B)$ /* The D-bit was calculated by vehicle B. */
3. Based on the position reports received, vehicle A classifies neighboring vehicles that have responded as following:

```
for each vehicle B that has sent in a position report do
  if |∠(A'A→, B'B→)| < δ /* same road, same direction */
```

if $|\angle(\overrightarrow{A'A}, \overrightarrow{AB})| \leq 90°$ and $A \in H(B)$ and $B \notin H(B)$
/* B in front of A */
add B to Same_Road_Same_Direction_Ahead(A)
else if $|\angle(\overrightarrow{A'A}, \overrightarrow{AB})| > 90°$ and $A \notin H(B)$ and
$B \in H(A)$ /* B behind A */
add B to Same_Road_Same_Direction_Behind(A)
else
add B to Different_Road(A)
elseif $|\angle(\overrightarrow{A'A}, \overrightarrow{B'B}) - 180°| < \delta$
/* same reoad, opposite direction */
if $|\angle(\overrightarrow{A'A}, \overrightarrow{AB})| \leq 90°$ and $A \notin H(B)$ and
$B \notin H(A)$ /* B in front of A */
add B to Same_Road_Opposite_Direction_Ahead(A)
else if $|\angle(\overrightarrow{A'A}, \overrightarrow{AB})| > 90°$ and $A \in H(B)$
and $B \in H(A)$ /* B behind A */
add B to Same_Road_Opposite_Direction_Behind(A)
else
add B to Different_Road(A)
else /* on a different road */
add B to Different_Road(A)

It is important to note that whether $A \in H(B)$ is determined by B and this information is passed to A via a single D-bit.

3.4 Selecting Border Vehicles

In the basic protocol of Section 3.1, after vehicle A classifies the neighboring vehicles into five classes, the next step is to select some ($\geq$ 0) vehicles in each class to relay the message. The selected vehicles are called *border vehicles*.

Different selection strategies may be used depending on (1) which vehicles the message is intended for and (2) how important reachability is. A broadcast message could include a flag that indicates whether the message is intended for

- all vehicles on all roads in an area
- all vehicles on the same road as the source vehicle
- all vehicles on the same road and on the same direction as the source vehicle

Based on the value of the flag, the vehicle selects appropriate border vehicles. For instance, if the message is intended for all vehicles on all roads, one possible strategy is to choose the following as border vehicles:

- the farthest away vehicle in Same_Road_Same_Direction_Ahead(A) $\cup$ Same_Road_Opposite_Direction_Ahead(A)
- the farthest away vehicle in Same_Road_Same_Direction_Behind(A) $\cup$ Same_Road_Opposite_Direction_Behind(A)
- all vehicles in Different_Road(A)

Here we assume that high reachability is important. If bandwidth utilization is more important than reachability, we may select only a few vehicles from Different_Road(A). Due to space limitations we only consider the strategy which messages are intended for all vehicles on all roads in an area for the rest of the paper.

4 Simulation Models

In order to verify our new broadcast protocol, we carried out computer simulations and performance comparisons of traditional and proposed broadcast algorithms. There are two type of objects in the simulation: One is a vehicle and the other is a message object.

4.1 Simulation model for vehicle behavior

The structure of the road network is as following: Each road intersection is represented as a node in the network. Between two nodes A and B, a link (from A to B) is defined when there is a road from A to B. Each link is divided into segments which represents part of the road with similar geometric characteristic. A link can contain a number of lanes, each of which contains vehicle information.

A vehicle is represented as an agent (automaton) that has a set of rules for action on the road. Each vehicle has its own origin, destination, and route to reach its destination. Along the way, it follows a standard set of traffic rules such as traffic signals and rules. Vehicle speeds and acceleration are determined by a number of factors surrounding the vehicle and they are updated at each simulation cycle. For example, when the distance between a vehicle V and its front vehicle becomes shorter, vehicle V is to decelerate. Our model is somewhat similar to prior work [12]. A characteristics of our model is that each driver can be characterized by a number of factors including driver visibility and preferences. For example, each vehicle has its own preference as to how much fast (over speed limit) it wants to move on the road, i.e., reckless behavior can also be modeled by adjusting some parameters. As a result, it is possible to have traffic accidents in an intersection in our vehicle model.

In our traffic software, there are a set of utility functions that are useful for the experiment. For a given vehicle, it is possible to access its surrounding vehicles and associated information such as their speeds, origins, and destinations. We have also built utility software to create maps of various sizes so that traffic simulation of various scales can be conducted.

Figure 2 and Figure 3 are the road maps we used in this simulations. To simulate the urban area traffic, a high vehicular density is used. To simulate the rural area or night time traffic, a low vehicular density is used. We applied both urban and rural traffic pattern on the map in Figure 2 and ordinary traffic pattern on the map in Figure 3.

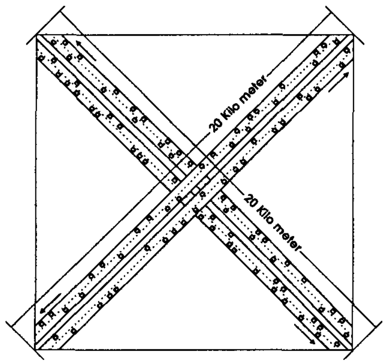

Figure 2. Road structure I

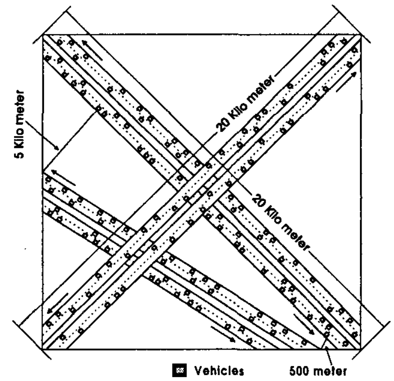

Figure 3. Road structure II

In the real world, even on highway, there are many special circumstances that these protocols may not work well, such as a big curve and off/on ramps. Basically our protocols do not have a category for vehicles in such circumstances. These vehicles will be catagorized into vehicles on different road. All vehicles in these circumstances may be responssible for rebroadcasting. Thus, to maintain high reachability, bandwidth utilization would decrease due to these special road structures. However, the percentage of vehicles to be under these circumstances on highways is relatively low. As a result our protocols are able to tolerate all types of road structure on the highway.

4.2 Simulation model for message transmission

On top of the data generated by the vehicular simulator, each vehicle is able to generate messages. Our simulations focus on the network layer, we do not take the Data Link layer into consideration except specific factors (position request and reply mentioned in new protocol) which may affect the fairness of our simulation result. We also assume that messages can be transmitted without collision and congestion.

Other assumptions for message transmission

1. Messages are generated according to uniform distribution (0.01 times/sec/vehicle)
2. Error occurs in uniform distribution (0.1
3. The size of message is 8Kb
4. The bit rate is 100Kb per second
5. The transmission radius for each vehicle (2000 m, if it is constant)
6. TTL (Time To Live) is 5 hops
7. Propagation delay is considered

The assumption for our new protocol

1. The size of each position request is 40 bits and reply is 100 bits in V-TRADE.
2. The size of each position request and reply are both 100 bits in HV-TRADE.
3. The threshold of inner product is 1 / sqrt(2) in V-TRADE protocol
4. The time interval to update history for each vehicle is 4 second in HV-TRADE protocol

5 Performance Comparison

Based on the simulation model and assumptions mentioned, we carried out computer simulations. We use two metrics for performance comparisons. One is bandwidth utilization (i.e., focus on one vehicle, and count the number of accepted messages over the number of received messages). Another is reachability (i.e., the number of vehicles that got the message over the number of vehicles that existed on the map when the message was generated).

Figure 4 shows the bandwidth utilization in an urban situation (high vehicle density) and Figure 5 shows that in a rural situation (low vehicle density), both using road structure in Figure 2. The x-axis is transmission radius in meters and the y-axis is bandwidth utilization. From the figures, one can observe that the traditional broadcast protocol suffers from extremely poor bandwidth utilization, which does not come as a surprise because of the protocol's flooding nature. However, our new protocols show significant improvement of bandwidth utilization in both Figures, because the new protocols pick up fewer vehicles to rebroadcast the message. The HV-TRADE protocol shows lower bandwidth utilization than the V-TRADE protocol in both situations. The reason is that HV-TRADE regards neighboring vehicles getting close and heading to opposite direction on the same road as border

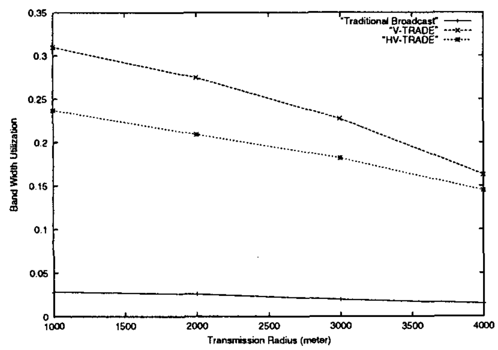

Figure 4. Bandwidth utilization for urban area

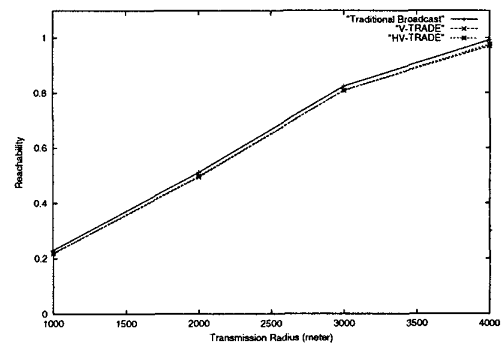

Figure 6. Reachability for urban area

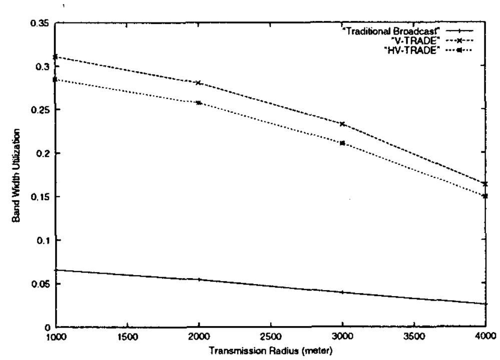

Figure 5. Bandwidth utilization for rural area

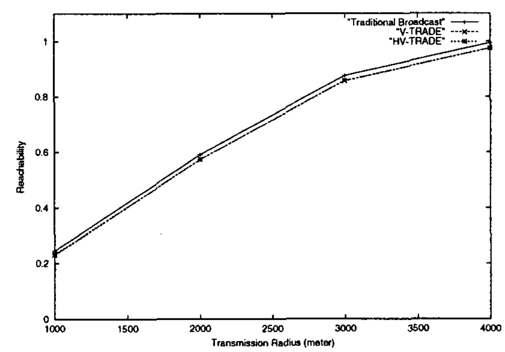

Figure 7. Reachability for rural area

vehicles, and let all of such neighbors rebroadcast messages to guarantee the maximal reachability. History information fails to distinguish if a neighbor is on different road or it is getting close on the same road. On the contrary, V-TRADE does not have this problem. Also, the HV-TRADE protocol shows higher bandwidth utilization in the urban situation than in the rural situation. This is because the number of neighbors getting close on the same road increases, resulting in a higher number of message re-transmissions.

Figures 6 and 7 show the reachability of each protocol in an urban area and in a rural area, respectively; where the x-axis represents the transmission radius in meters, and the y-axis indicates the reachability. We observed that in both the urban area and the rural area, our protocols are comparable to the traditional broadcast protocol in reachability. Furthermore, there is almost no difference in reachability between the H-TRADE protocol and the HV-TRADE protocol.

Figures 8 and 9 show how road structure affects the performance of the protocols. The x-axis is transmission radius and the y-axis is bandwidth utilization and reachability in Figure 8 and Figure 9, respectively. The road structure used is from Figure 3). Figure 8 shows both V-TRADE and HV-TRADE protocols perform far better than the traditional broadcast protocol in bandwidth utilization regardless what road structure is used. However, in Figure 9 the reachability of the V-TRADE protocol is lower compared with that of HV-TRADE and traditional broadcast protocols if road structure Figure 3 is used. The reason is because the angle of two close-by roads in this Figure is within the threshold so the vehicles moving on these two roads can not tell they are on different road in the V-TRADE protocol. This result in incorrect classifications of neighbors and lower reachability. In the HV-TRADE protocol, the history information is used to correctly distinguish vehicles on the same road from vehicles on the close-by road so that reachability is not suffer from different road structure. Therefore, even if V-TRADE shows a little higher bandwidth utilization, the performace of reachability of the V-TRADE protocol is also sensitive to road structure.

6 Conclusions

We have proposed a broadcast protocol in inter-vehicle communication. This is the first work focusing on using GPS information to utilize the bandwidth required for message broadcast. The simulation results show that both V-TRADE and HV-TRADE protocols perform well in bandwidth utilization with slightly loss of reachability. The V-TRADE has a little higher bandwidth utilization than the HV-TRADE protocol. If reachability is a major concern, the HV-TRADE

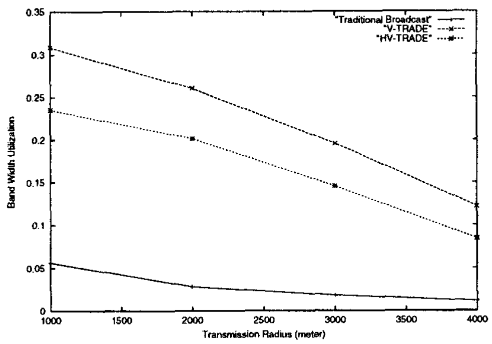

Figure 8. Road structure tolerance for bandwidth utilization

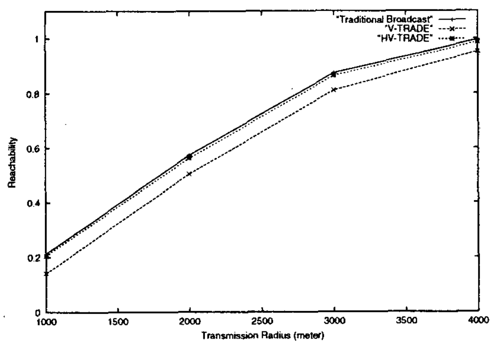

Figure 9. Road structure tolerance for reachability

protocol shows high reachability regardless of the road structure.

There are many interesting topics remain to be explored. For instance, our protocols could be extended to provide single-cast service. Many routing protocols are available in the field of ad hoc network. Among them, route discovery (dynamic source routing) is one of the promising protocols to be used for IVC. In the route discovery protocol, when the sender want to locate the route to the destination, the query is generated and broadcast through the network. In order to reach as many nodes as possible, a large time-to-live value is set for such query. However, such query will flood the network and waste the wireless bandwidth considerably. With the help of our protocol, we can modify the route discovery protocol to greatly reduce the bandwidth consumption for query and still be able to query as many nodes as the traditional query broadcast.

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