An Information Propagation Scheme for VANETs[1]

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Abstract– A goal in Vehicular Ad hoc Networks (VANETs) is to enable the dissemination of traffic and road conditions such as local congestion and surface ice as detected by independently moving vehicles. This activity known as Information Warning Functions is useful for vehicles on the highway and enables early reaction. This problem can be described as the directional propagation of information originating from linearly-distributed mobile nodes on a rectilinear plane.

By using limited-range packet radios and attribute-based routing, we are able to isolate vehicular from network traffic and permit directional propagation of messages outward from the point of origin. For example, it is desirable to propagate the occurrence of congestion created by an accident in both the forward and backward directions on a highway.

We assume the use of multi-hop routing in clusters of connected vehicles to achieve a propagation rate that exceeds the speeds of individual carrier vehicles. We characterize the bounds of information propagation under various traffic patterns and describe a new technique and algorithm that can achieve these limits. We also show an implementation of the dissemination algorithm as a routing protocol using a combination of MANET (mobile ad hoc networking) and DTN (delay tolerant networking) methodologies.

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1 Introduction

Vehicular Ad hoc Networks (VANETs), like MANETs (mobile ad hoc networks) embody the objective of providing useful communications among an arbitrarily-formed collections of vehicles that are geo-located. Information shared in VANETs can be location specific as in the case of information about local attractions, rest areas and fuel stations or it can originate from moving vehicles that detect events such as road congestion or dangerous road conditions. Vehicles can be equipped with terminals intended to access the Internet. The models and techniques for addressing each of these scenarios can be quite different. In this paper, we focus on the propagation of local information originating in vehicles that is useful for other vehicles in the system. This type of activity has been described as Information Warning Functions (IWF), [1, 2].

The purpose of IWFs is to warn vehicles to approach a possibly dangerous area with caution. While authors in [3, 4] have concentrated on tight latency bounds to enable immediate response systems, we focus on the more general problem of information propagation. For Example, one may pose the question, what is the wait time at the toll booth a vehicle may be approaching? What is the average speed of vehicles five miles up ahead on the road? Such messages can be useful in warning the vehicle to approach the area with caution or adopt a different route to its destination if it exists. This kind of information propagation can also be useful in other vehicle-to-vehicle distributed applications.

There are different architectures for enabling communication between vehicles discussed by Wu et al. in [5], including pure ad hoc, wired backbone with wireless last hop, and hybrid architectures. For this paper, we concentrate on a pure ad hoc architecture absent any fixed infrastructure such as access points or satellite communication for data propagation. A common requirement for these vehicular networks is the existence of in-vehicle computing and communication capabilities and the assumption that geo-location is achieved via GPS.

VANETs present a unique challenge in enabling message propagation. They are not nearly as constrained as MANETs in terms of available energy for computation and communication, rather, VANETs are characterized by extremely high mobility and rapidly changing topology. However, this mobility is constrained in motion due to the existence of roadways and can therefore be cleverly exploited for message propagation. There are some existing routing protocols that have been explored for application in this domain but they have not used these characteristics; mobility, direction of motion, and location information, to enhance the performance of the routing protocols. There are several challenges to adopting existing

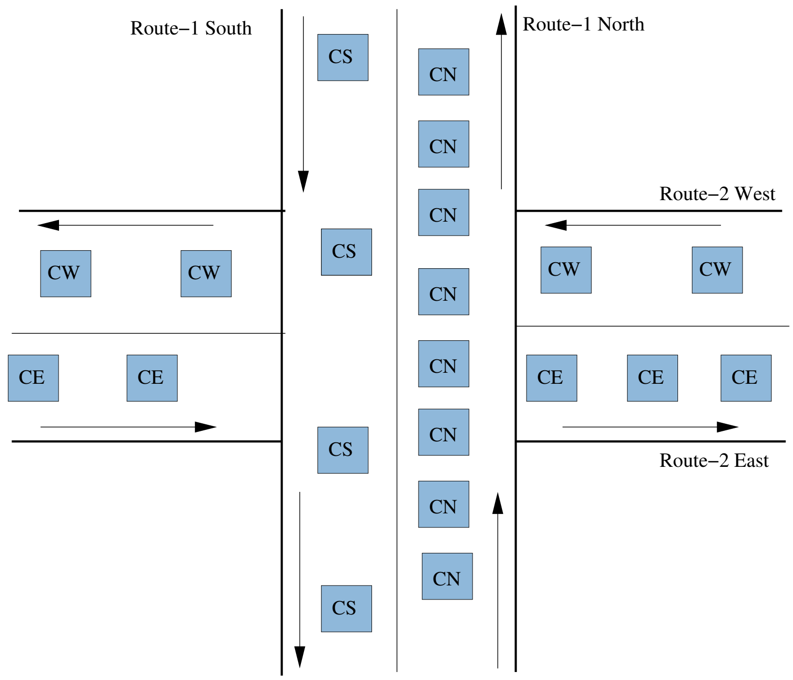

Figure 1: A VANET scenario involving intersecting multi-lane highways. Vehicles (cars) are designated with their direction (CE - car east, CN - car north. etc.) In this example, we seek to isolate E-W data from N-S data (although our proposal does not preclude an alternative behavior).

routing protocols from the field of MANETs [6, 7]. First, the network can frequently form partitions preventing end-to-end communication strategies. Second, resource discovery and naming are problematic as the vehicles are in general unreliable and frequent arrivals and departures occur.

In our proposed scheme, called Directional Propagation Protocol (DPP), we utilize the directionality of data and vehicles for information propagation. DPP is comprised of three components; a Custody Transfer Protocol (CTP), an Inter-Cluster Routing Protocol, and an Intra-Cluster Routing Protocol. The custody transfer mechanism has been adopted from Delay Tolerant Networking concepts [8] for the purpose of overcoming the lack of a sustained end-to-end path between source and destination. Inter-Cluster communication, the message exchange between nodes within a cluster, is a function of the clustering mechanism, while the Intra-Cluster Routing Protocol governs the communication between clusters to achieve the global routing goal. This scheme, operating in store-and-forward mode, permits the bridging of network partitions when they exist. Moreover, the use of attribute-based routing isolates message traffic destined for non-participating routes, Fig. 1.

The remainder of this paper is organized as follows. In Section 2 we characterize the vehicular application scenario and assumptions about the nature of the system. In Section 3 we describe our proposed DPP routing and data propagation techniques. An analysis and discussion of performance of the scheme is covered in Section 4. Section 5 concludes the paper.

2 The Vanet Characteristics and Assumptions

We concentrate on information propagation in a highway scenario in which there are multiple vehicles traveling on both sides of the highway with possibly multiple lanes. In this context, information warning messages are destined for multiple and possibly all vehicles in a region. Location information is used as an attribute to limit data propagation to regions. We model the highway as rectilinear under the assumption that packet radio is tolerant to local variations in directionality and curvature of the roadway. We define each direction of the roadway as a directed pathway; and thus each roadway has two opposing directed pathways.

Vehicles are assumed to be equipped with sensing, communication, computation and storage capabilities such that vehicles can form nodes of an infrastructure-less ad hoc network and can source information warning messages. Vehicles traveling in the same direction are assumed to travel with a relatively constant velocity bounded by [v_{min} and v_{max}]. There will be exception conditions such as stranded vehicles; however, with the use of attributes these nodes can be mapped out of participation in the routing scheme. In this paper, we only discuss the propagation along single directed pathway. The dissemination of information to other pathways can be extended from this scheme using map-based information.

2.1 Clustering

Vehicles traveling on the same directed pathway can form interconnected *blocks* of vehicles, illustrated in Fig. 2. We envision this kind of node arrangement to represent common highway behavior of vehicles where vehicles tend to travel in blocks with gaps occurring between consecutive blocks. The cardinality of each block is related to the vehicle density. At one extreme, under dense conditions, the directed pathway is covered by a long continuous block, while at the other extreme, the block size will be one. Additionally, vehicles that are within range r and maintain connectivity for a minimum time t are said to be part of a *cluster*. We use the term *cluster* consistent with MANET jargon; essentially a group of nodes in close communication range with one another. Thus, a block maybe comprised of

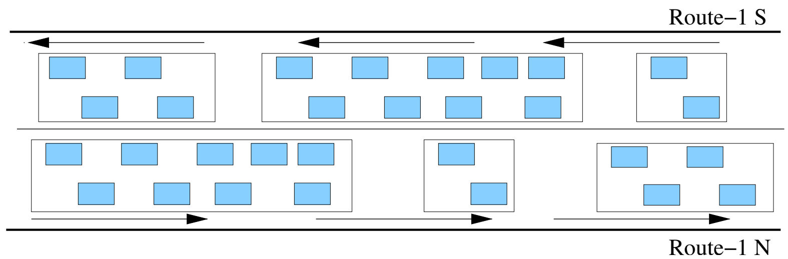

Figure 2: *Blocks* of vehicles comprised of vehicles within radio range of one another with common directionality. Note that long blocks may be comprised of multiple clusters to reduce VANET routing overhead

several clusters.

2.2 Effect of Traffic Density

In sparse and intermediate traffic conditions, there will be frequent gaps between vehicles and infrequent blocking of vehicles. In terms of the network, the partition is time varying and described as having network fragmentation. The network fragmentation prevents continuous end-to-end connectivity between all nodes. Data propagation rates achievable in different cases are illustrated in Fig. 3 assuming multi-hop communications. The dense traffic is described as high density of vehicles with end-to-end connectivity and no fragmentation (in the area of interest) and propagation is limited by routing, medium access, and link layer latencies. The sparse case is instead limited by the speed of the vehicle that carries the message (forward or backward). The shaded region corresponds to the intermediate case. The nearness to either bound depends on the traffic pattern. Using the algorithms we propose allows successive use of the opportunistic contacts with opposing traffic to gain distance faster than by a single vehicle's mobility.

2.3 Related Work

There is existing research exploring vehicle-to-vehicle communications such as FLEETNET and CARTALK [1, 2, 9, 10]. The VANET approach used in CARTALK [1, 2] is characterized by the use of map information, GPS coordinates and spatially aware routing. The key feature of this technique is the use of map information to forward messages using awareness of roadway paths instead of infeasible line-of-sight chord paths. However, the authors make different assumptions about the VANET operational scenario. In particular, they focus on fully connected multi-hop scenarios. Although this scheme provides performance

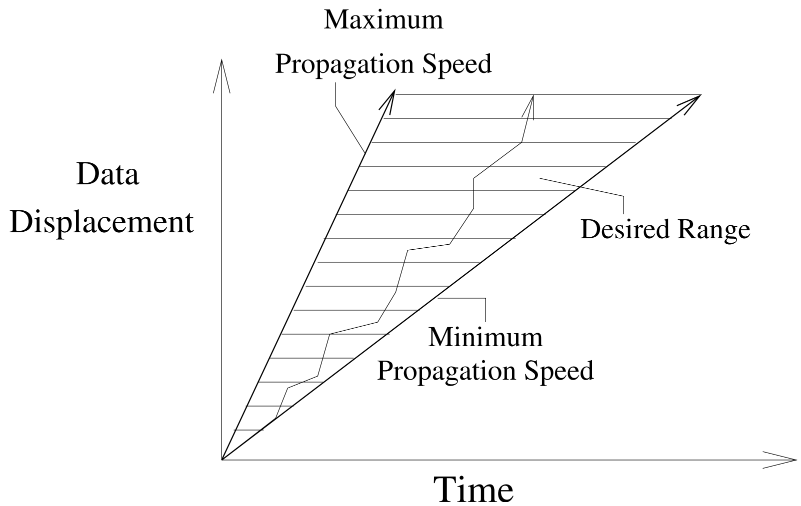

Figure 3: Achievable data propagation depending upon traffic conditions

gains by routing using spatial awareness (essentially using roadway maps), and thus dealing with directionality of vehicular and routed message traffic, the authors do not consider a model characterized by constant network fragmentation due to transiting blocks of vehicles. Moreover, in our scheme, although we use position-based information, we do not require detailed mapping information, rather, we rely on very limited attributes characterizing vehicular route selection.

In the FleetNet project [9, 10], the authors explored the prospect of using roadside gateways to deal with the sparse traffic scenario. By contacting gateways, clusters of vehicles associated with local FleetNet routing group are able to bridge gaps due to network fragmentation. With a goal of providing additional services including connection-oriented traffic, this approach requires additional mechanisms and the deployment of infrastructure in contrast to our proposal.

In [11, 12], the authors have shown the likelihood of occurrence of partitions. Wu et al. [13] present a detailed analysis of information propagation along a directed pathway using a multi-hop model. Füßler et al. [12] show the traffic connectivity statistics by taking snapshots of real-time traffic. They also study the application of various routing strategies and assert the need for using traffic along both sides of a highway to increase connectivity. The custody transfer mechanism discussed here is a part of Delay Tolerant Networking research [8].

3 Proposed DPP Scheme for VANETs

Here we describe the components of our data propagation protocol including the use of attribute-based data, cluster formation and maintenance, and custody transfer.

3.1 Cluster Formation and Maintenance

For implementation of our scheme, vehicles must form a cluster when within a target range of other vehicles on the highway. For cluster stability, we require a threshold duration of connectivity before admitting a node to the cluster. We do not consider the effects of speed differentials within the cluster as the faster vehicles will leave one cluster and join another as the vehicle progresses on the road. Also, there are intersections on a highway where vehicles may join or leave the clusters. Once a cluster becomes very large we expect to split the cluster to better manage intra-cluster traffic.

Due to the large number of vehicles on a highway in dense traffic conditions, it is essential to implement a clustering scheme to localize and manage network collisions. By clustering vehicles, we can isolate classes of inter-cluster and intra-cluster traffic. The intra-cluster communication described later will be used for message custody transfer.

There are many techniques for cluster formation based on node ID and node mobility; we choose to adopt a technique relying on a distributed algorithm suited for the characteristics of our vehicular blocks [14]. We do not discuss the cluster creation or maintenance further here.

Each cluster has a header and a trailer, located at the front and rear of each cluster, entrusted with the task of communicating with other clusters. A node at the head or tail of the cluster will elect itself as the header or trailer for our protocol. (Node election is not covered here.) This allows us to limit congestion caused by the large number of participating nodes. The remaining nodes in the cluster, nodes which are not header or trailer, are described as intermediate nodes. Within a cluster, communicated messages are shared with all nodes to both facilitate header/trailer replacement and general awareness of disseminated messages.

The intermediate nodes retain a passive role of receiving messages and acknowledgments from opposing blocks and forwarding them to the header or trailer sharing the information within the cluster. Similarly, messages originating from intermediate nodes are immediately

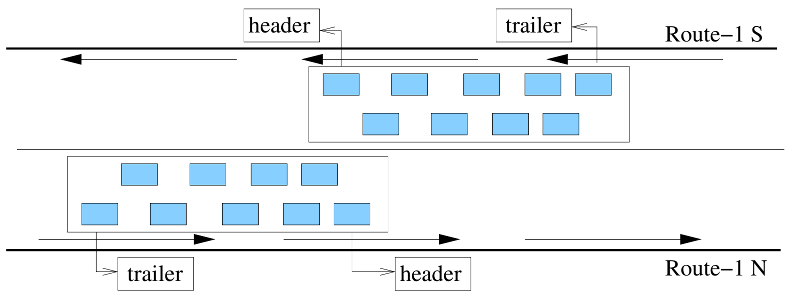

Figure 4: Example illustrating a cluster traveling along a highway with nodes assuming the role of *header* and *trailer*.

routed to header or trailer depending upon the direction in which information needs to propagate. Any duplicate messages received at any of the nodes are dropped. End-to-end path formation can be assumed to be taking place within a cluster.

The communication between nodes within a cluster is governed by the Inter-Cluster Communication Protocol is a function of the clustering scheme adopted.

3.2 Custody Transfer Mechanism

In most message passing schemes, a message is buffered until an acknowledgment from the destination is received. However, due to network fragmentation in a VANET and the resultant lack of continuous end-to-end connectivity at any given instant, the message can require buffering for an indeterminate amount of time. The result translates to the requirement for large buffer sizes or dropped messages and difficulty in exchanging acknowledgments. For applications that do not require continuous end-to-end connectivity, a store-and-forward approach can be used.

We propose the use of a custody transfer mechanism adopted from DTN techniques [8]. With such a scheme, a message is buffered for retransmission from the originating cluster until it receives an acknowledgment from the next-hop cluster. In the scenario under consideration, the goal is to propagate data in a single direction. The custody is implicitly transferred to another cluster that is in front along the direction of propagation and is logically the next hop in terms of the message path. The traffic in opposing direction acts as a bridge but is never given custody of the message. The custody is not released until an acknowledgment is received from the cluster in front. Once the message reaches the next hop cluster, it has custody of the message and the responsibility for further relaying the message is vested with this cluster. The custody of the message may be accepted or denied by a cluster by virtue of it being unable to satisfy the requirements of the message. The rules for custody transfer, governed by the Custody Transfer Protocol, would be explored in future work.

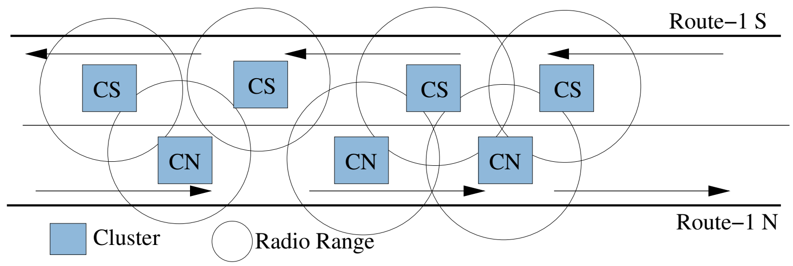

Figure 5: Illustration of multi-hop path between clusters. In our proposed scheme, the data are propagated whenever there is contact with another cluster.

3.3 The Use of Attribute Based Data

We specify the use of data attributed with properties such as the intended direction, age, and intended classes of recipients. Under this scheme, recipients can route or discard data according to the rules of the application. For example, it is essential to alert vehicles approaching a problem area on highway rather than those that are leaving the problem area. Similarly, the warning is intended for vehicles which are five miles away from the problem area rather than vehicles which are 50 miles away from the problem area.

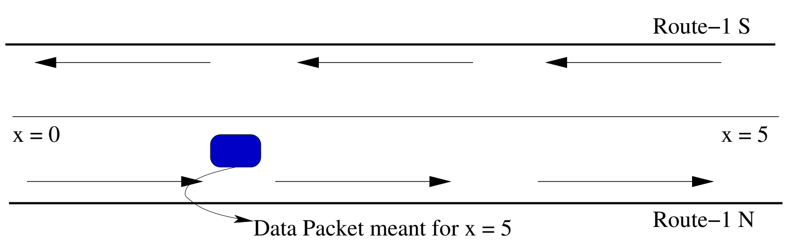

Figure 6: Demonstration of directionality of data with distance as its attribute.

Because data are perishable in this context and useful when localized, we associate a location and time-based time to live (TTL) parameter. Clearly, a TTL function is dependent on the data type and the application. We focus on the general case here. Attributing data with direction also helps minimize the noise generated by congestion and traffic at intersections by vehicles traveling in orthogonal directions.

By using a combination of attributes, we are able to create a routing structure that is based on local parameters leading to a distributed routing algorithm. This algorithm is able to route in the absence of a global naming scheme and the presence of rapid topology changes. Additionally, the attributes are tunable parameters thus, providing more flexibility in routing. This scheme enables each node to make a routing decision based on the message attributes and its own state. The nodes, each acting independently, are able to achieve the global routing goal. The choice of attributes is application dependent and not detailed here.

3.4 Implementation of Directional Propagation Protocol

The vehicles, assumed to be equipped with sensing equipment, generate data to be propagated along the highway. The data are attributed with parameters such as TTL, direction, class of recipients, etc. The routing structure identifies these attributes along with the location and heading of each vehicle. The propagation is called *Reverse Propagation* if the data are headed in a direction opposite to the direction of motion of vehicle and *Forward Propagation* if data are headed along the direction of motion of the vehicle. This idea is illustrated in Fig. 7. We will not discuss the reverse propagation scheme in detail here as it can be modeled as an extension of the forward propagation scheme.

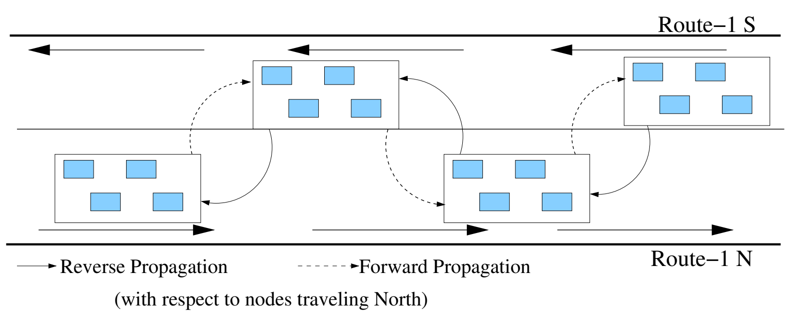

Figure 7: Forward propagation and Reverse Propagation of data from one block to another using blocks on either side of the directed pathway.(with respect to nodes traveling North)

We assume the vehicles to be traveling at a constant velocity c. Let v, the message propagation rate within a cluster, be equal to transmission range over the time for a complete successful transmission. For simplicity, nodes are separated by a transmission range distance. The directions along the highway are denoted by N and S for North and South.

Forward Propagation: In forward propagation, the vehicle is assumed to be traveling along the N direction and the data are also to be propagated in the N direction. The data can travel at a minimum rate of the speed of the vehicle since the data are traveling along the vehicle. The data are propagated to the header of the cluster. The header now tries to propagate the data further along the N direction, trying to communicate with other clusters located ahead of this cluster. If the clusters are partitioned, the header attempts to use the clusters along the S direction which may overlap with other clusters along the N direction to bridge this partition. Thus, the data are propagated to nodes traveling along N direction which are otherwise partitioned from each other, by using clusters along the S direction. This temporary path occurs due to opportunistic contact with nodes in the overlapping clusters. Once the data are forwarded to the next hop and an acknowledgment is received, the custody is transferred to that cluster. The entire process is repeated until the data reaches its required destination.

Algorithmically, the routing at header nodes can be described as follows:

```
Initialize Node_Direction
for any Message do
  if Message is not in Queue then
    Add Message to Queue
    if Message_Direction = Node_Direction then
      send ACK
      do ForwardPropagation
    else
      Route to Trailer
    end if
  else if Message_Direction = Node_Direction then
    send ACK // Duplicate Message
  else
    if ACK for Message exists then
      send ACK // re-transmission
    else
      do nothing // Duplicate Message
    end if
  end if
end for
```

The routing algorithm at the trailer node can be described in a similar manner, with corresponding parameters governing the routing rules.

4 Analysis and Discussion

4.1 Analysis

Vehicles are assumed to be traveling with a constant velocity c m/s. The data propagation speed within a cluster is assumed to be v m/s. For simplicity, the size of the vehicles is ignored.We characterize the behavior of the system in terms of four transition states for analyzing the performance of the proposed scheme. These are:

1. Data are traveling along on a vehicle in the N direction
2. Data are propagating multi-hop within a cluster in the N direction
3. Data are traveling along a vehicle in the S direction
4. Data are propagating multi-hop within a cluster in the S direction

These states are illustrated in Fig. 8 where the propagation rate in connected blocks is $(c + v)$ and c m/s in disconnected clusters.

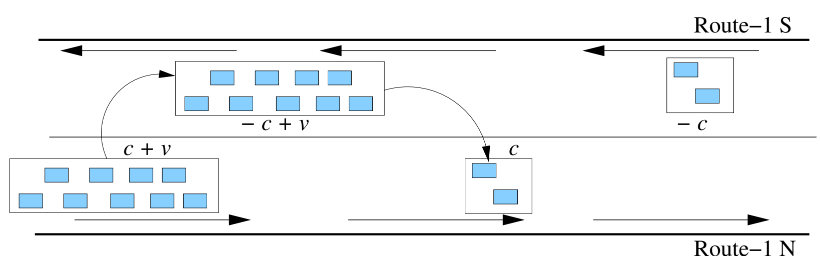

Figure 8: Illustration of velocity of data in different phases of routing in Forward Propagation.

As a measure of performance, we calculate the average message propagation rate of the data for varying traffic conditions. In each state, the data propagates with certain rate and the net displacement is a function of time. Let the displacement be denoted by x, where $x(t)$ is the displacement at time t. This average rate will vary for different traffic scenarios and different network conditions. Any achievable rate will lie within these bounds.

The graphs of Figs. 9 and 10 show the displacement rate for a typical scenario. The data displacement is determined based on the current state and the propagation rate is described by the slope of the graph. For the forward propagation scheme, the displacement goal is positive while for the reverse propagation scheme, it is negative.

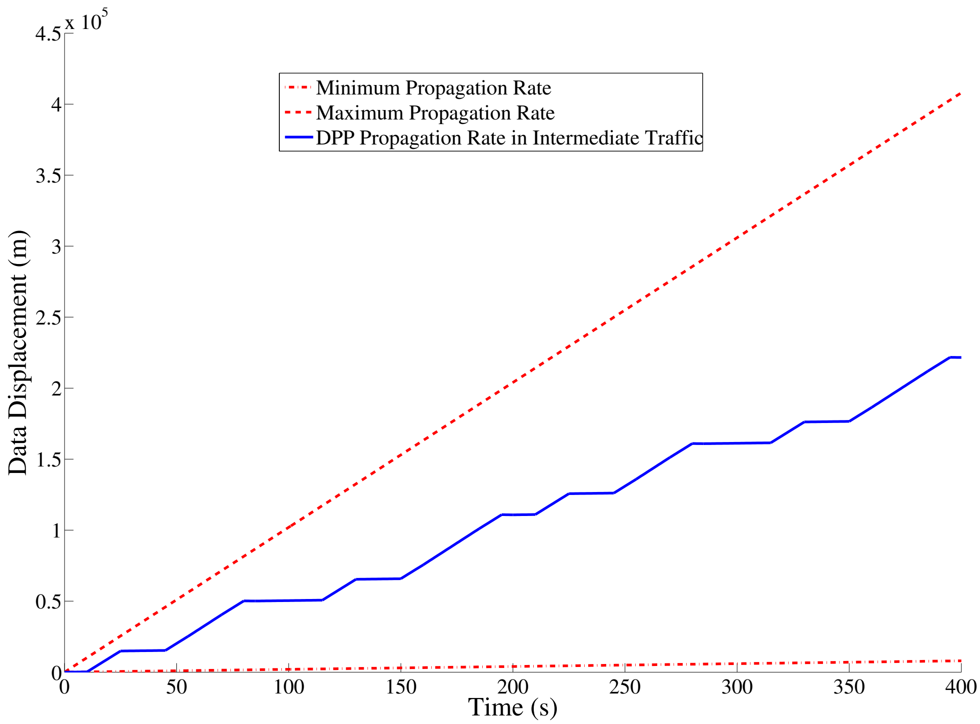

Figure 9: Forward Propagation: Data Displacement vs. Time

Forward Propagation: For forward propagation, the data travel along the carrier at a propagation rate equal to the speed of the vehicle, c m/s. While using multi-hop routing within a cluster, a propagation rate of $c+v$ m/s can be achieved in a cluster along the N direction and $-c+v$ m/s in a cluster traveling in the S direction. If data are propagated by a vehicle along the S direction, the rate achieved would be $-c$ m/s. These properties are invariant with the algorithm (deterministic), but dependent on the traffic profile.

$$x_i = c * t_i$$
$$x_i = (c+v) * t_i$$
$$x_i = (-c+v) * t_i$$
$$x_i = (-c) * t_i$$
$$Avg(v) = \frac{\sum_{\forall i} x_i}{\sum_{\forall i} t_i}$$

Reverse Propagation: In reverse propagation, the data propagation rate is c m/s as the data are traveling along a car in the N direction, this becomes $-c$ m/s as soon as it can be passed on to a vehicle on the S direction. In multi-hop, the N direction cluster provides a propagation rate of $c-v$ m/s, while a cluster along the S direction would facilitate propagation rate of $-c-v$ m/s.

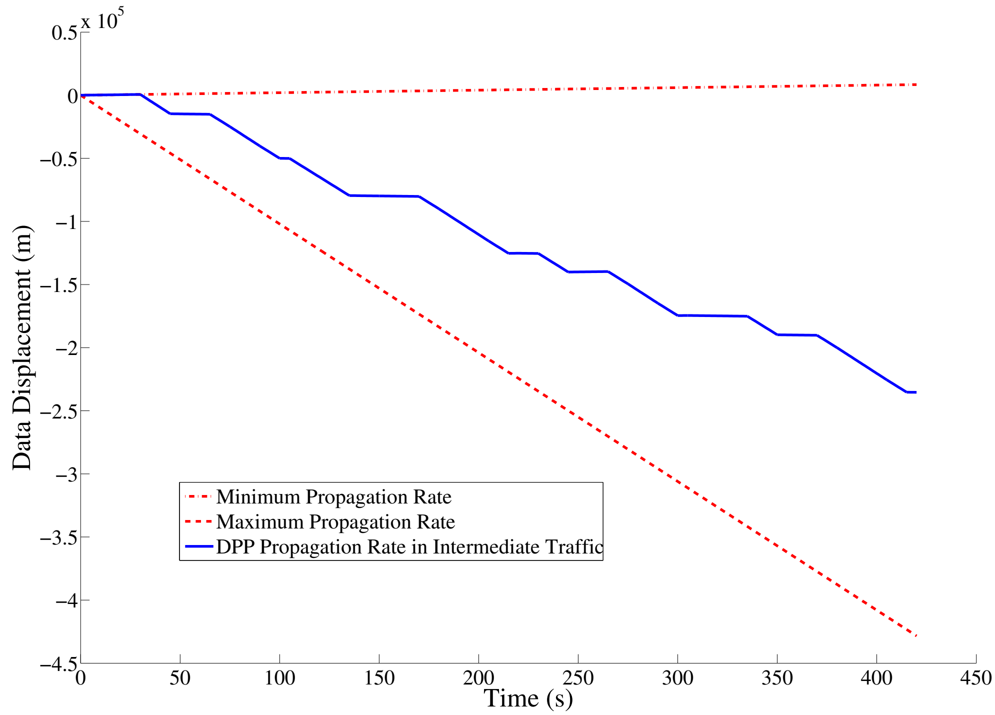

Figure 10: Reverse Propagation: Data Displacement vs. Time

4.2 Discussion

The average speed can be described as the total displacement achieved from the origin within a specified time window. For typical traffic scenarios as shown in Figs. 9 and 10, under any given set of conditions, the displacement will be characterized by the equations and the net displacement will be the sum total of displacement in different phases of the protocol.

In forward (reverse) propagation, a maximum propagation rate of $c+v$ m/s $(-c-v)$ m/s will be achieved in dense traffic conditions when there is an end-to-end path in the form of multi-hop clusters from source to destination. The minimum propagation rate of c (c) m/s, the speed of original carrier, will be achieved in sparse conditions when the formation of a data path for faster propagation will be difficult. In intermediate traffic conditions, where there will be instances along the highway where there is no data path to the next cluster and others where the partitions will be bridged by opportunistic contacts with clusters traveling in opposite direction. This is illustrated in graph in Fig. 9 (10).

For comparative purposes, we have used c as $20m/s$ and v as $1000m/s$, which are consistent with the values used by Wu et al. [13]. The information propagation speed in this case is an ideal case scenario. Realistically, the velocity will be constrained by MAC backoffs, collisions, cluster management and other physical layer issues. A better lower bound can be achieved using a traffic model that has Poisson arrivals and has heterogeneous speeds of traffic. The performance of this protocol is also dependent on the size of inter-connected blocks on either side of the highway and the occurrence of opportunistic contacts.

5 Conclusion

In this work, we have proposed a new algorithm and protocol to enable data propagation of messages in VANETs without the use of fixed infrastructure such as access points or satellite communication. The algorithm is distributed in nature which does not require a global naming function and can perform irrespective of the traffic density. We have characterized the upper and lower bounds, and typical performance behavior of the scheme. We have shown that the cost of message exchange is deterministic and the cost in different scenarios is a function of c, speed of vehicle, v, speed of message propagation and the different traffic conditions. In the future, we expect to gain more detailed performance characterization between the indicated bounds by considering the latencies associated with message handling, MAC contention, and clustering.

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