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EFD: A Flexible Routing Metric for Delay Sensitive Urban VANETs

By

Mir TafseerNayeem
Student # 074413

Md. Mamunur Rashid Akand
Student # 074430

Md. Rokon Uz ZamanSumon
Student # 074420

Supervisor:
Dr.Muhammad MahbubAlam

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CERTIFICATE OF RESEARCH

This is to certify that the work presented in this paper is the outcome of the research carried out by the candidates under the supervision of Dr.Muhammad MahbubAlam, Assistant Professor, Department of CIT, IUT, Gazipur. It is also declared that neither of this thesis nor any part thereof has been submitted anywhere else for the award of any degree or for any publication.

Authors:

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Mir TafseerNayeem Student # 074413	Md. Mamunur Rashid Akand Student # 074430	Md. Rokon Uz ZamanSumon Student # 074420

Date: ________________

Supervisor:

Dr.MuhammadMahbubAlam
Assistant Professor
Department of
Computer Science and Information
Technology, IUT.

Signature of Head of the Department:

Prof. Dr. M.A. Mottalib
Head
Department of
Computer Science and Information
Technology, IUT.

Date: ________________

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Abstract

This paper proposes an Expected Forwarding Delay (EFD) forwarding scheme, tailored for the data forwarding for delay sensitive urban vehicular ad hoc networks. State-of-the-art schemes have demonstrated the effectiveness of their data forwarding strategies by exploiting known vehicular traffic statistics (e.g., densities and speeds). These results are encouraging; however, further improvements can be made by taking advantage of the growing popularity of GPS-based navigation systems. This paper presents the first attempt to make data forwarding scheme of delay sensitive urban networks. In urban scenarios co-directional traffic consists of a collection of disconnected clusters. Since end-to-end connectivity between the sender and receiver is not guaranteed to exist, a car that stores a packet may have to carry it for a while before a suitable next hop can be identified. We begin by offering an analytical expression for the expected forwarding delay (EFD) in co-directional traffic. The proposed scheme uses co-directional clusters (e.g. clusters that run in the same direction as the packets to deliver to the next vehicle). When disconnection occurs between two co directional clusters, clusters in the opposite direction are used as bridges to the next co-directional cluster. For the accurate end-to-end delay computation we have used city blocks .Furthermore, once a packet has been forwarded along a path, our scheme tries to reuse this path for the next subsequent data packets to reduce the broadcasting overload. Through theoretical analysis and extensive simulation, it is shown that our link delay model provides the accurate link delay estimation and our forwarding design outperforms the existing scheme in terms of both the data delivery delay and packet delivery ratio in case of delay sensitive urban VANETs.

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CHAPTER-1

INTRODUCTION

1. INTRODUCTION

Vehicular Ad hoc Networks (VANETs) is a subclass of mobile ad hoc networks (MANETs) with special mobility pattern and rapidly changing topology. So the existing routing protocol of MANETs cannot be directly applied to VANETs. However, processing power and storage efficiency are not an issue in VANETs as they are in MANETs. VANETs a major component of the intelligent transportation systems (ITS) [1], becomes the important issue on providing safety and comfort of passengers in both highway and city scenarios. ITS is typically classified into two categories, road-to-vehicle communications (RVC) and inter-vehicle communications (IVC). Vehicular ad-hoc network (VANET) is a representative model for IVC. Inter-vehicle communications (IVC) has been gaining a great deal of importance over the past few years. Its increasing importance has been recognized by academia, industry and standards organizations for protocol design, major car manufacturers and governmental organizations.

To support their development the US FCC (Federal Communications Commission) has allocated 75 MHz in the 5.9 GHz band for licensed Dedicated Short Range Communication (DSRC) [2] and IEEE has defined a new standard for DSRC named IEEE 802.11p. In recent years, the radio range of VANETs is extended to almost 1,000 meters. This has encouraged lots of governments and prominent industrial corporations such as Toyota, BMW and Daimler-Chrysler to launch several projects like Advanced Driver Assistance Systems (ADASE2) [3], Crash Avoidance Metrics Partnership (CAMP) [4], CarTALK2000 [5], FleetNet [6], and DEMO 2000 by Japan Automobile Research Institute (JSK). It is expected that ITS will bring huge economic and social impacts by enabling inter-vehicle communications with or without the support of roadside infrastructures.

Many new technologies have been studied for Intelligent Transport Systems (ITS) to increase vehicle safety and comfort. These technologies are visualized to be implemented into two ways: (i) by the deployment of proper communication infrastructure along the roads to act as gateways to the Internet, or (ii) by the implementation of the "Vehicle Ad-hoc NETwork" (VANET) where vehicles communicate with each other in absence of specific communication infrastructure. In Roadside-to-Vehicle Communications (RVC) the cost of setting up wireless infrastructure (e.g., 3G) at every junction point (JP) is high .Each AP installation with power and wired network connectivity can cost US$5,000 [7]. Moreover, data forwarding may not be possible when such infrastructure does not exist or damaged due to disaster, whereas wireless LANs and vehicular networks can be used to provide important traffic, rescue, and evacuation information to the users. Currently, the Car-2-Car Communication Consortium [8] identified guidelines for providing vehicle-to-vehicle communications as well as a reference protocol architecture, but did not define channel and traffic models, channel usage, and routing algorithms yet. This leaves the floor to further study and proposals, especially in the context of routing.

However, due to the high mobility of the vehicles, it is generally difficult to find an end-to-end connection between two specific locations in a VANET. This introduces opportunities for mobile vehicles to intermittently connect with each other when moving. Therefore much attention have been paid to a technology called a DTN (Delay or Disruption Tolerant Network), which improves the message delivery rate in a sparsely connected network. In a DTN, no relaying node forwards a message if no suitable node is available for receiving the message. Hence the carry-and-forward strategy was proposed to overcome this network disconnection .The node *store and carry* the message with itself and forwards it later when such a node becomes available in its vicinity. In this way, a DTN can efficiently deliver messages even in a case with frequent network partitions as well as without an end-to-end connection for delay-tolerant applications.

Along with the recent developments in the VANET field a number of attractive applications such as collision warnings, file sharing, navigation system, and automatic toll and poll collection, have attracted many eyes. Embedding sensors in vehicles can be established to monitor road states and other environmental conditions in large areas. Several commercial applications (e.g., hotels, restaurants and parking space availability, announcements of sale information, deliver advertisements, remaining stock at a department store, mobile e-commerce) help to reduce the extra time and fuel wasted by the drivers and passengers while traveling, entertainment applications (e.g. Internet access ,multimedia content sharing and music downloads) have been envisioned. Without Internet connection, vehicular networks can also act as “data delivery networks” to query a data center several miles away. The aforementioned applications are not limited to vehicles within one hop or few hops away. The requester can issue a query from several miles away through multi-hop relay by a number of intermediate vehicles. In these types of applications the users (e.g. passengers or drivers) can tolerate up to seconds or minutes of delay as long as the reply will finally return.

On the other hand, to support the intelligent transportation system (ITS) for drivers VANETs have been investigated to be useful in new class of delay critical e-safety applications such as cooperative collision avoidance, pre or post-crash warning, abrupt obstacle avoidance (e.g., animal or tree) or other hazard detection (e.g., icing, surface water, pool of oil, pothole, etc.) that require time-critical responses (less than 50 ms).Emergency vehicles such as ambulances, fire engines, and police cars can be caught in traffic jams, and the resulting delay can lead to inestimable loss of life or injury. The occurrence of a traffic accident should be immediately reported to approaching vehicles to prevent secondary accidents, and this information can also be propagated by an inter-vehicle communications system. The accident information should also be passed to the road-control operator through road-control networks so that the operator can take systematic action over a wide area to prevent further traffic disorder.

This paper, for the first time, proposes a microscopic data forwarding scheme specially for these delay sensitive or critical applications.

CHAPTER-2

RELATED WORKS

2. Related works

This section highlights major attempts made in routing protocols in VANET scenarios.

In previous works there have some major attempts in applying conventional MANET routing protocols to VANETs. On-demand approaches such as AODV [9] or DSR [10] suffer from Broadcast storm problem. Consequently, in these approaches an established route is a fixed succession of nodes between the source and destination leads to frequent broken routes in the presence of VANETs' high mobility, Proactive approaches such as OLSR [11] suffered from count to infinity problem and oscillation problem due to high node mobility.

VANET being a special type of MANET has unique characteristics which differentiate VANET from traditional MANET. First, as vehicles move at high speeds the topology of the vehicular network changes rapidly. Second, unlike MANETs where an end-to-end connection is usually assumed, vehicular networks are frequently disconnected depending on the vehicle density which results temporary network fragmentation. In addition, Vehicle velocities are also restricted according to speed limits, degree of congestion in roads, and traffic control strategies (e.g., RSU (Road Side Units), stop signs and traffic lights) which in turn results uneven distribution of vehicles that causes topology holes in the network. These characteristics make the classical MANET routing algorithms [9, 10, 11] inappropriate for vehicle-to-vehicle communications over VANETs, and significantly influence the design of alternative routing protocols.

Position-based routing has proven to be well suited for highly dynamic environment such as VANETs Due to the low cost and popularity of global positioning system (GPS) and Geo-

Location Services [12, 13, 14]. In geographic routing data are routed to vehicles based on their geographic location. Examples for position-based routing algorithms are face-2 [15], GPSR [16], DREAM [17] and terminodes routing [18]. Among them GPSR (which is algorithmically identical to face-2) is seems to be scalable and well suited for very dynamic networks. In GPSR [16], greedy forwarding is used to send packets to nodes that are always progressively closer to the destination. However, there are some cases where packets will reach a local maximum. In such a case, the node switches from greedy mode to perimeter mode to recovers from a local maximum based on the right-hand rule. So this protocol is inefficient and not suitable for high mobile network e.g. VANETs.

Naumov et al. [19] presented the Advanced Greedy Forwarding (AGF) and also incorporated a velocity vector of speed and direction to accurately determine the location of a destination that significantly improves the effectiveness as well as the performance of GPSR [16]. Naumov et al. [19] also introduced Preferred Group Broadcasting (PGB) with route auto-correction strategy to improve AODV [17]. PGB uses adaptive beaconing based on the number of neighbors to reduce control message overhead.

To deal with the challenges of city scenarios, Lochert et al. [21] proposed GSR, a position-based routing with topological information. This approach employs greedy forwarding along previously selected shortest path. Simulation results show that GSR outperforms topology based approaches like (AODV [9] and DSR [10]) with respect to packet delivery ratio and latency by using realistic vehicular traffic. Later Lochert et al. [20] also designed GPCR without the help of map information, which is similar to GSR [21] but does not rely on planarization of nodes. GPCR [20] employs a restricted greedy forwarding strategy which has a better recovery strategy than the perimeter mode of GPSR [16]. However, both of the protocols didn't consider the case of low traffic density and vehicles' movement, which make it difficult to find an end-to-end connection along the pre-selected path thus it failed to maintain route stability. Leeet al. [22] proposed GpsrJ+ to improve GPCR in Packet delivery ratio and hop count. Ma et al. [23] presented a path pruning algorithm to reduce the number of hops in perimeter mode. All of these geographic routing protocols are developed to improve GPSR [16] to provide a suitable routing solution for sparsely connected VANETs.

MDDV [25] and VADD [26] are two multi-hop routing protocols, which utilize the predictable mobility in VANET for data delivery in high mobility and frequently disconnection situations. The basic idea is without an end-to-end connection the message can be delivered through carry and forward, to the destination. When a network disconnection occurs, nodes carry the packet with itself and forward the packet to the nearest neighbor that moves into its vicinity or communication range. In VADD [26] dynamic route selection should continuously be executedconsidering delay into account throughout the packet forwarding process at the intersection. With the invalid assumption that the traffic density is static MDDV [25] combines geographical, opportunistic and trajectory-based forwarding. This mainly focuses on reliable routing. The Messages are forwarded opportunistically along the forwarding trajectory through intermediate nodes. VADD only considers how to find a path from a mobile vehicle to a coffee shops where the destination is static and proposes a delay model which is over simplified. However, when the vehicle density is low, the optimal path may not always be available at the moment. Thus, VADD has to deliver packets via detoured paths. In the worst case, the packet may go through a much longer path that's why VADD experiences dramatic performance degradation in packet delivery delay, and MDDV even renders poor reliability.

Mo et al. [24] proposed on demand multi-hop routing protocol for urban vehicular ad hoc networks (MURU) to address the most important challenges of VANETs like high mobility and frequent link disconnection. The proposed protocol uses a special parameter called expected disconnection degree (EDD) to minimize the probability of path breakage by exploiting mobility information of each vehicle. However, this assumption is unfit in highway scenarios when traffic decomposes into disconnected clusters.

In sparse scenarios, the best path is not always available at the moment a packet reaches an intersection, SADV [27] an Opportunistic Forwarding Protocol deployed a static node at each intersection in a completely mobile vehicular network to assist relay data. The static node can store the packet for a while until there are vehicles moving along the best path become available to forward the packet. Although it is quite expensive to install an infrastructure at each intersection but it reduces the overall data delivery delay. However, SADV can't handle changing node density.

Due to traffic light at intersection point vehicles decomposes into disconnected clusters. Taking this assumption into account, authors in [28] examined the network connectivity of message propagation in a two-dimensional grid without considering vehicle mobility. They derive connectivity probability for 2-d ladder (main-side streets) and formulate the problem for 2-d lattice (city blocks) where combinatorial explosion problem arises. Here inter vehicle distance is considered exponential random variable, while it should be truncated exponential random variable. This leads the cluster size distribution into an approximation. When the cluster size is not greater than the street segment then disconnection occurs in 1-d spaces (e.g., a street segment), they overcame this disconnection by propagating the message to other perpendicular streets instead of along the street where the vehicle is currently moving. Reflection, diffraction, and shadowing effect may arise in cities with high-rise buildings in perpendicular streets.

A few recent protocols such as TBD [29] and TSF [30] also tried to derive the cluster size in a 1-d road segment with unidirectional traffic. These protocols tried to improve data forwarding by combining the physical trajectory information of a packet carrier and traffic statistics in the network. In TBD and TSF vehicles did not fully share and utilize trajectory information available in the network due to privacy reasons. In other words, individual vehicle only knows its own trajectory and does not share with other vehicles, thus leading to longer delays if the traffic density varies by time. In sparsely connected network a vehicle may needs to carry the packet indefinitely along its trajectory. In worse case, the validity of the data packet may be expired in case of delay sensitive applications when the vehicle is in the middle of its trajectory.

CHAPTER-3

PROBLEM FORMULATION

3. Problem Formulation

In this section, we formulate the data forwarding in vehicular networks as follows: Given a road network topology graph (RNTG) without APs installed at every road intersection, our goal is to select a forwarding path from a moving source vehicle to a moving destination vehicle with the smallest End-to-End forwarding delay in bidirectional vehicular networks. Furthermore without re-broadcasting for the next data packet the previously selected path is dynamically reused (if possible) to maximize the lifetime of the communication.

3.1 Assumptions

Our work is based on the following assumptions:

1) Vehicles as OBUs (**O**n **B**oard **U**nits) communicate with each other through a wireless communication device (e.g. DSRC [31]).In recent years the extension of DSRC device can support data rate of 6 to 27 Mbps and transmission range can extend to almost 1,000 meters. Car manufacturers and device vendors such as GM [33] and Toyota [32] are providing network devices with double interfaces that support both (DSRC or 802.11p and Wi-Fi protocols (802.11a/b/g).
2) All vehicles are equipped with GPS-based navigation system, digital road maps [34, 35] and optional sensors. Location information of all vehicles/nodes can be identified with the help of GPS receivers and updated map information can be downloaded to car navigation systems. Nowadays, the price of a typical navigation device, which has a GPS receiver and Wi-Fi capability, is as cheap as 100 dollars therefore becoming affordable to many people. The only communications paths available are via the ad-hoc network

and there is no other communication infrastructure. Vehicle's power is not the limiting factor for the design.

3) Many commercial navigation service vendors such as Garmin Ltd [34], MapMechanics [36] and Yahoo Maps provide automatic/periodic updates of context based maps and traffic conditions such as vehicle density, vehicle arrival rate λ and average vehicle speed v per road segment. However, static information's such as co-ordinates of different intersection point I_{x_i,y_i}, road segment length l and the full road network topology graph (RNTG) $G = (V, E)$can be updated on a daily, weekly, or monthly basis.
4) Traffic density and speed of vehicles is affected by location and time. In rural areas traffic density is very low that's why it is beyond the scope of our paper. In case of large populated or urban areas during night hours very low density and high speed traffic ($v_{\max}$). On the other hand rush-hour traffic has low speed ($v_{\min}$) with high volume. For the sake of simplicity our delay model assumes that each vehicle has an independent speed taken uniformly from the interval $[v_{\min}, v_{\max}]$ and travels at this constant speedv_c independently from other vehicles.

GPS navigation devices only consider the inherent static characteristics of roads, such as length and speed limit, as the parameters in determining the shortest-distance path for users. Thus, traditional shortest path algorithms like dijkstra cannot meet people's dynamic demand. Now the question is: how can one find the shortest-time route at the real time? Geographical forwarding approaches such as greedy perimeter stateless routing GPSR) [16], which always chooses the next hop closer to the destination is unsuitable for sparsely connected VANETs. In VADD [26] they showed that in case of urban area, especially at peak hours, shortest time path is often different from shortest distance path because of varying traffic densities. TBD [29] comes to the conclusion that when the inter-arrival time of the vehicles decreases then the forwarding delay will eventually decrease.

Let's consider the packet forwarding scenarios described in fig. 1 where source S wants to communicate with destination denoted by D. There are two alternate paths from source intersection I_{11} such as $I_{11} \rightarrow I_{12} \rightarrow I_{22}$ or $I_{11} \rightarrow I_{21} \rightarrow I_{22}$ to reach at I_{22} which is the closest intersection to the destination D. Where two paths have the same distance from I_{11} to I_{22} , that means $l_{11,12} + l_{12,22} = l_{11,21} + l_{21,22}$. On the other hand, path A ($I_{11} \rightarrow I_{12} \rightarrow I_{22}$) has higher network density than path B ($I_{11} \rightarrow I_{21} \rightarrow I_{22}$).

We know that, $\text{Network density} = \frac{\text{number of vehicles}}{road\ segment\ length}$

$$\rho_{11,22}(I_{12}) = \frac{15}{(l_{11,12} + l_{12,22})}$$ For path A if we use I_{12} as an intermediate intersection

$$\rho_{11,22}(I_{21}) = \frac{8}{(l_{11,21} + l_{21,22})}$$ For path B if we use I_{21} as an intermediate intersection

$$\rho_{11,22}(I_{21}) = \frac{8}{(l_{11,12} + l_{12,22})}$$ as $l_{11,12} + l_{12,22} = l_{11,21} + l_{21,22}$.

Surely, we can see that $\rho_{11,22}(I_{12}) \gg \rho_{11,22}(I_{21})$ but the packet forwarding delay is less in path B. That means, $d_{11,21} + d_{21,22} < d_{11,12} + d_{12,22}$ since path A has the temporary network fragmentation problem .That's why packet carrier n_1 in path A needs to carry the packet further to overcome the link breakage .On the other hand; path B has well connectivity hence data packets can be forwarded by multi-hop wireless transmission manner. The carry delay is the dominating part of the total forwarding delay because carry delay is several times longer than the multi-hop communication delay. For example, a vehicle takes 90 seconds to travel along a road segment of 1mile with a speed of 40MPH; however, it takes only 10 milliseconds to forward a packet over the same road segment.

So the conclusion of TBD [29] doesn't fit in this scenario described in fig. 1. The forwarding delay depends on the inter-vehicle distance which is exponentially distributed with parameter λ and the vehicle's arrival at different time period is a Poisson distribution [37].The authors of [38,39] found that an exponential model is a good fit for highway vehicle traffic in terms of inter-vehicle distance and time distribution. These two distributions both combinedly define the connectivity of the forwarding path segments.

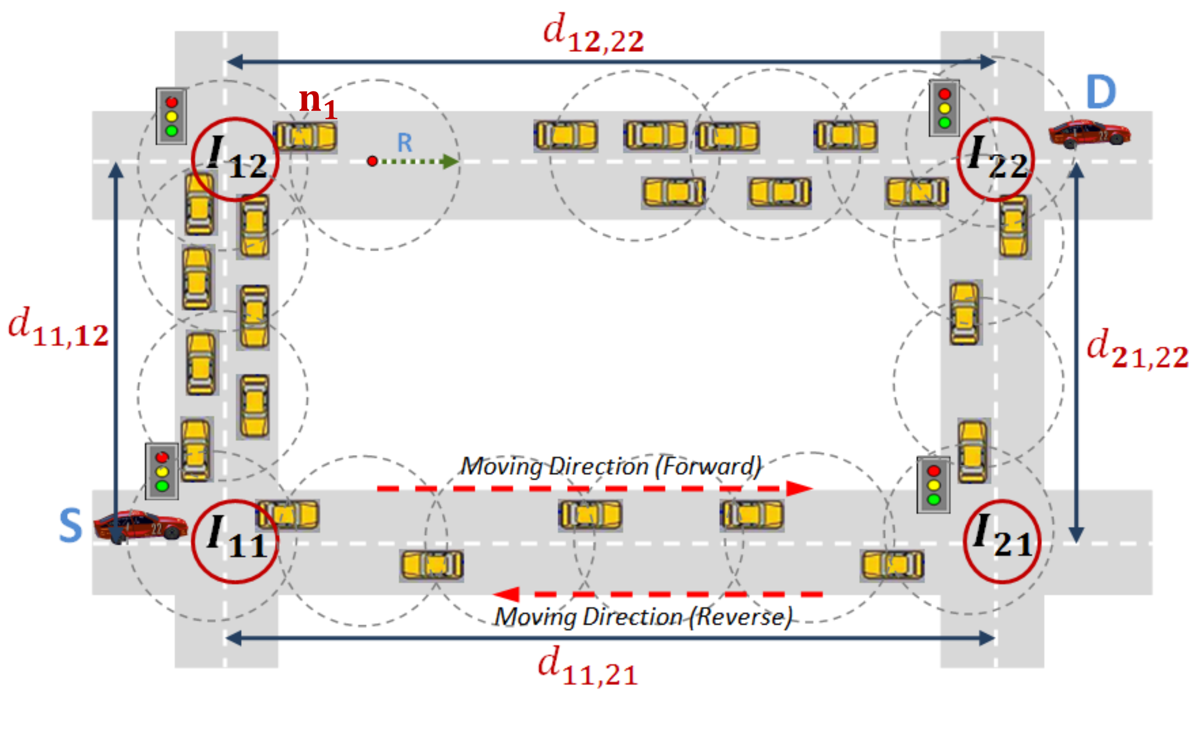


Fig. 1.Packet forwarding scenarios.

CHAPTER-4

EFD: LINK DELAY MODEL

4. EFD: Link Delay Model

In this section we analyze the link delay for one road segment with bidirectional vehicular traffic with the arrival rate λ, variable vehicle speed v , road segment length L and the communication range R in $2D$ road network topology graph (RNTG).

In this paper, we define

1. *Connected Component or Cluster* connected group of vehicles that can communicate with eachother via either one-hop or multi-hop communication
2. *Microscopic Expected Forwarding Delay (MEFD) as* the expected time taken by a packet carrier to forward a data packet through VANET to a moving destination vehicle.
3. *Disconnection length*(l_d)a part of total forwarding length l_f come into play when a packet carrier doesn't find any suitable next hop in its communication range R ,thus it carry the data packet with itself to overcome this disconnection.
4. *Connection Length*(l_c)a part of total forwarding length l_f comes into play when a data packet is forwarded by multi-hop communication among vehicles through connected component.

Most of the previous works only focus on the one way road segment but in this paper we are going to define a routing metric called MEFD (Microscopic Expected Forwarding Delay) using bidirectional road segment that especially for delay sensitive or time critical applications.

In TBD [29] one way road segment is used to calculate the forwarding delay .As shown in *fig.2* disconnection occurs in vehicle n_2, therefore vehicle n_2 needs to carry the data packet with itself in the whole road segment. As the carry delay is significantly larger than the multi-hop delay this will also make the forwarding delay larger. Thus, this will not suitable for the delay sensitive applications. To reduce the delay further, we have used cluster in the opposite direction as bridges to fill this gap between the clusters in the same direction as the packets to deliver to the next vehicle. The proposed scheme will have less delay than the TBD [29], as we can see in the *fig 3* that the disconnection length l_d has significantly reduced compare to in *fig. 2.* As the carry distance is the dominating part in the total forwarding delay here the carry delay is reduced in fig. 3 by using the opposite directional cluster.

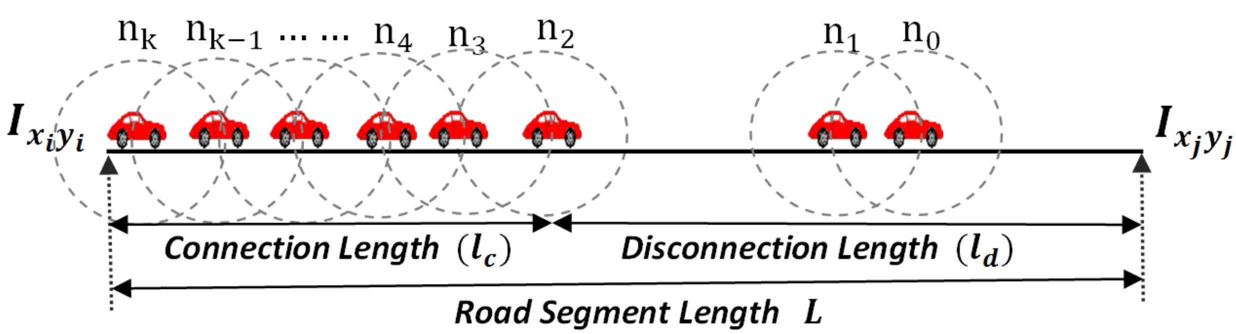


fig :2. One way road segment is used for calculating the forwarding distance

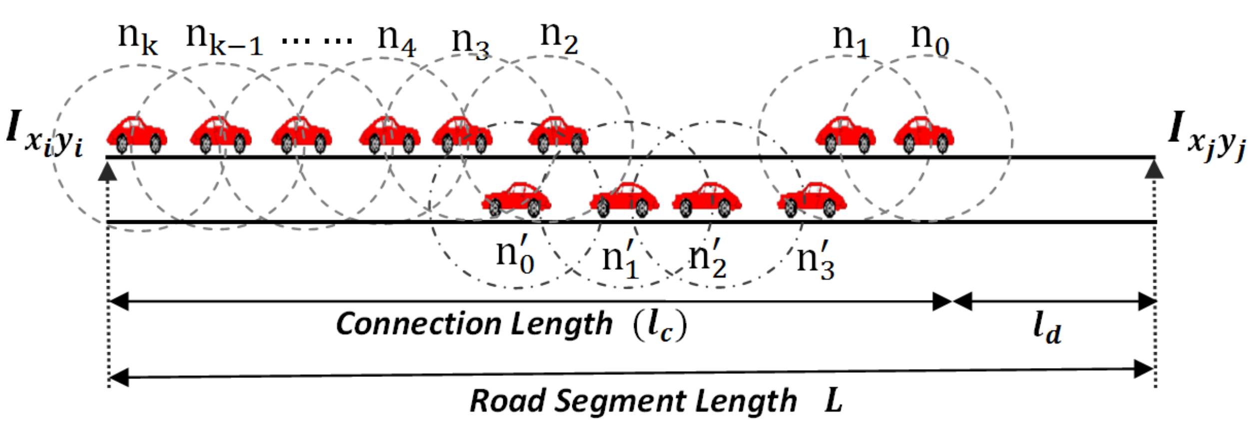


fig :3. Bidirectional road segment is used for calculating the forwarding distance

In realistic scenarios, there can be more than one disconnection in the path .So, in one way road segment, forwarding length will be the series of connection and disconnection length. In this paper we define a routing metric by analyzing these typical scenarios and propose a microscopic routing metric named MEFD (Microscopic Expected Forwarding Delay) which is suitable for delay sensitive applications.

We have used a probabilistic approach to derive the road segment delay as follows.

4.1 Expected forwarding Delay in a cluster

Expected forwarding delay in a cluster $E[D_c|C]$ is derived in 4 steps as follows.

Step 1: *Determining expected number of vehicle in a cluster*

A group of vehicles form a cluster if inter-vehicle distance between any two vehicles in that group does not exceed the transmission range as in *fig. 5.*

We can determine the probability that V number of vehicles are inside a cluster using geometric distribution as follows.

$$P_v(V) = \left(1 - P(X \leq R)\right). P(X \leq R)^{V-1}, V \geq 1$$

Here,

V = Number of vehicles inside a cluster

X = Inter-vehicle distance inside a cluster

R = Transmission range of a vehicle

Inter-vehicle distance X is truncated at right by R. According to (JMS4'08), $P(X \leq R)$Can be obtained as follows:

$$P(X \leq R) = \frac{\mu e^{-\mu r}}{1-e^{-\mu r}}$$

Where, $\mu = \lambda v$

Here,

μ= mean inter-vehicle distance

λ = arrival rate of vehicles

r= a constant transmission range of vehicle

$E[X]$can be obtained as follows: (JMS4'08)

$$E[X] = \frac{1}{\lambda} - R.\left(e^{\lambda r} - 1\right)^{-1}$$

Here, λ = arrival rate of vehicles

So, expected number of vehicle in a cluster is-

$$E[V] = \frac{1}{P(X \leq R)} = -\frac{1-e^{-\lambda r}}{\lambda e^{-\lambda r}}$$

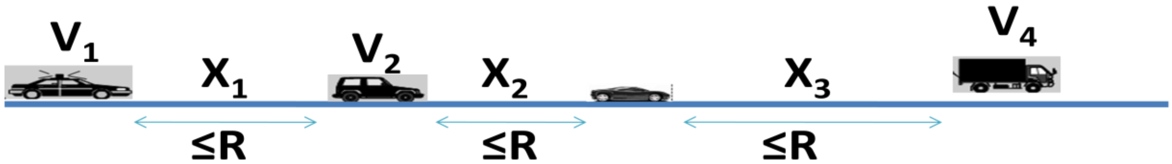


Fig. 5. Inter-vehicle distances in a cluster.

Step 2: *Determining expected length of the cluster* $E[L]$

Expected length of cluster $E[l_c]$ can be obtained-

Inter-vehicle distance X is independent and identically distributed random variable with truncated exponential distribution. Number of vehicle V is also a random variable.

We can use Wald's equation to determine $E[L]$

$$E[l_c] = E[\sum_{i=1}^{V-1} X_i] = E[V-1] \times E[X]$$

Step 3: *Determining Expected Hop count in a cluster* $E[H]$

We have to compute $E[H]$ for each cluster in a road segment, and then we will take the sum.

Minimum number of hop count in a cluster:

$$H_{min} = \frac{E[l_c]}{R}$$

Maximum number of hop count in a cluster:

$$H_{max} = \frac{E[l_c]}{E[X]}$$

H is uniformly distributed between H_{min} and H_{max}

Expected hop count, $E[H] = \frac{H_{max} + H_{min}}{2}$

Step 4: *Determining expected forwarding delay in a cluster* $E[D_c|C]$

Now we have computed expected hop count $E[H]$ and we know per hop delay D_h.

From this information, we can determine expected forwarding delay $E[D_c|C]$ in a cluster-

$$E[D_c|C] = E[H] \times D_h$$

4.2 Delay due to Carry and forward

There can be three cases due to a disconnection in the road segment.

Case 1: Best situation:

From Fig. 5(a). There is a disconnection between cluster d and g, but there is an opposite cluster f within the range of both d and g which can multihop the data from d to g.The probability of this situation is-

$$P_1 = \Pr\{X_{d,f} \le R\} \Pr\{X_{f,g} \le R\}$$
$$Y_1 = 0$$
$$f_{Y_1}(y) = \begin{cases} 1, & y = 0 \\ 0, & otherwise \end{cases}$$

Case 2: Average situation:

From Fig. 5(b). There are disconnections between d and g and d and f, but f is connected with g. eventually f will be connected with d, but there is a restriction- f still has to be connected with g to multihop the data from d to g.The probability of this situation is-

$$P_2 = \Pr\{X_{d,f} > R\} \Pr\{X_{f,g} \le R\}$$
$$a = R - X_{f,g}$$
$$Y_2 = a$$
$$f_{Y_2}(x) = \frac{\lambda e^{-\lambda x}}{1 - e^{\lambda(R+2a)}}$$
$$for\; x < R + 2a$$

Case 3: Worst situation:

From Fig. 5(c). There are disconnections between d and g and d and f and g. There is no way that d can transmit the data to g. The probability of this situation is-

$$P_3 = \Pr\{X_{d,f} \leq R\} \Pr\{X_{f,g} > R\}$$

In this case, cluster d will store the data in the buffer- so that it can carry and forward when cluster f fails to forward it to cluster g.

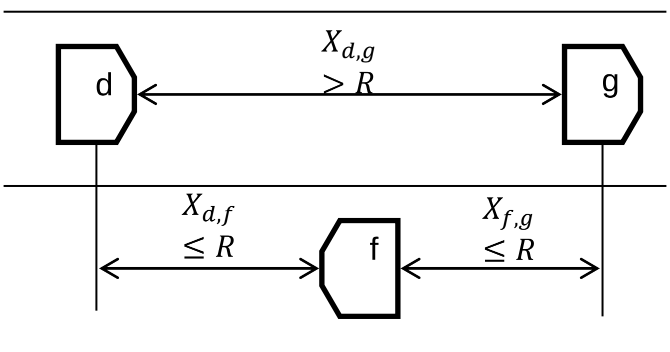


Fig. 5(a).

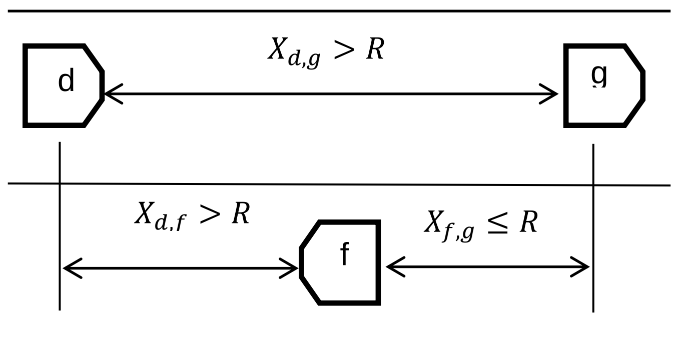


Fig. 5(b).

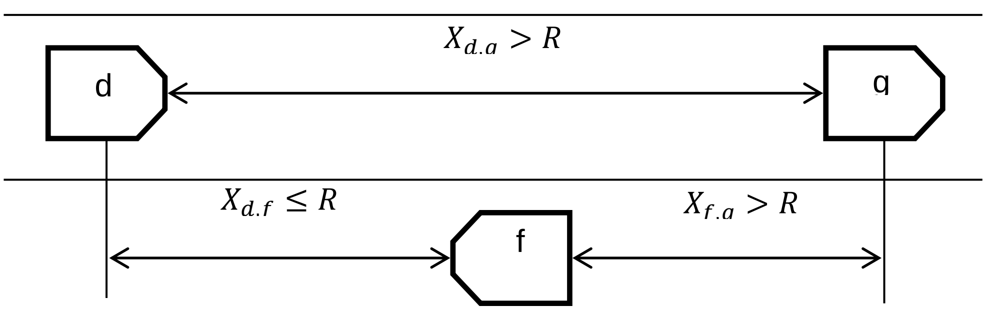


Fig. 5(c).

Based on above 3 cases, the density function of the disconnection distance is

$$f_Y(y) = \sum_{i=1}^{3} P_i \times f_{Y_i}(y)$$

4.3 One road segment delay:

Now we have determined both connected delayD_c and disconnection delayD_d. We can use the following recursive equation to determine total one road segment delay.

$$E[D] = E[D|l_r > R] \times \Pr\{l_r > R\}$$

Here, $D = D_c + D_d$

l_r= remaining road length

CHAPTER-5

EFD: E2E DELAY MODEL

5.EFD: E2E Delay Model

In this section we model the E2E delay with the use of dynamic programming. E2E delay is the summation of the per-hop delay along the path. We mainly map the famous dynamic programming problem LCS (Longest Common Subsequence) to construct our E2E delay model. We define the road network topology graph for the E2E delay computation as follows:

Definition (road network topology graph (RNTG)). Let Road network topology graph (RNTG) be the directed graph of $G = (V, E)$, where $V = \{v_1, v_2, \ldots., v_n\}$ is a set of intersections in the network topology graph and $E = [e_{ij}]$ is a matrix of edge e_{ij} for vertices v_i and v_j where v_i and v_j are adjacent to each other such that $e_{ij} \neq e_{ji}$. Fig.6. Shows a road network topology graph.

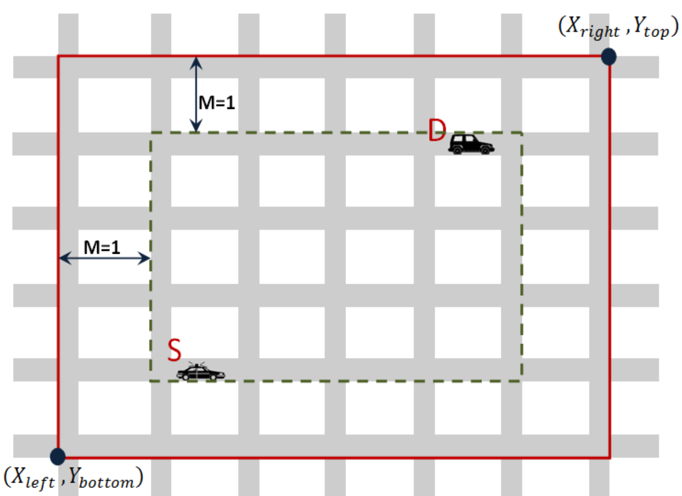


Fig. 6. Road network topology graph (RNTG)

5.1 Setting the Restricted Forwarding Area

Our job is to find the minimum microscopic expected forwarding delay between two arbitrary intersections. Unfortunately, it is impossible to find since it involves unlimited unknown intersections. However, by placing an area, including the source and the destination in a road network topology graph, we can surely able to find it. This will reduce the control message overhead because only the road segments within the area are used as available paths to compute the delay and only nodes within the road segments may be a possible intermediate node on the path. Restricted forwarding area is like a rectangle and can easily be calculated according to the location of the current sender, denoted by S, and the destination, denoted by D in fig. 6. We limit the forwarding range as follows:

$$ForwardingArea.X_{left} = \lceil \min(S.X, D.X) \rceil - M$$

$$ForwardingArea.X_{right} = \lceil \max(S.X, D.X) \rceil + M$$

$$ForwardingArea.Y_{bottom} = \lfloor \min(S.Y, D.Y) \rfloor - M$$

$$ForwardingArea.Y_{top} = \lceil \max(S.Y, D.Y) \rceil + M$$

Where M is the system parameter that can be tuned dynamically based on the traffic statistics. It is usually equal to the length of street segment. Floor (⌊⌋) and ceiling (⌈⌉) is used to find the closest intersection point $I_{x_i y_i}$ for source as well as destination.

5.2 Expected Forwarding Delay (EFD) at Intersection

In this section, we explain how to compute the EFD at an intersection, using dynamic programming. Suppose that a packet carrier at intersection $I_{x_i y_i}$ expected to deliver towards intersection $I_{x_j y_j}$. At first we introduce the following notations:

1) $d_{x_i y_i, x_j y_j}$: The expected forwarding delay for edge $e_{x_i y_i, x_j y_j}$ when a packet carrier at intersection $I_{x_i y_i}$ chooses to deliver data packet towards $I_{x_j y_j}$ as the next intersection.
2) $P(x_i y_i, x_j y_j)$: Probability that the packet is forwarded through edge $e_{x_i y_i, x_j y_j}$ at intersection $I_{x_i y_i}$.
3) $D_{I_{x_i y_i}}(I_{x_n y_n})$: Denote the cost of least-delay path from current intersection $I_{x_i y_i}$ to $I_{x_n y_n}$, where $I_{x_n y_n}$ is the final intersection before the destination.

Thus, we formulate $D_{I_{x_i y_i}}(I_{x_n y_n})$ recursively as follows:

$$D_{I_{x_i y_i}}(I_{x_n y_n}) = \min\left\{d^{(c)}_{x_i y_i, x_j y_j} P(x_j y_j) + D_{I_{x_j y_j}}(I_{x_n y_n})\right\}$$

5.2.1 Calculating $\boldsymbol{d^{(c)}_{x_i y_i, x_j y_j}}$

Previous calculation of $d^{(c)}_{x_i y_i, x_j y_j}$ is only for one-dimensional spaces (e.g., a street segment).There might be series of $d^{(c)}_{x_i y_i, x_j y_j}$ for determining the E2E(End to End) delay and this must be calculated at every intersection from source intersection($I_{x_i y_i}$) to destination intersection($I_{x_n y_n}$) with updated map information. Although the traffic statistics is changing over time but during this time a message can be propagated 3 or more intersection away depending on the vehicle density from where the current delay calculation has been done. To reduce this computational complexity (computing delay at every intersection) and number of sub-paths through to the destination we have considered two-dimensional spaces (e.g. city blocks) into our delay calculation.Now we define the block as follows:

Definition 4 (City Block) Let City Block be the smallest element in the road network topology graph (RNTG) grid layout which consists of exactly 4 intersection point such as $I_{x_i\, y_i}$,$I_{x_{i+1}\, y_i}$,$I_{x_{i+1}\, y_{i+1}}$$I_{x_i\, y_{i+1}}$ such that each intersection point is adjacent to one another and forms a rectangle(in fig.7. *case: 1*).

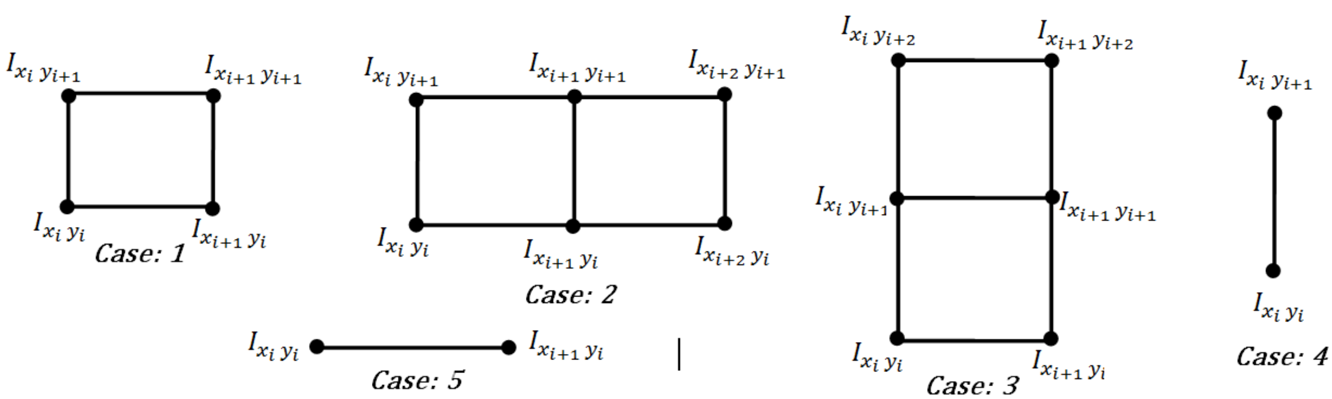


Fig. 7.Data forwarding cases

In calculating $d^{(c)}_{x_i y_i, x_j y_j}$,when a packet carrier at intersection $I_{x_i\, y_i}$ chooses to deliver data packet towards $I_{x_j\, y_j}$, we have considered five cases where c determines case number.

$$if\ |x_i - x_j| = 1 \bigcap |y_i - y_j| = 1\ \ then\ c = 1$$

$$if\ |x_i - x_j| = 2 \bigcap |y_i - y_j| = 1\ \ then\ \ c = 2$$

$$if\ |x_i - x_j| = 1 \bigcap |y_i - y_j| = 2\ then\ \ c = 3$$

$$if\ |x_i - x_j| = 0 \bigcap |y_i - y_j| = 1\ then\ \ c = 4$$

$$if\ |x_i - x_j| = 1 \bigcap |y_i - y_j| = 0\ then\ \ c = 5$$

In case: 2 we have extended one block horizontally and in case: 3 one block vertically this will reduce the number of sub-paths in total route and eventually increase the number of alternate paths in each block. When disconnection occurs in one path we can use other alternate paths in case of c=1,2,3.If we increase the number of blocks more we can find more close-to-optimal paths but with more computation and control message overhead. However, when the number of block is larger, then combinatorial explosion problem may arise in this approach. Thus, there is a tradeoff between computational complexity and accuracy in delay estimation when extending the block. In the worst case scenario when no such block is found then by default case 4 and case 5 is used to calculate the delay.

Therefore, in case: 1, where $I_{x_{i+1}\,y_{i+1}}$ is the immediate destination then $I_{x_j\,y_j} = I_{x_{i+1}\,y_{i+1}}$ .There are two different alternate paths such as $I_{x_i\,y_i} \rightarrow I_{x_{i+1}\,y_i} \rightarrow I_{x_{i+1}\,y_{i+1}}$ or $I_{x_i\,y_i} \rightarrow I_{x_i\,y_{i+1}} \rightarrow I_{x_{i+1}\,y_{i+1}}$ when value of c=1 for case: 1

$$d^{(c)}_{x_i y_i, x_j y_j} = d^{(1)}_{x_i y_i, x_{i+1} y_{i+1}}$$

$$= min\left(d_{x_i y_i, x_i y_{i+1}} + d_{x_i y_{i+1}, x_{i+1} y_{i+1}}, d_{x_i y_i, x_{i+1} y_i} + d_{x_{i+1} y_i, x_{i+1} y_{i+1}}\right)$$

is calculated to choose one sub-path with the minimum expected data packet forwarding delay between $I_{x_i y_i}$ and $I_{x_{i+1} y_{i+1}}$ from the two different alternate paths.

Therefore, in case: 2, where $I_{x_{i+2} y_{i+1}}$ is the immediate destination then $I_{x_j y_j} = I_{x_{i+2} y_{i+1}}$ .There are three different alternate paths such as $I_{x_i y_i} \rightarrow I_{x_{i+1} y_i} \rightarrow I_{x_{i+2} y_i} \rightarrow I_{x_{i+2} y_{i+1}}$ or

$I_{x_i y_i} \rightarrow I_{x_i y_{i+1}} \rightarrow I_{x_{i+1} y_{i+1}} \rightarrow I_{x_{i+2} y_{i+1}}$ or

$I_{x_i y_i} \rightarrow I_{x_{i+1} y_i} \rightarrow I_{x_{i+1} y_{i+1}} \rightarrow I_{x_{i+2} y_{i+1}}$ when value of c=2 for case: 2

is calculated to choose one sub-path with the minimum expected data packet forwarding delay between $I_{x_i y_i}$ and $I_{x_{i+2} y_{i+1}}$ from the three different alternate paths.

$$d^{(c)}_{x_i y_i, x_j y_j} = d^{(2)}_{x_i y_i, x_{i+2} y_{i+1}} = min\begin{pmatrix} d_{x_i y_i, x_i y_{i+1}} + d_{x_i y_{i+1}, x_{i+1} y_{i+1}} + d_{x_{i+1} y_{i+1}, x_{i+2} y_{i+1}}, \\ d_{x_i y_i, x_{i+1} y_i} + d_{x_{i+1} y_i, x_{i+1} y_{i+1}} + d_{x_{i+1} y_{i+1}, x_{i+2} y_{i+1}}, \\ d_{x_i y_i, x_{i+1} y_i} + d_{x_{i+1} y_i, x_{i+2} y_i} + d_{x_{i+2} y_i, x_{i+2} y_{i+1}} \end{pmatrix}$$

Therefore, in case: 3, where $I_{x_{i+1} y_{i+2}}$ is the immediate destination then $I_{x_j y_j} = I_{x_{i+1} y_{i+2}}$ .There are three different alternate paths such as $I_{x_i y_i} \rightarrow I_{x_{i+1} y_i} \rightarrow I_{x_{i+1} y_{i+1}} \rightarrow I_{x_{i+1} y_{i+2}}$

$$I_{x_i y_i} \rightarrow I_{x_i y_{i+1}} \rightarrow I_{x_i y_{i+2}} \rightarrow I_{x_{i+1} y_{i+2}}$$

$$I_{x_i y_i} \rightarrow I_{x_i y_{i+1}} \rightarrow I_{x_{i+1} y_{i+1}} \rightarrow I_{x_{i+1} y_{i+2}}$$

$$d^{(c)}_{x_i y_i, x_j y_j} = d^{(3)}_{x_i y_i, x_{i+1} y_{i+2}} = min\begin{pmatrix} d_{x_i y_i, x_i y_{i+1}} + d_{x_i y_{i+1}, x_i y_{i+2}} + d_{x_i y_{i+2}, x_{i+1} y_{i+2}}, \\ d_{x_i y_i, x_{i+1} y_i} + d_{x_{i+1} y_i, x_{i+1} y_{i+1}} + d_{x_{i+1} y_{i+1}, x_{i+1} y_{i+2}}, \\ d_{x_i y_i, x_i y_{i+1}} + d_{x_i y_{i+1}, x_{i+1} y_{i+1}} + d_{x_{i+1} y_{i+1}, x_{i+1} y_{i+2}} \end{pmatrix}$$

When value of c=3 for case: 3 is calculated to choose one sub-path with the minimum expected data packet forwarding delay between $I_{x_i\,y_i}$ and $I_{x_{i+1}\,y_{i+2}}$ from the three different alternate paths

5.2.2 Calculating $P(x_j y_j)$

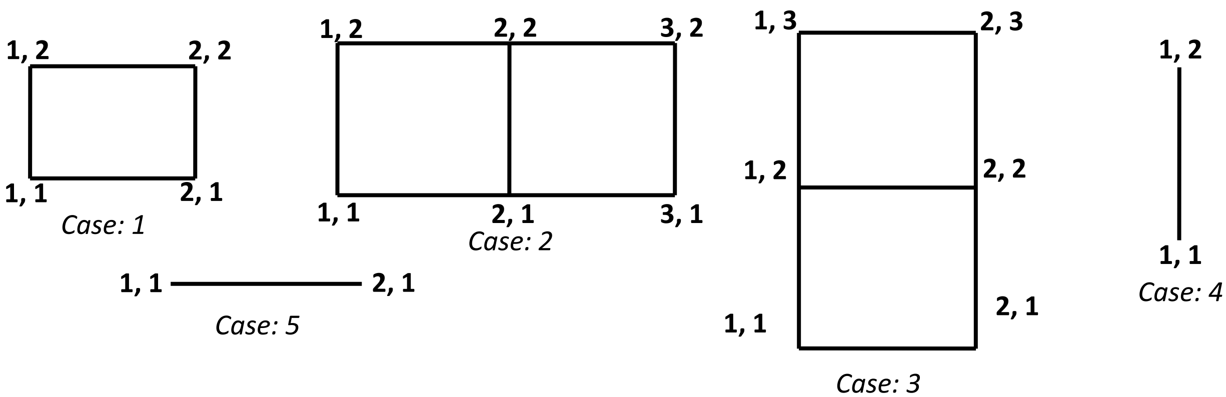


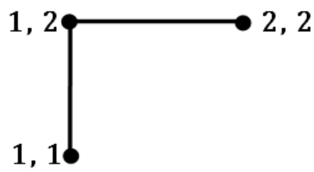
Fig. 8. Forwarding Probability cases

Case 1: where (2, 2) is the destination, there are two alternate paths to reach from (1, 1) to (2, 2).

Path A: (1, 1)→ (1, 2)→ (2, 2)

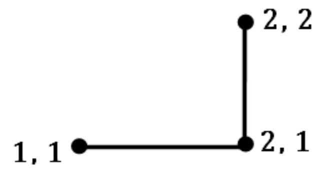
Path B: (1, 1)→ (2, 1)→ (2, 2)

Path A where (1, 1) and (2, 2) are connected by the intermediate node (1, 2), and path B where the intermediate node is (2, 1). For the simplicity of the calculation let assume that each edge or street segment is connected with equal probability P, we have the connectivity probability for (2, 2). Path A and Path B both are independent to each other as both paths have no overlapping street segments.



Path A

Path B



B|A

$$P(2,2) = P(A \cap B) = P(B|A)P(A)$$

$$= P(B)P(A)$$

$$= P^2 * P^2 = P^4$$

Case 2: where(3, 2) is the destination, there are three alternate paths to reach from (1, 1) to (3, 2).

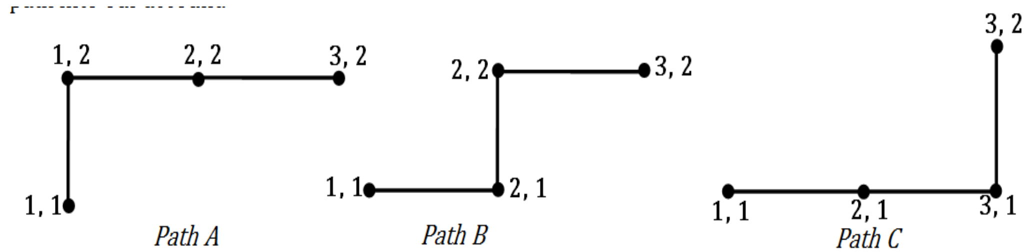
Path A: (1, 1)→ (1, 2)→ (2, 2) →(3, 2)

Path B: (1, 1)→ (2, 1)→ (3, 1) →(3, 2)

Path C: (1, 1)→ (2, 1)→ (2, 2) →(3, 2)

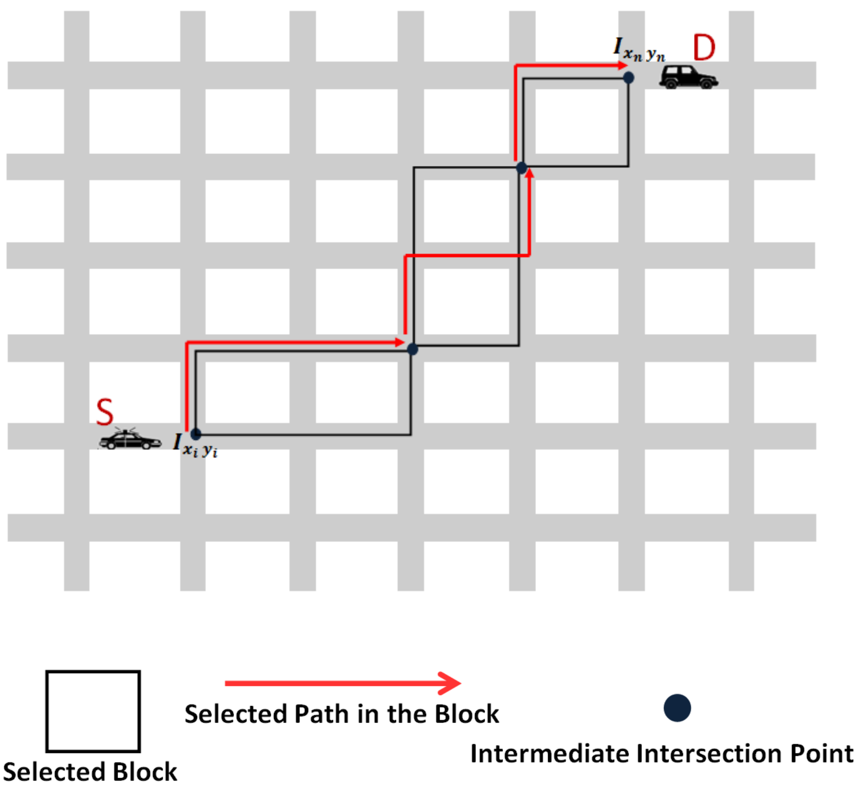
There is also one extra path possible e.g. (1, 1)→ (1, 2)→ (2, 2)→ (2, 1)→ (3, 1) →(3, 2) but this will significantly increase the number of path segments and therefore leads to more delay. Moreover a packet should not be forwarded to the edge that is worse than the edge the carrier moves toward, as (2, 2) is more geographically closer to (3, 2) than (2, 1). So we will not take this path into our account.

Here all paths are dependent on each other. So $P(C|(A \cap B))$ can be found by seeing how many path segments are in path C which is not overlap compares to both path A and B. In path C there are 2 such path segments are non-overlapping.



$$P(3,2) = P(A \cap B \cap C) = P(C|(A \cap B))P(B|A)P(A)$$

$$= P^2 * P^2 * P^3 = P^7$$

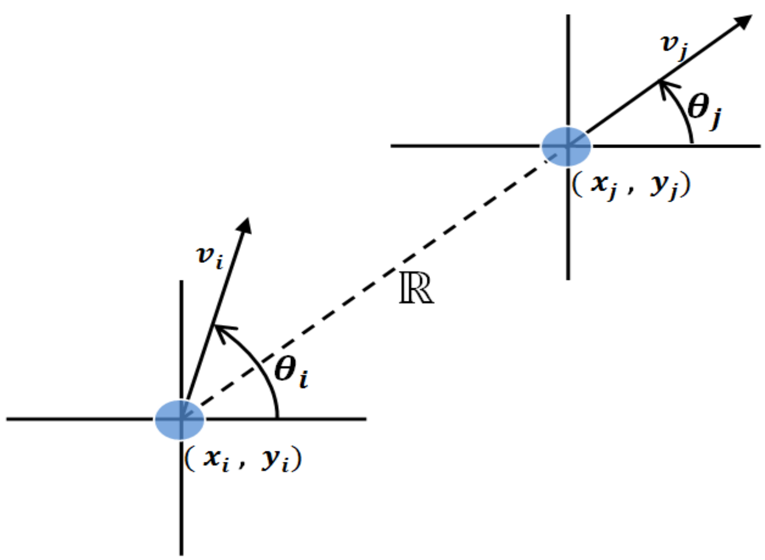


CHAPTER-6

FLEXIBLE PATH RECONSTRUCTION

6. Flexible Path Reconstruction

Unlike MANETs, the mobility of vehicles in VANET is constrained by the roads. Although the topology changes dramatically in VANET but still a path can be alive during certain duration of time due to roadmap geometry. This has significantly encouraged us to reuse the previous path without further re- broadcasting.This also reduces broadcasting load in the network and thus noticeably improves the delay for critical delay sensitive applications. Moreover, transport layer protocol like TCP relies on acknowledgement of the sent data packet within certain duration of time .However, previous data packet forwarding path also can be used for the ack packet for vehicular internet access.



To identify path duration time first we need to know the individual link duration time along the path. Link duration time means the maximum time of connectivity between two neighboring vehicles. We assume that two nodes i and j within the transmission range $\mathbb{R}$ of each other. Let (x_i, y_i) and (x_j, y_j) be the coordinate for node or vehicle i and j with velocity v_i and v_j and direction θ_i and θ_j (0 <θ_1 and θ_2<2π) respectively in fig.. Minimum connectivity duration time of series of valid intermediate pair of nodes in the sub-path constitutes the individual link duration time (LDT) for the sub-path.

$$LDT\left[C_{I_{x_i y_i}}, C_{I_{x_j y_j}}\right] = \min(LDT[i,j], LDT[j,k], \dots \dots .., LDT[(n-1), n])$$

$LDT\left[C_{I_{x_i y_i}}, C_{I_{x_j y_j}}\right]$is the link duration time of the sub-path starting from $I_{x_i y_i}$ to $I_{x_j y_j}$from the total path.$C_{I_{x_j y_j}}$, the valid packet carrier at $I_{x_i y_i}$ is i and packet carrier at $I_{x_j y_j}$is.

$LDT[i,j]$means the link duration time between two neighboring vehicles i and j . We can predict the link duration time (LDT) from [40] is derived in equation.

$$LDT[i,j] = -(ab+cd) + \frac{\sqrt{(a^2+c^2)r^2 - (ad-bc)^2}}{a^2+c^2}$$

Where, $a = v_i cos\theta_i - v_j cos\theta_j$

$$b = x_i - x_j$$

$$c = v_i sin\theta_i - v_j sin\theta_j$$

$$d = y_i - y_j$$

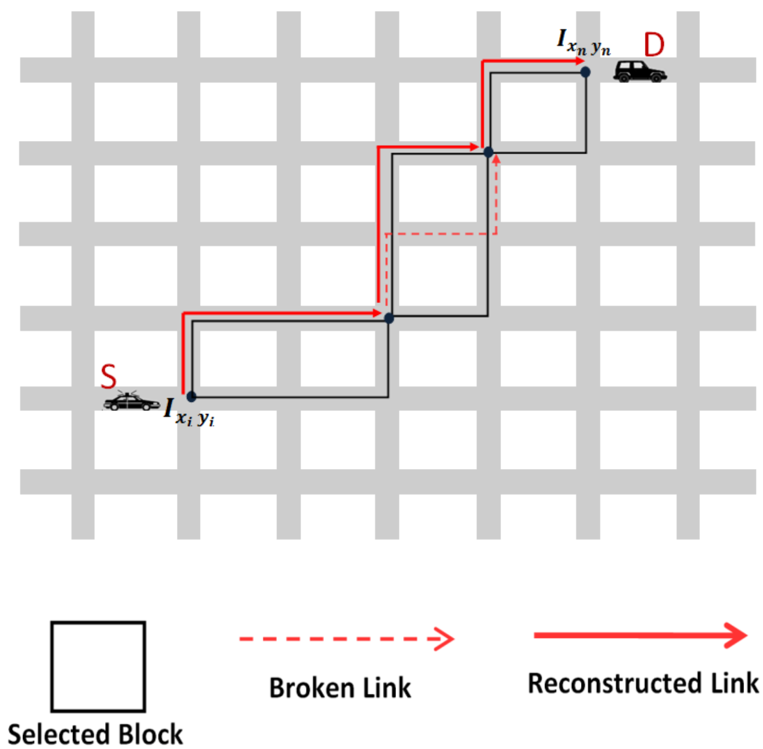
Note that when v_i = v_j and θ_i= θ_j, LDT becomes ∞. Most of previous research works considered vehicle speed v is constant for all the vehicles and vehicles in the same direction are used as the next hop packet carrier but here in this paper, we have worked with variable packet velocities in respect to each other in bidirectional road traffic.

Now the total path duration time (PDT) is the minimum duration time of sub-can be calculated as

$$PDT[s,d]$$
$$= min(LDT\left[s, C_{I_{x_i y_i}}\right], LDT\left[C_{I_{x_i y_i}}, C_{I_{x_j y_j}}\right], \dots, LDT\left[C_{I_{x_{(n-1)} y_{(n-1)}}}, C_{I_{x_n y_n}}\right], LDT\left[C_{I_{x_n y_n}}, d\right])$$

Where, $PDT[s,d]$ is the total path duration time from source s to destination d.

In fig we can see that



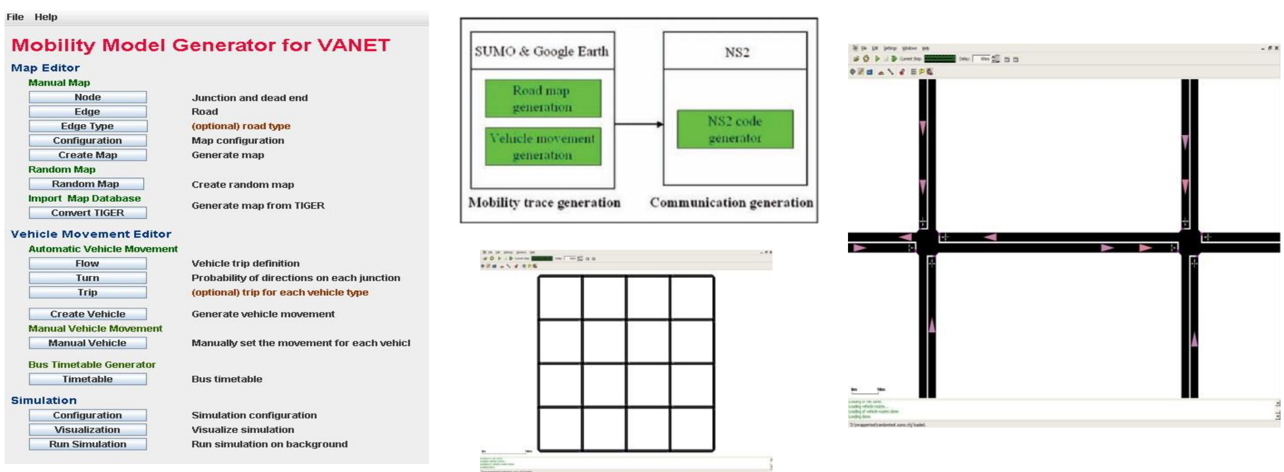
CHAPTER-7

PERFORMANCE EVALUATION

7. Performance Evaluation

In this section, we evaluate the performance of EFD by comparing it with a state-of-the-art scheme, TBD while for the fairness; our link delay model is EFD.

- ☐ We use a tool MOVE (MObility model generator for VEhicular networks) to generate realistic mobility models for VANET simulations.
- ☐ MOVE is built on top of an open source micro-traffic simulator SUMO (S. S. of Urban Mobility, 2009).
- ☐ The output of MOVE is a mobility trace file that contains information of realistic vehicle movements which can be used by ns-2.



The evaluation is based on the following:

Performance Metric: Expected Forwarding Delay (EFD)
Parameters: In the performance evaluation, we investigate the impacts of

(i) Vehicle arrival rate
(ii) Vehicle speed
(iii) Vehicle density

Note that the link delay model and E2E delay models in both TBD and VADD are based on constant vehicle speed(s) given to road networks. These two E2E delay models are used to make a forwarding decision-making metric called EDD.We have used the varying traffic velocities not the constant; this has a dramatic change in the performance of the E2E delay. We investigate the effectiveness of these two forwarding schemes in terms of performance metrics.

Each vehicle’s movement pattern is determined by a Hybrid Mobility model of City Section Mobility model and Manhattan Mobility model. From the characteristics of City Section Mobility, the vehicles are randomly placed at one intersection as start position among the intersections on the road network and randomly select another intersection as end position. The vehicles move according to the roadways from their start position to their end position. Also, the vehicles wait for a random waiting time (e.g., uniformly distributed from 0 to 10 seconds) at intersections in order to allow the impact of stop sign or traffic signal.

- **Simulation Environments**
  - Simulation area(1000 meter X 1000 meter)
  - Number of intersections: 20
  - Number of vehicles: 20-200
  - Communication range: 250 meters
  - Vehicle speed distribution (V_{max}, V_{min}): (30,5) MPH
  - Time-To-Live (TTL): 40 sec

7.1 Forwarding Behavior Comparison

We compare the forwarding behaviors of EFD and TBD with the cumulative distribution function (CDF) of the actual packet forwarding delays. From Fig. 7.1 , it is very clear that EFD has smaller packet forwarding delay than TBD. For any given packet deliver delay, EFD always has a larger CDF value than TBD before they both reach 100 percent CDF. For example, EFD reaches 90 percent CDF with a delivery delay of about 1,500 seconds while the value for TBD is about 1,800 seconds. In other words, on average, the packet forwarding delay for EFD is smaller than that for TBD.

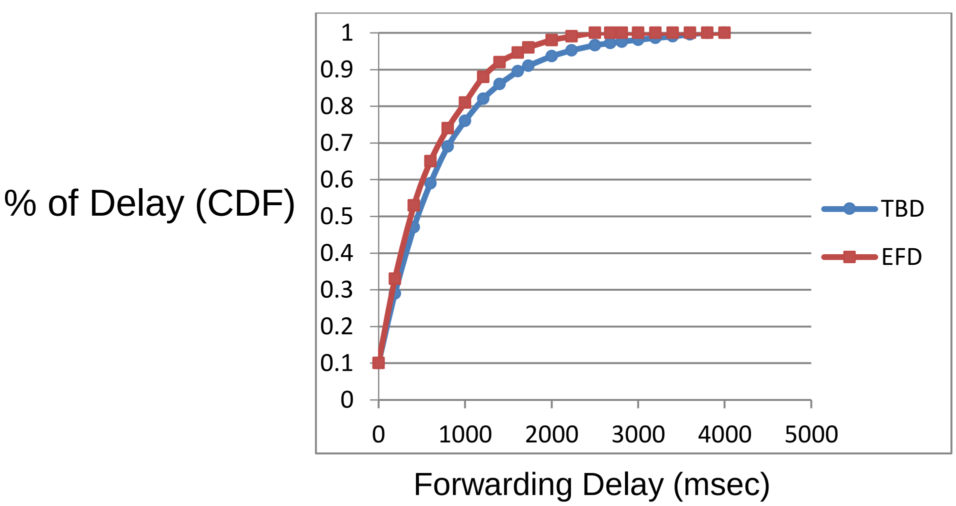


Fig. 7.1 Forwarding Delay vs. % of Delay (CDF)

Fig. 7.2 shows the forwarding ratio comparison between EFD and TBD with varying the number of vehicles in the road network. As expected, the larger number of vehicles yields the higher average forwarding ratio .The forwarding ratio for EFD is increasing roughly linearly with respect to the number of vehicles. On the other hand, in TBD, the increase of the number of vehicles under the light-traffic does not contribute much to the increase of delivery ratio. Clearly, we can see even at light-traffic condition, EFD has better forwarding ratio than TBD. Especially, at N=40, the forwarding ratio for EFD is 7.8 percent higher than that for TBD. This has been well suited for delay sensitive urban vehicular networks.

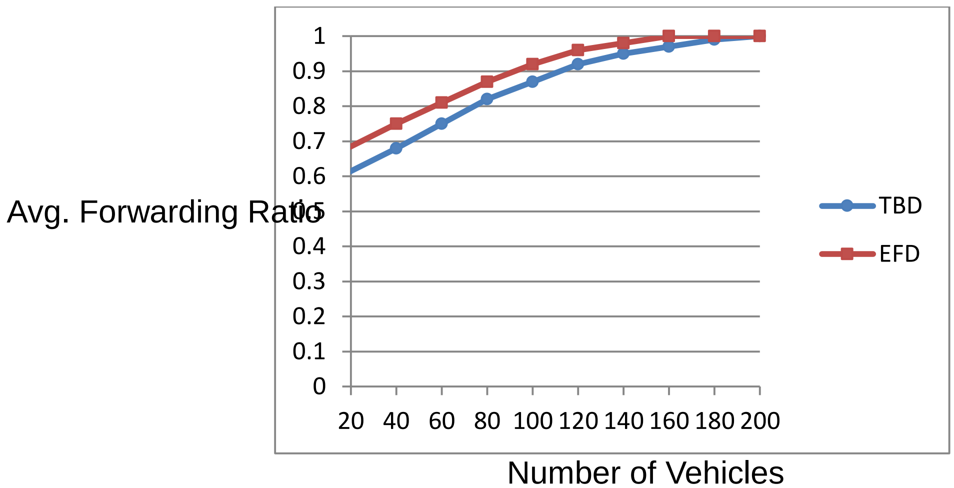


Fig. 7.2Number of Vehicles vs. Avg. Forwarding Ratio

Through the performance evaluation, we can conclude that EFD can provide better data forwarding than TBD in light-traffic vehicular networks at a variety of settings in terms of the vehicular traffic density, vehicle speed distribution for delay sensitive urban vehicular networks.

References

[1] J. Blum, A. Eskandarian, and L. Hoffman, "Challenges of inter-vehicle ad hoc networks," IEEE Trans on Intelligent Transportation Syst, 5(4):347–351, 2004.

[2] "Dedicated Short Range Communications (DSRC)Home,"

[Online].http://www.leearmstrong.com/DSRC/DSRCHomeset.htm

[3] M. Heddebaut, J. Rioult, J. P. Ghys, C. Gransart, and S. Ambellouis, "Broadband vehicle-to-vehicle communication using an extended autonomous cruise control sensor," Meas. Sci. Technol., vol. 16, no. 6,pp. 1363–1373, Jun. 2005.

[4] M. Shulman and R. Deering, "Third annual report of the crash avoidance metrics partnership April 2003–March 2004," Nat. Highw.Traffic Safety Admin. (NHTSA), Washington, DC, Jan. 2005. DOT HS 809 837.

[5] L. Andreone and C. Ricerche, "Activities and applications of the vehicle to vehicle and vehicle to infrastructure communication to enhance road safety," in Proc. 5th Eur. Congr.Exhib. ITS, Hannover, Germany,Jun. 2005.

[6] R. Kruger, H. Fuler, M. Torrent-Moreno, M. Transier, H. Hartenstein, and W. Effelsberg, "Statistical analysis of the FleetNet highway movement patterns," University of Mannheim, Mannheim, Germany, Tech. Rep. TR-2005-004, Jul. 2005.

[7] Jupiter Research, "Municipal Wireless: Partner to Spread Risks and Costs While Maximizing Benefit Opportunities," Tech. Rep., Jun. 2005.

[8] Car2Car Communication Consortium, http://www.car-2-car.org/ 2011.

[9] C.E. Perkins, E.M. Royer, Ad hoc on-demand distance vector routing, in: Proceedings of the 2nd IEEE Workshop on Mobile Computing Systems and Applications, February 2005, pp. 90–100.

[10] D.B. Johnson, D.A. Maltz, Dynamic source routing in ad hoc wireless networks, in: Imielinski, Korth (Eds.), Mobile Computing, vol. 353, Kluwer Academic Publishers, 1996.

[11] P. Jacquet, P. Muhlethaler, T. Clausen, A. Laouiti, A. Qayyum, L.Viennot, Optimized link state routing protocol for ad hoc networks, in: Multi Topic Conference, IEEE INMIC 2001. Technology for the 21st Century, Proceedings IEEE International, 2001, pp. 62–68.

[12] R. Flury, R.Wattenhofer, MLS: an efficient location service for mobile ad hoc networks, in: MobiHoc '06: Proceedings of the 7th ACM International Symposium on Mobile Ad Hoc Networking and Computing, New York, NY, USA, 2006, pp. 226–237.

[13] J. Li, J. Jannotti, D.S.J.D. Couto, D.R. Karger, R. Morris, A scalable location service for geographic ad hoc routing, in: MobiCom '00: Proceedings of the 6th Annual International Conference on Mobile Computing and Networking, New York, NY, USA, 2000, pp. 120–130.

[14] Y. Yu, G.-H.Lu, Z.-L. Zhang, Enhancing location service scalability with high-grade, in: 2004 IEEE International Conference on Mobile Ad-hoc and Sensor Systems, 25–27 October 2004, pp. 164–173

[15]. P. Bose, P. Morin, I. Stojmenovic, and J. Urrutia, “Routing with guaranteed delivery in ad hoc wireless networks,” in Proc. of 3rd ACM Intl. Workshop on Discrete Algorithms and Methods for Mobile Computing and Communications DIAL M99, 1999, pp. 48–55.

[16]. Brad Karp and H. T. Kung, “GPSR: Greedy perimeter stateless routing for wireless networks,” in Proceedings of the 6th Annual ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom 2000), Boston, MA, U.S.A., August 2000, pp. 243–254.

[17]. Stefano Basagni, ImrichChlamtac, Violet R. Syrotiuk, and Barry A.Woodward, “A distance routing effect algorithm for mobility (dream),” in ACM MOBICOM ’98. ACM, 1998, pp. 76 – 84.

[18]. LjubicaBlazevic , Silvia Giordano , and Jean- Yves Le Boudec , “Self-organizing wide-area routing,” in Proceedings of SCI 2000/ISAS 2000,Orlando, July 2000.

[19]. Naumov, V., Baumann, R., & Gross, T. (2006). An evaluation of inter-vehicle ad hoc networks based on realistic vehicular traces. In ACM international symposium on mobile ad hoc networking and computing (MOBIHOC 2006) (pp. 108–119), Florence, Italy, May 2006.

[20] Lochert, C., Mauve, M., Fusler, H., & Hartenstein, H. (2005). Geographic routing in city scenarios. ACM SIGMOBILE Mobile Computing and Communications Review, 9(1), 69–72.

[21]. C. Lochert, H. Hartenstein, J. Tian, D. Herrmann, H. Fubler, M. Mauve: “A Routing Strategy for Vehicular Ad Hoc Networks in City Environments”, IEEE Intelligent Vehicles Symposium (IV2003).

[22] Lee, K. C., Haerri, J., Lee, U., &Gerla, M. (2006). Enhanced perimeter routing geographic forwarding protocols in urban vehicular scenarios. In IEEE global communications conference(GLOBECOM 2007) (pp. 1–10), New Orleans, LA, USA, November 2006.

[23] Ma, X., Sun, M.-T., Liu, X., & Zhao, G. (2006). Improving geographical routing for wireless networks with an efficient path pruning algorithm. In IEEE communications society conference on sensor, mesh and ad hoc communications and networks(SECON 2006) (pp. 246–255), Reston, VA, USA, September2006.

[24] Z. Mo, H. Zhu, K. Makki and N. Pissinou, “MURU: A multi-hop routing protocol for urban vehicular ad hoc networks”, In proceedings of Mobile And Ubiquitous Systems – workshops (3rd Annual International Conference), 2006, pp. 1–8.

[25]. H. Wu, R. Fujimoto, R. Guensler and M. Hunter. “MDDV: A Mobility-Centric Data Dissemination Algorithm for Vehicular Networks”, ACM VANET 2004.

[26] Jing Zhao and Guohong Cao, “VADD: Vehicle-Assisted Data Delivery in Vehicular Ad Hoc Networks”, In Vehicular Technology, IEEE Transactions, Vol. 57, No. 3, 2008, pp. 1910-1922.

[27] Y. Ding, C. Wang, L. Xiao, “A Static-Node Assisted Adaptive Routing Protocol in Vehicular Networks,” ACM International Workshops on Vehicular Ad Hoc Networks, MOBICOM 2007.

[28] Y. Zhuang, J. Pan, and L. Cai, “A probabilistic model for message propagation in two-dimensional vehicular ad-hoc networks,” in Proc.ACM VANET’10, pp. 31–40, 2010.

[29] J. Jeong, S. Guo, Y. Gu, T. He, and D. Du, “TBD: Trajectory-Based Data Forwarding for Light-Traffic Vehicular Networks,” in ICDCS. IEEE, Jun.2009.

[30] J. Jeong, S. Guo, Y. Gu, T. He, and D. Du, “TSF: Trajectory-based Statistical Forwarding for Infrastructure-to-Vehicle Data Delivery in Vehicular Networks,” in ICDCS. IEEE, Jun. 2010.

[31] A. Carter, “The Status of Vehicle-to-Vehicle Communication as a Means of Improving Crash Prevention Performance,” Technical Report 05-0264, http://www-nrd.nhtsa.dot.gov/pdf/nrd-01/esv/esv19/05-0264-W.pdf, 2005.

[32] Toyota Motor Corporation (TMC), “TMC Develops Onboard DSRC Unit to Improve Traffic Safety,” http://www2.toyota.co.jp/en/news/09/09/0903.html.

[33] General Motors (GM), “Vehicle-to-Vehicle (V2V) Communications,” http://www.gm.com/experience/technology/research/overview/isl/vcim.jsp.

[34] Garmin Ltd., “Garmin Traffic,” http://www8.garmin.com/traffic/.

[35] Savari Networks, “StreetWAVE: Roadside Unit,” http://www.savarinetworks.com/files/StreetWAVE-DS-final.pdf.

[36] GB Traffic Volumes.(2011, September).[Online]. Available: www.mapmechanics.com

[37] Papoulis A, Pillai S U. Probability, Random Variables and Stochastic Processes [M]. McGraw-Hill, 2002

[38] F. Bai and B. Krishnamachari, “Spatio-temporal variations of vehicle traffic in VANETs: facts and implications,” in Proc. ACM International Workshop on VehiculArInterNETworking (VANET’09), 2009.

[39] H. Zhu, L. Fu, G. Xue, etc, “Impact of traffic influxes:understanding exponential inter-contact time in VANETs”, in Proc. IEEE INFOCOM’10, 2010.

[40] W. Su and M. Gerla, “IPv6 flow handoff in ad hoc wireless networks using mobility prediction,” In Proceedings of GLOBECOM ’99, vol. 1A, pp. 271–275, 1999.