A Flexible Routing Metric for Delay Sensitive Urban Vehicular Networks

Group members :

Mir Tafseer Nayeem (074413)

Md. Rokon Uz Zaman Sumon (074420)

Md. Mamunur Rashid Akand (074430)

Supervised by :

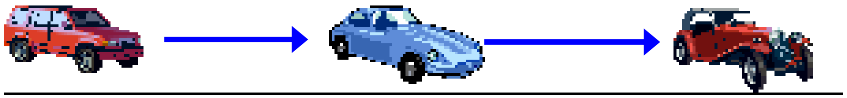
Dr. Muhmmad Mahbub Alam

Asst. Professor , CIT Department, IUT.

Introduction

- VANETs has become an important research area on providing safety and comfort of passengers in both highway and city scenarios.

- The environments for the vehicular networks
  - Every vehicle has a DSRC (Dedicated Short Range Communication) device with double interfaces for wireless communication.
  - Every vehicle has GPS-based navigation system, digital road maps and optional sensors for driving information.
  - In recent years, the radio range of VANETs is extend to almost 1,000 meters and can support data rate of 6 to 27 Mbps .

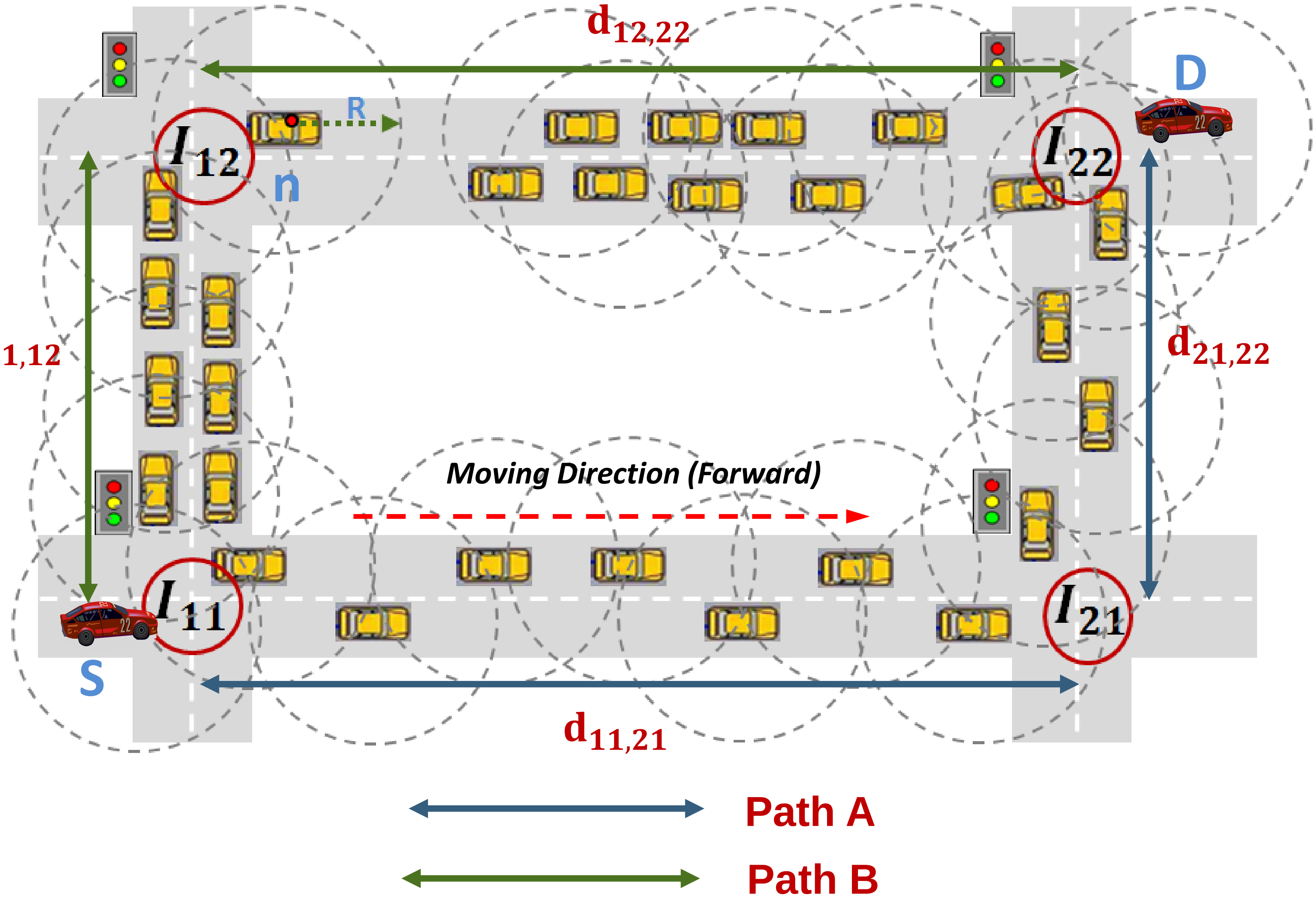


- The objective in this paper
  - Vehicles can deliver their packets through the multi-hop forwarding with the help of other vehicles for time critical applications.

Literature Review

- Greedy perimeter stateless routing (GPSR) [MobiCom 2000], which always chooses the next hop closer to the destination, is unsuitable for sparsely connected VANETs.
- VADD [IEEE INFOCOM' 08] showed that shortest time path is often different from shortest distance path because of varying traffic densities.
- TBD [IEEE ICDCS' 10] comes to the conclusion that when the inter-arrival time of the vehicles decreases then the forwarding delay will eventually decrease.
- In [ACM VANET'10] authors solved network partition by propagating the message to other perpendicular streets instead of along the street.

Problem Statement



Problem Definition

- **2 paths from S to D :**

Path A ($I_{11} \rightarrow I_{21} \rightarrow I_{22}$)

Path B ($I_{11} \rightarrow I_{12} \rightarrow I_{22}$)

- **We know that,**

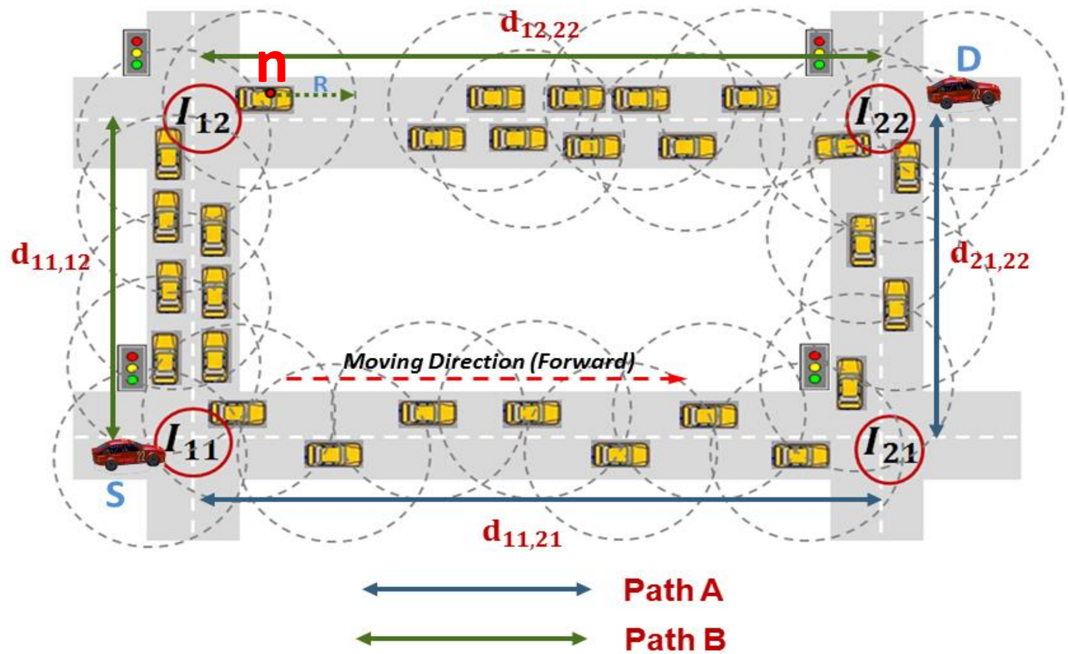
$$\text{Path density} = \frac{\text{number of vehicles}}{\textit{road segment lengt}}$$

$$So, \quad \mu_A = \frac{11}{(l_{11,21} + l_{21,22})}$$

$$\mu_B = \frac{17}{(l_{11,12} + l_{12,22})}$$

Surely, $\mu_B > \mu_A$ as $l_{11,12} + l_{12,22} = l_{11,21} + l_{21,22}$

- Since path B has the temporary network fragmentation after vehicle *n* , the message cannot be forwarded via multi-hop communication.
- As, $d_{path\ A} < d_{path\ B}$, Path A seems to be better path to send data from S to D .



Using Bi-directional Traffic

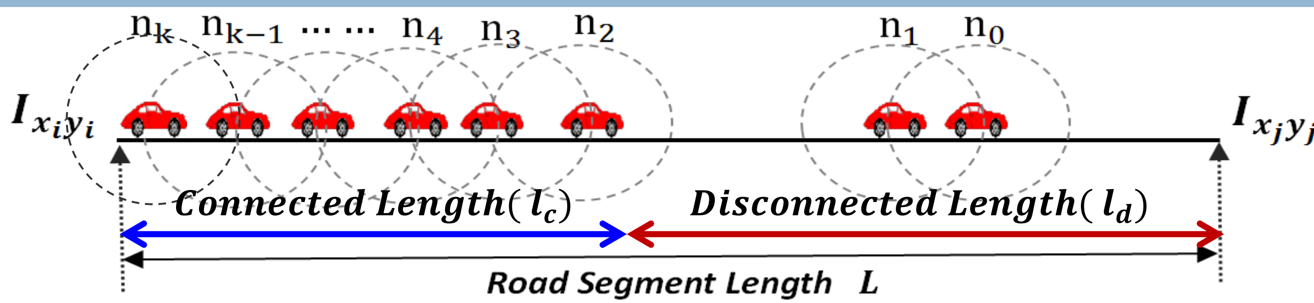


Fig 2: One way road segment is used for calculating the forwarding length

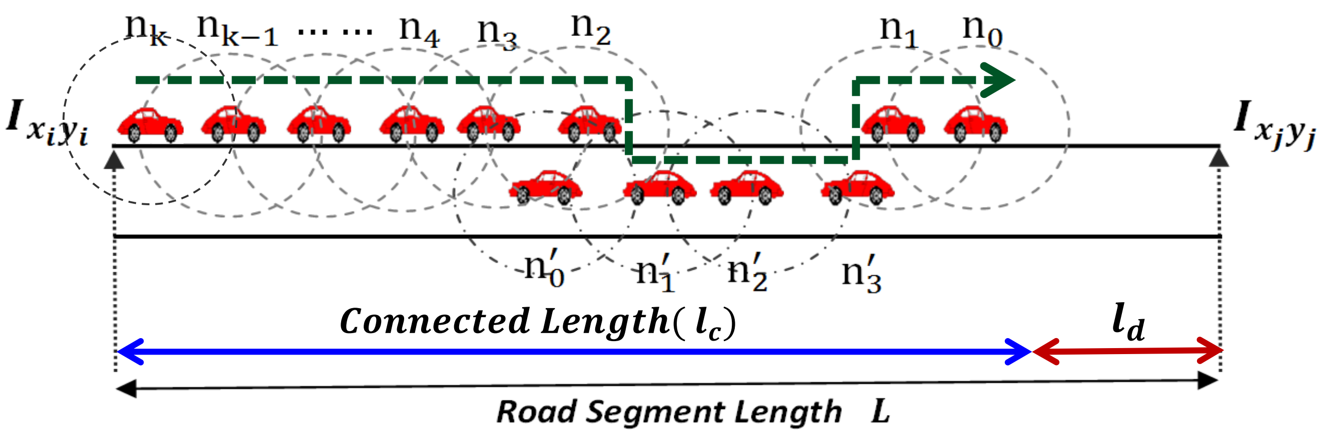


Fig 3 : Bidirectional road segment is used for calculating the forwarding length

So, the Total Forwarding Length: $l_f = l_c + l_d$

l_c = Length of the connected road segment
l_d = Length of the disconnected road segment
l_f = Total forwarding length of the road segment

Challenges and Contribution

- **Challenges**
  - Data forwarding for delay sensitive applications in urban areas.
  - Reducing frequent network partitions utilizing bidirectional traffic.
- **Contribution**
  - A more accurate link delay model compare to both VADD and TBD without using roadside units (e.g., APs).
  - Delay estimation considering the behavior of bi-directional traffic.
  - End-to-End delay model based on city blocks.
  - Reusing existing path for subsequent data forwarding.

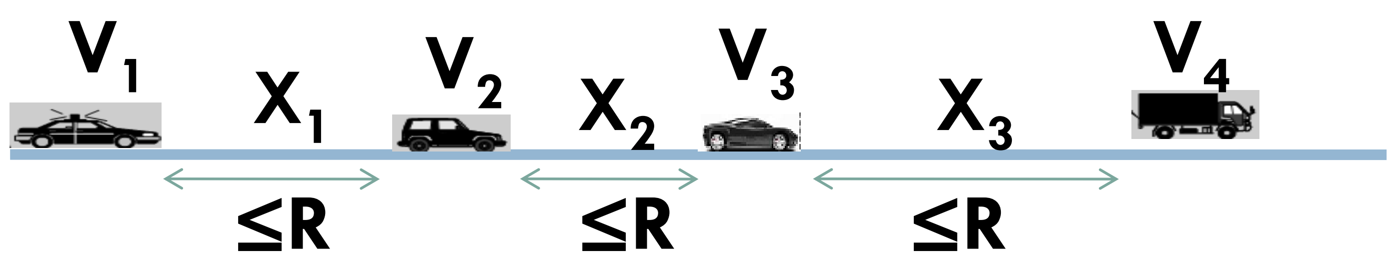
EFD: Link Delay Model

A. Expected forwarding Delay in a cluster $E[D_c]$

- Expected forwarding delay in a cluster $E[D_c]$ 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 shown below.



EFD: Link Delay Model (continued)

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

$$P_V(v) = \big(1 - P(X \leq R)\big). P(X \leq R)^{v-1}, v \geq 1$$

Here,

V = Number of vehicles in a cluster

X = Inter-vehicle distance in 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:

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

EFD: Link Delay Model (continued)

- So, expected number of vehicle in a cluster is-

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

- ***Step 2: Determining expected length of the cluster*** $\boldsymbol{E[L]}$

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

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

- $E[X]$ 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

EFD: Link Delay Model (continued)

Step 3: Expected Hop count in road segment($\boldsymbol{E[H]}$)

- We have to compute $\boldsymbol{E[H]}$ for each cluster in a road segment, then we will take the sum.
- We assume-

  Minimum number of hop count in a cluster : $H_{min} = \frac{E[L]}{R}$

  Maximum number of hop count in a cluster: $H_{max} = \frac{E[L]}{E[X]}$

- *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 $\boldsymbol{E[D_c]}$

- 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 $E[D_c]$ in a cluster as follows-

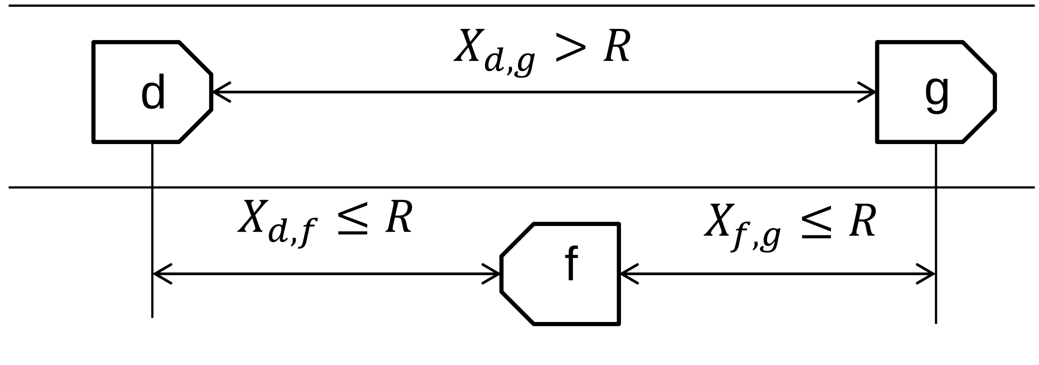
$$E[D_c] = E[H] \times D_h$$

EFD: Link Delay Model (continued)

B. Delay due to Carry and forward

Case 1:

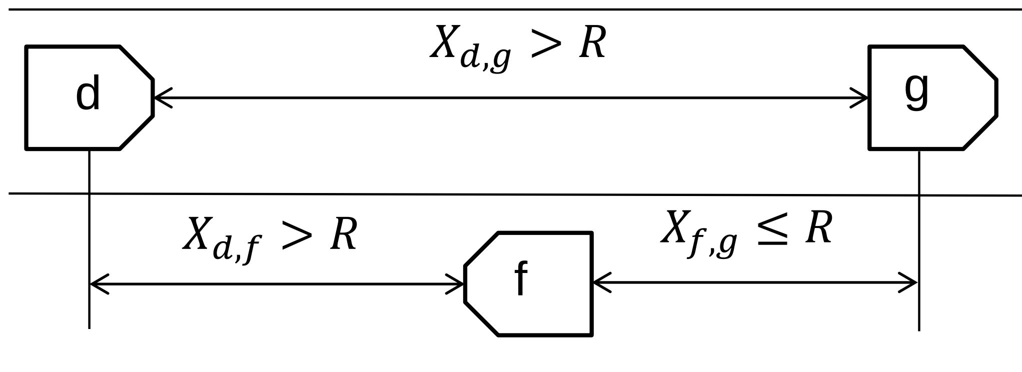
- $P_1 = \Pr\{X_{d,f} \le R\} \Pr\{X_{f,g} \le R\}$
- $Y_1 = 0$
- $f_{Y_1}(y) = \begin{cases} 1, & y = 0 \\ 0, & otherwise \end{cases}$



- Fig. Case 1

Case 2:

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



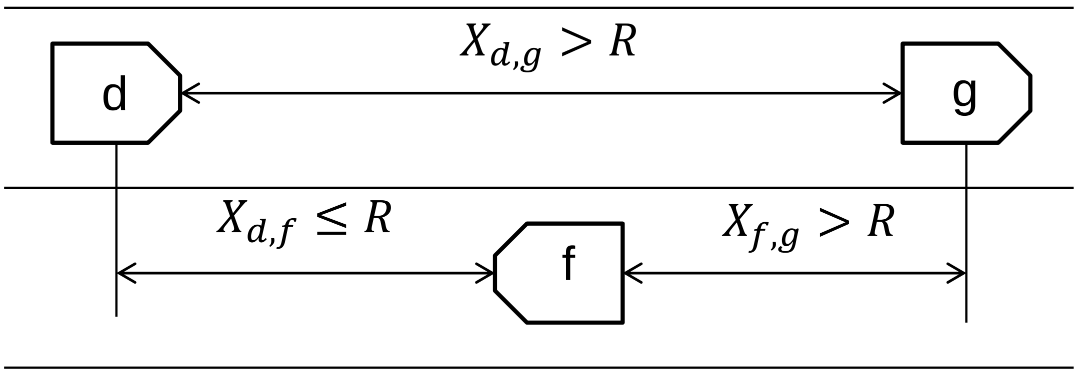
- Fig. Case 2

EFD: Link Delay Model (continued)

- **Case 3:**

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

- 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.



EFD: Link Delay Model (continued)

- Based on above 3 cases, the density function of the disconnection distance is $f_Y(y) = \sum_{i=1}^{3} P_i \times f_{Y_i}(y)$
- Now, we have estimated both connection delay(D_c) and disconnection delay(D_d).
- ***One road segment delay :***

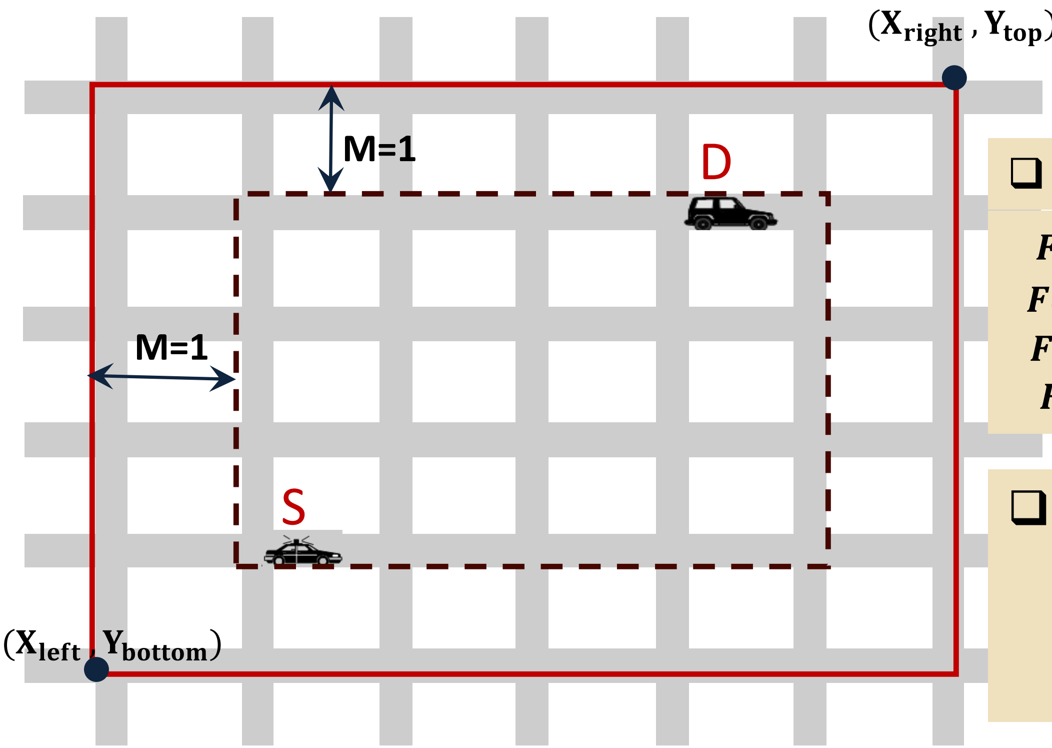
$$E[D] = E[D|l_r > R] \times \Pr\{l_r > R\}$$

Here, $D = D_c + D_d$

l_r= remaining road length

EFD: E2E Delay Model

- Objective
  - To compute the expected end-to-end delay from a moving source (S) vehicle to destination (D) using dynamic programming.
- Road network topology graph (RNTG) for Data Forwarding.
  - Setting the forwarding area like [MURU'06].



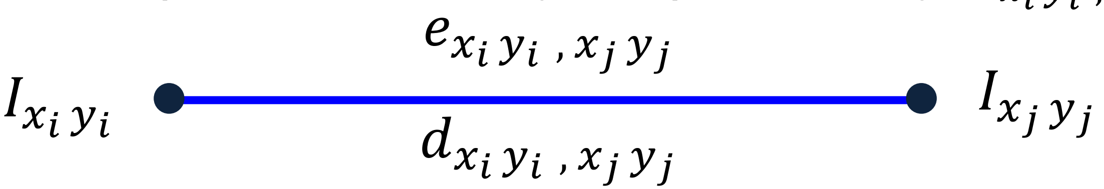
- ***Setting the Restricted Forwarding Area:***

$$ForwardingArea.X_{left} = \lceil min(S.X, D.X) \rceil - M$$
$$ForwardingArea.X_{right} = \lceil max(S.X, D.X) \rceil + M$$
$$ForwardingArea.Y_{bottom} = \lfloor min(S.Y, D.Y) \rfloor - M$$
$$ForwardingArea.Y_{top} = \lceil max(S.Y, D.Y) \rceil + M$$

- 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.

EFD: E2E Delay Model (continued)

- 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:
- $d_{x_i y_i, x_j y_j}$: The expected forwarding delay for an edge $e_{x_i y_i, x_j y_j}$.



- $P(x_j y_j)$: Forwarding Probability for edge $e_{x_i y_i, x_j y_j}$.
- $D_{I_{x_i y_i}}(I_{x_n y_n})$: 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.

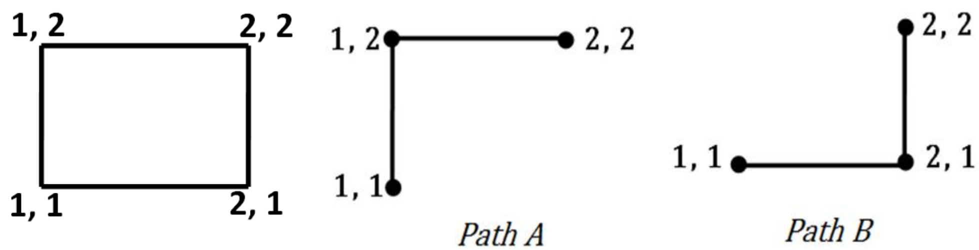
- We formulate $D_{I_{x_i y_i}}(I_{x_n y_n})$ recursively as follows:

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

EFD: E2E Delay Model (continued)

A. Next intersection selection based on city blocks

- Block is the smallest element in the Road network topology graph (RNTG).
- City blocks can be extended in 2 ways based on the traffic statistics:
  - Horizontal Block Extension(***C=1***)
  - Vertical Block Extension(**C=2**)



- **Basic Block(*b=1*)**
  - Where (2, 2) is the intermediate intersection, there are two alternate paths ***path A*** and ***path B*** from (1, 1) to reach (2, 2) via one intersection.

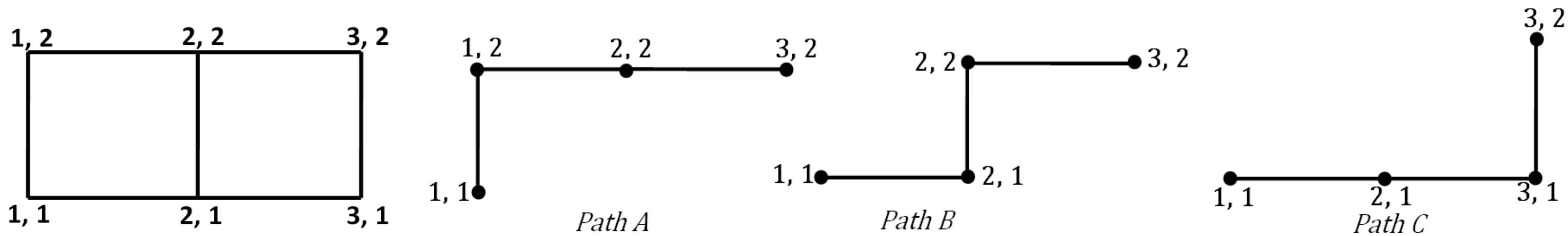
$$d^{(c)}_{x_i y_i, x_j y_j} = d^{(1)}_{11,22} = min\left(d_{11,12} + d_{12,22}, d_{11,21} + d_{21,22}\right)$$

  - Forwarding Probability at intersection point (2, 2) is :

$$P(x_j y_j) = P(2,2) = P(A \cap B) = P(B|A)P(A)$$
$$= P(B)P(A)$$
$$= P^2 * P^2 = P^4$$

EFD: E2E Delay Model (continued)

- **Horizontal Block Extension(*b=2* and *C=1*)**
  - One block is extended in the horizontal, where (3, 2) is the intermediate intersection, there are three alternate paths ***path A* , *path B and* *path C*** from (1, 1) to reach (3, 2) via two intersection points.



$$d^{(c)}_{x_i y_i, x_j y_j} = d^{(1)}_{11,32} = min\begin{pmatrix} d_{11,12} + d_{12,22,} + d_{22,32}, \\ d_{11,21} + d_{21,22,} + d_{22,32}, \\ d_{11,21} + d_{21,31,} + d_{31,32} \end{pmatrix}$$

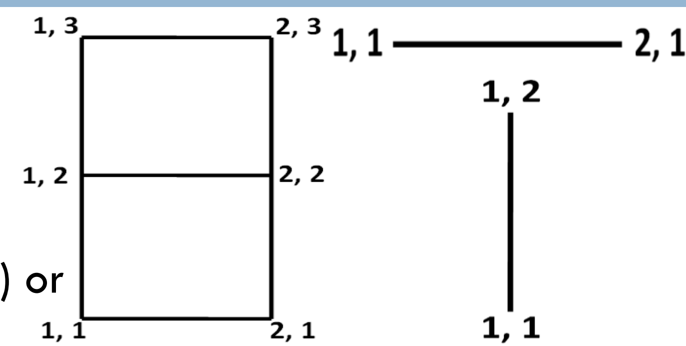
  - Forwarding Probability at intersection point (2, 2) is :

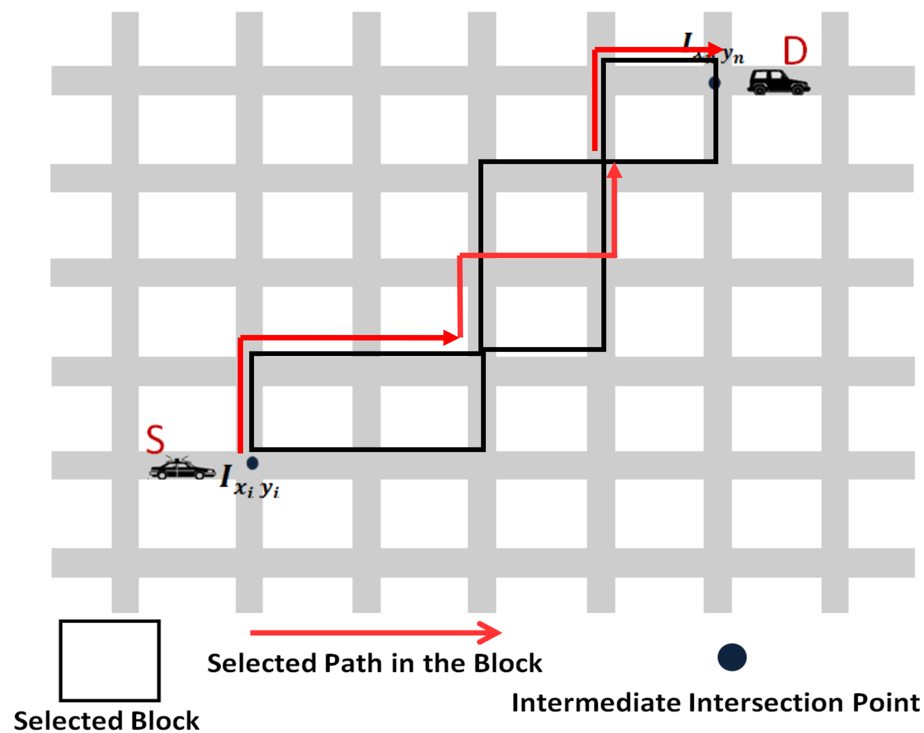
$$P(3,2) = P(A \cap B \cap C) = P(C|(A \cap B))P(B|A)P(A)$$
$$= P^2 * P^2 * P^3 = P^7$$

- Horizontal Blocks can be extended up to *n* depending on the traffic statistics .

EFD: E2E Delay Model (continued)

- **Vertical Block Extension(b=2 and C=2)**
  - One block is extended in the vertical. So, $d_{11,23}^{(2)}$ $P(2,3)$ calculation is same as horizontal block.
  - When no suitable block is found then (1,1)→(2,1) or (1,1)→(1,2) is used as the forwarding segment.





- So, the complete block based data forwarding in the complete path from source to destination is shown in figure.

Flexible Path Reconstruction

- 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 encouraged us to reuse the previous path without further re-broadcasting to reduce the broadcasting load in the network .
- Link duration time means the maximum time of connectivity between two neighboring vehicles as defined in [].

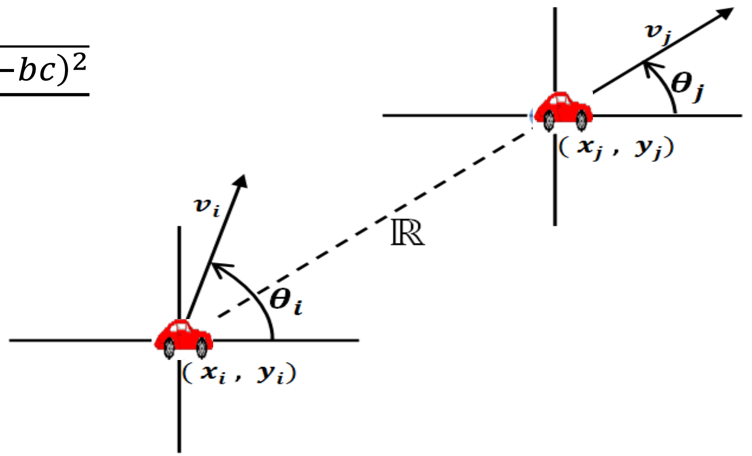
$$LDT[i,j] = -(ab+cd) + \frac{\sqrt{(a^2+c^2)r^2-(ad-bc)^2}}{a^2+c^2}$$

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

$b = x_i - x_j$

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

$d = y_i - y_j$



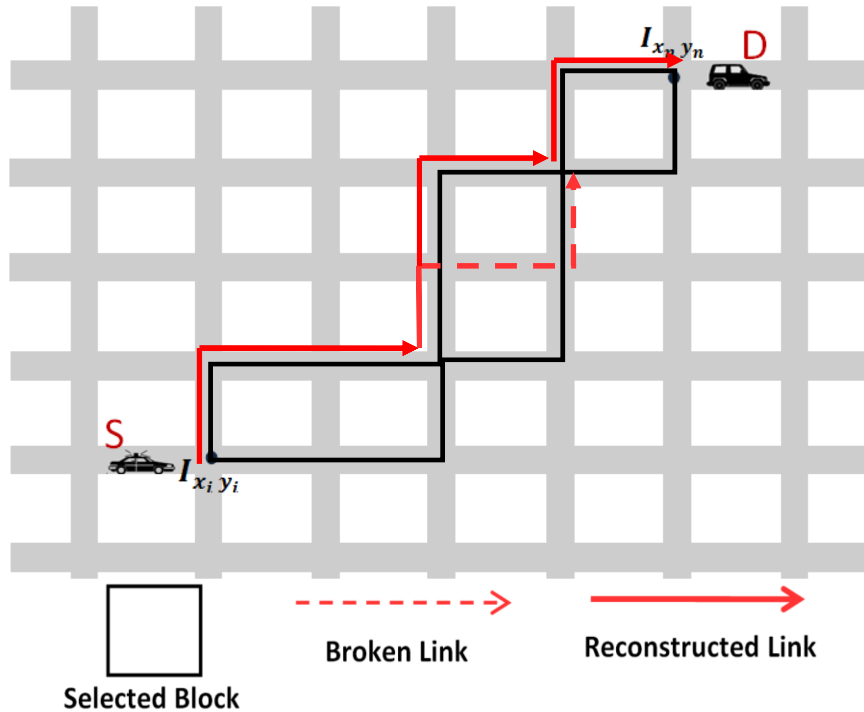
Flexible Path Reconstruction (continued)

- So, Link Duration Time (LDT) for the sub-path is

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

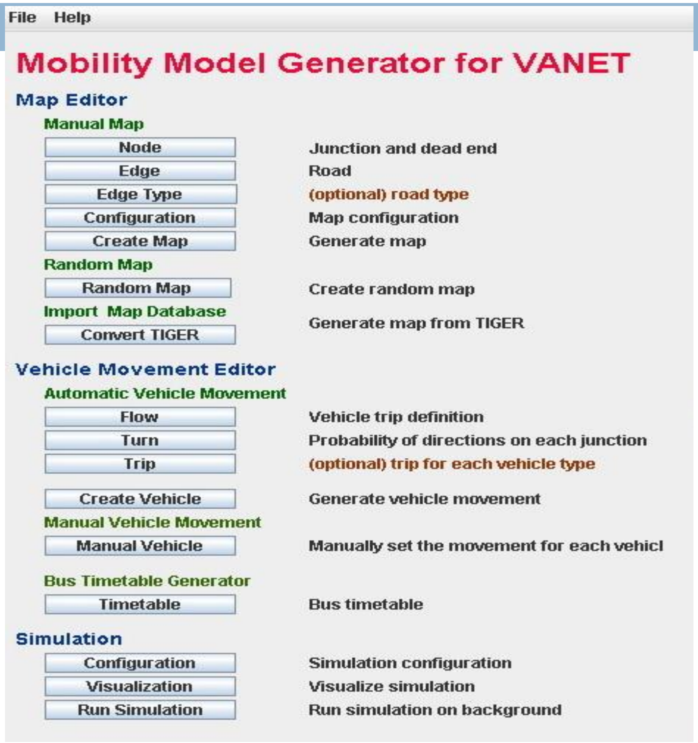
- Now the total path duration time (PDT) is the minimum duration time of sub-can be calculated as

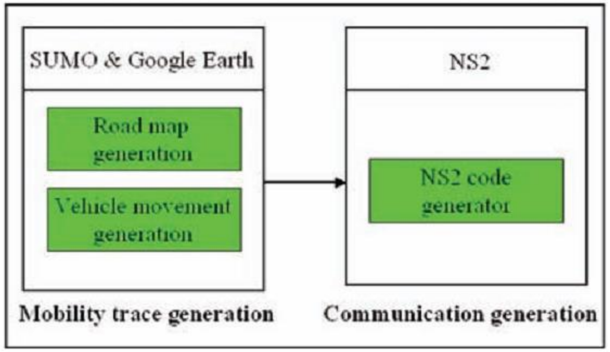
$$PDT[s,d] = min(LDT\left[s,\ I_{x_i y_i}\right], LDT\left[\ I_{x_i y_i}, I_{x_j y_j}\right], \dots, LDT\left[I_{x_n y_n}, d\right])$$

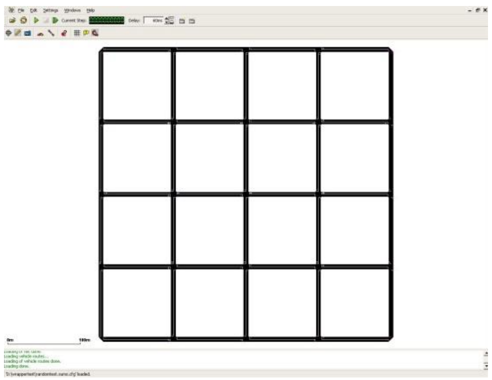


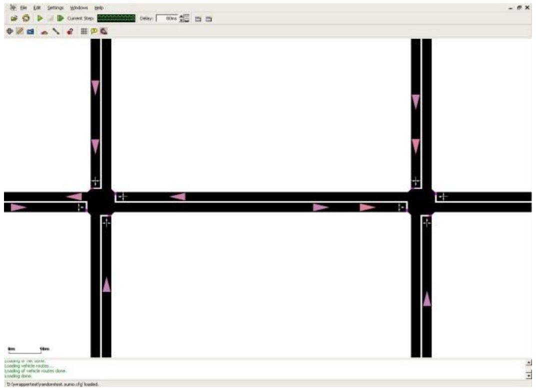
VANET Simulation: A gap between transportation and networking

- 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.





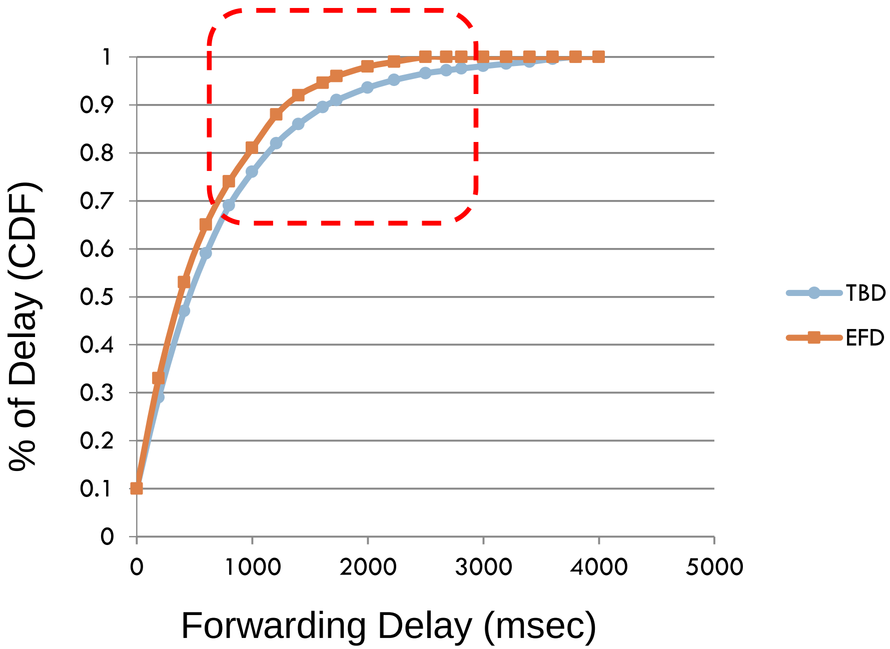


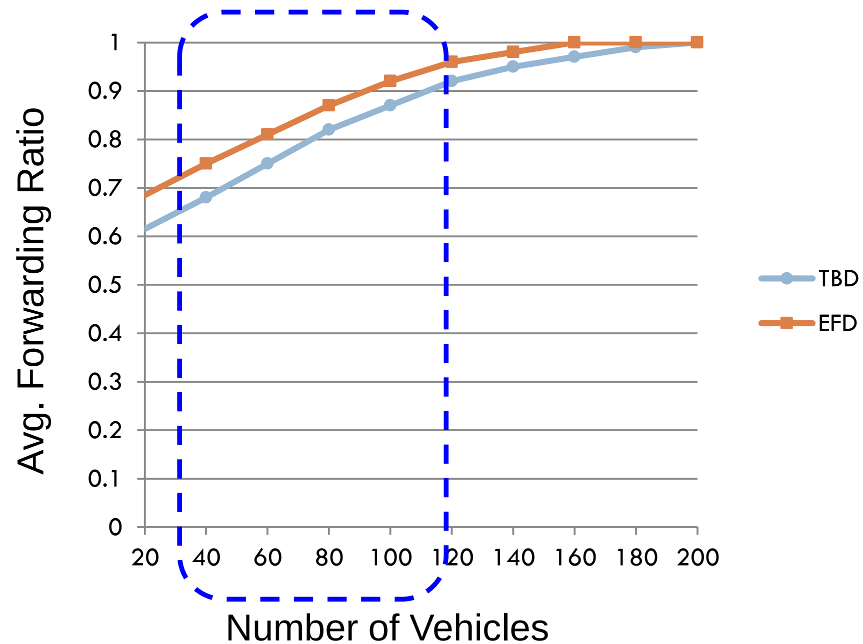


Performance Evaluation

- Evaluation Setting
  - Performance Metric: Expected Forwarding Delay(EFD)
  - Parameters: (i) Vehicle arrival rate, (ii) Vehicle speed, and (iii) Vehicle density
- 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

Average Forwarding Delay and forwarding ratio comparison between EFD and TBD





✓EFD reaches 90% CDF with a forwarding delay of about 1100ms while the value of TBD is 1900ms.

✓EFD outperforms TBD under the light traffic, such 40~100 vehicles.

✓As the traffic density increases, two schemes are converged.