Delay-bounded Routing in Vehicular Ad-hoc Networks

MobiHoc 2008

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2008/11/13

Outline

- Introduction
- System Model
- Proposed Algorithms
- Performance Evaluation
- Conclusions

Introduction

- Two categories of VANET-based applications
  - Those that require **broadcasting** of information from one vehicle to many nearby vehicles, e.g. for collision avoidance
  - Those that require the propagation of information **hop-by-hop** to a single destination point or area, e.g. Sending an emergency message from an accident side to the closest roadside unit that is connected to a fixed network
    - Motivating example: ambient traffic sensor application
    - Accident , road fault , traffic congestion
    - Different priority and different user-defined delay threshold

Introduction

- Network resources will be shared by applications that provide internet access to passengers, provide the driver with safety information and so on
- This matter is further aggravated if we take into account inter-system interference
- The goal is to design algorithms that try to optimize bandwidth utilization ,by being frugal in wireless packet
  - Leverage knowledge of traffic information (density, speed)

System Assumptions

- We assume location-aware vehicle that obtain their geographical position from a GPS
- Vehicles also have access to a digital map of the area
- We assume that the map is preloaded with historical traffic statistics about the street network (average speed , average vehicle density per road segment)
- The street map is abstracted as a directed graph G(V,E)
- Message containing the event description and generation time t_g and a time-to-live value λ

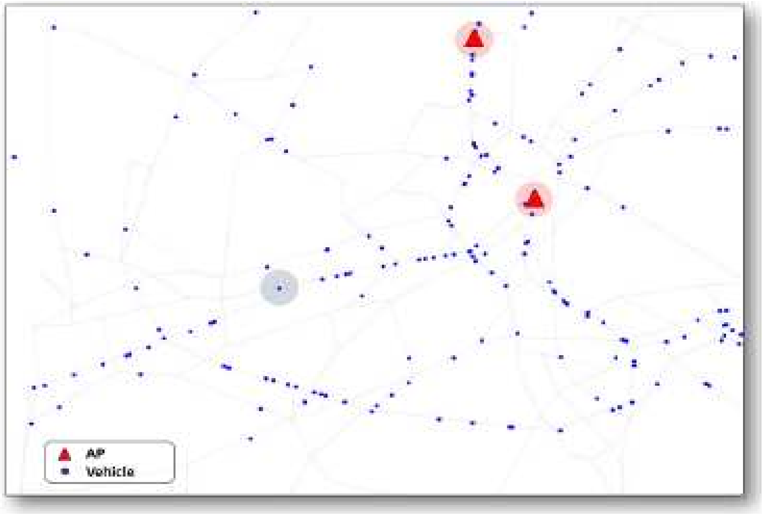


Figure 1: Our Model. Shaded circles indicate the communication range.

System Objective

- Considering a densely populated urban area where typically the wireless medium is shared by a large number of vehicles, running a variety of application competing the network resources
  - It is crucial to be frugal in the use of the wireless channel
  - We aim to minimize bandwidth utilization by minimizing the number of transmitted messages
- When traffic density is low , the vehicular network often becomes disconnected
  - Carry-and-forward
  - Assume that vehicles have very large buffers to store messages
- Our algorithms intend to minimize the number of transmissions while forwarding a message to an access point within the message-specific delay threshold

Forwarding strategies

- Multihop Forwarding
  - Aggressive forwarding messages to vehicles that are better positioned
  - Traffic needs to be dense enough so that better positioned vehicles exist within communication range
- Data Muling
  - Buffering messages in local memory and carrying them at the vehicle's speed
  - It is a feasible option as long as the current vehicle is traveling on the path selected by the routing algorithm
- The novelty of the proposed algorithms lies in their careful alternation between the Multihop Forwarding and Data Muling to achieve a good tradeoff between delay and communication cost

Delay-bounded Greedy Forwarding(D-Greedy)

- D-Greedy assumes that the best path to an access point is the shortest one
- Each vehicle maintain a neighbor list by periodically broadcast beacons
  - Vehicle identifier (id)
  - Length of the shortest path (distToAP)
- D-Greedy assumes that the remaining message delay budget can be uniformly distributed among the edges that compose the shortest path to the AP
- Each edge on the path is allocated delay budget that is proportional to its length

$$Del = TTL \times \frac{distToInt}{distToAP}$$

$$Del_{DM} = \frac{distToInt}{u}$$

u: average speed during a k-second

disToInt : the remaining length until the next intersection

$Del_{DM} \leq Del$: Data Muling strategy

Otherwise : Multihop Forwarding strategy

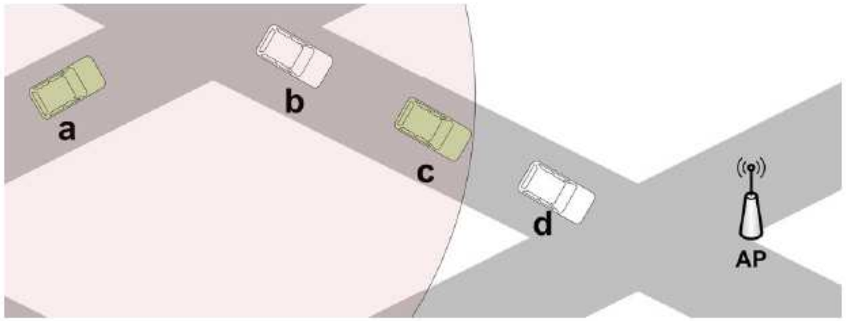


Figure 2: Node a will choose to forward the message to node c, the closest node to the AP among those in range.

Delay-Bounded Minimum Cost Forwarding (D-MinCost)

- To annotate each edge with two metrics: 1) **cost (C),** representing the number of message transmissions along the edge, and 2) **delay (Del),** denoting the time required to forward a message along the edge
- We convert the original directed graph G(V,E) that represents the street map to a new G'(V,E'), which contains the same set of vertices, and twice as many edges

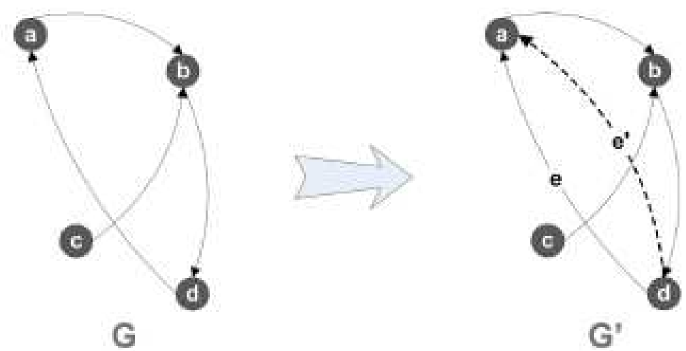


Figure 4: Replacing edge (d, a) in G by two sibling edges, one per strategy.

D-MinCost

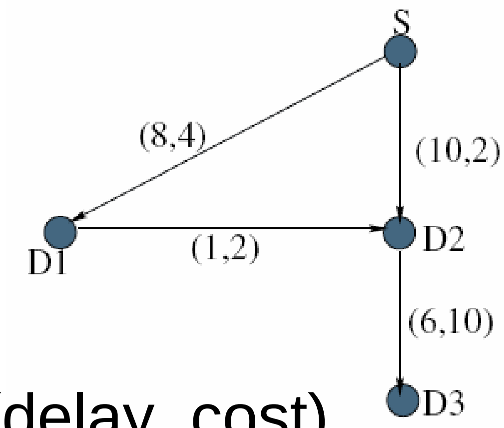
- Data Muling strategy : $Del_{DM} = \frac{\ell}{u}, C_{DM} = 1$
- Multihop Forwarding strategy: $C_{MH} = \frac{\ell}{R}, Del_{MH} = C_{MH} \times q$

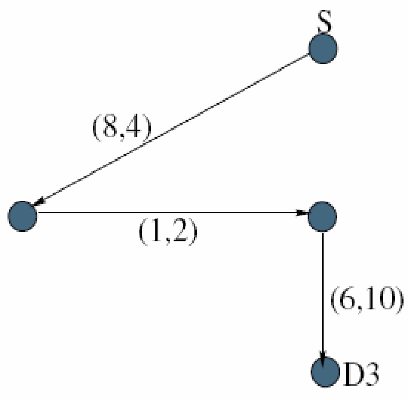
  q: the time required for the node to check its neighbor list and identify the best next hop
- D-MinCost utilizes the Delay Scaling Algorithm to efficiently compute delay-constrained least cost path from the vehicle's location to all access points
  - The access point that can be reached with the least cost.
  - The exact min-cost path to that access point.
  - The strategy that should be followed at each edge of the path in order to adhere to the message's remaining delay budget.

DSA (Delay Scaling Algorithm)

Inputs: Graph G with link costs l_{ij} and delays t_{ij} and a delay threshold T.
Outputs: Tables $L(v,t)$ and $P(v,t), 1 \leq v \leq n, 0 \leq t \leq t$. The entry $L(v,t)$ is the cost of the cheapest path from 1 to v whose delay is no more than t. The entry $P(v,t)$ encodes the cheapest path from 1 to v, whose delay is no more than t.
1. Initialize $L(1,t) = 0, \quad t = 0, \cdots, T$
2. Initialize $L(j,0) = \infty, \quad j = 2, \cdots, n$
3. Compute $L(j,t) = \min\{L(j,t-1),$
$\min_{k | t_{kj} \leq t \text{ and} (k,j) \in E} \{L(k,t-t_{kj}) + l_{kj}\}\}$
where $j = 2, \cdots, N, t = 1, \cdots, T$

Fig. 2. Subroutine DAD which iterates on integer delays.





(delay ,cost)

$L(3,15)=\min\{ L(3,14) , \min\{ L(2,9) + (l_{23}=10) \} \} = 16$

$L(2,9)= \min\{ L(2,8) , \min\{ L(1,8) + (l_{12}=2) \} \} = 6$

$L(S,-1) + (l_{12}=2)$

||

∞

Delay-Bounded Minimum Cost Forwarding (D-MinCost)

- When a message p is generated at the node, the algorithm applies the DSA heuristic on the extended graph G' for message p with delay budget TTL
- From the path returned by DSA(I, TTL), D-MinCost selects the minimum cost path that leads to an access point and encodes it in the message header
- The message path will be recomputed at the next intersection by its carrier only if it is not feasible to follow the suggested edge and its associated strategy
  - In this case , the edge is removed from graph G' and the DSA is reinvoked on the resulting graph in order to compute an alternative min-cost path

Performance Evaluation

Number of Iterations	30
Iteration Duration	1800 sec
Beacon Period	5 sec
Number of Vehicles	[200-1000]
Delay Threshold (λ)	[300-1800] sec
Number of Messages Generated	100
Message Generation Interval	First 50 sec
Message Size	1500 KBytes
Communication Range	250m
Bitrate	500 Kbps

Table 1: Simulation Parameters

20km* 10km

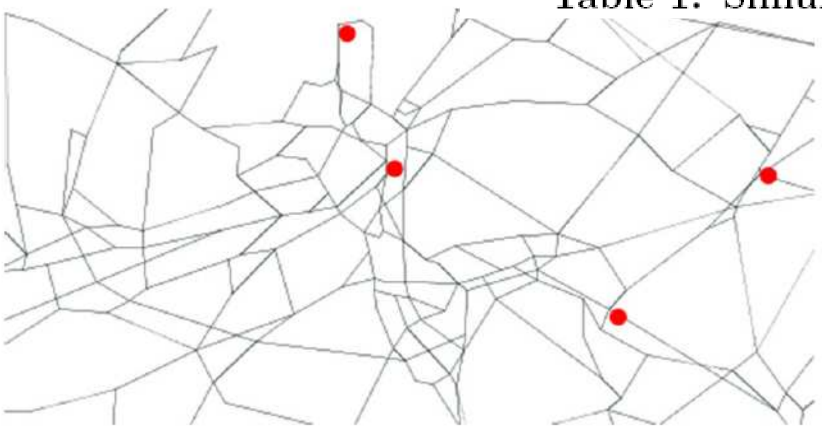
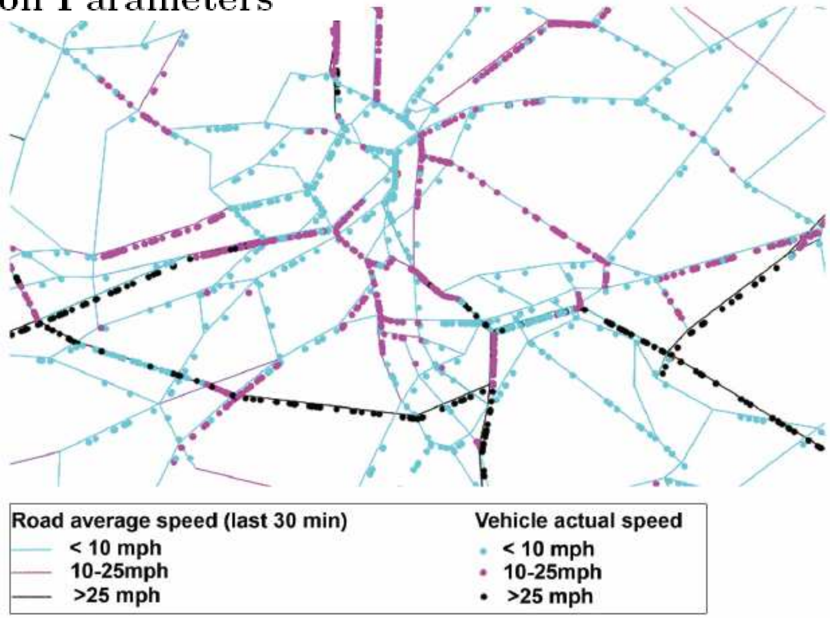


Figure 5: The section of the map of Zurich used in our experiments. Circles represent access points.



Delivery Ratio

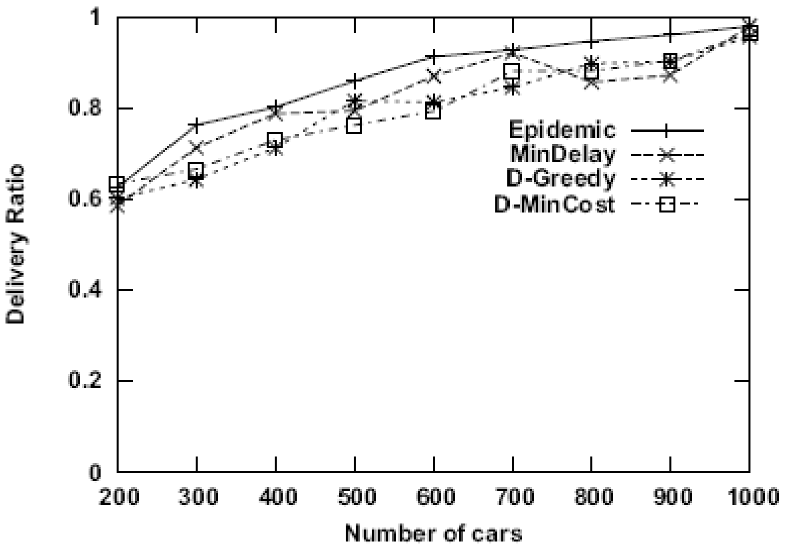


Figure 7: Message Delivery Ratio varying the number of cars (λ=1200sec)

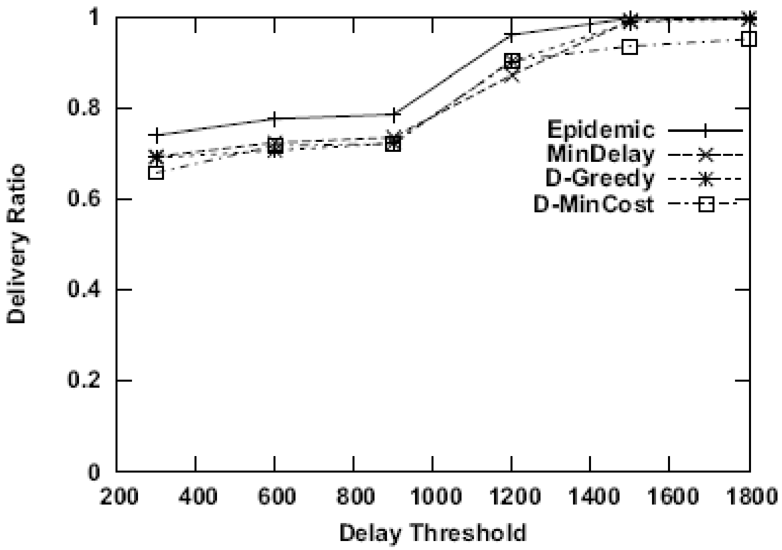


Figure 8: Message Delivery Ratio varying λ (number of cars=900)

Transmitted Bytes

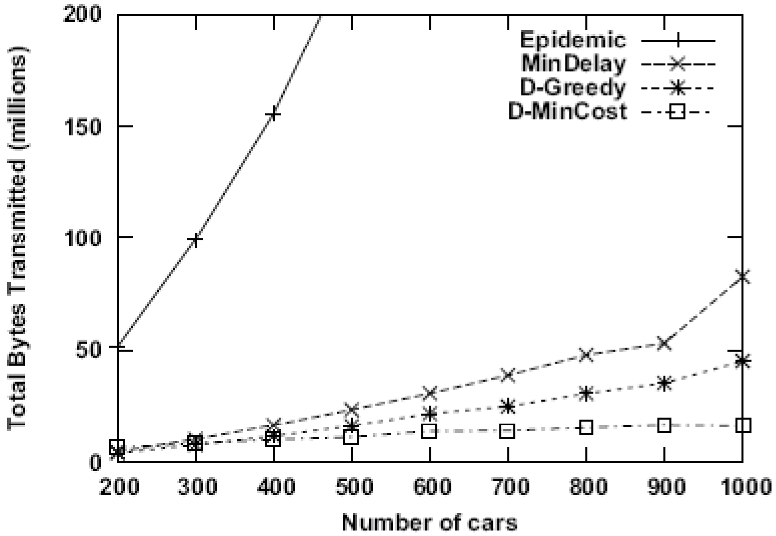


Figure 9: The total number of bytes sent for different car densities (λ=1200sec)

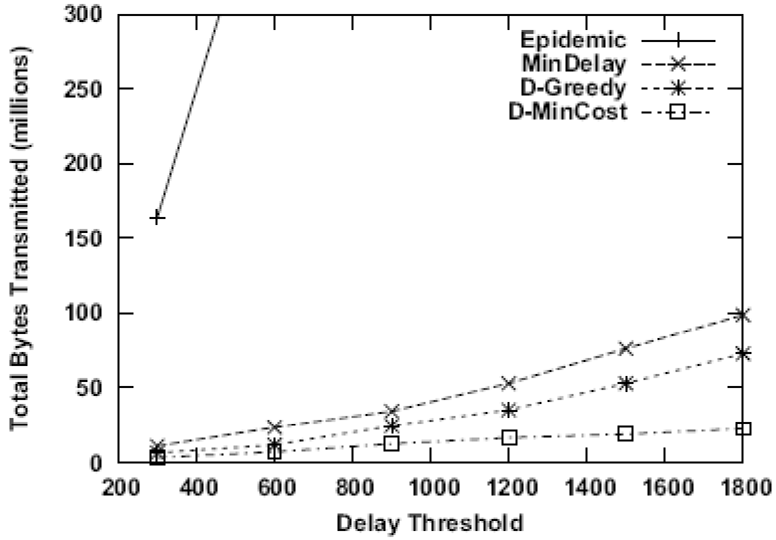


Figure 10: The total number of bytes sent for different values of λ (number of cars=900)

Message Delay

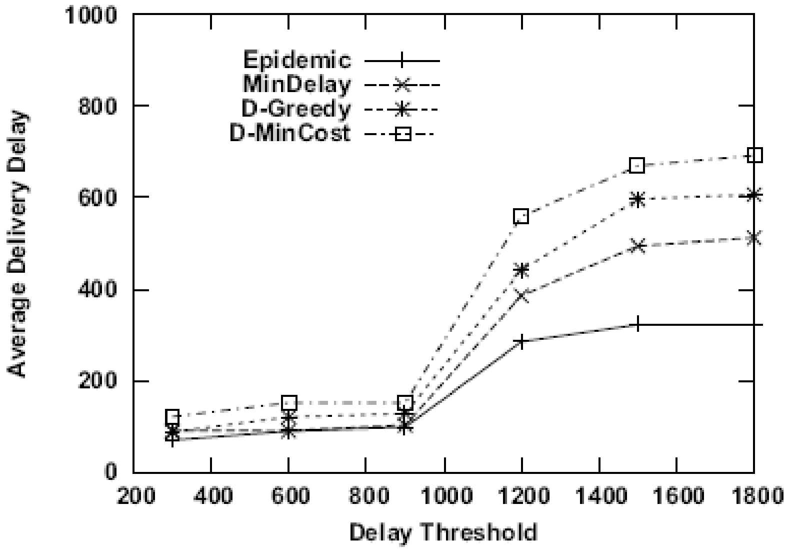


Figure 11: Average delivery delay for different values of λ (number of cars=900)

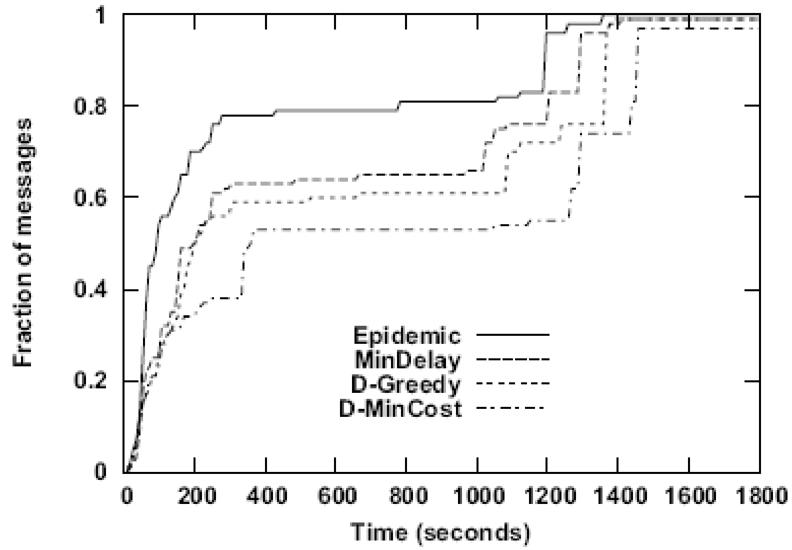


Figure 12: CDF of message delivery delay (900 cars, λ=1500)

Effect of λ

- D-Greedy and D-MinCost gracefully alternate between the Multihop Forwarding and Data Muling strategies aiming to exhaust the message delay threshold and minimize the communication cost, effectively trading allowable delay for bandwidth

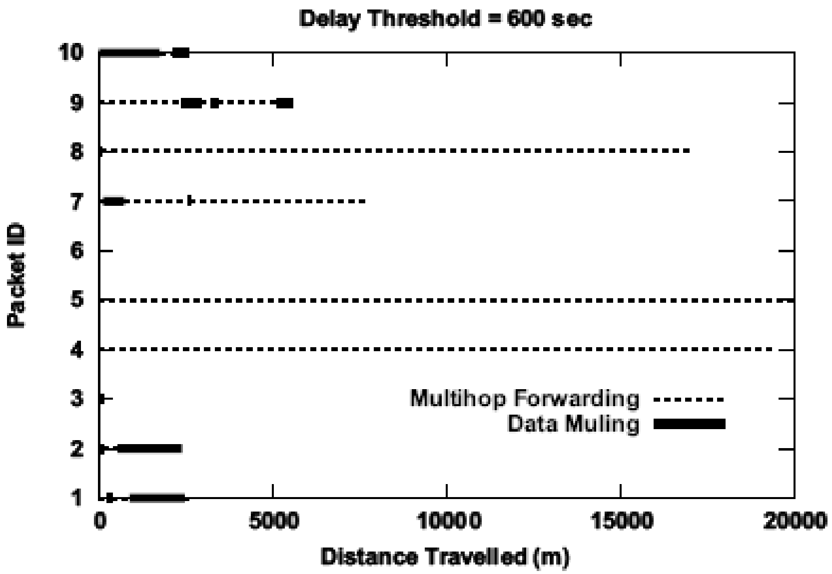


Figure 13: Strategy chosen for low $\lambda = 600s$

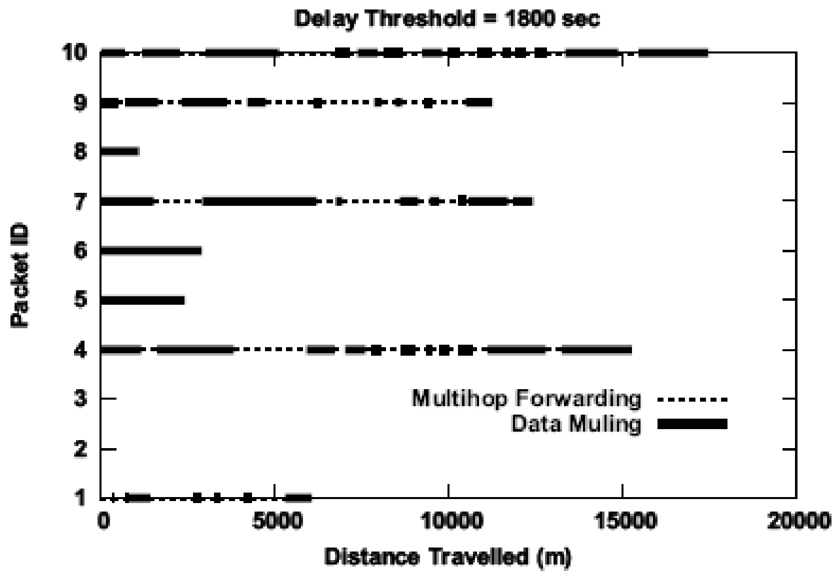


Figure 14: Strategy chosen for high $\lambda = 1800s$

Conclusions

- Our algorithm leverage traffic statistics to reach forwarding strategy decisions that minimize communication cost and at the same time adhere to a per-packet application defined-delay threshold
- The cost savings of D-Greedy and D-MinCost are derived from carefully alternation between the Multihop Forwarding and Data Muling strategies