

# Anonymous DTN routing

September 15, 2013

## 1 Experimental Result

### 1.1 Overview

#### 1.1.1 Simulation model

- ONE simulator, modified default scenario/setting
- Map: Helsinki (4500m \* 3500m)
- Simulation running time: 12 hours
- Nodes: 246 (160 humans, 80 cars, 6 trams)
  - Packet buffer: Humans and cars (50MB), trams (500MB).
  - Contact interval: Humans (2 mins 30 secs), cars (1 min), trams ( 40 secs)
- Packet(message) generation
  - Packet size: 500KB - 1MB
  - Packet generation interval: 35sec - 50sec
  - TTL: 5 hours
  - Packet generation stopped when 5 hours (packet TTL) are left.
  - Total number of packets generated: about 575
- Movement: Random way point, map-based movement.
- Network interface: bluetooth, wlan (determine communication distance and bandwidth)
  - Humans, cars: Bluetooth (Bandwidth: 2Mbps, Communication range: 10m)
  - Trams: WLAN (Bandwidth: 10Mbps, Communication range: 100m)

### 1.1.2 Anonymous DTN routing setup

- # group: 1
- # nodes in a group: [5%, 10%, 15%, 20%, 25%]
- Epoch: [10mins, 20mins, 30mins, 60mins]
- Ephemeral ID duration: [3 epochs, 6 epochs]
- Base routing protocol: epidemic (flooding)

### 1.1.3 Assumptions & simplification

- Strict time sync  
Epoch starts exactly at the same time in all nodes
- No “beacon”, “hello”, “pull” messages  
Once two nodes are located within a specific distance, they know ephemeral addresses, packet digest, pulling list of each other without any message exchange.
- “Out-of-group” nodes do not use ephemeral IDs.  
Those nodes use permanent IDs which are not changed during the simulation.
- Forwarding policy  
On contact, a node first forwards packets whose destinations are either trusted by the next-hop node or in neighbor list of the next-hop node. Then it tries to forward remaining packets in FIFO manner.

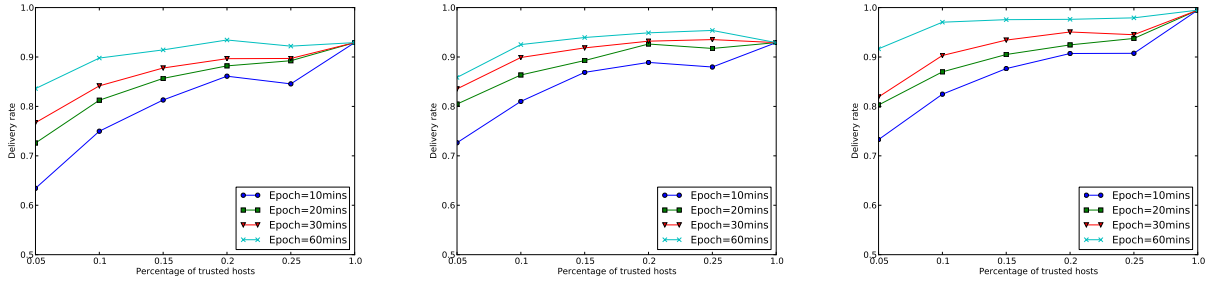
## 1.2 Results

### 1.2.1 Communication within the group

In this test scenario, only nodes belong to the group can send packets to other nodes it trusts. Nodes that don't belong to the group cannot generate packets.

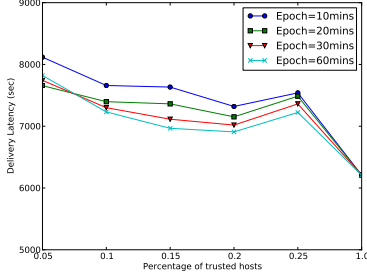
Ephemeral ID duration	Trusted nodes %	Epoch
3 epochs	10%	60 mins
6 epochs	10%	30 mins
6 epochs	20%	20 mins

Table 1: **Example settings with delivery rate of about 90% (Flooding: 92.91%).**

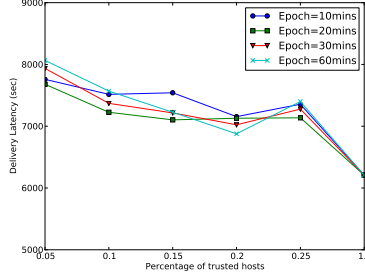


(a) Ephemeral ID valid for 3 epochs (b) Ephemeral ID valid for 6 epochs (c) Ephemeral ID valid for 6 epochs. Infinite packet buffer.

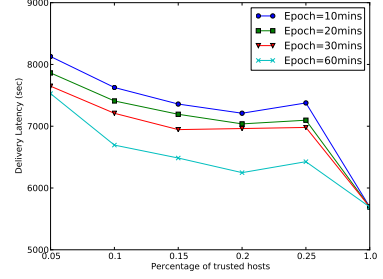
Figure 1: **Packet delivery rate.** Delivery rate of pure epidemic routing: 92.91%. Delivery rate of pure epidemic routing with infinite packet buffer: 99.48%. Increasing ephemeral ID duration from 3 epochs to 6 epochs enhances the delivery rate significantly. In Figure 1c, ephemeral ID expiry does not occur when epoch is 60 mins.  $[TTL (5 \text{ hours}) < Epoch (1 \text{ hour}) * \text{Ephemeral ID duration (6 epochs)}]$  In this case, packet drop occurs only when TTL expires, and the delivery rate is almost as high as that of epidemic (flooding) routing



(a) Ephemeral ID valid for 3 epoch

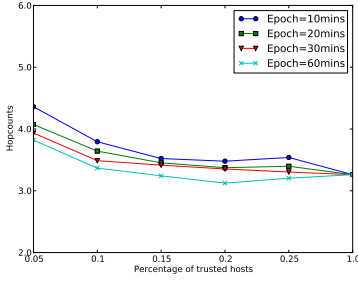


(b) Ephemeral ID valid for 6 epochs

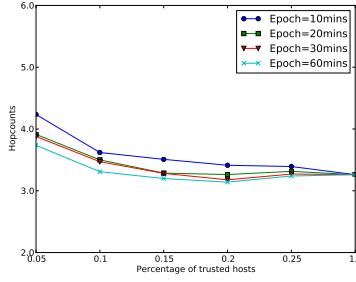


(c) Ephemeral ID valid for 6 epochs. Infinite packet buffer.

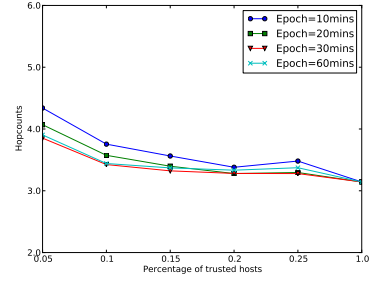
Figure 2: **Packet delivery latency.** With finite packet buffer, delivery latency of our protocol is 1000 - 2000 secs longer than that of flooding protocol.



(a) Ephemeral ID valid for 3 epochs

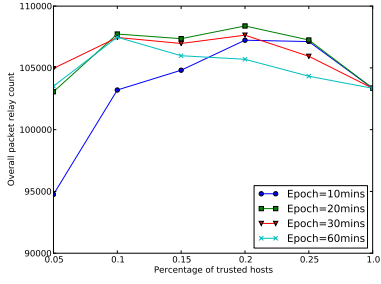


(b) Ephemeral ID valid for 6 epochs

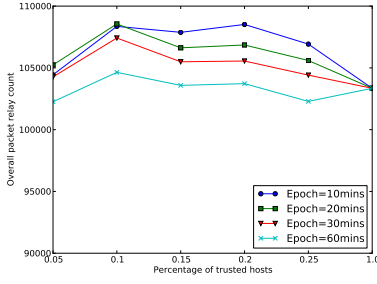


(c) Ephemeral ID valid for 6 epochs. Infinite packet buffer.

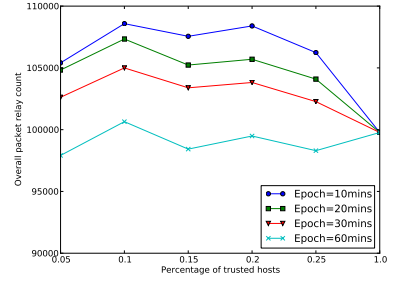
Figure 3: **Packet delivery hop count.** In general, delivery hop count is increased by less than 1 hop.



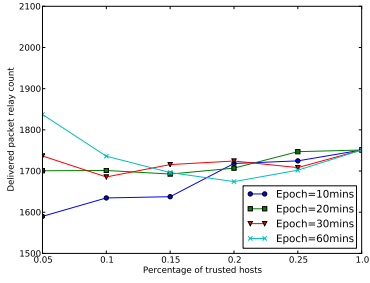
(a) Overall packets. Ephemeral ID valid for 3 epochs.



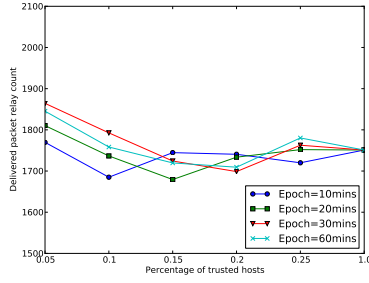
(b) Overall packets. Ephemeral ID valid for 6 epochs.



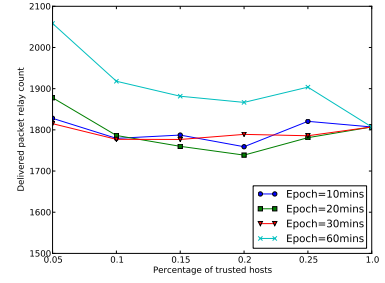
(c) Overall packets. Ephemeral ID valid for 6 epochs. Infinite packet buffer.



(d) Delivered packets. Ephemeral ID valid for 3 epochs.

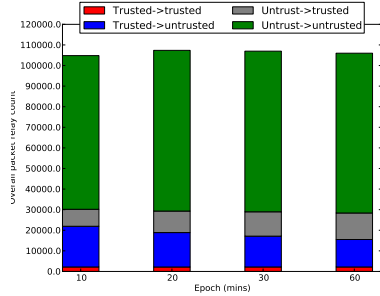


(e) Delivered packets. Ephemeral ID valid for 6 epochs.

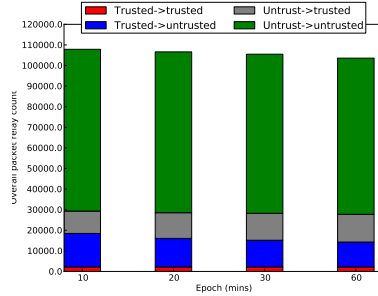


(f) Delivered packets. Ephemeral ID valid for 6 epochs. Infinite packet buffer.

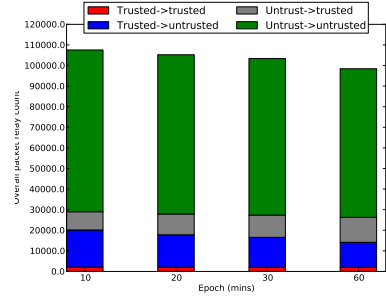
Figure 4: **Packet relay count.** Only about 2% of packet relays are used for actual packet deliveries.



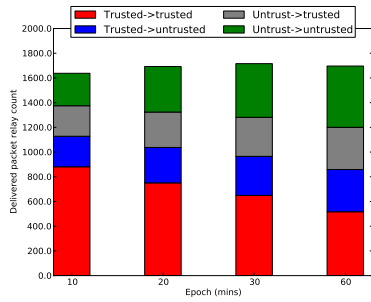
(a) Overall packets. Ephemeral ID valid for 3 epochs



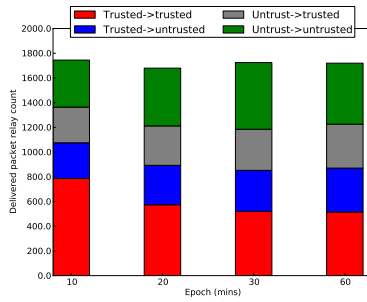
(b) Overall packets. Ephemeral ID valid for 6 epochs



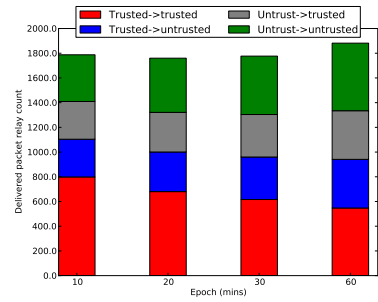
(c) Overall packets. Ephemeral ID valid for 6 epochs. Infinite packet buffer.



(d) Delivered packets. Ephemeral ID valid for 3 epochs

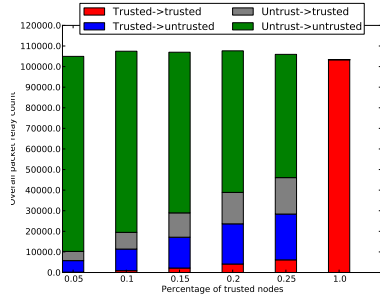


(e) Delivered packets. Ephemeral ID valid for 6 epochs

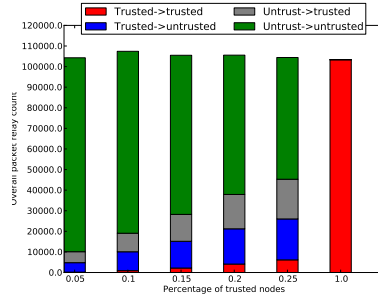


(f) Delivered packets. Ephemeral ID valid for 6 epochs. Infinite packet buffer

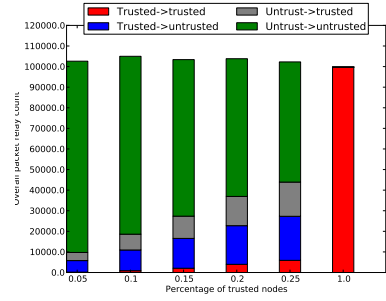
Figure 5: **Packet relay classification over varying epoch. Percentage of trusted nodes is 15%.** Ephemeral ID duration does not affect overall packet relay classification, but it affects delivered packet relay classification. When ephemeral ID duration is 6 epochs, packet relays between two trusted nodes are slightly decreased while other types of relays are increased.



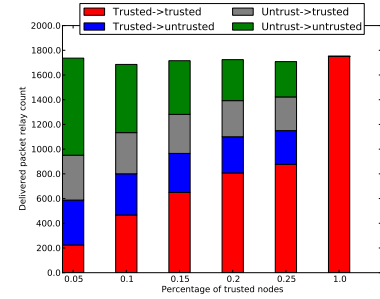
(a) Overall packets. Ephemeral ID valid for 3 epochs.



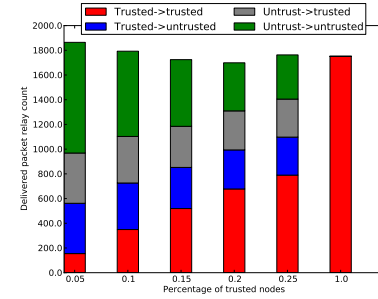
(b) Overall packets. Ephemeral ID valid for 6 epochs.



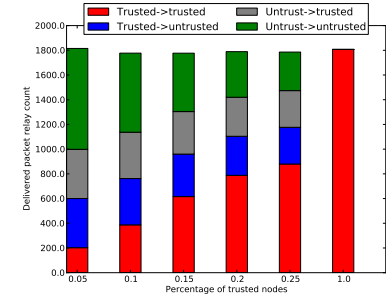
(c) Overall packets. Ephemeral ID valid for 6 epochs. Infinite packet buffer.



(d) Delivered packets. Ephemeral ID valid for 3 epochs.



(e) Delivered packets. Ephemeral ID valid for 6 epochs.



(f) Delivered packets. Ephemeral ID valid for 6 epochs. Infinite packet buffer.

**Figure 6: Packet relay classification over varying percentage of trusted nodes. Epoch is 30 mins.** As in Figure 5, ephemeral ID duration does not affect overall packet relay classification but affects delivered packet relay classification.

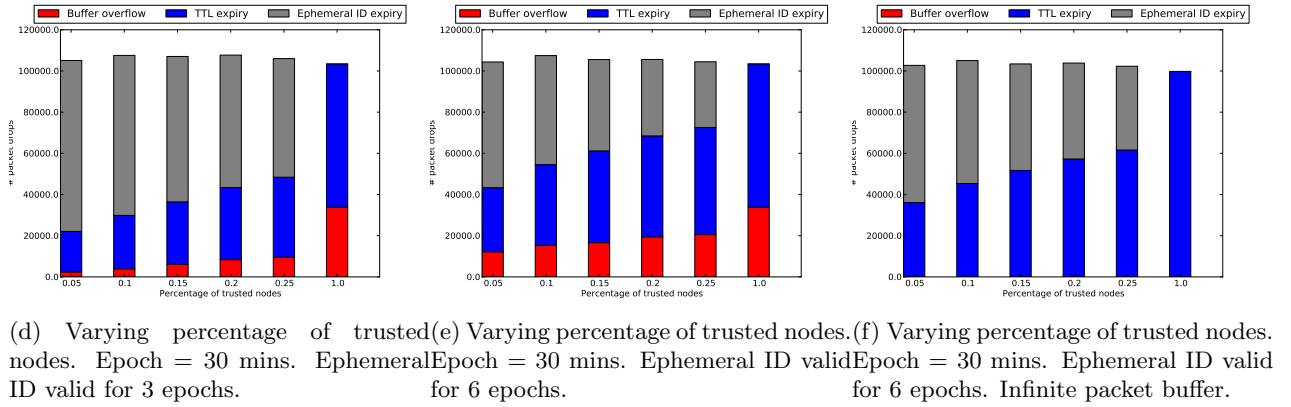
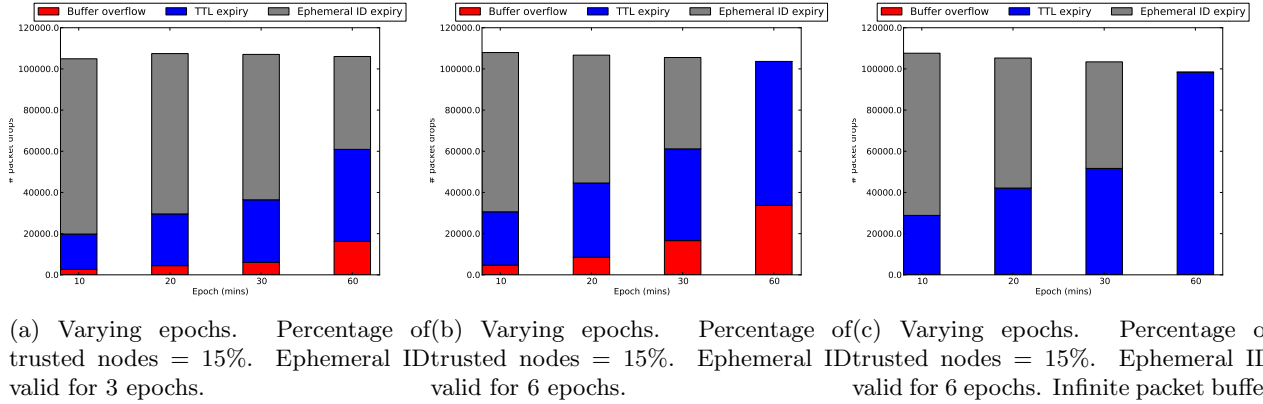


Figure 7: **Packet drop classification.** With ephemeral ID valid for 6 epochs (Figures 7b and 7e), packet drops due to ephemeral ID expiry are decreased significantly. Note that packet drop due to ephemeral ID expiry does not occur when epoch is 60 mins and ephemeral ID duration is 6 epochs. [TTL (5 hours) < Epoch (1 hour) \* Ephemeral ID duration (6 epochs)]

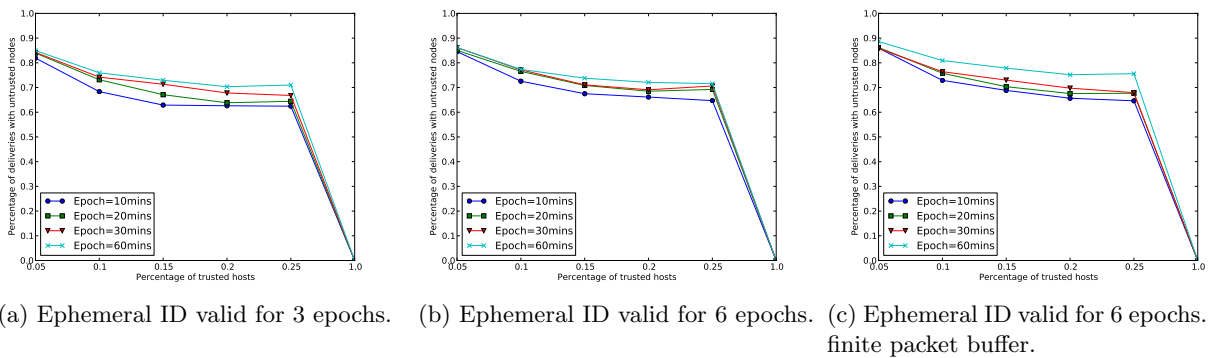


Figure 8: **Packet deliveries with untrusted nodes.** Percentage of packet delivery routes containing at least one untrusted node.



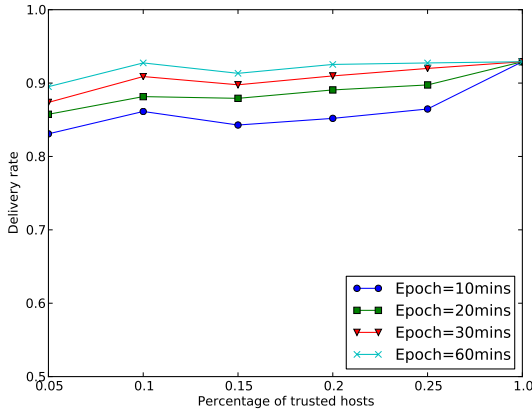
### 1.2.2 Communication among all nodes

In this test scenario, every node can send packets to any other nodes. Packet generation follows rules below:

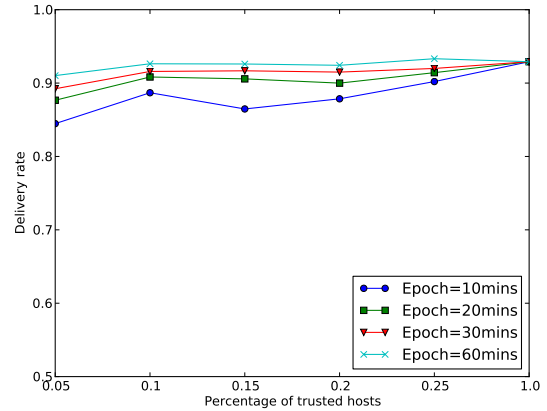
- Nodes belong to the group generate and receive about 20% of overall packets generated during the simulation.
- For the rest 80% of packet generation, sender and receiver are randomly selected from all node.

Ephemeral ID duration	Trusted nodes %	Epoch
3 epochs	5%	60 mins
	10%	30 mins
6 epochs	5%	30 mins
	10%	20 mins

Table 2: **Example settings with overall delivery rate of about 90% (Flooding: 92.91%).**

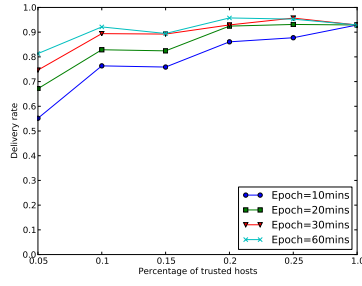


(a) Ephemeral ID valid for 3 epochs

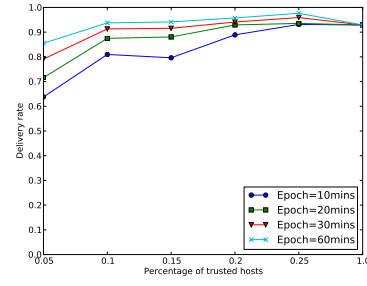


(b) Ephemeral ID valid for 6 epochs

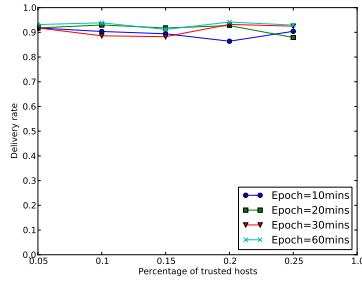
Figure 9: **Overall packet delivery rate.** Delivery rate of pure epidemic routing: 92.91%. With epoch=60 mins, overall delivery rate is almost similar to that of epidemic routing regardless of the percentage of trusted nodes. In Figure 9b, delivery rates with epoch  $\geq 20$  mins are about 90%, especially when the percentage of trusted nodes  $\geq 10\%$ .



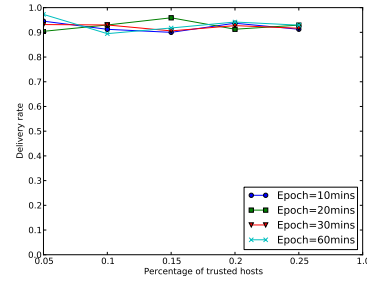
(a) In-group to In-group. Ephemeral ID valid for 3 epochs



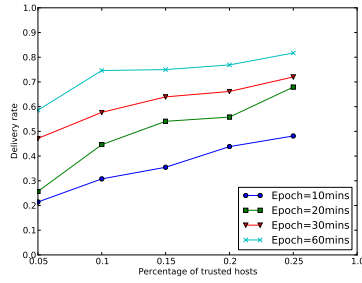
(b) In-group to In-group. Ephemeral ID valid for 6 epochs



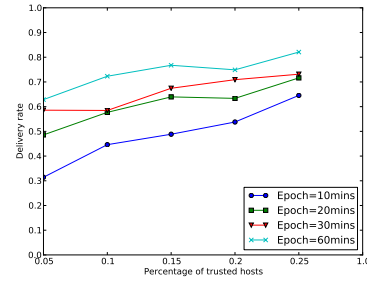
(c) In-group to Out-of-group. Ephemeral ID valid for 3 epochs



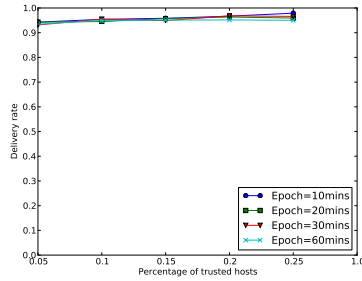
(d) In-group to Out-of-group. Ephemeral ID valid for 6 epochs



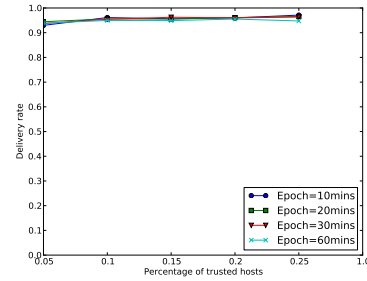
(e) Out-of-group to In-group. Ephemeral ID valid for 3 epochs



(f) Out-of-group to In-group. Ephemeral ID valid for 6 epochs

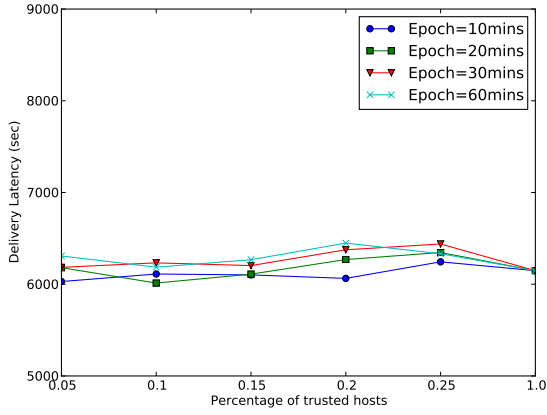


(g) Out-of-group to Out-of-group. Ephemeral ID valid for 3 epochs

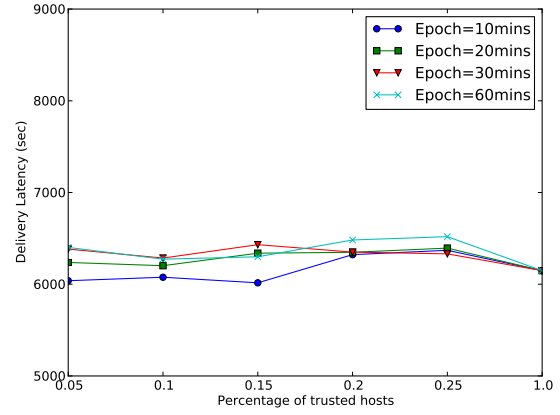


(h) Out-group to Out-of-group. Ephemeral ID valid for 6 epochs

Figure 10: **Detailed packet delivery rate.** Delivery rate of packets destined for ‘out-of-group’ is almost same to that of epidemic routing, regardless of epoch and percentage of trusted nodes. Delivery rate of ‘Out-of-group’ to ‘In-group’ is relatively low, ranging from 20% to 80%.

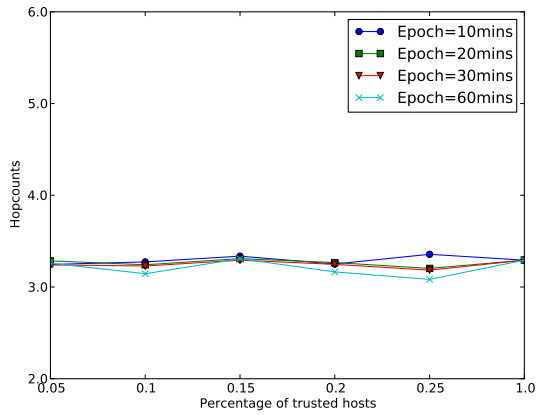


(a) Ephemeral ID valid for 3 epoch

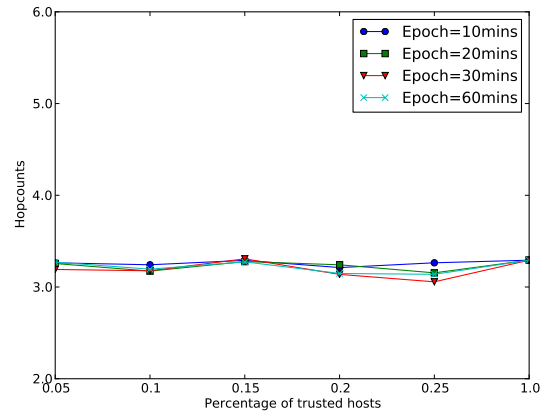


(b) Ephemeral ID valid for 6 epochs

Figure 11: **Overall packet delivery latency.** Overall packet delivery rate is almost same to that of epidemic routing.



(a) Ephemeral ID valid for 3 epochs



(b) Ephemeral ID valid for 6 epochs

Figure 12: **Overall packet delivery hop count.** Overall delivery hop count is almost same to that of epidemic routing.