Talk on Routing in Delay tolerant networks

Is it different from conventional routing algorithms?

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1. Introduction

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What is a Delay Tolerant Network?
Network that operates with intermittent and highly delayed connections and low degree of interactivity, but the flexibility of the Network architecture allows them to be connected to each other.
Introduction

Why not conventional Routing Algo ???

Some Reasons!

- The conventional protocols trying to first establish a complete route and then, after the route has been established, forward the actual data.
- Count to $\infty$ problem.

What is the solution?

Since instantaneous end-to-end paths are difficult or impossible to establish, routing protocols must take to a "store and forward" approach.
The network is a DTN and consists of n nodes (including the source and destination).

At any point of time there is a single copy of the message in the network.

The inter-contact times between any 2 nodes $i$ & $j$ is iid exponential distributed with parameter $\lambda_{ij}$.

If the nodes $i$ & $j$ never meet then we set $\lambda_{ij} = 0$.

The remaining inter-contact time between 2 nodes $i$ & $j$ at time instant $t$ is denoted by $R_{ij}^t$. We know that this is also exponential distributed with parameter $\lambda_{ij}$. 
The 2-Hop relay strategy

\[ X = \inf \left( R_{sd}^t, R_{sr_1}^t, \ldots, R_{sr_{n-2}}^t \right) \]

\( X \) is exponentially with parameter \( \Lambda_s \) given by

\[ \Lambda_s = \lambda_{sd} + \sum_{i=1}^{n-2} \lambda_{sr_i} \]

Mean delivery time for the 2-hop network

\[ E[D_{sd}^{2-MH}] = \frac{1 + \sum_{r \neq s, r \neq d} \frac{\lambda_{sr}}{\lambda_{rd}}}{\sum_{r \neq s} \lambda_{sr}} \]
Taking only a subset $R$ of the rest of the nodes and setting $\frac{1}{\lambda_{dd}}$ to 0 we have,

**Mean delivery time for a variation of the 2-hop relay strategy**

$$E[D_{sd}^{2-MH^R}] = \frac{1 + \sum_{r \in R} \frac{\lambda_{sr}}{\lambda_{rd}}}{\sum_{r \in R} \lambda_{sr}}$$
To find the subset $R$ that minimizes the mean delivery time for the variation of the 2-hop relay strategy the following algorithm is proposed.

**Algorithm**

```plaintext
for every destination $d$ do
    Sort its neighbors in increasing mean inter-contact times, in which case we have: $0 \leq \frac{1}{\lambda_{1d}} \leq \frac{1}{\lambda_{2d}} \leq \ldots \leq \frac{1}{\lambda_{nd}}$
    Initialize the result set $I = \emptyset$ and corresponding minimal mean delivery time (using set $I$) $c_I = \frac{1}{\lambda_{1d}}$

    for $i = 1,...,k$ do
        Add node $i$ to set $I$ and compute $E[D_{sd}^{2-MH}]$. If this value is strictly larger than $c_I$, remove node from $I$ and stop Otherwise, place this value in $c_I$
    end

end
```
Mean delivery time for a variation of the 3-hop relay strategy

\[
E[D_{sd}^{3-MHR^*}] = \frac{1 + \sum_{r \in R^*} \lambda_{sr} \times E[D_{sd}^{2-MHR^*}]}{\sum_{r \in R^*} \lambda_{sr}}
\]

- On recursion any \( E[D_{sd}^{k-MHR^*}] \) can be found.
- It can be shown that \( E[D_{sd}^{k-MHR^*}] \) decreases with \( k \).
Outline

1. Introduction

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The network is a DTN and consists of $N+1$ nodes (including the source and destination).

The inter-contact times between any 2 nodes $i$ & $j$ is iid exponential distributed with same parameter $\lambda$.

This is a generalized version of Epidemic Routing.

When the relay node without the message encounters a source node or another relay node with the message, then it accepts the packet with a prob $q$ (for source) or prob $p$ (for relay).

Once the Dest. receives the message, corresponding anti-packets are broadcasted to all nodes. This recovery scheme is called VACCINE.
Each node has a list of outstanding messages and the anti-packets with it.

When 2 nodes encounter they share information about the anti-packets and discard all outstanding messages corresponding to the newly received anti-packets.

A limit $M_{anti}$ is set on the number of anti-packets in the list. When new anti-packets arrive, the ones with oldest generation times are discarded.
Special cases of \((p,q)\)-Epidemic Routing

- Direct Source-Destn delivery \((p = q = 0)\)
- Two-hop Forwarding \((p=0,q = 1)\)
- Probabilistic Forwarding \((0 < p=q < 1)\)
- Conventional Epidemic Routing \((p =q = 1)\)
We have a MC

The process \( \{X(t); t \leq 0\} \) representing the number of copies of the message in the network is a MC with state space \( \{0, 1, 2, \ldots, N\} \). State 0 representing the sink (or dest)

**Generator matrix**

\[
q_{i,0} = i \ast \lambda \\
q_{i,i+1} = a(i) \ast \lambda \\
\text{where } a(i) = (N - i) \ast ((i - 1) \ast p + q)
\]
first and second moments of delivery delay $T_D$

\[
E[T_D] = \sum_{k=1}^{N} r_k \cdot \frac{1}{k \cdot \lambda}
\]

\[
E[T_D^2] = \sum_{k=1}^{N} r_k \left[ \sum_{m=1}^{k} \left( \frac{1}{\{a(m) + m\} \cdot \lambda} \right)^2 \right]
\]

where \( r_k = \left( \prod_{m=1}^{k-1} \frac{a(m)}{a(m) + m} \right) \cdot \left( \frac{k}{a(k) + k} \right) \)
References

- Fixed Point Opportunistic Routing in Delay Tolerant Networks  
  IEEE JSAC VOL. 26, NO. 5, JUNE 2008  
  Authors: Vania Conan, Jérémie Leguay, Timur Friedman

- (p,q)-Epidemic routing for sparsely populated mobile ad hoc networks  
  IEEE JSAC VOL. 26, NO. 5, JUNE 2008  
  Authors: T. Matsuda, T. Takine
Thanks!!!