Prediction-based Routing with Packet Scheduling under Temporal Constraint in Delay Tolerant Networks

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Outline

• Background
• Motivation
• PRPS Protocol
• Simulation
• Conclusion
Background

• Delay- or Disruption-Tolerant Networks (DTNs)
  – Characteristics:
    • Heterogeneous network
    • Temporary or intermittent connectivity

Wildlife Tracking
Providing Connectivity to rural areas
Vehicular Communications
Stable infrastructure destroyed
Background

• Routing in DTNs:
  – Suffers from the lack of continuous connectivity.
  – Two categories:
    • Flooding strategies:
      – Direct Contact, Two-hop Relay, Tree-based Flooding, Epidemic Routing.
    • Forwarding strategies with topology information:
      – Location-based Routing, Gradient Routing, Link Metric Routing
Motivation

• Consider the messages in DTN

Where?
How?
When?

My work bad or good? QoS
Delivery ratio
Delivery delay
Motivation

• Add a dose of altruism to a network.
  – Add packet scheduling to the routing

• Constraints:
  – Messages may have different sources, destinations and TTLs.
  – Resources like the contact opportunities and duration are limited
    • Each contact, only one message can be forwarded.
Prediction-based routing with packet scheduling (PRPS)

• Goal: increase the overall delivery ratio.
• Two phases:
  – Depict Ability Graph:
    • model the probability of each message arriving at its destination within its TTL
  – Packet Scheduling Process:
    • schedule the packets in the pairs of nodes
Ability Graph

• Model of contact process:
  – contact process of each pair of nodes is modeled as a homogeneous Poisson process.
  – $P_{ij}$ Can be described as the number of events that happen between entities $i$ and $j$ with time interval $\tau$.
    $$P[(N(t+\tau) - N(t)) = \mu] = \frac{e^{-\lambda \tau} (\lambda \tau)^\mu}{\mu!}, \mu = 0, 1, \ldots$$
  – When $\mu = 0$
    $$P[(N(t+\tau) - N(t)) = 0] = e^{-\lambda t}$$
Ability Graph

• Probability of no contact between pair of nodes $a$ and $b$ during time interval $\tau$.

$$q_{ab} = e^{-\lambda_{ab} \tau}$$

• The contact probability:

$$c_{ab} = 1 - q_{ab}$$

• Define $P_{ab}^{TTL}$ as the probability that message $m$ arrives at $b$ from $a$ with $m$’s $TTL$.

$$P_{ab}^{TTL} = 1 - \prod_{s=0}^{S} (1 - R_{P_s})$$
Ability Graph

• Calculate $P_{ab}^{TTL}$
  – NP-hard (finding $k$ shortest paths with limited length is NP-hard if $k$ increases to infinity)

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**Algorithm 1: Constructing an Ability Graph**

**Input:** A graph $G = (V, E)$, two distinct nodes $a$ and $b$ in $G$, and time constraint $TTL$

**Output:** The probability of successfully forwarding a message from $a$ to $b$ within $TTL$: $P_{ab}^{TTL}$

1. $S = \emptyset$.
2. $N_a = \{v \mid (a, v) \in E\}$. $S = \{(a, v) \mid v \in N_a\}$. Regard every edge in $S$ as a path and $S = \{P_1, P_2, \cdots, P_{|S|}\}$.
3. $RP_r = \max(RP_i)$ where $RP_i$ is the reachable probability of path $P_i$ and $P_i \in S$.
4. Set $h$ to be the endpoint of $P_r$. Let $N_h = \{v \mid (h, v) \in E\}$. Remove $P_r$ from $S$ and add $P_r + (h, v)$ in $S$ if $|P_r| < TTL$ where $v \in N_h$ and $|P_r|$ is the number of edges in $P_r$.
5. Output $P_i \in S$ if the endpoint of $P_i$ is $b$. Remove $P_j$ from $S$ if $\exists e (e \in P_i \land e \in P_j)$ where $e$ is an edge in any path.
6. Repeat Step 3 and Step 4 until $S = \emptyset$, or $k$ paths are found, or there are no more edges which can be added;
7. Calculate $P_{ab}^{TTL}$. 
Packet Scheduling Process

• Utility in each node:

\[ U_{ab}(\omega) = \sum_{i=0}^{t} P_{b,i}^{TTL} \omega_{i,0} + \sum_{i=0}^{t} \sum_{j=1}^{TTL} P_{a,i}^{TTL-j} \omega_{i,j} \]

• Find the schedule to maximize the utility for each encounter.

\[
U^*_{ab} = \max_{\omega} \sum_{i=0}^{t} P_{b,i}^{TTL} \omega_{i,0} + \sum_{i=0}^{t} \sum_{j=1}^{TTL} P_{a,i}^{TTL-j} \omega_{i,j}
\]

subject to

\[ \sum_{i=0}^{K} \omega_{i,j} \leq 1, \forall j \in TTL \]

\[ \sum_{j=0}^{\kappa} \omega_{i,j} \leq 1, \forall i \in t \]

\[ \omega_{i,j} \in \{0, 1\} \]
Packet Scheduling Process

• The optimal packet scheduling problem can be transformed to Maximum Weight Bipartite Matching.

| TTL | $m_1$ | | $m_2$ | | $m_3$ | |
|-----|------|-----|------|-----|------|
|     | a    | b   | a    | b   | a    | b   |
| 4   | 0.6  | 0.65| 0.8  | 1.0 | 0.5  | 0.5 |
| 3   | 0.5  | 0.6 | 0.8  | 1.0 | 0.3  | 0.35|
| 2   | 0.5  | 0.5 | 0.7  | 1.0 | 0.1  | 0.3 |
| 1   | 0.4  | 0.4 | 0.6  | 1.0 | N/A  | N/A |

TABLE I: EXAMPLE OF UTILITY EXPECTATION
Simulation

• Data Sets:
  – Synthetic traces
  – Infocom06
  – Sigcomm09

• Methods:
  – Epidemic
  – FCFS
  – PRPS-Greedy
  – PRPS-MWBM
Simulation

- Delivery Ratio:

Fig. 2: Comparison of delivery ratio on different data sets with Maximum $TTL = 15$.

Fig. 3: Comparison of delivery ratio on different data sets with average density of messages $\sigma = 10$. 
Simulation

• Delivery Delay:

Fig. 4: Comparison of delivery latency on different data sets with Maximum $TTL = 15$.

Fig. 5: Comparison of delivery latency on different data sets with average density of messages $\sigma = 10$. 
Conclusion

• A practical prediction-based routing protocol with packet scheduling.

• Add a dose of altruism of packet priorities to increase the overall delivery ratio.

• Simulations show that our protocol can effectively increase the overall delivery ratio without decreasing overall delivery delay much.
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Thank You

Q&A