RelayCast: Scalable Multicast Routing in Delay Tolerant Networks

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DTN Multicast Routing

- Delay tolerant networking:
  - Suitable for non-interactive, delay tolerant apps
  - Ranging from connected wireless nets to wireless mobile nets with disruptions (or delay tolerant networks)
- DTN multicast provides reliable data multicast even with disruptions
- DTN multicast routing methods:
  - Tree/mesh (+ mobility), ferry/mule, epidemic dissemination
- DTN multicast questions: **Throughput/delay/buffer bounds?**
- Focus: dissemination; upper bound of all cases

![Diagram of DTN multicast routing](http://www.dtnrg.org)
DTN Model

- Pair-wise inter-contact time: interval between two contact points

  ![Diagram of contact points between two nodes: i and j](image)

  - Contact points between two nodes: i and j
    - $T_{ic}(1)$
    - $T_{ic}(2)$
    - $T_{ic}(3)$

- Common assumption: exponential inter-contact time
  - Random direction, random waypoint, etc.
  - Real world traces also have “exponential” tails [Karagiannis07]

- **Exponential inter-contact time** $\Rightarrow$ **Inter-contact rate:** $\lambda \sim \text{speed x radio range}$ [Groenevelt05]

- Assumption: $n$ nodes in 1x1 unit area; radio range: $O(1/\sqrt{n})$ and speed: $O(1/\sqrt{n})$ $\Leftrightarrow$ meeting rate: $\lambda = O(1/n)$
2-Hop Relay: DTN Unicast Routing

- Each source has a random destination (n source-destination pairs)
- 2-hop relay protocol:
  1. Source sends a packet to a relay node
  2. Relay node delivers a packet to the corresponding receiver

![2-hop Relay by Grossglauser and Tse](image)
2-Hop Relay: Throughput/Delay

- Throughput is determined by **aggregate meeting rate**
  - [Src ↔ relay nodes], [Dest ↔ relay nodes]
- 2-hop relay throughput: $\Theta(n\lambda)$
  - G&T’s results: $\Theta(n\lambda) = \Theta(1)$ for $\lambda = 1/n$ (i.e., speed=radio=1/$\sqrt{n}$)
- 2-hop relay delay: $\Theta(1/\lambda)$
  - Avg. time for a relay to meet a dest (~exp dist!): $1/\lambda$
  - Ex) For $\lambda = 1/n$, avg. delay is $\Theta(n)$ (Neely&Modiano)

![Diagram of 2-hop relay](image)
RelayCast: DTN Multicast Routing

- 2-hop relay based multicast:
  1. Source sends a packet to a relay node
  2. Relay node delivers the packet to **ALL** multicast receivers

NB. Source & Destinations are also mobile
RelayCast: Throughput Analysis

- RelayCast throughput: $\Theta(n\lambda/n_x)$
  - $n_s$ srcs, each of which associated with $n_d$ random dests
  - Multiple srcs may choose the same node as a dest
  - Avg. # of competing sources per receiver: $n_x$

Each src chooses 3 rand dests

$n_x = n_s * n_d / n$

Relay Node in RelayCast
RelayCast: Delay Analysis

- Relay node delivers a packet to ALL destinations
- $n_x$ competing srcs per dest: individual rate is split to $\lambda/n_x$
- RelayCast avg. delay: $\Theta(n_x/\lambda(\log n_d+\gamma))$
  - where $\gamma = \text{Euler constant}$

\[
\text{Avg. delay} = \sum n_x/k\lambda = n_x/\lambda \sum 1/k = n_x/\lambda \left( \log n_d + \gamma \right)
\]
RelayCast: Buffer Requirement

- Little’s law: buffer = (rate) x (delay)
- Buffer per source = $\Theta(nn_d)$
  - Avg. sub-queue length: $\lambda/n_x^*n_x/\lambda = \Theta(1)$ by Little’s law
  - Each src has $n_d$ dest: packet is replicated to $n_d$ copies
  - Per src buffer at a relay = $\Theta(n_d) \Rightarrow n$ relays: buffer = $\Theta(nn_d)$
- Buffer upper bound per source = $\Theta(n^2)$
Comparison with Previous Results

- Assumptions; $n$ fixed, and $r = \sqrt{\log n}/n$ for G&K; $r = 1/\sqrt{n}$ for 2-hop relay
- Throughput scaling with $n_s = \Theta(n)$; $n_x = n_s n_d/n = n_d \Leftrightarrow \text{RelayCast} = \Theta(1/ n_d)$
- Better throughput than conventional multi-hop multicast ($w/ r = \sqrt{\log n}$)

![Graph showing throughput scaling with different multicast schemes.](image-url)
Simulation Results

*RelayCast throughput with varying # of relay nodes*

- DTN with fixed $\lambda$: throughput linearly increases
  - RelayCast throughput = $\Theta(n\lambda)$ for $n_s n_d \leq n$
- As # node increases, interference comes in; throughput is tapered off

![Graph showing throughput vs. number of relay nodes]

QualNet v3.9.5
Network: 5000mx5000m
Random waypoint
802.11b: 2Mbps
250m radio range
Traffic: $n_s=1$, $n_d=$# of relay nodes
Simulation Results

Comparison with conventional multicast protocol

- RelayCast is scalable; ODMRP’s throughput decreases significantly, as # sources increases.
- But delay has significantly increased; RelayCast ~ 2000s vs. ODMRP < 1s.
Simulation Results

Average delay with varying # of receivers

- RelayCast delay = $\Theta(n_x/\lambda(\log n_d+\gamma))$
- Delay increases as # of receivers increases
Conclusion

- **RelayCast:**
  - Provides reliable multicast even with disruption
  - Achieves the maximum throughput bound of DTN multicast routing

- **DTN routing protocol design and comparison must consider throughput/delay/buffer trade-offs**

- **Future work**
  - Analysis of other DTN routing strategies
  - Impact of correlated motion patterns: i.e., power-law head and exponential tail inter-contact time distribution