RelayCast: Scalable Multicast Routing in Delay Tolerant Networks

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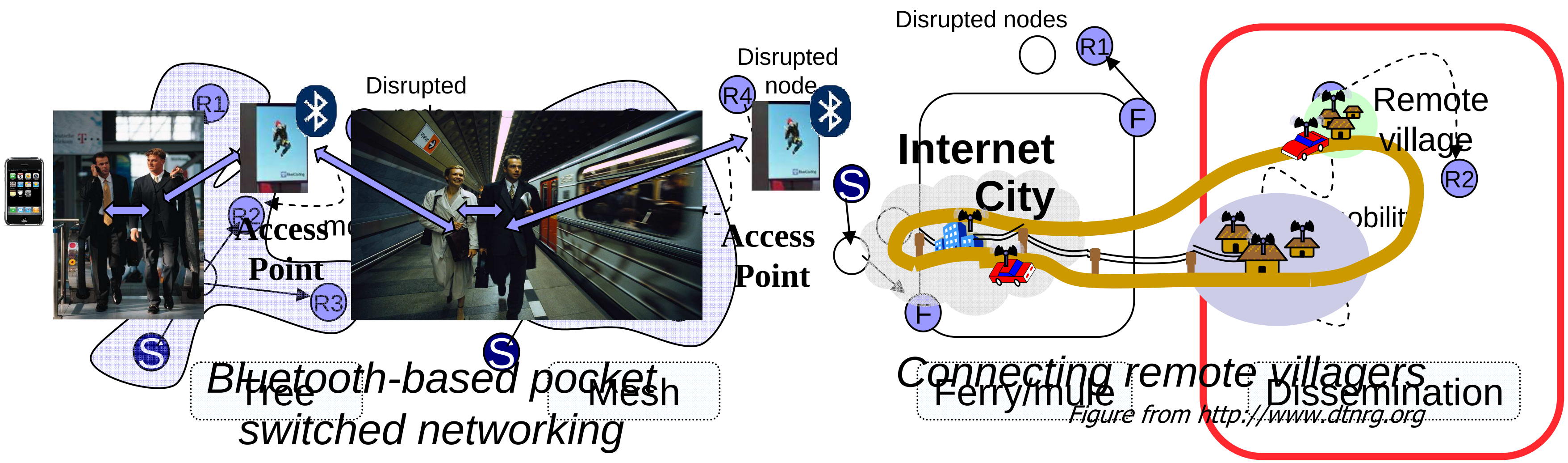
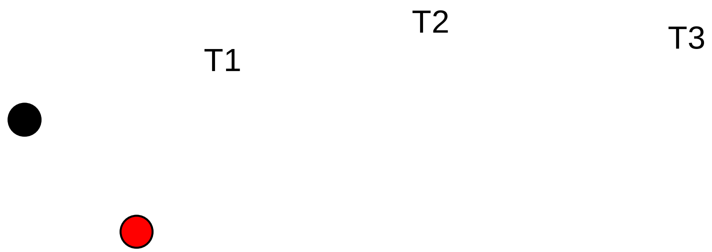
DTN Multicast Routing

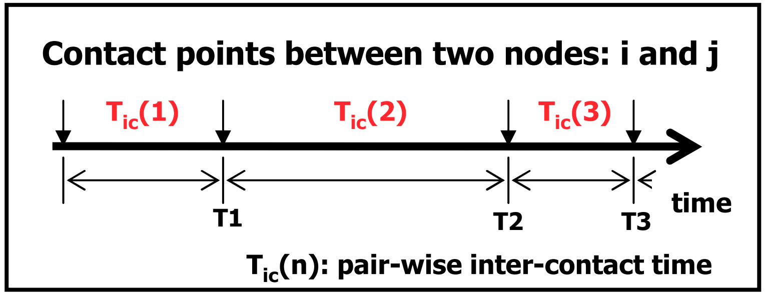
- Delay tolerant networking:
  - Suitable for non-interactive, delay tolerant apps
  - Ranging from connected wireless nets to wireless mobile nets with disruptions (or delay tolerant networks)
- DTN multicast provides reliable data multicast even with disruptions
- DTN multicast routing methods:
  -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



DTN Model

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

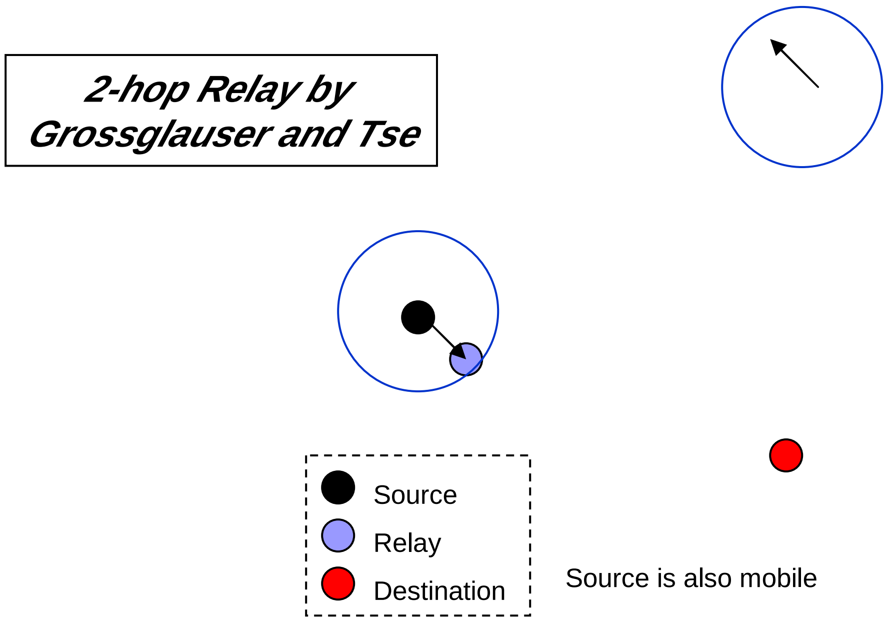




- Common assumption: exponential inter-contact time
  - Random direction, random waypoint, etc.
  - Real world traces also have "exponential" tails *[Karagiannis07]*
- **Exponential inter-contact time ➔ Inter-contact rate: λ ~ speed x radio range** *[Groenevelt05]*
- Assumption: *n* nodes in 1x1 unit area; radio range: $O(1/\sqrt{n})$ and speed: $O(1/\sqrt{n})$ ⇔ meeting rate: $\lambda=O(1/n)$

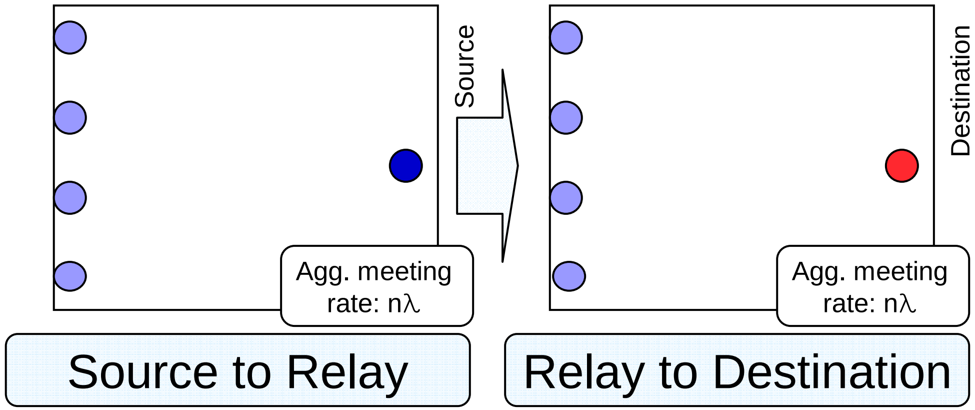
2-Hop Relay: DTN Unicast Routing

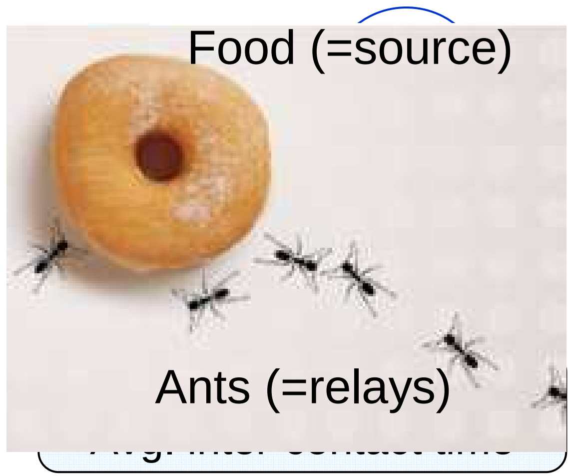
- Each source has a random destination (n source-destination pairs)
- 2-hop relay protocol:
  1. Source sends a packet to a relay node
  2. Relay node delivers a packet to the corresponding receiver



2-Hop Relay: Throughput/Delay

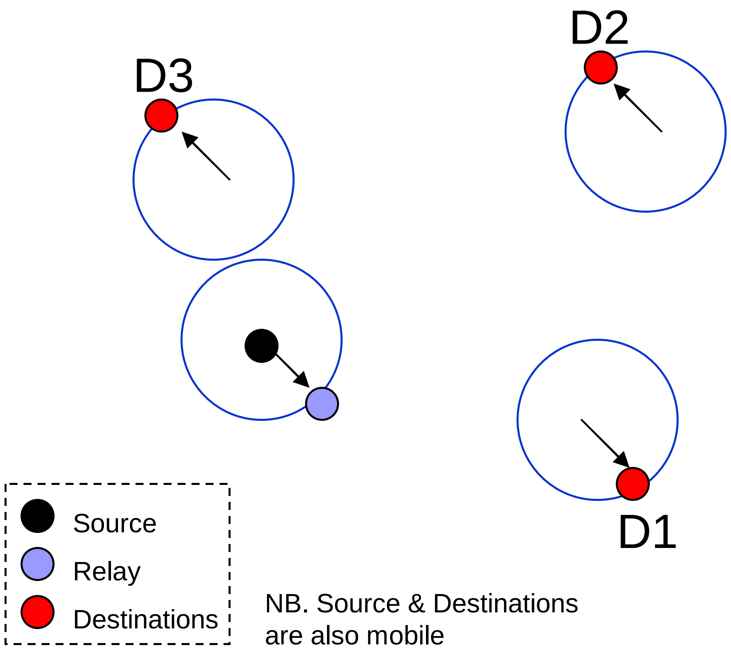
- Throughput is determined by <u>**aggregate meeting rate**</u>
  - [Src ⇔ relay nodes], [Dest ⇔ relay nodes]
- 2-hop relay throughput: $\Theta(n\lambda)$
  - G&T's results: $\Theta(n\lambda)=\Theta(1)$ for $\lambda=1/n$ (i.e., speed=radio=$1/\sqrt{n}$)
- 2-hop relay delay: $\Theta(1/\lambda)$
  - Avg.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



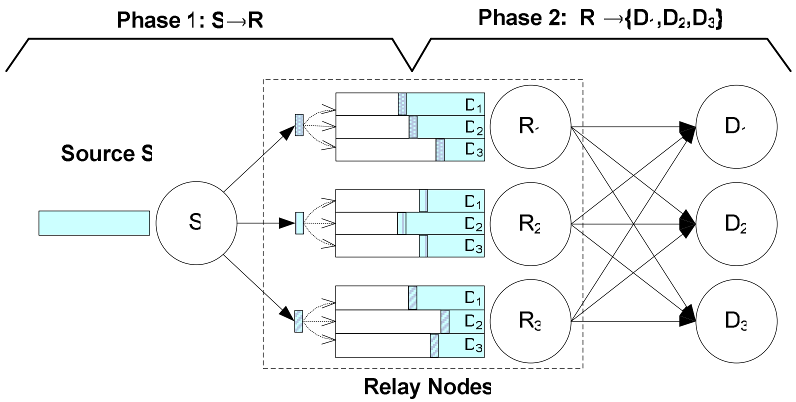


RelayCast: DTN Multicast Routing

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



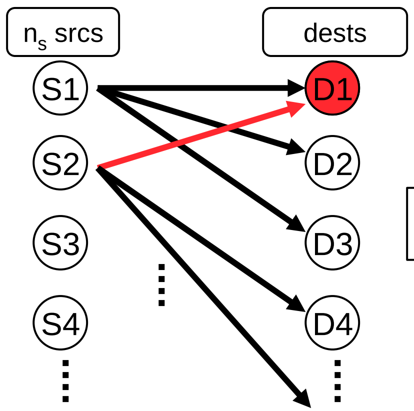
NB. Source & Destinations
are also mobile



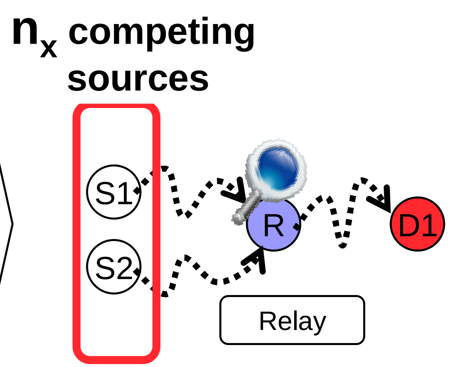
RelayCast: 2-hop relay based multicast

RelayCast: Throughput Analysis

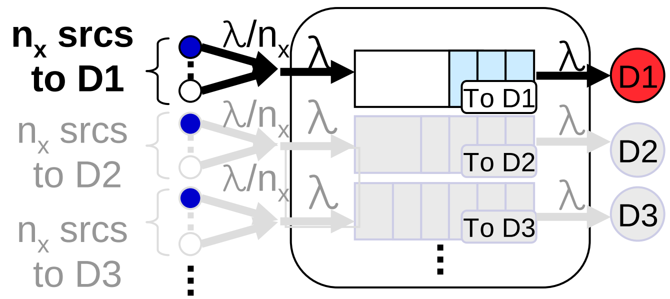
- RelayCast throughput: $\Theta(n\lambda/n_x)$
  - n_s srcs, each of which associated with n_d random dests
  - Multiple srcs may choose the same node as a dest
  - **<u>Avg. # of competing sources per receiver</u>: n_x**



Each src chooses 3 rand dests



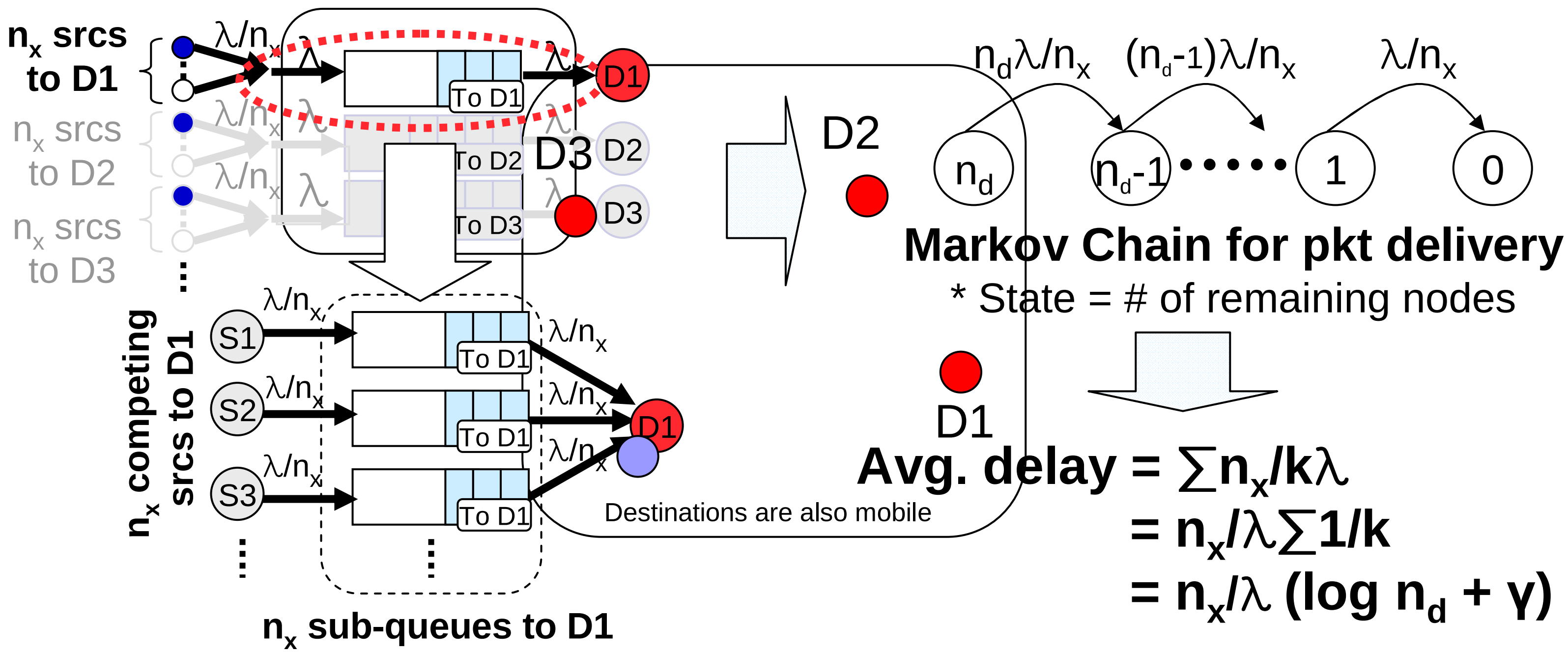
$n_x=n_s*n_d/n$



Relay Node in RelayCast

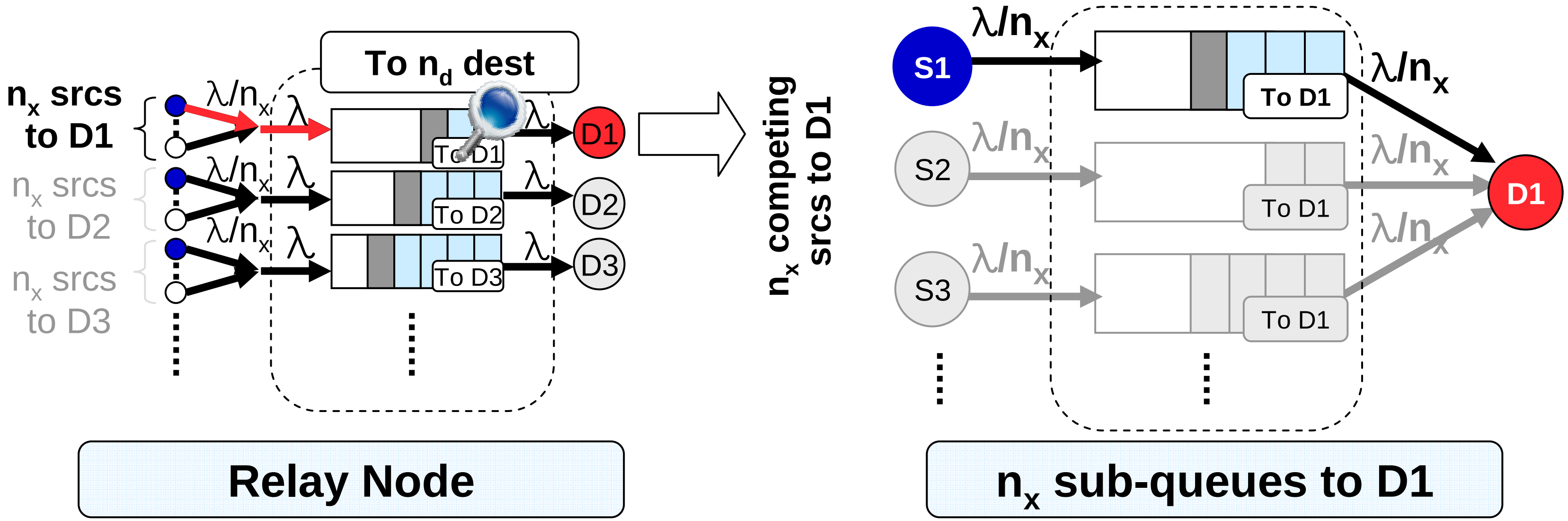
RelayCast: Delay Analysis

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



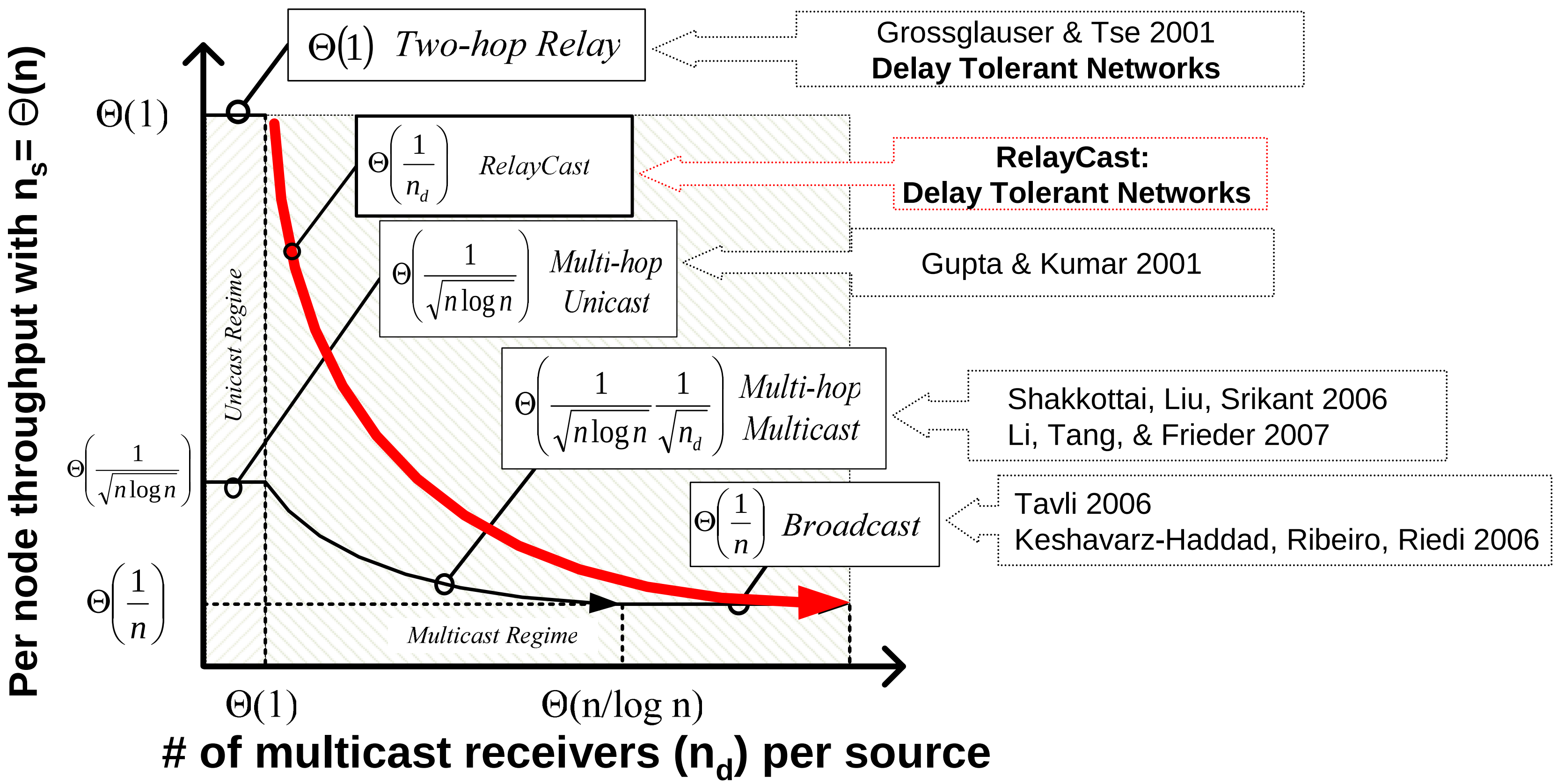
RelayCast: Buffer Requirement

- 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 = $\Theta(n_d)$ ➔ *n* relays: buffer = $\Theta(nn_d)$
- Buffer upper bound per source = $\Theta(n^2)$



Comparison with Previous Results

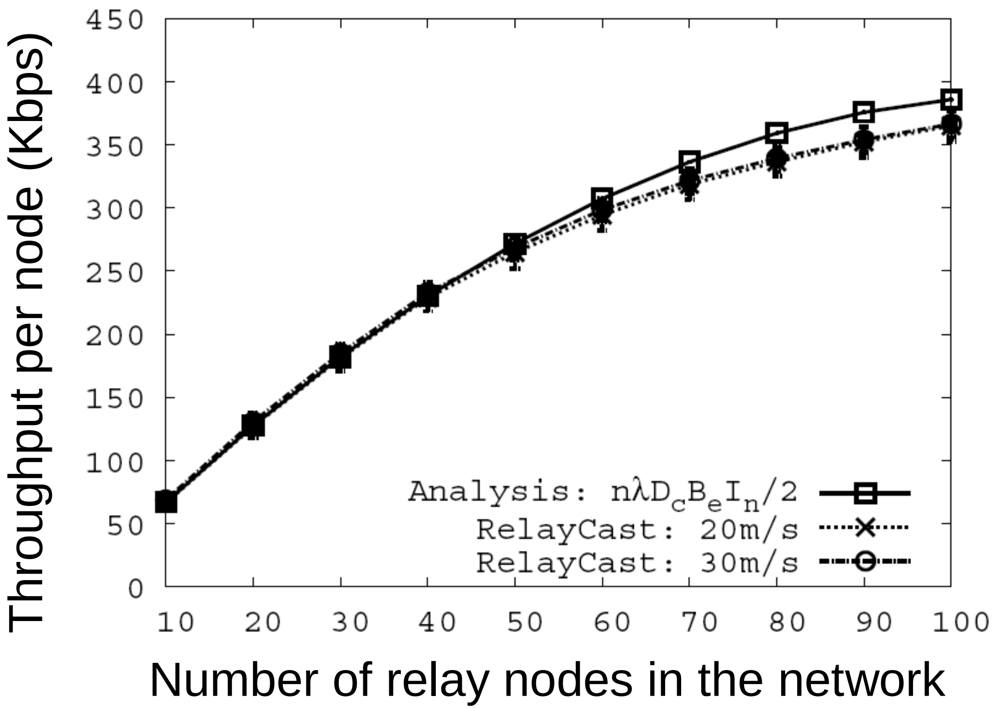
- Assumptions; *n* fixed, and r = √log*n*/*n* for G&K; r=1/√*n* for 2-hop relay
- Throughput scaling with $n_s = \Theta(n)$; $n_x = n_s n_d / n = n_d \Leftrightarrow$ RelayCast = $\Theta(1/n_d)$
- ***Better throughput than conventional multi-hop multicast (w/ r=√log*n*/*n*)***



Simulation Results

RelayCast throughput with varying # of relay nodes

- DTN with fixed λ: 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

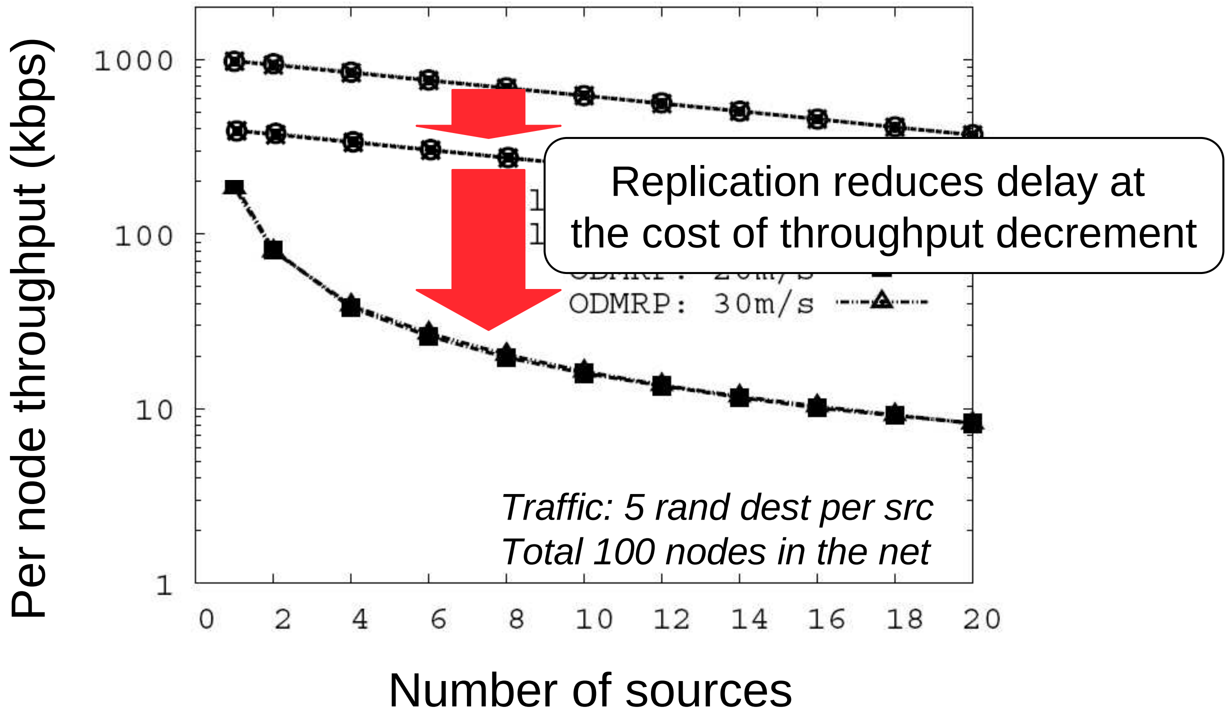


QualNet v3.9.5
Network: 5000mx5000m
Random waypoint
802.11b: 2Mbps
250m radio range
Traffic : n_s=1, n_d=# of relay nodes

Simulation Results

Comparison with conventional multicast protocol

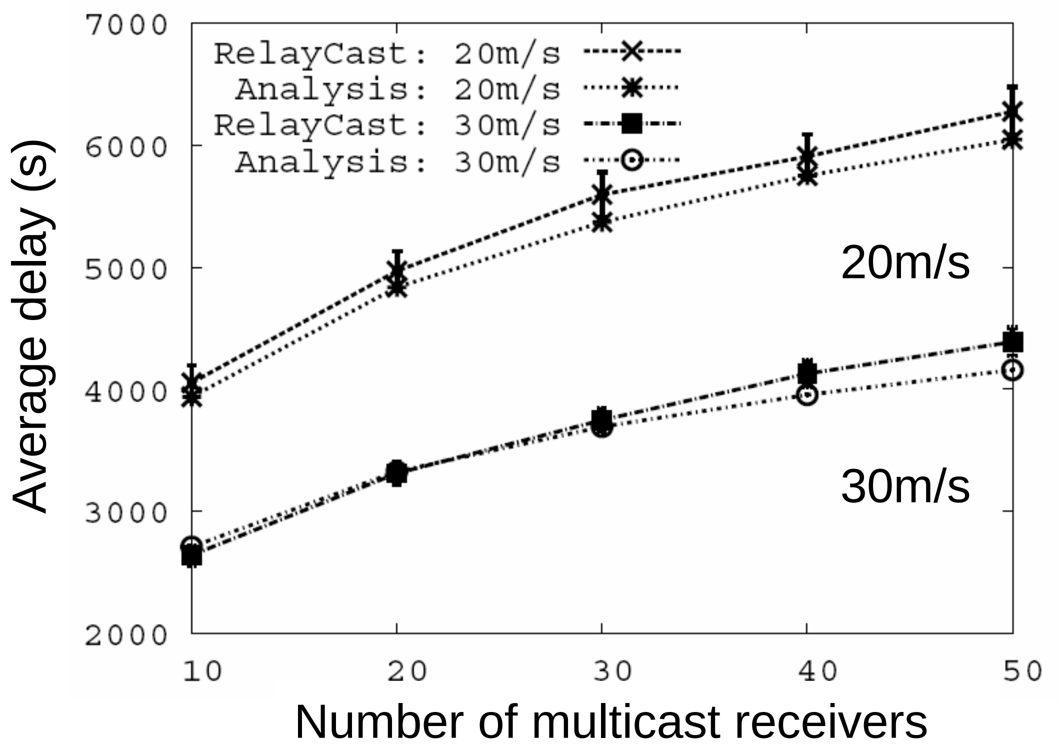
- RelayCast is scalable; ODMRP's throughput decreases significantly, as # sources increases
- But delay has significantly increased; RelayCast ~ 2000s vs. ODMRP < 1s



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