Mobile Ad-Hoc Networks (MANETs), Capacity bounds

Jorge García-Vidal
CompNet, DAC-UPC

Transport capacity in ad-hoc

- Problem: Assume that we randomly place N nodes in a square of 1 m^2 of area. Links have a capacity of R bps.
- What is the maximum throughput per node C we can achieve? What's the best strategy?
- Main results
  - Use the minimum transmission radius that ensures connectivity, obtaining

$$C = O(\frac{cR}{\sqrt{N \log N}})$$

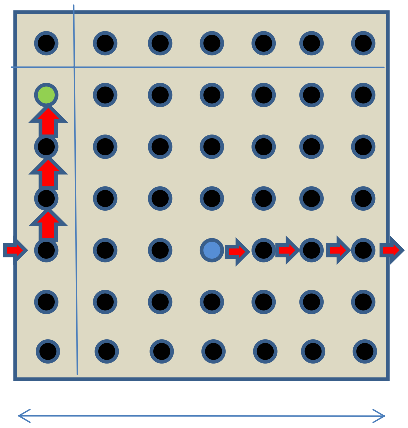
Gupta&Kumar, '00:

  - With node mobility, no delay-bounds, use a two-hop relay strategy, obtaining

$$C = O(cR)$$

Grosslauser, Tse, '01

Simplified scenario



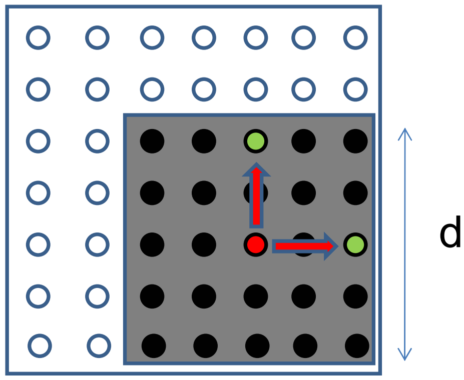
$\sqrt{N}$

N **fixed** nodes distributed in a grid

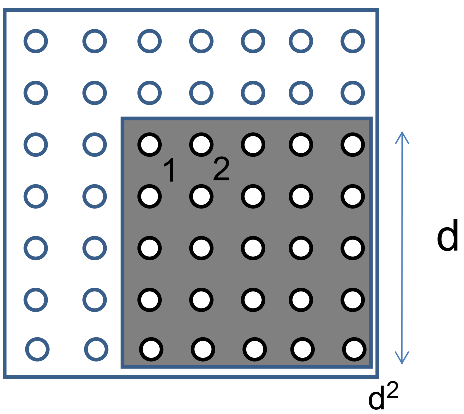
Sphere (boundaries are connected)

Routing: tx always horizontal-rigth, vertical-up
Chose always the node which minimizes # of hops

Tx range: d/2.



Simplified scenario



Scheduling: follow order in a d^2 square
(nodes have a tx opportunity every d^2 time-slots)

Pairing: every node choses randomly another node as destination.

Assume we are targeting the central node
(note than in a sphere we have symmetry).

Time is slotted in time units and we transmit **1** bit per slot.

Note that given our routing, packets start in horizontal, in average moving $\sqrt{N}/2$ nodes, and then they turn to a vertical path with same average length

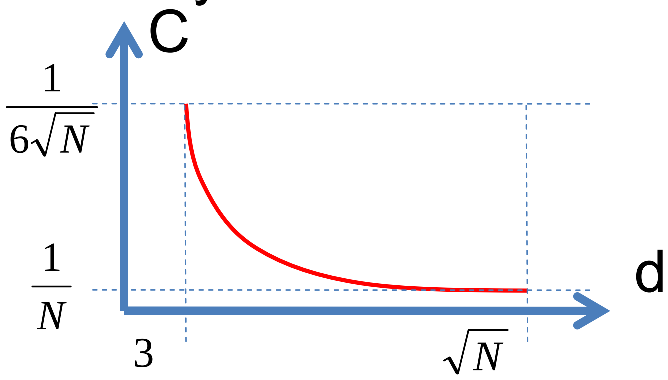
Transport capacity

- A node has to forward, in average, packets of $\frac{\sqrt{N}/2}{d/2}$ nodes on its left and same number of node above it.
- A node can transmit every d^2 time slots.

$$C(1+2\frac{\sqrt{N}}{d}) = \frac{1}{d^2} \quad \Rightarrow$$

$$C = \frac{1}{d^2 + 2d\sqrt{N}}$$

Note approx related with routing



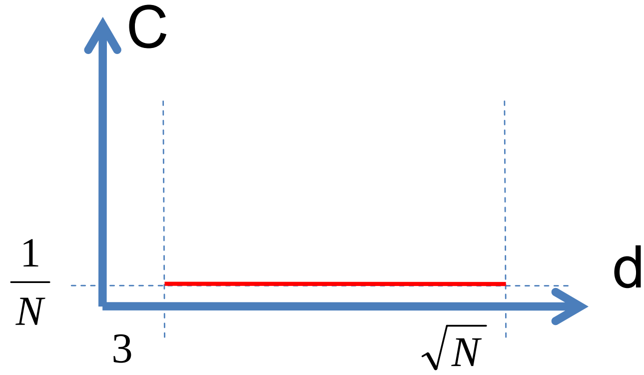
Mobile network

- Assume now that in every time slot, nodes move randomly. Infinite buffering in nodes and unbounded delay is allowed
- *First strategy*: do not use relays. Transmit whenever the destination node is in range
- *Second strategy*: two phases with two-hop relays
  - 1st phase: if a node carries a packet to another node which is in range, transmit.
  - 2nd phase: transmit to another node which will be a relay node.

Mobile nodes, no relaying

- Destination node will be in range every N/d^2 time slots.
- Transmission opportunity every d^2 slots. =>

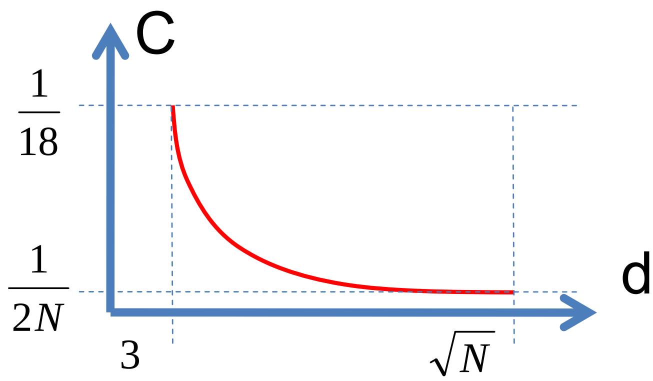
$$C = \frac{1}{N}$$



Mobile nodes, relaying

- Every $2d^2$ node has tx opportunity to a relay.
- In the long term, all nodes will have packets addressed to the other nodes. This means that every $2d^2$ slots they will have the opportunity of delivering a packet to its final destination

$$C = \frac{1}{2d^2}$$



Time to reach destination

- Note that once a packet is delivered to a relay, the time to reach a given destination follows a geometric law, with *finite* average of 18xN:

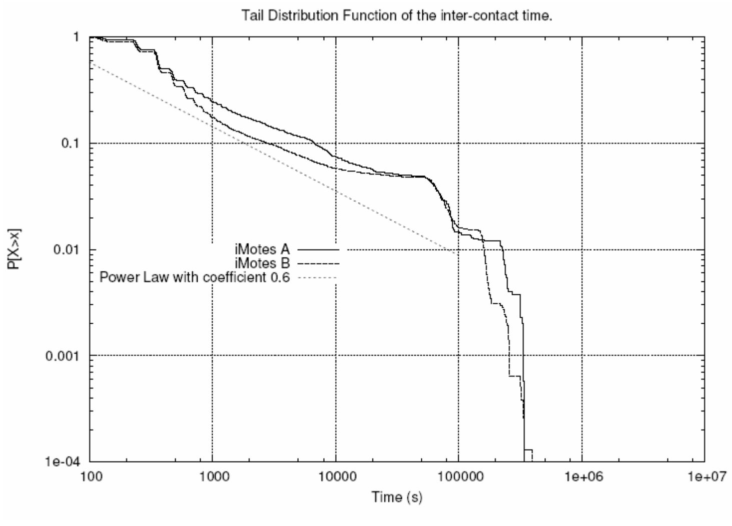
$$\Pr\{D = k \cdot 18\} = \frac{1}{N}(1-\frac{1}{N})^{k-1}$$

- Due to the memoryless property, this is the same as the intercontact times (S) between nodes (except the factor 18)

Measured times intercontact times

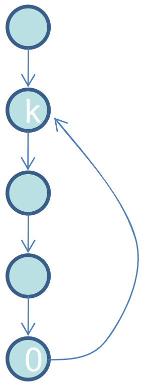
- Some measurements suggest that intercontact times follow a power law:

$$\Pr\{S >= k\} = ck^{-\alpha}$$



Power law consequences

- Note that when we pick a node as relay, this node is in a random point of its intercontact time to the destination node



Markov chain

$$\Pr\{D = K\} = \pi(k) = \pi(0)\Pr(S >= k)$$

$$P_{0,k} = \Pr\{S >= k\} = ck^{-\alpha}$$

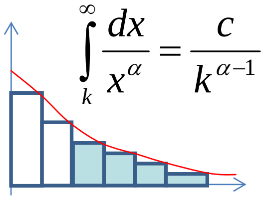
Infinite averages…

- The expected time to reach the destination is infinite when α<2

$$E[D] = c\sum_{k=1}^{\infty} k^{-(\alpha-1)}; \quad converges\ iff\ \alpha - 1 > 1$$

Assume that we transmit 2 (m) copies of the packet…

$$\int_k^{\infty} \frac{dx}{x^{\alpha}} = \frac{c}{k^{\alpha-1}}$$



$$\pi(k,i) = \pi^2(0)\Pr(S >= k)\Pr(S >= i)$$

$$E[D] = 2\sum_{k=1}^{\infty} k \sum_{i=k}^{\infty} \pi(k,i) = 2\sum_{k=1}^{\infty} k\pi(k) \sum_{i=k}^{\infty} \pi(i) =$$

$$\leq 2\sum_{k=1}^{\infty} k\pi(k) \frac{c}{k^{\alpha-1}} = \sum_{k=1}^{\infty} \frac{c'}{k^{2\alpha-2}}, \; convergent\ iff\ \alpha > 3/2$$

In general, with m copies, the expected time is finite iff : $\alpha > \frac{m+1}{m}$

NOTE: some assumptions on the value of N are required: $N > \frac{2}{1-\alpha}$

Conclusions

- Multihop routing has intrinsic limitations due to broadcast transmission
- Multichannel, multiradio can be used to break those limits
- Some other practical bounds
  - E.g. MANET horizon: paths are unestable for more than 4-5 hops
- MANETs are
  - small or low-throughput networks.
- Otherwise, go to cellular network model