Reachability: An Alternative to Connectivity for Sparse Wireless Multi-hop Networks

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Connectivity

- Indicates the extent to which a Wireless Multi-hop Network (WMN) is connected
- Defined as the probability that all nodes in the network form a single connected component

Sparse Networks

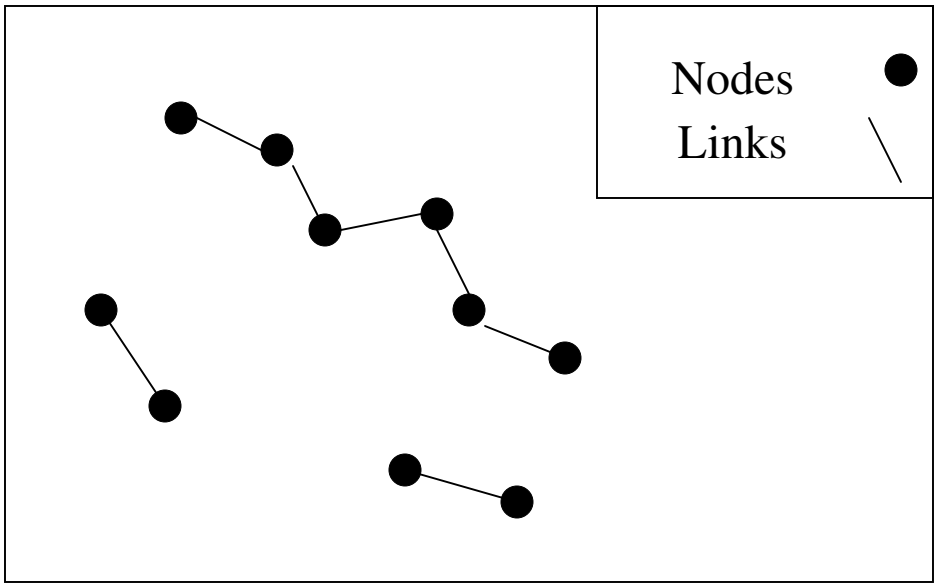
- A sparse WMN is one in which nodes are not connected with high probability
- Examples:
  - Vehicular ad hoc network at low traffic density
  - Sensor network after some nodes have died
  - Incrementally deployed ad hoc network

Our claim . . .

- In a sparse WMN
  - Connectivity not indicative of extent to which network supports communication
  - Connectivity is unresponsive to fine changes in network parameters
- Instead use
  - Reachability: fraction of connected node pairs in the network

$$\text{Reachability} = \frac{\text{No. of connected node pairs}}{\text{No. of possible node pairs}}$$

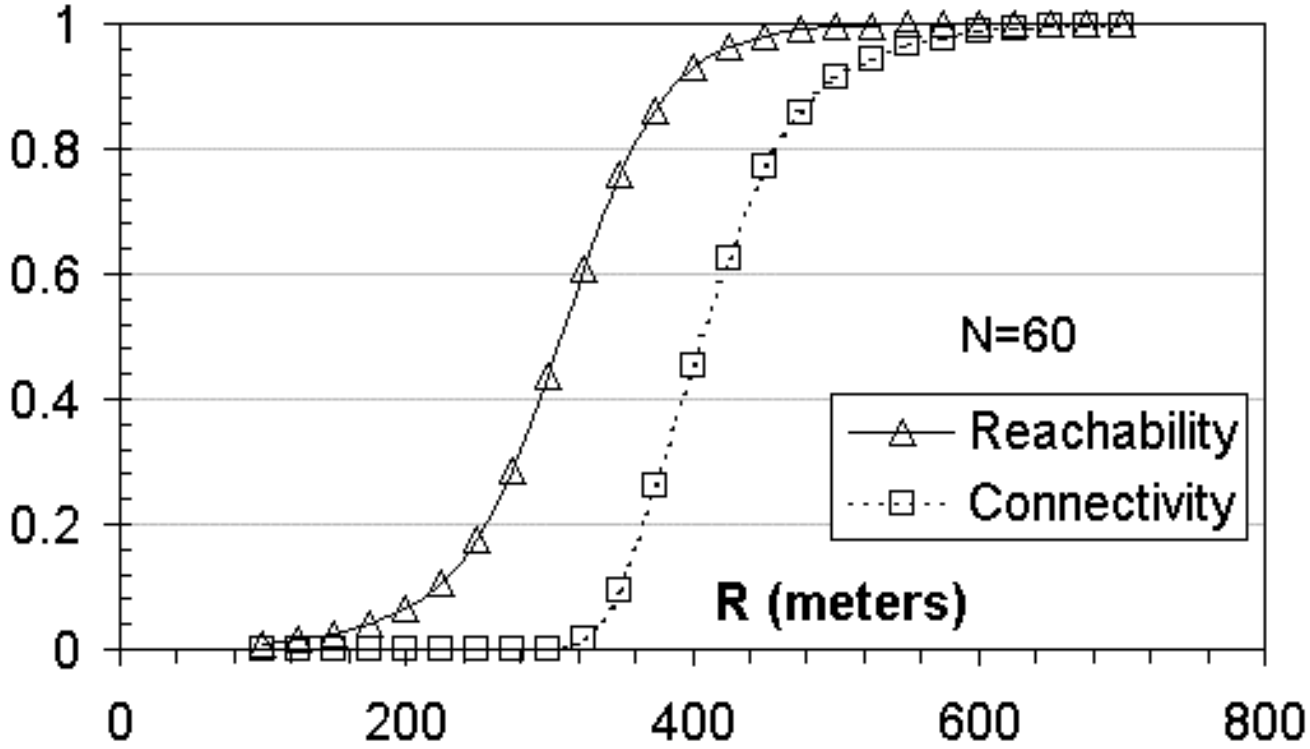
Calculating reachability



$$Rch. = \frac{NumConnectedPairs}{N\,C_2}$$

$$Rch. = \frac{17}{10\,C_2} = 0.378$$

How connectivity can be misleading

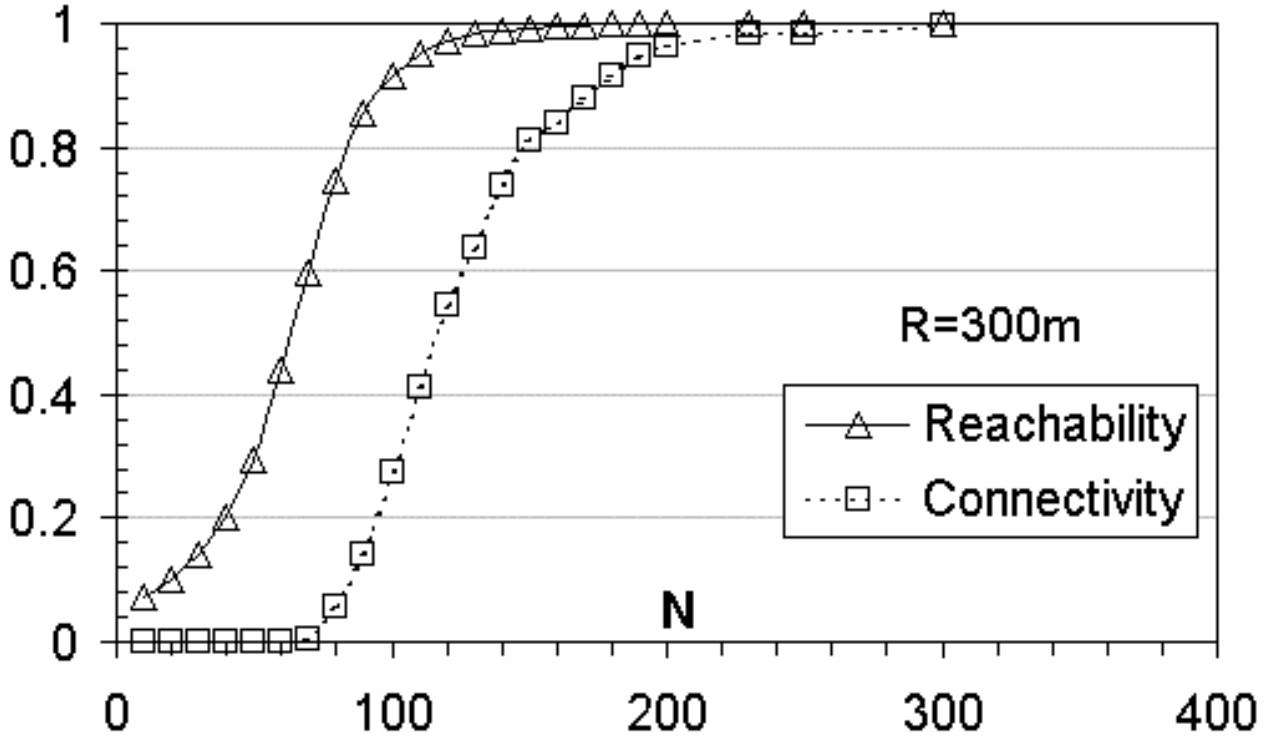


60 static nodes in 2000m x 2000m distributed uniformly at random

How connectivity can be misleading

- When reachability is 0.4
  - 40% of node pairs are connected
  - But connectivity is still at 0
- Connectivity remains at 0 from R = 50 to R = 320
  - Does not indicate actual extent of communication supported by the network
- Similarly, when N is varied . . .

How connectivity can be misleading

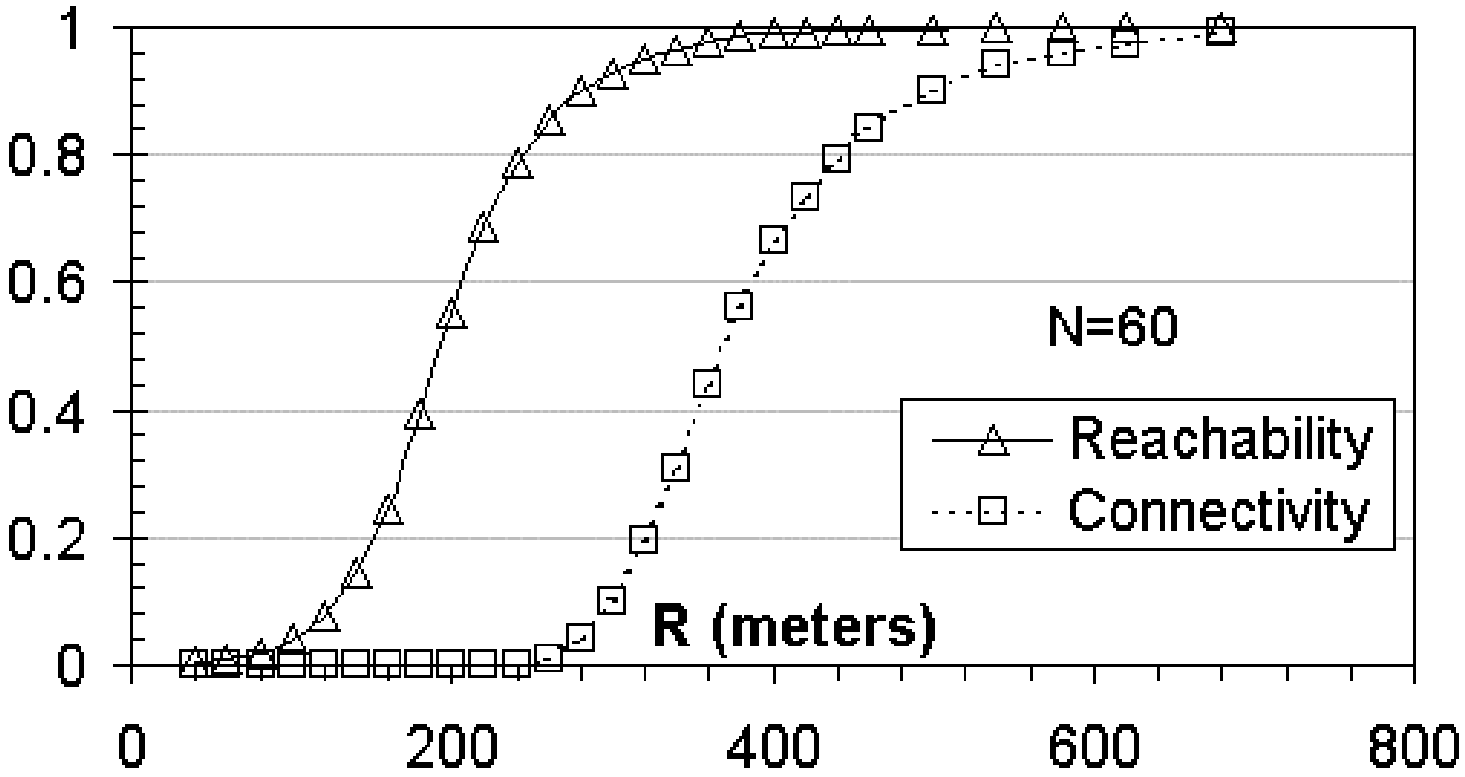


Transmission range, R, set at 300m, and N varied

Context

- It is important to be able to evaluate tradeoffs between deployment parameters
  - Gupta and Kumar [1] – throughput vs. node density
  - Grossglauser and Tse [2] – throughput vs. delay by exploiting mobility
- Sparse networks trade connectivity for delay
  - Ex: Delay tolerant routing [3], Message Ferrying [4]
- In this context metrics like reachability allow fine-grained tradeoffs

Asynchronous communication



- Uniformly velocity of 5 ms^{-1} with 30 second buffers at each node
- Difference between reachability and connectivity curves increases with mobility and asynchronous communication

Modeling Reachability

- Static multihop network
  - N - nodes
  - R - uniform transmission range
  - l – side of square area
- Reachability is a function of:
  - N
  - r – normalised transmission range
    - r = R/l
    - Connectivity properties do not change when R and l are varied proportionally
  - Denoted as $Rch_{N,r}$

Modeling Reachability

- If N nodes form k components with m_i nodes in the i^{th} component:

$$Rch_{N,r} = \frac{\sum_{i=1}^{k} \binom{m_i}{2}}{\binom{N}{2}} = \frac{\sum_{i=1}^{k} m_i(m_i - 1)}{N(N-1)}$$

- Asymptotic bounds for $Rch_{N,r}$ may be possible to derive
- Since sparse networks are often small we model $Rch_{N,r}$ using regression on simulated data

Characterizing Reachability

- The logistic curve
  - Often used to model population growth
- For fixed N, reachability varies logistically with r:

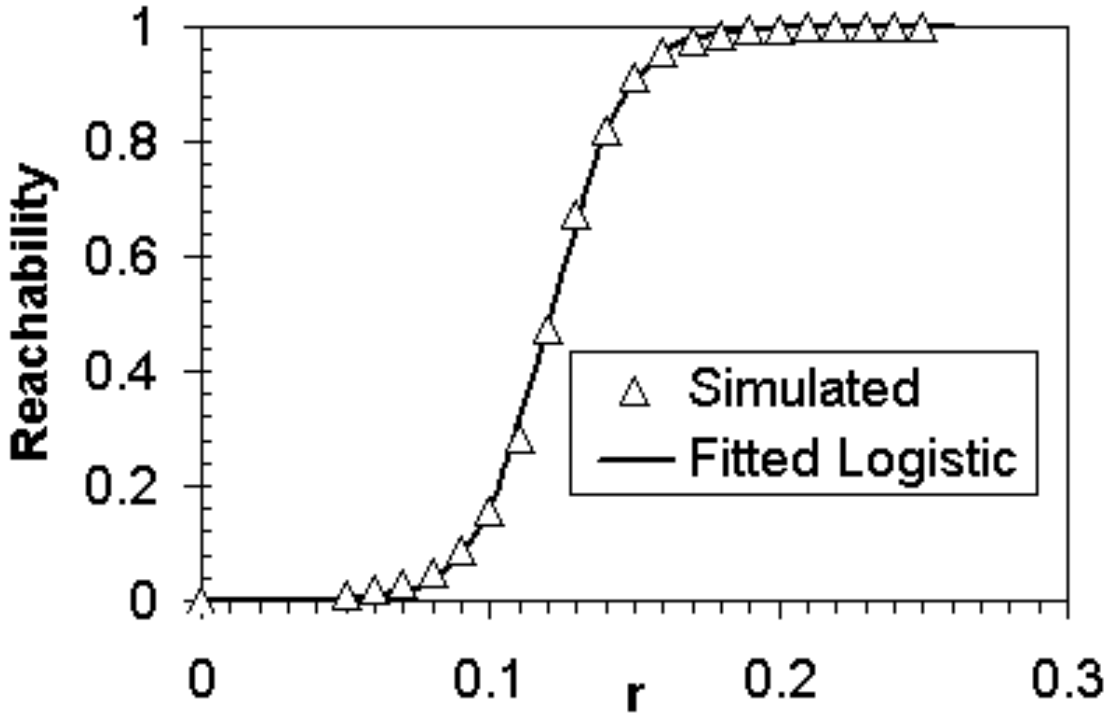
$$Rch_{N,r} = \frac{1}{1 + e^{\alpha_N - \beta_N r}}$$

  - r – transmission range normalized with side of square
  - α and β are estimated by fitting to simulation results of runs for various values of N

Characterizing Reachability

- Simulations
  - 55 values of N between 2 and 500
  - For each N, several values of r to span reachability from 0 to 1
    - Each simulation run on 1000 randomly generated network graphs
    - Yields a table of r vs. reachability for one value of N
- Regression
  - Table corresponding to each value of N fitted to yield α and β in the logistic equation
  - α and β values fitted to yield a expressions in terms of N

Characterizing Reachability



- Logistic Fit for N = 100

Characterizing Reachability

- α and β fitted in terms of N:

$$\alpha_N = 3.815(1-e^{-4.091\times10^{-2}N}) + 15.4(1-e^{-2.055\times10^{-3}N}) + 3.004 \qquad 2 \le N \le 500$$

$$\beta_N = 5.141 + 0.9421N - 2.597\times10^{-3}N^2 + 8.42\times10^{-6}N^3$$
$$-1.37\times10^{-8}N^4 + 1.058\times10^{-11}N^5 - 3.209\times10^{-15}N^6 \qquad 2 \le N \le 500$$

- Average relative error around 3.5% for cases that didn't contribute to the model [5]

Applying Reachabilty

- Can be applied where sparse multihop networks are encountered
  - Case study: achieving tradeoff between deployment cost and communication capability [6]
- Design tools incorporating reachability
  - Simran – topological simulator for WMN (http://www.it.iitb.ac.in/~srinath/simran/)
  - Spanner – Sparse network planner (http://www.it.iitb.ac.in/~srinath/tool/rch.html)

References

[1] P. Gupta and P. R. Kumar, “The capacity of wireless networks,” IEEE Transactions on Information Theory, vol. 46, no. 2, pp. 388–404, March 2000.

[2] M. Grossglauser and D. Tse, “Mobility increases the capacity of ad-hoc wireless networks,” in IEEE INFOCOM, vol. 3, 2001, pp. 1360–1369.

[3] S. Jain, K. Fall, and R. Patra, “Routing in a delay tolerant network,” in ACM SIGCOMM ’04, 2004, pp. 145–158.

[4] W. Zhao, M. Ammar, and E. Zegura, “A message ferrying approach for data delivery in sparse mobile ad hoc networks,” in ACM MobiHoc ’04, 2004, pp. 187–198.

[5] S. Perur and S. Iyer, “Characterization of a connectivity measure for sparse wireless multi-hop networks,” To appear in Proc. of WWASN ’06, in conjunction with ICDCS, July 2006.

[6] S. Perur and S. Iyer, “Sparse multi-hop wireless for voice communication in rural India,” Proc. of 12th National Conference on Communications, New Delhi, 2006, pp. 534 –538

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