

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

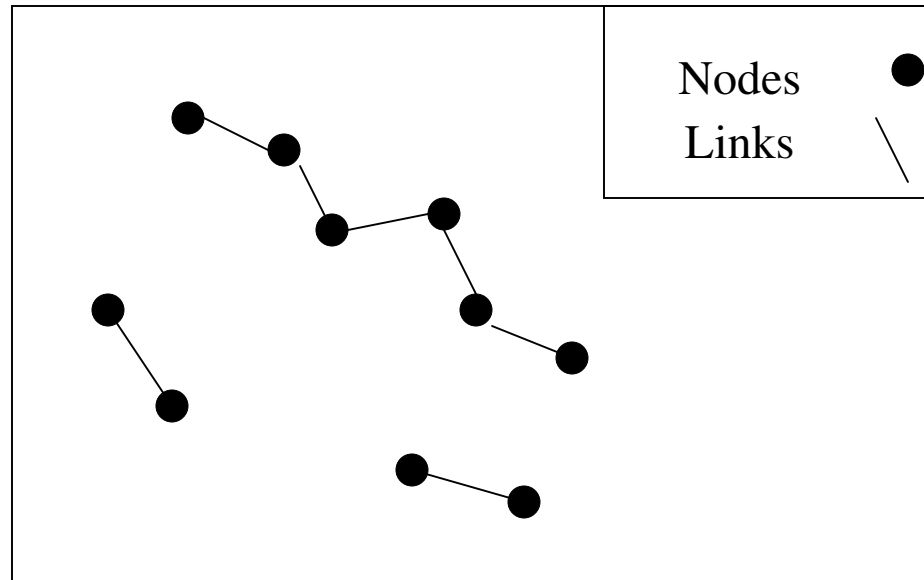
- A sparse WMN is one in which nodes are not connected with high probability
- Examples:
 - Vehicular ad hoc network at low traffic density
 - Sensor network after some nodes have died
 - Incrementally deployed ad hoc network

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

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

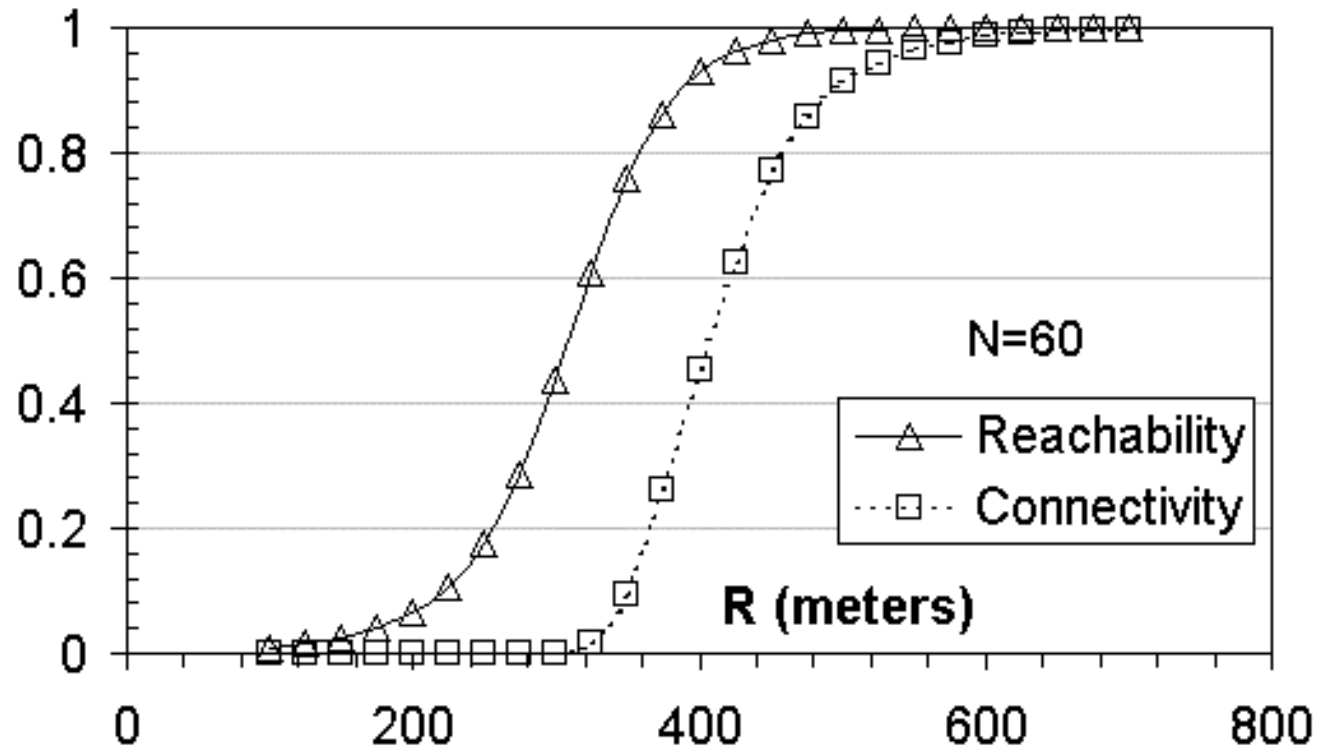
Calculating reachability



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

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

How connectivity can be misleading

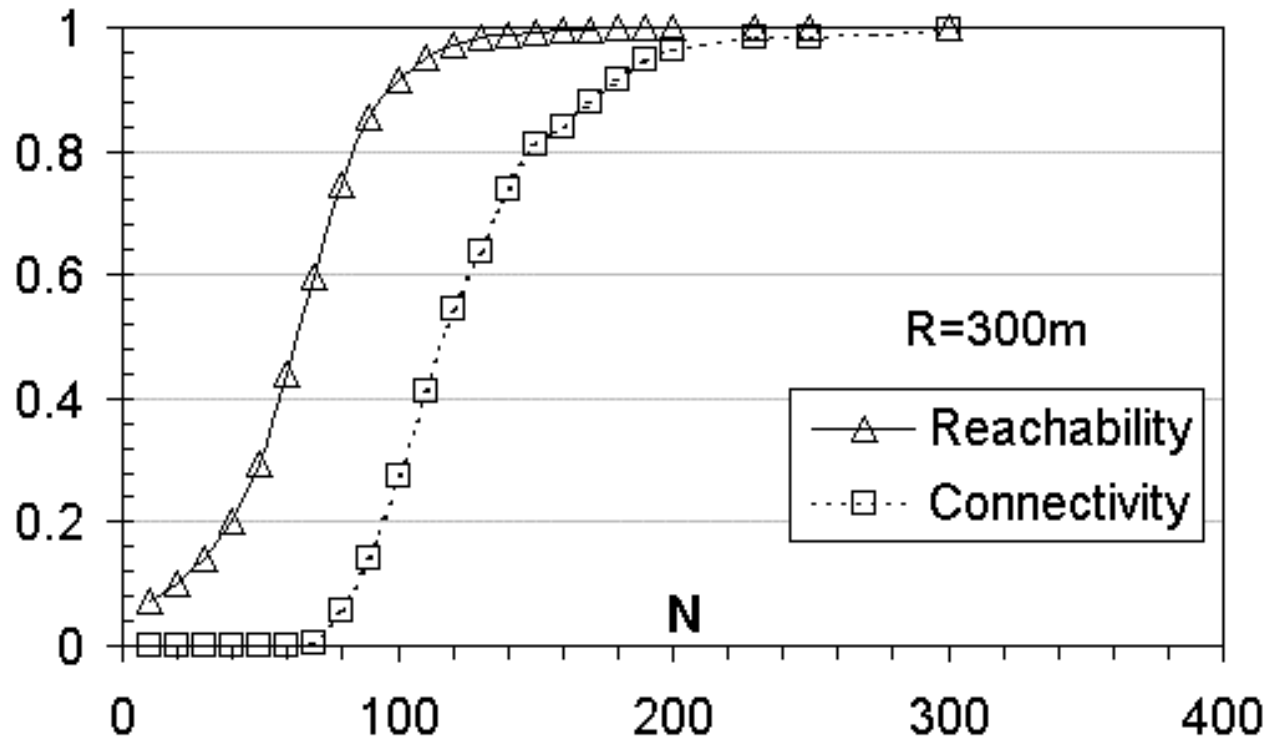


60 static nodes in 2000m x 2000m distributed uniformly at random

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

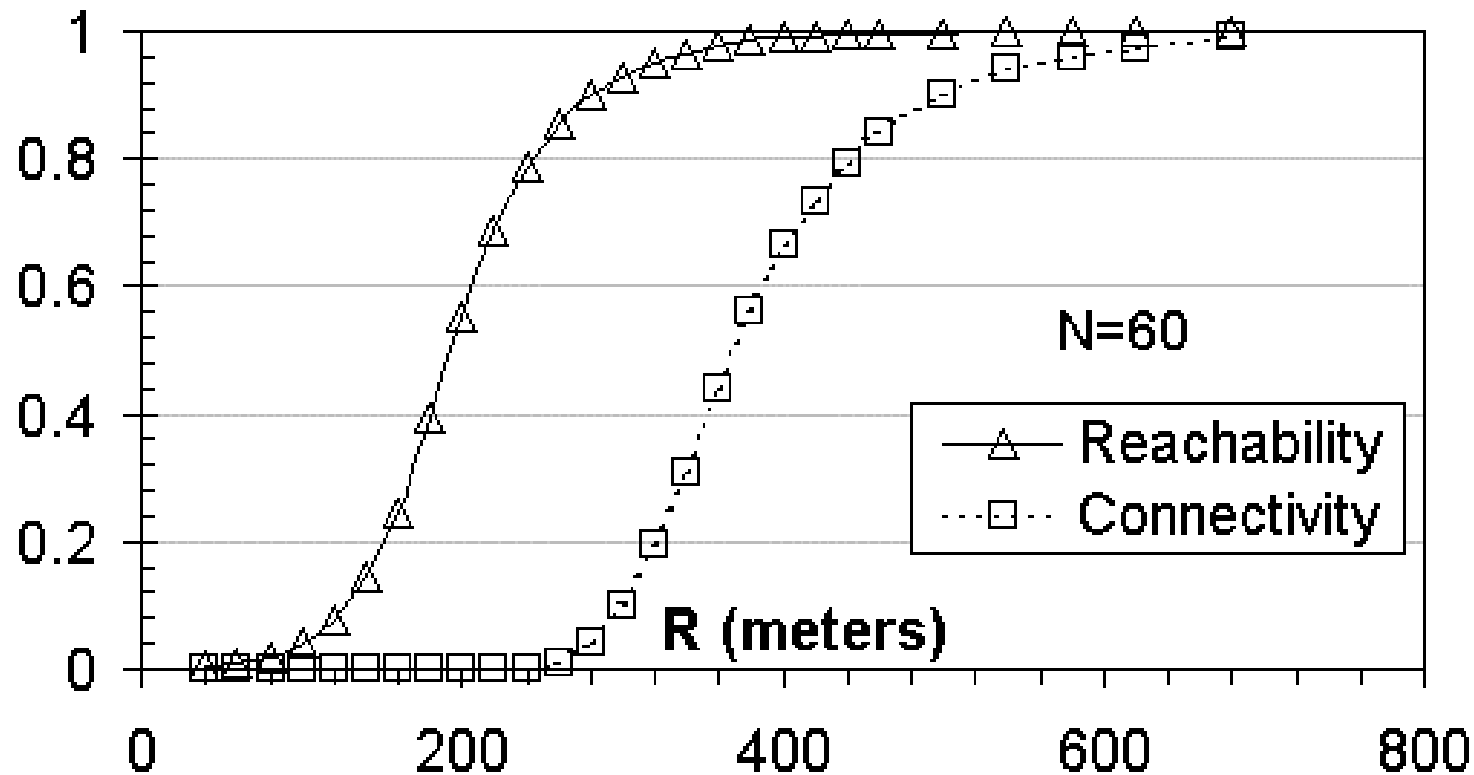


Transmission range, R , set at 300m, and N varied

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 :

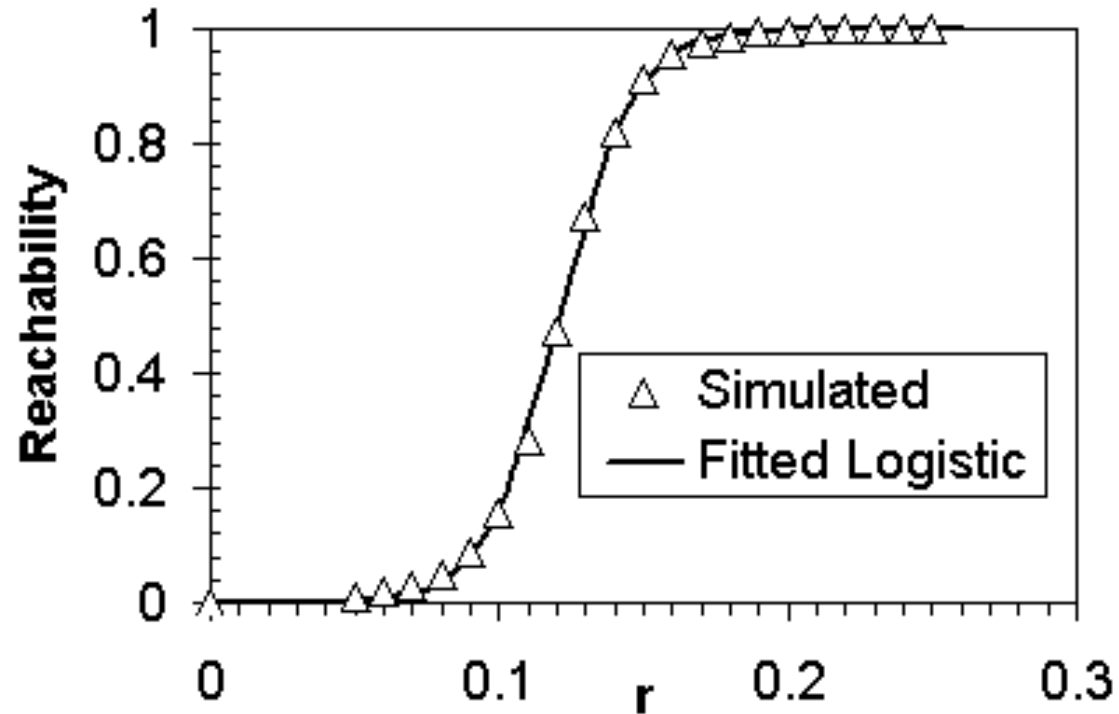
$$Rch_{N,r} = \frac{1}{1 + e^{\alpha N - \beta N r}}$$

- 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 :

$$\alpha_N = 3.815(1 - e^{-4.091 \times 10^{-2} N}) + 15.4(1 - e^{-2.055 \times 10^{-3} N}) + 3.004 \quad 2 \leq N \leq 500$$

$$\beta_N = 5.141 + 0.9421N - 2.597 \times 10^{-3} N^2 + 8.42 \times 10^{-6} N^3 - 1.37 \times 10^{-8} N^4 + 1.058 \times 10^{-11} N^5 - 3.209 \times 10^{-15} N^6 \quad 2 \leq N \leq 500$$

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

Applying Reachability

- 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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