Multi-Tier Networks for Rural Connectivity

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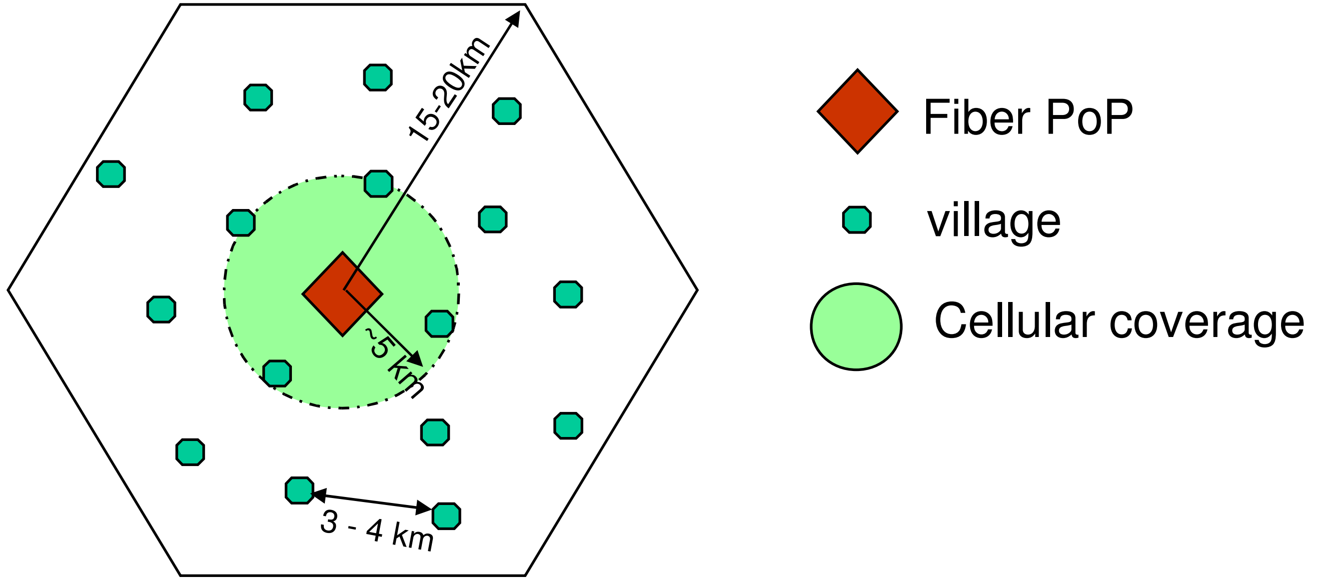
Rural India : Background



- 250-300 villages per PoP

Ref: Prof. Bhaskar Ramamurthi, IITM

Background

- 6,07,491 villages – 1991 census
  - Each village: average 250 households
- DoT's Village Public Telephone scheme
  - One public telephone per village (currently 84% complete)
  - Next phase – Installing a *second* phone where pop. > 2000
- Internet services viable through public kiosks
  - Ref: Work by TeNeT group at IIT Madras (www.tenet.res.in)
- Attempts to increase reach using long-haul wireless links
  - WiMAX – Still expensive
  - WiFi - Spectrum is free; Equipment cost is low
  - Ref: Work by CEWiT to develop modified MAC (www.cewit.org.in)

Telecommunication within villages

- Can we do more than just ‘connect’ the village?
- Issues with fixed and cellular telephony
  - Infrastructure establishment and maintenance
  - Investment recovery
- Questions:
  - Can we use WiFi to reach from the kiosk to the homes?
  - Can we use multi-hop wireless networks?

Using WiFi for intra-village communication

Timbaktu Experiment

Timbaktu Collective

- Rural NGO setting
  - One old BSNL telephone line
  - Poles get stolen periodically
  - No further landlines possible due to railway track
  - No cellular coverage due to hills around
  - No towers permitted on hills due to being reserved forest
- Problem:
  - Each time there is an incoming phone call, somebody has to run to call the person to the phone
  - Distance between various buildings (kitchen, school, homes) is about 100m average

Experiment Objective

- Can we use off-the-shelf VoIP and WiFi equipment to establish low-cost internal connectivity?

1. Communication within Timbaktu (rLAN)
2. Interfacing with the landline

- Later generalize to other rural scenarios?

Experimenters

- PhD Students:
  - Srinath Perur
  - Raghuraman Rangarajan
  - Sameer Sahasrabuddhe
- MTech Students:
  - Janak Chandrana
  - Sravana Kumar
  - Ranjith Kumar
  - Moniphal Say
  - Annanda Rath

The Equipment (Hardware)

The Equipment (Software)

- Netstumbler
  – For signal strength measurements
- Ping
  – For round trip delay and packet loss measurements

- Netmeeting; SJ Phone
  – VoIP clients for actual testing
- Simputer VoIP client
  – SIP based VoIP connectivity

- Asterisk
  – Software exchange

Theoretical Solution

- Very Easy ☺

1. Put an Access Point (AP), with a directional antenna on top of the highest structure
2. Put additional APs here and there to extend the range of coverage, if required
3. Run Asterisk (software exchange) on an low-end PC and connect it to the landline
4. Configure the VoIP and WiFi on other devices properly
5. DONE

- In reality, it is not so simple.

Environment Complicators

- Power Supply Issues
  - Timbaktu has only Solar power; mostly D/C.
  - Off-the-Shelf APs, PCs, etc. have A/C power plugs.
  - Naïve solution (as outlined earlier) is not useful
  - Only one place had an inverter for A.C. power points (school bldg) => Location of AP determined by default!
- Cable Issues
  - Antenna cable loss
  - Ethernet cable required for connecting phone adapter or PC to AP

- Radio Issues
  - Attenuation by Haystack!
  - Insect mesh on windows
  - Assymmetric transmit power of AP versus client devices

The Setup

Testing – 1 (VoIP over WiFi using Laptops)

Findings – 1 (VoIP over WiFi using Laptops)

- Easily done
  - Works as expected, similar to preliminary testing at IITB.
- Decent signal strength; ping and VoIP results

- Plus pts: Easy to configure Netmeeting; SJ Phone
  - Asterisk server can be eliminated using peer-2-peer mode
- Minus pts: Not practical for following (obvious) reasons:
  - Users are comfortable with phone instruments
  - Laptop needs to be always on just in case there is a call
  - Not convenient to carry around
  - Too expensive

Testing – 2 (Simputers and phone Adapter)

Findings – 2 (Simputers and phone Adapter)

- Do-able with some difficulty
- Signal strength; ping and VoIP results are significantly different from those using Laptops
- Unacceptable delays on the Simputer
- Needs Asterisk server for interconnection
- Not practical from a cost perspective

Technology Transfer

- Continued field tests
- Timbaktu students trained in taking signal strength measurements, VoIP usage trails under various conditions

Cost of Current Solution

- Access Point –
- Antenna –

- Simputer –
  - (one per mobile user)
  - Cost can be amortized by also using it as an educational tool in the school
- Phone Adapter
  - (one per location)
- Phone -
  - (one per location)

Learnings (obvious in retrospect)

- Theoretical assumptions regarding 'ease' of setup and configuration are misleading
  - Took quite some time to get everything going (even after preliminary work)
- Environment issues have to be handled afresh each time
  - Scenario for one village may be quite different from another

- Asymmetric transmission capabilities of the access point and client devices is a major issue
  - Seeing a good signal strength from the access point does not imply that VoIP (or even ping) tests would be successful

Multi-hop wireless for intra-village communication

Multi-hop Wireless Networks (MWNs)

- Widely studied in the context of
  - Ad hoc networks
  - Mesh networks
- No infrastructure required; No single point of failure
- However, real-time multi-hop VoIP calls over a WiFi ad hoc network show poor performance
- Alternative: Short voice messages
  - Exploit message relaying; may be delay tolerant
- Questions:
  - How many nodes do we need?
  - How do we route the packets?

How many nodes do we need?

- Depends on
  - Transmission power; Area of operation
  - Terrain; Mobility; Interference
  - Desired communication capabilities; Deployment cost
- Not much work in **sparse networks (**connectivity < 1)
- **Connectivity**: probability that a MWN forms a fully connected component
  - Not very useful for our scenario

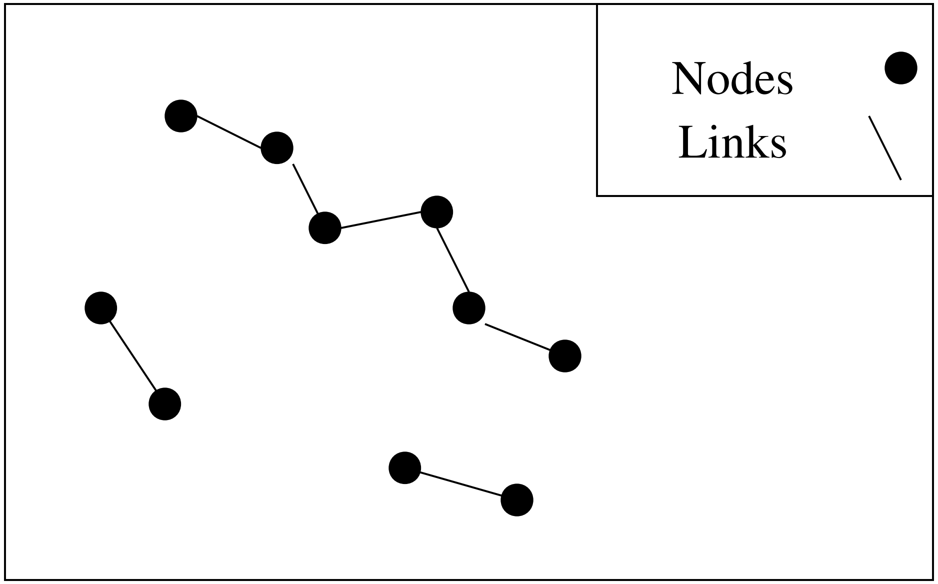
Reachability

- Reachability is useful for evaluating tradeoffs in sparse networks
  - communication ability versus deployment cost

- Defined as the fraction of connected node pairs:

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

Calculating reachability



$$Rch. = \frac{NumConnectedPairs}{{}^{N}C_{2}}$$

$$Rch. = \frac{17}{{}^{10}C_{2}} = 0.378$$

Probabilistic Reachability

- Static network graph
  - Measured by averaging over value of reachability for many instances
- Dynamic network graph
  - Average of reachabilities for frequent static snapshots

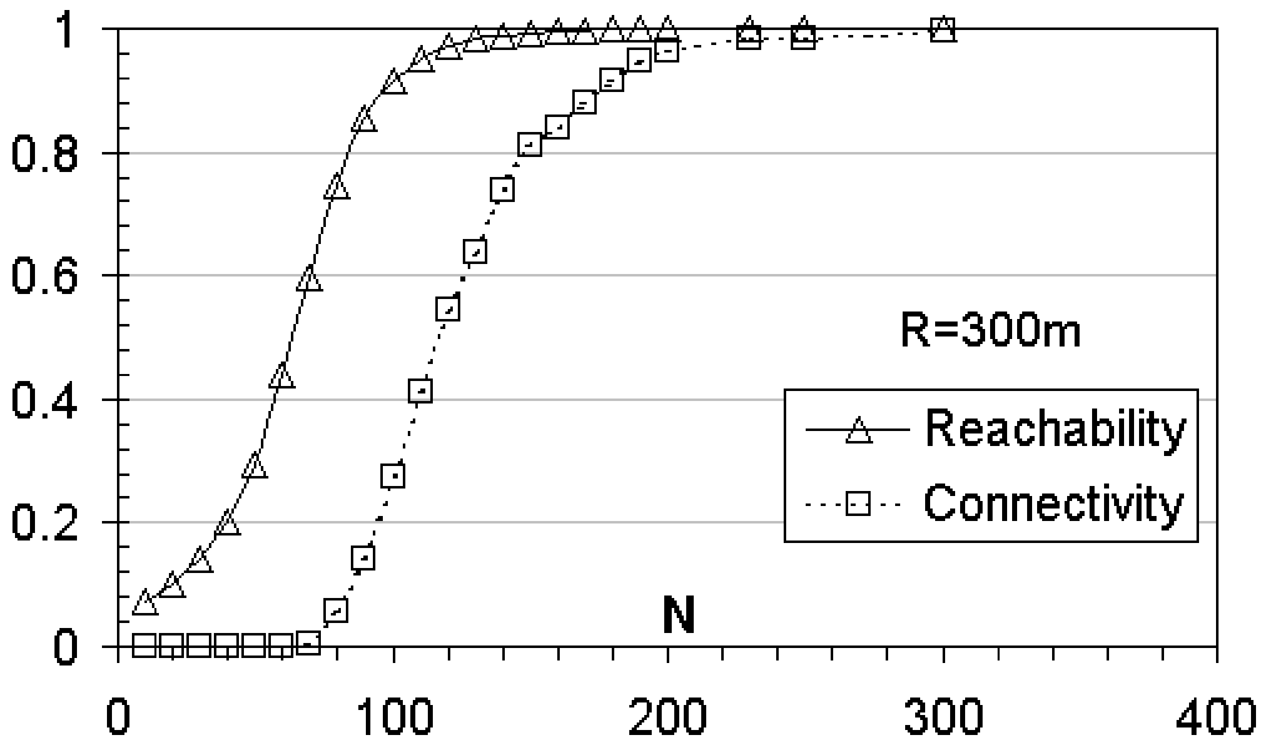
- Designing for reachability of 0.6 means that over a long period, we can expect 60% of calls to go through

Simulation study

- Village spread across 2km x 2km
  - Low population density
  - Agricultural land
- Simulations performed using Simran - a simulator for topological properties of wireless multi-hop networks
- Assumptions:
  - Devices capable of multi-hop voice communication
  - Negligible mobility
  - Homogenous range assignment of R
    - Not a realistic propagation model
    - Results will be optimistic, but still indicative
  - Nodes randomly distributed

Choosing N

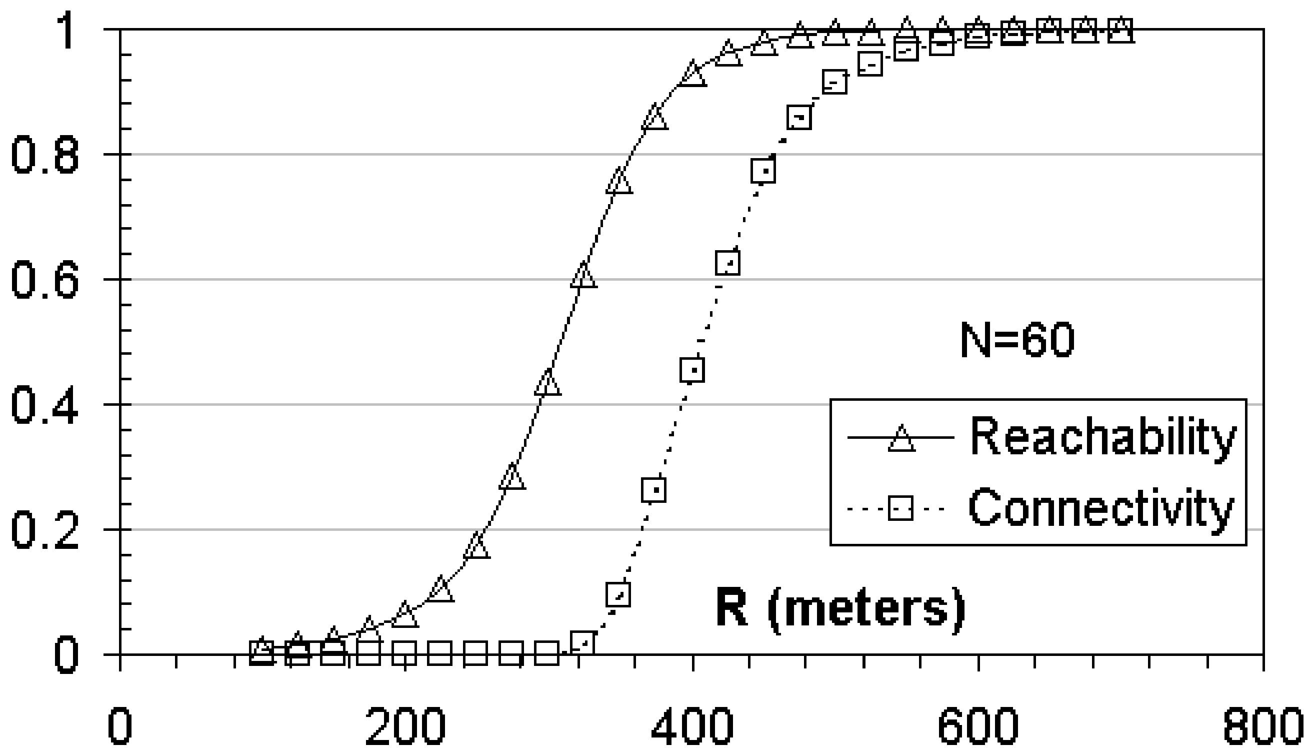
If a device has R fixed at 300m, how many nodes are needed to ensure that 60% of calls go through?



- Around 70 nodes are required
- When reachability is 0.6, connectivity is still at 0

Choosing R

If 60 nodes with variable transmission range are to be deployed in the village, how should R be set?



- **Connectivity at zero when reachability > 40%**
- **Connectivity insensitive to change when R < 320 m**
- **Increase in R requires power-law increase of transmit power**
- **Tradeoff between R, reachability, power, battery life**
- **Increase in R as connectivity tends to 1 is not very useful in increasing communication capabilities**

Coverage

- Are nodes connecting only to nearby nodes?

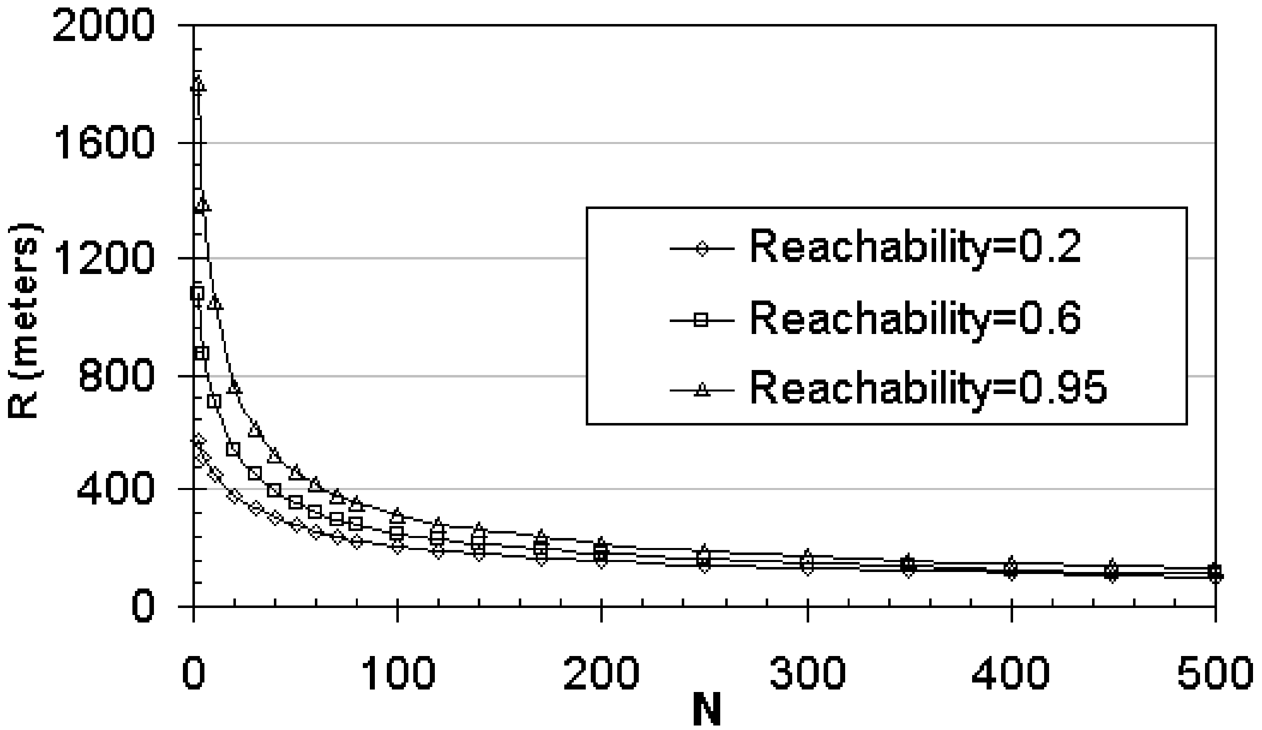
Theorem 3.1. *Let $G = (V, E)$ be a graph in which every pair of nodes $(u, v) \in V \times V$ is assigned a distance $|uv|$, and $(u, v) \in E$ iff $|uv| \leq R$. Then, if the shortest path between some two nodes in V has k edges, $k > 1$, the sum of the distances of those k edges, L, is bounded as: $\lfloor \frac{k}{2} \rfloor R < L \leq kR$.*

- For N=70, R=300m, average shortest path lengths between nodes in a run (from 500 runs)
  - Max = 9.24
  - Average = 5.24
  - Min = 2.01
- Shortest path length of 5 implies a piece-wise linear distance greater than 600m and upto 1500m

Adding mobility

- For the previous case, (N=70, R=300m) we introduce mobility
  - Simulation time: 12 hours
  - Random way-point
    - V_{min}=0.5 ms^{-1}
    - V_{max}=2 ms^{-1}
    - Pause = 30 mins
- Reachability increases from 0.6 to 0.71
- Especially useful for short voice messages
  - asynchronous communication

R vs. N

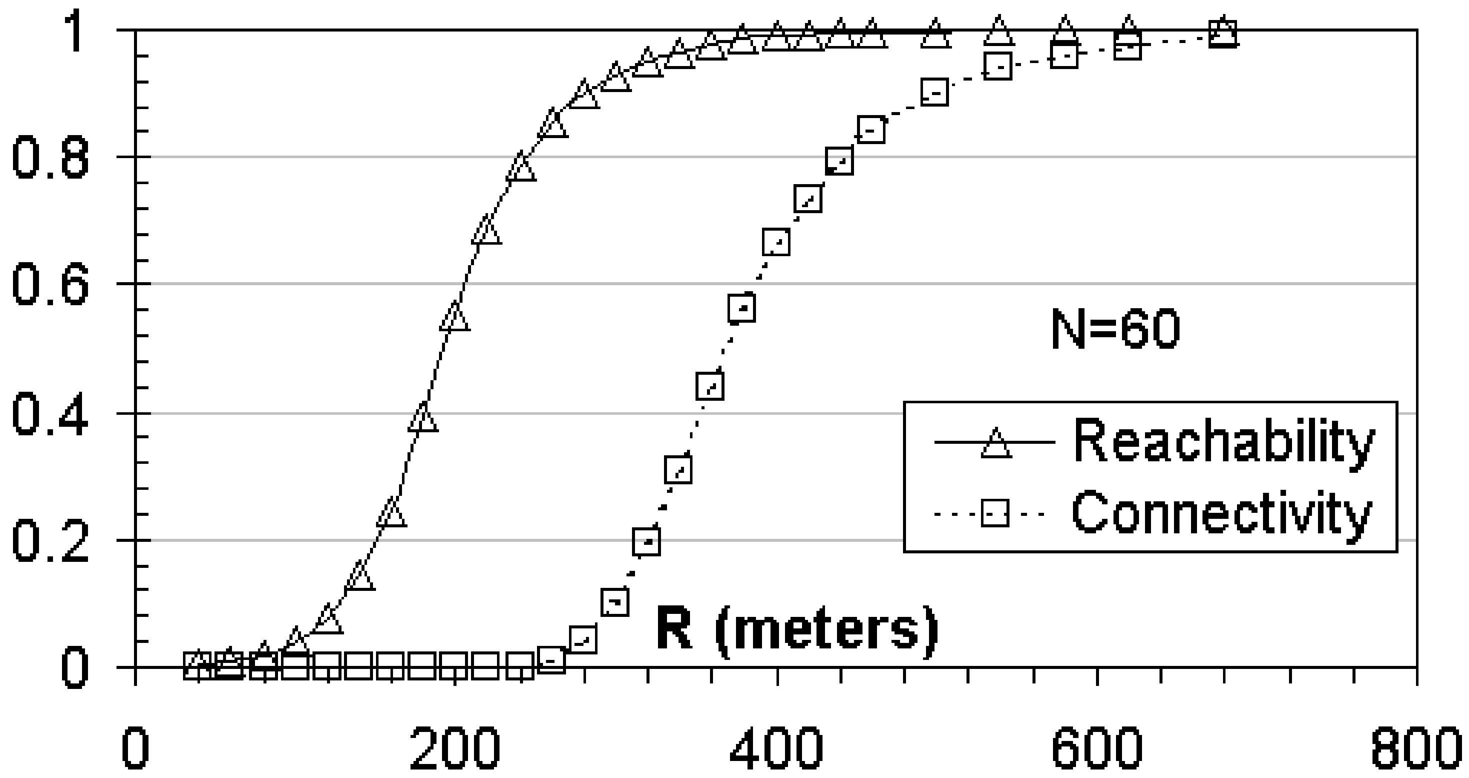


- Can be used for power control
- Maintain reachability as nodes die or R decreases

Asynchronous Communication

- N=60, varying R
- Uniform velocity of $5ms^{-1}$
- Two nodes are connected at simulation time t if a path, possibly asynchronous, existed between them within time t+30
- That is, can store-and-forward message passing happen between the two nodes in 30 seconds
- 20 simulations of 500 seconds each

Asynchronous communication



- 80% of node pairs are connected before connectivity increases from 0
- Asynchronous messaging helps sparse network achieve significant degree of communication

Ongoing Work

- Routing protocol for communication over sparse and partially connected, ad hoc network
  - Existing schemes assume a fully connected network

- Tool for capacity-constrained design of multi-tier networks