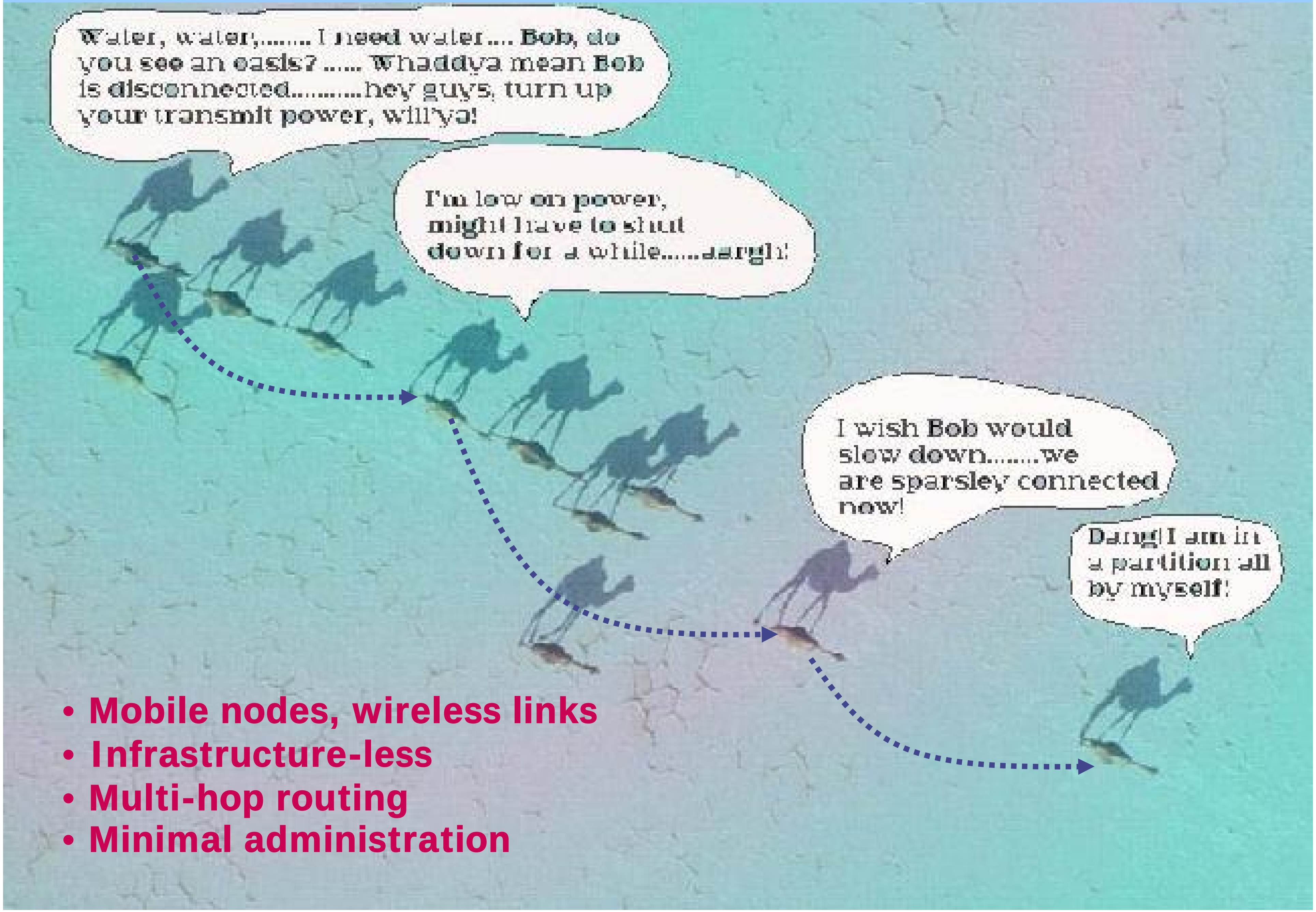
Node Clustering in Mobile Peer-to-Peer Multihop Networks

Chansu Yu
Cleveland State University

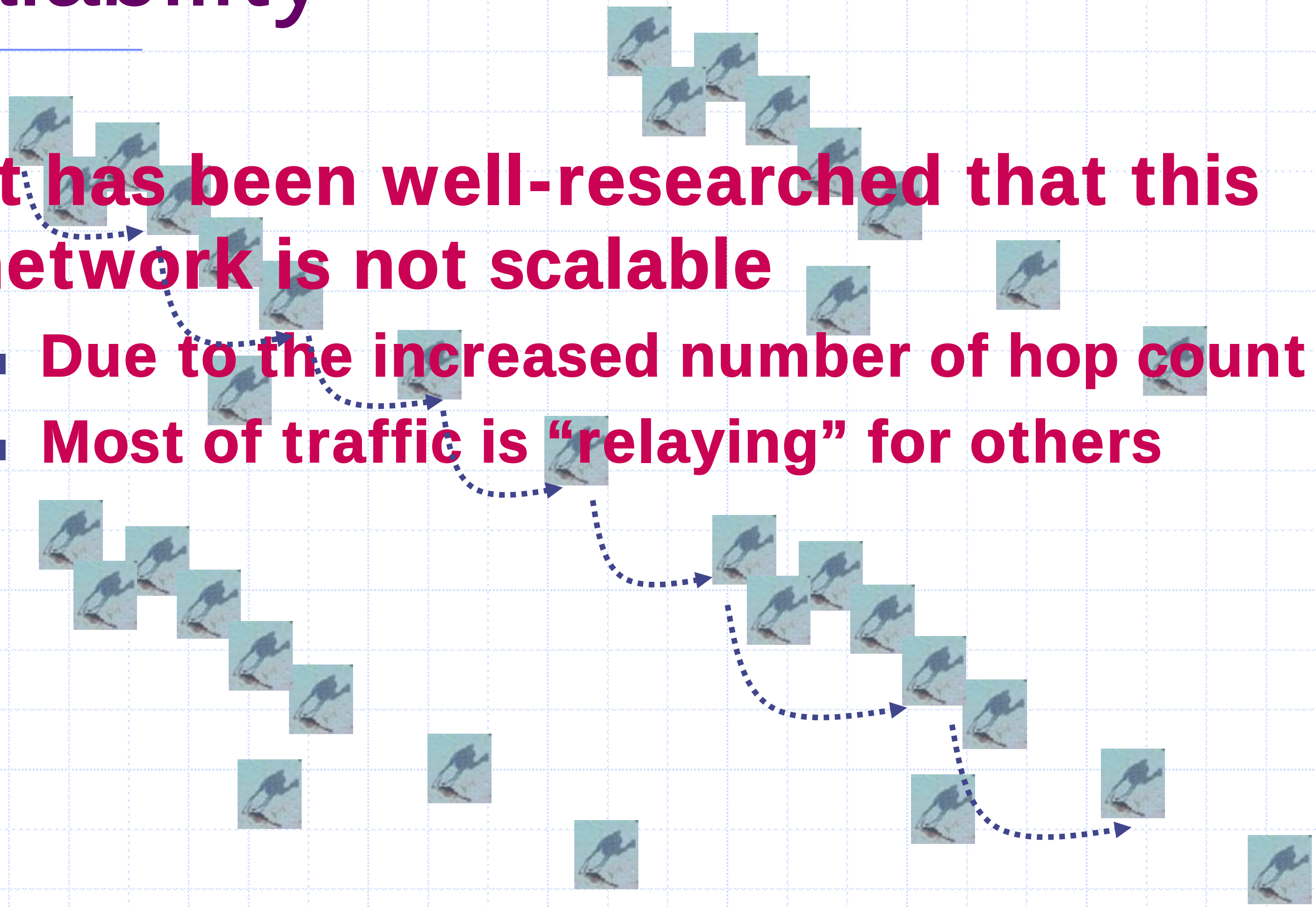
Mobile Peer-to-Peer Multihop Networks



- Mobile nodes, wireless links
- Infrastructure-less
- Multi-hop routing
- Minimal administration

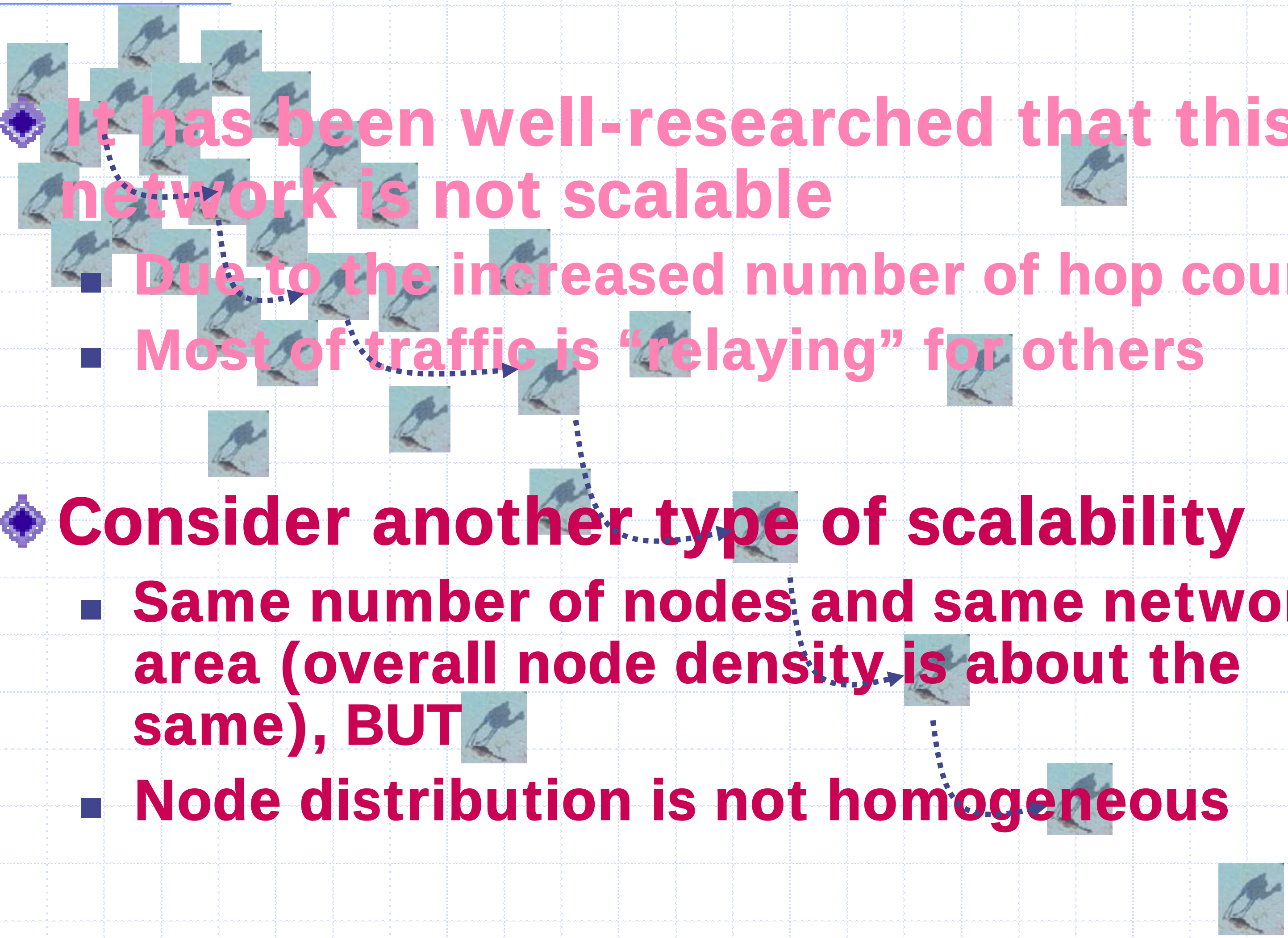
Scalability

- **It has been well-researched that this network is not scalable**
  - **Due to the increased number of hop count**
  - **Most of traffic is "relaying" for others**



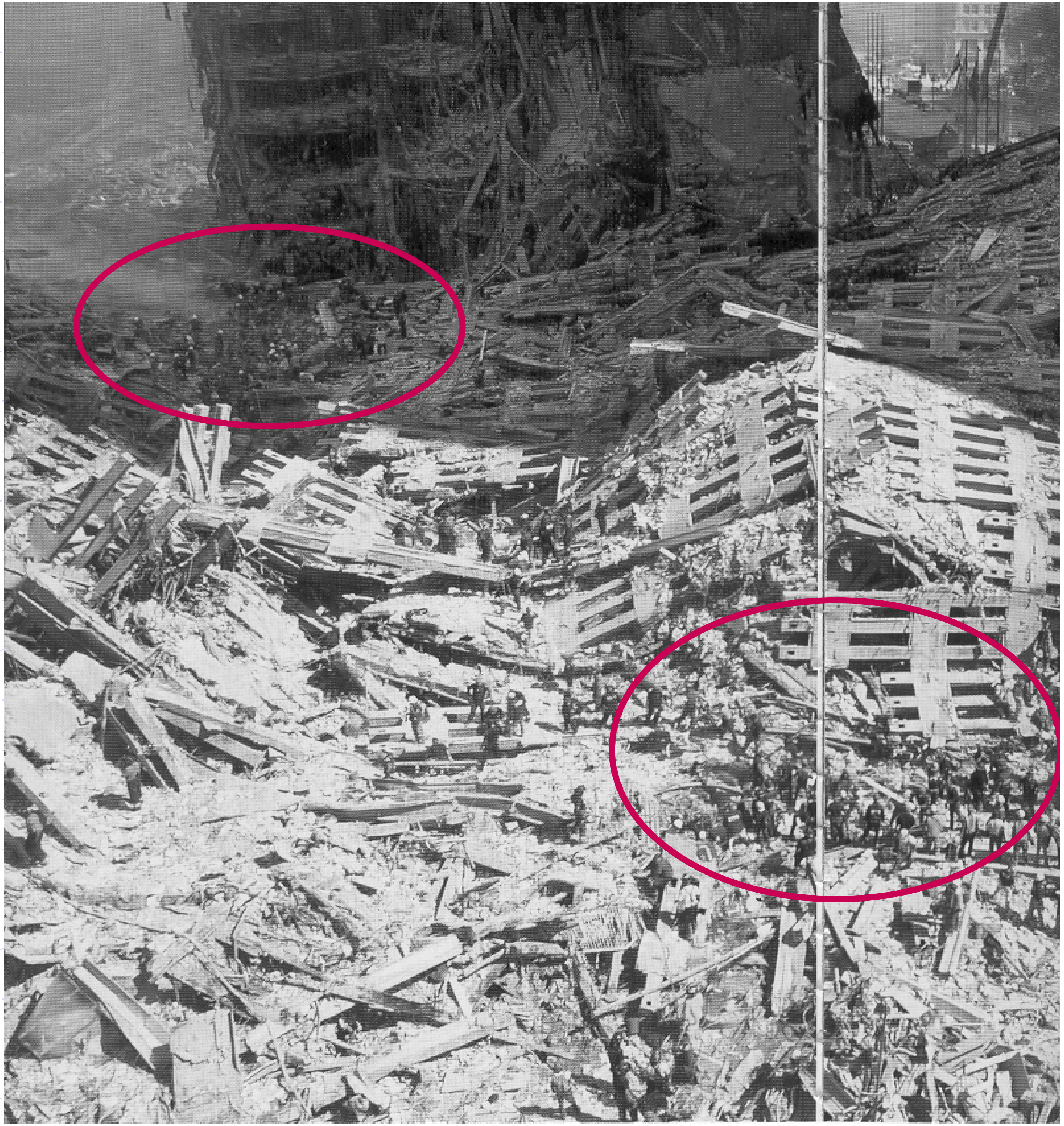
Scalability

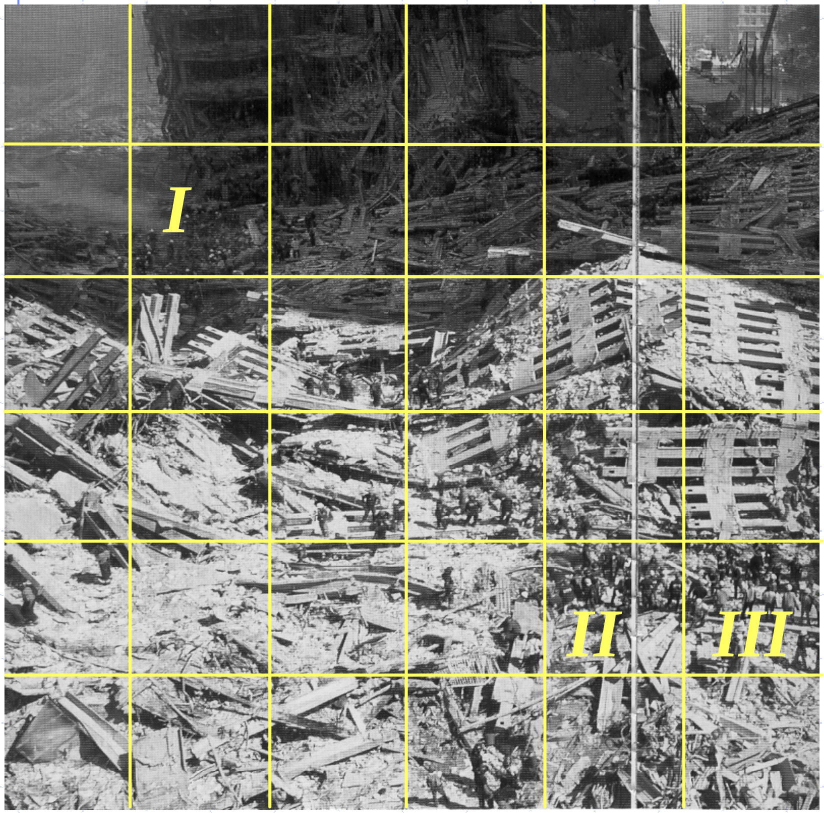
- It has been well-researched that this network is not scalable
  - Due to the increased number of hop count
  - Most of traffic is "relaying" for others
- Consider another type of scalability
  - Same number of nodes and same network area (overall node density is about the same), BUT
  - Node distribution is not homogeneous



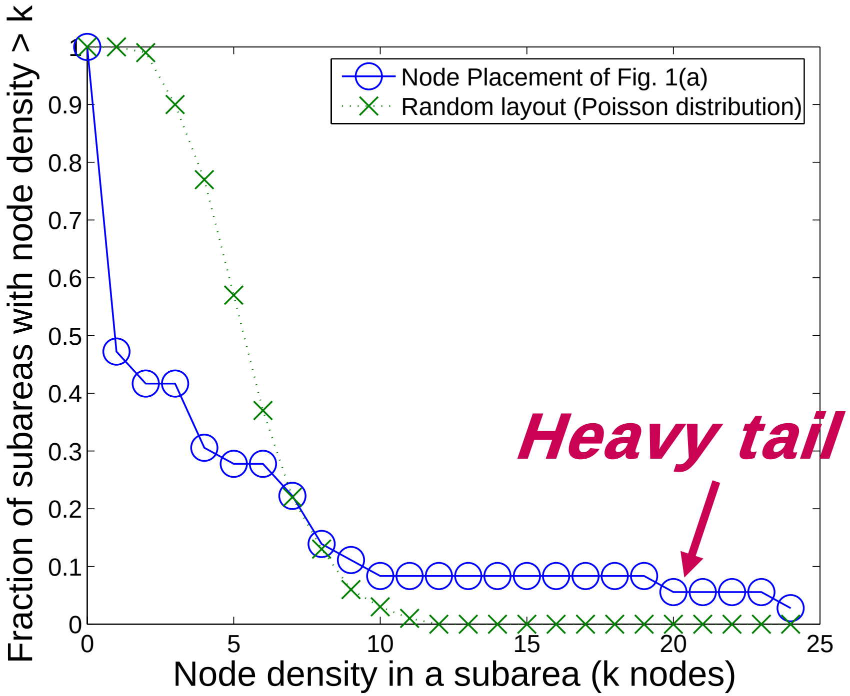
- Are they randomly distributed?

R. Sullivan (Editor), *One Nation: America Remembers September 11, 2001*, Time Warner Trade Publishing, 2001.





Rescue Team At Ground Zero



Node Density Distribution

Why Do We Care?

- Performance degradation due to the existence of “hot spot” nodes playing as bottlenecks
- Hot spot nodes may exhaust their battery life earlier than others
- Higher probability of network partition with the same number of mobile hosts

Problem Statement

- How to model non-random, non-uniform node distributions?
  - Random layout of nodes (e.g. Random Waypoint)
  - “Clustered layout of nodes”
- What are the performance impact of node clustering?
  - More collisions in hot spot area
  - Connectivity problem in sparse area
- We do not offer solutions but
  - Effectiveness of solutions can be evaluated based on the clustered layout model
  - MAC layer complexities revealed in this paper help find solutions such as constructing an overlay structure over non-homogeneous peer-to-peer network

Spatial Distribution

- Random distribution
  - Assume network is divided into a number (s) of equal-sized subareas and there are n nodes
  - Each node is positioned in a particular subarea with independent probability p (=1/s)
  - The probability p_k that a subarea has exactly k nodes is given by the binomial distribution

$$p_k = \binom{n}{k} p^k (1-p)^{n-k}$$

  - As a limiting case, this becomes the well-known Poisson distribution (when z=n/s)

$$p_k = \frac{z^k e^{-z}}{k!}$$

Spatial Distribution

- Clustered distribution
  - Node distribution contains a heavy tail unlike the Poisson distribution and can be modeled by a power-law distribution.
  - “Bounded Pareto” distribution is used to model the clustered layout
    - Pareto distribution is a simple power-law distribution
    - Bounded Pareto to limit the maximum and minimum number of nodes in each subarea, i.e., a<k<b
  - Cumulative density function is given by

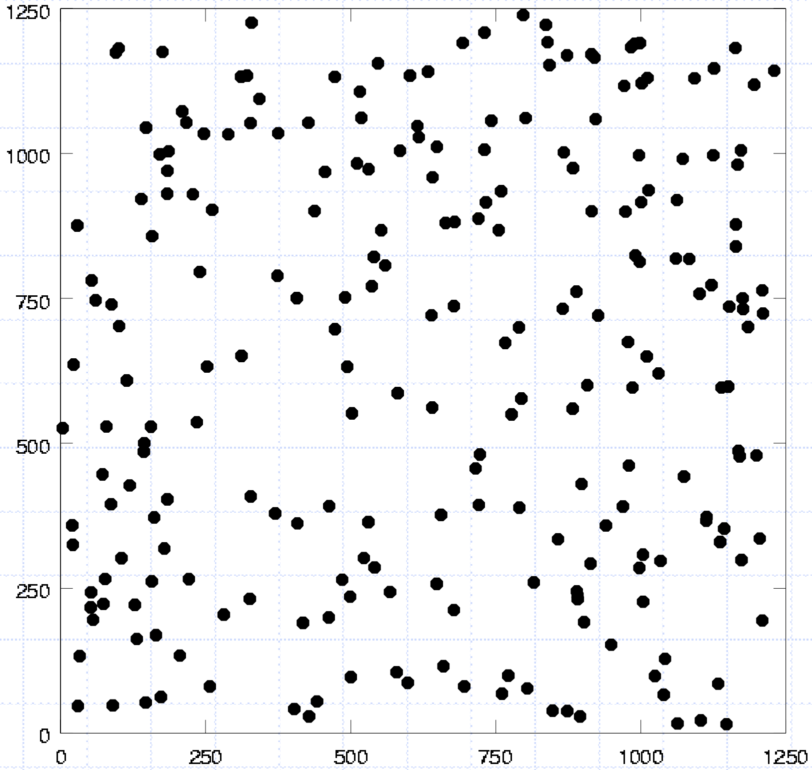
$$F(k) = \frac{1-(a/k)^{\alpha}}{1-(a/b)^{\alpha}}$$

To maintain connectivity

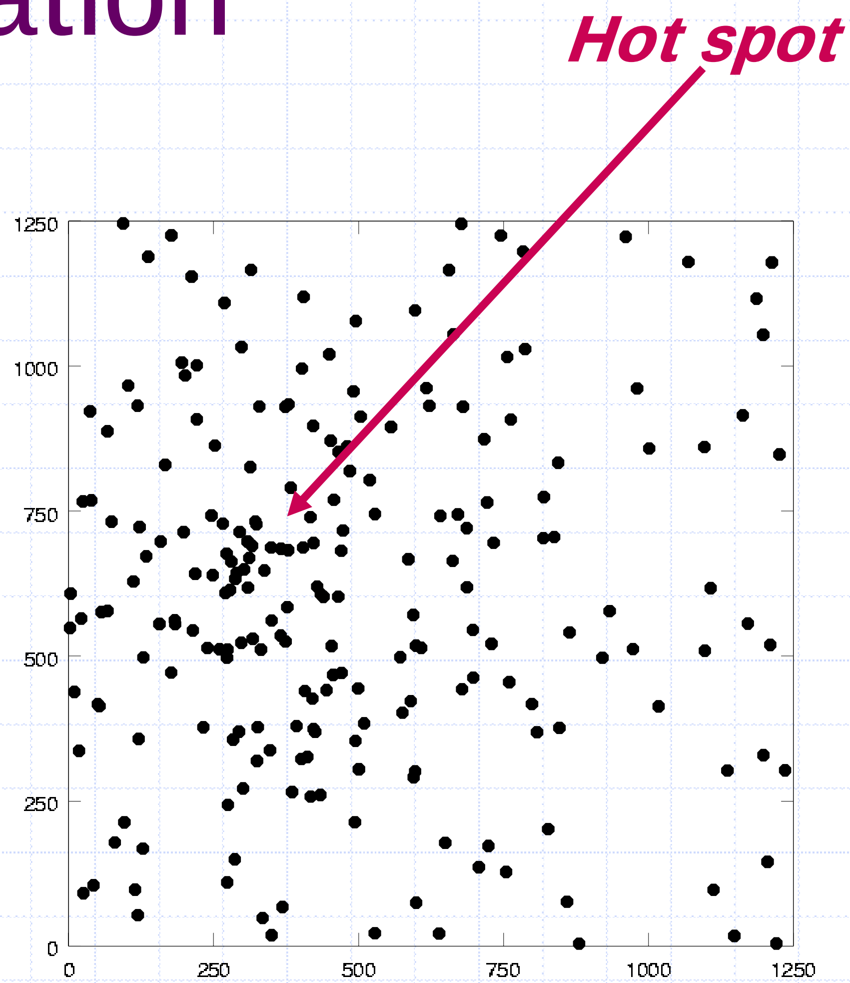
Topology Generation

- First, network area is divided into a number of square subareas
- Then, the Bounded Pareto distribution is used to determine the number of nodes in each subarea
- Once the number of nodes in a particular subarea is determined, they are randomly positioned within that subarea

Topology Generation



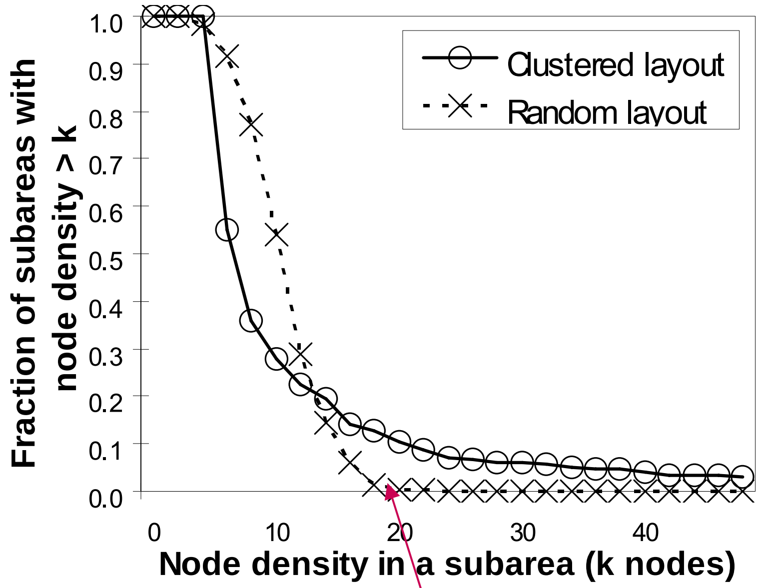
Random layout



Clustered layout

(n=250, s=25, α=1.1, a=3, and b=100)

Node Density/Degree Distribution

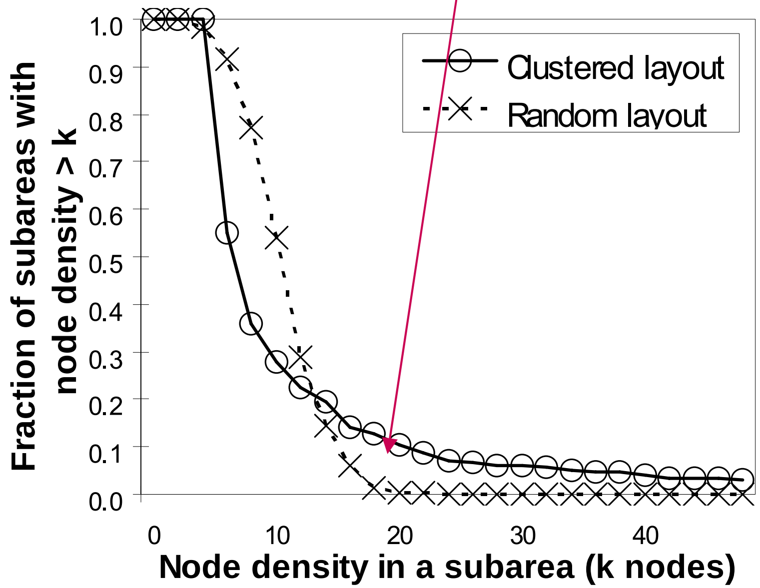


Node density distribution

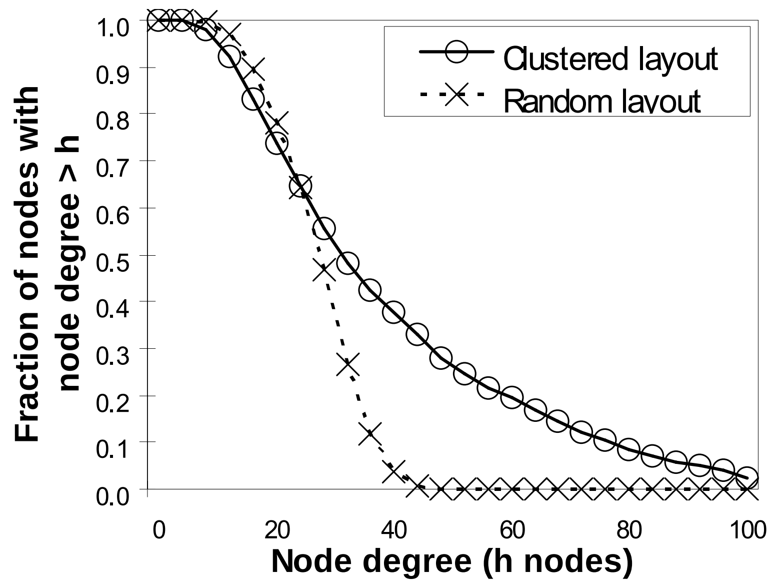
No subarea has more than 20 nodes

Node Density/Degree Distribution

About 15% of subareas have more than 20 nodes



Node density distribution

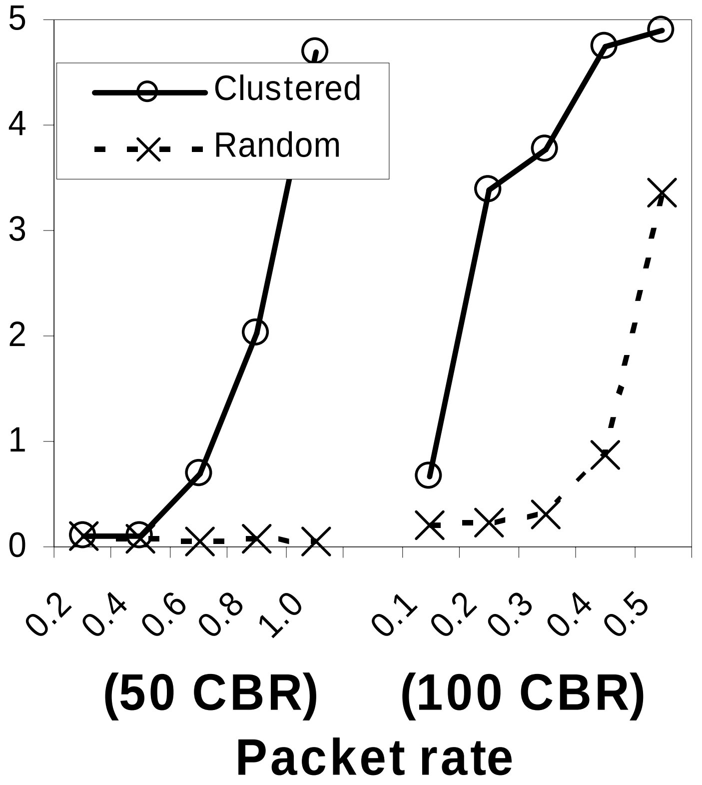


Node degree distribution (250m Tx range)

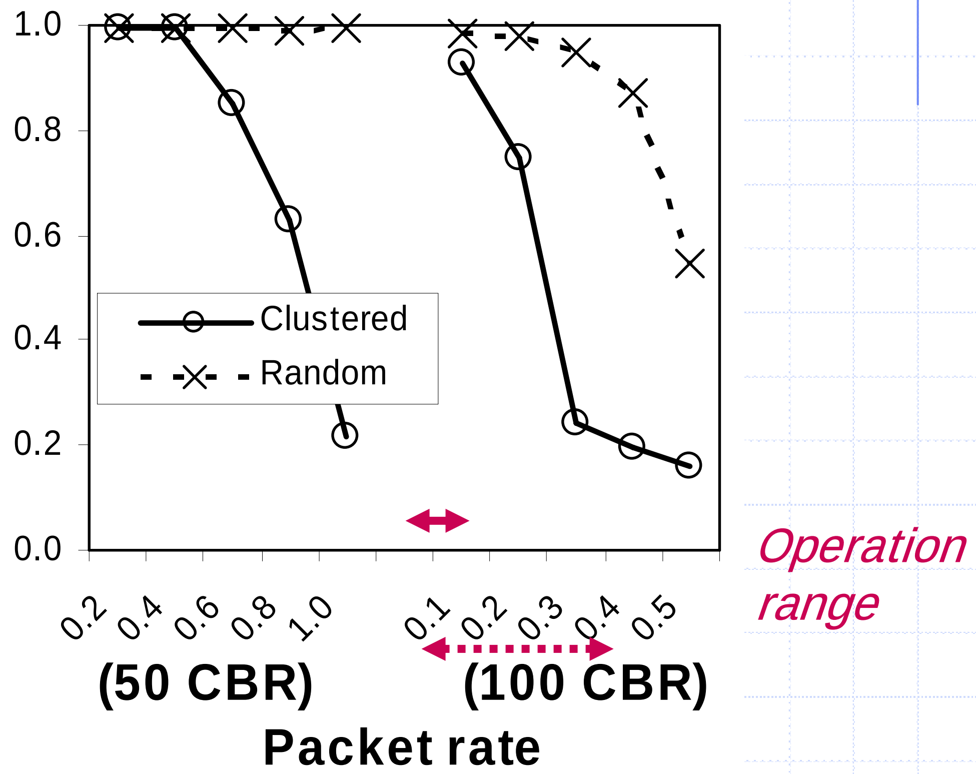
Simulation with Network Simulator

- Ns-2 simulator
  - Network size: 1250x1250m^2
  - Number of nodes: 250
  - Two-ray ground reflection propagation model
  - IEEE 802.11 MAC with RTS/CTS
  - AODV (Ad-hoc On-demand Distance Vector) routing algorithm
  - Traffic model
    - 25-125 CBR (constant bit rate) sources
    - One 256-byte packet every 0.1~1 second
  - Mobility
    - Not considered
- We'll see
  - General performance such as delay and PDR
  - QoS performance
  - MAC level parameters

Simulation Results: Basic

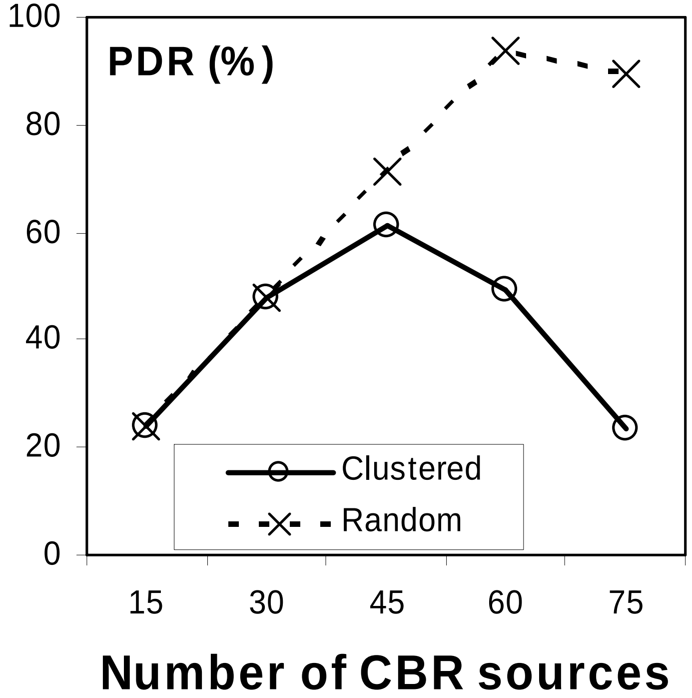


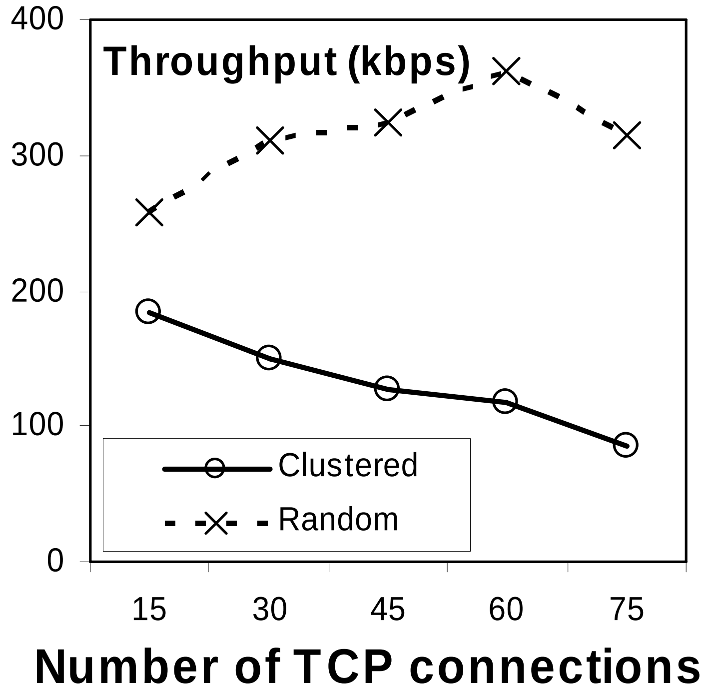
Packet delay (s)



Packet delivery ratio (%)

Simulation Results with Varying Traffic Intensity

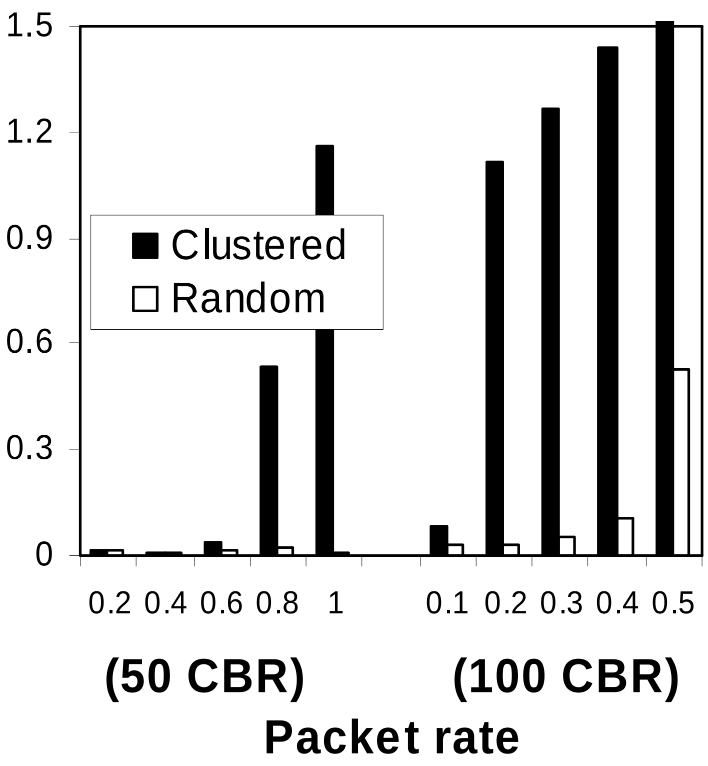




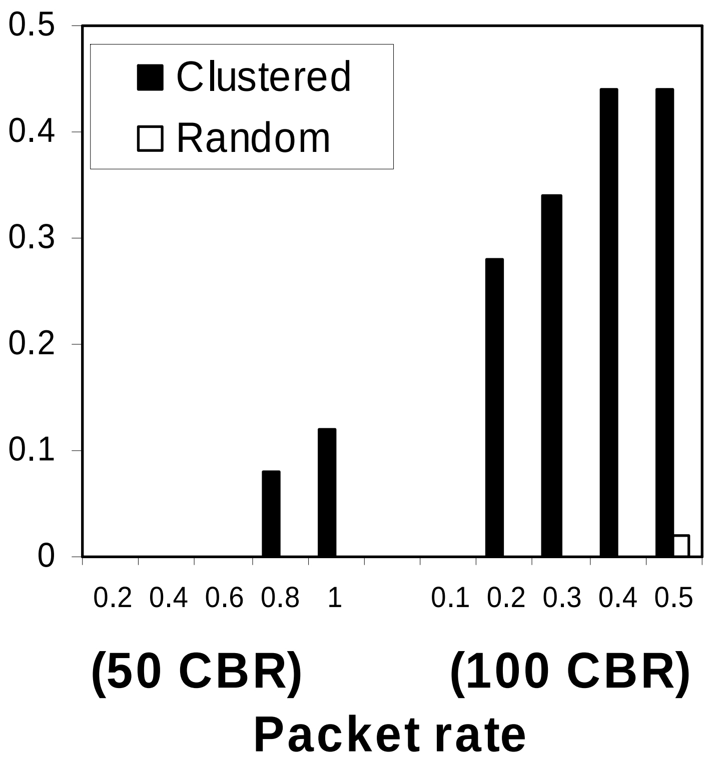
CBR Traffic

TCP Traffic

Simulation Results: QoS Measures



Deviation of PDR

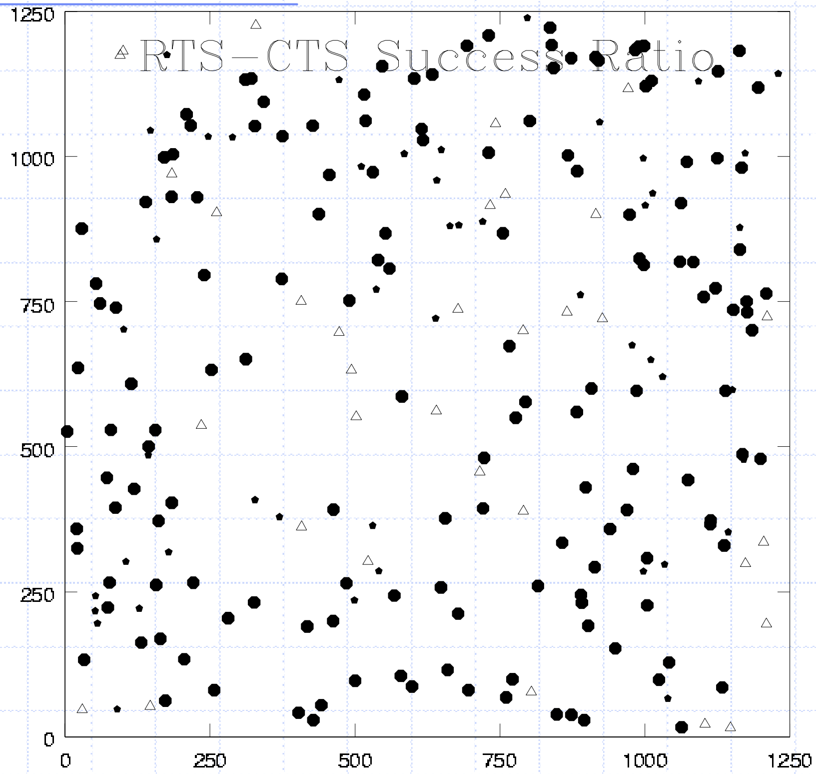


Ratio of “blackout” nodes

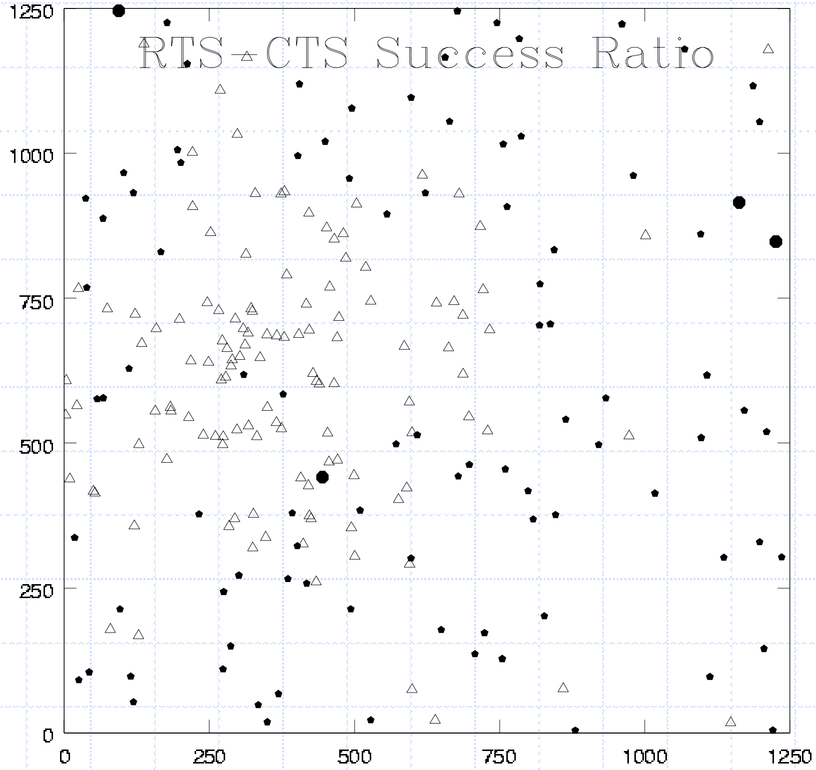
Analysis

- Two MAC layer parameters have been monitored during simulation
- Success ratio of RTS-CTS handshake
- Contention window size
  - When a packet collides, each node adjusts its contention window size to reduce the chance of further collisions
  - Minimum window size is 32 and is doubled whenever a collision occurs until the maximum window size (1024) is reached
  - This is obtained by sampling the window size during the simulation when each node decides to transmit a packet

Bottleneck Analysis: Success ratio of RTS-CTS Handshake



Random layout



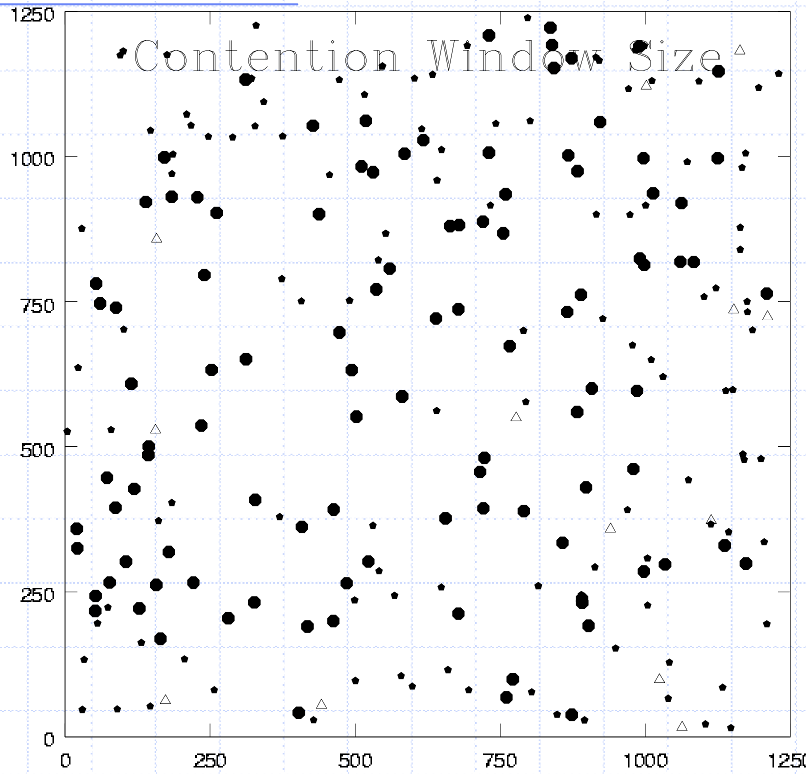
Clustered layout

(Triangle: <30%, small dot: 30~60%, large dot: >60%)

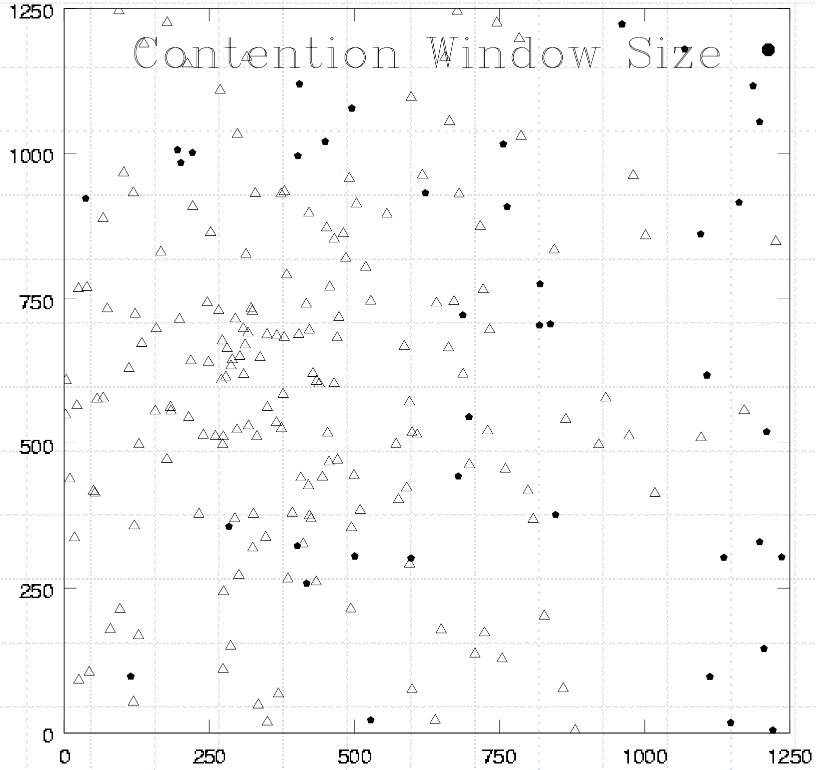
(More than half of the nodes are successful more than 60% of the time, marked as large dots)

(Most of the nodes receive a CTS packet less than 30% of the time in response to a RTS packet, marked as triangles)

Bottleneck Analysis: Average contention windows size



Random layout



Clustered layout

(Triangle: >160 slots, small dot: 64~160 slots, large dot: <64 slots)

(Smaller than 64 for most of the nodes, marked as large dots)

(Mostly larger than 160 with the clustered layout, marked as triangles)

Conclusions

- We studied capacity scalability of a multihop peer-to-peer network when node distribution is not random
- Analyzed an example clustered layout of nodes
- Proposed a topology generation method for the clustered layout
- Simulation via ns-2
  - General network performance suffers
  - QoS metrics, such as variation in packet delivery service and the number of blackout nodes, suffer too

Conclusions

- What's the main cause of the performance degradation?
  - MAC layer parameters, such as success ratio of RTS-CTS handshake and contention window size, suffer a lot with the clustered layout
- Potential solutions (Future work)
  - Adaptive capability at the MAC layer is desirable in order to provide consistent performance irrespective of node distribution
  - Overlay structure over peer-to-peer multihop networks (divide-and-conquer approach)

Questions?