Clustered Mobility Model for Scale-Free Wireless Networks

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Outline

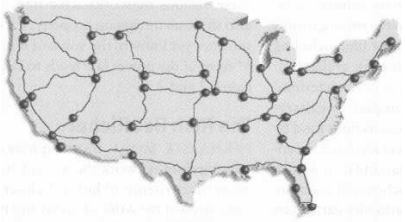
- Motivation
- Related Work
- Clustered Mobility Model (CMM)
- Performance Analysis
- Conclusions & Future Works

Motivation

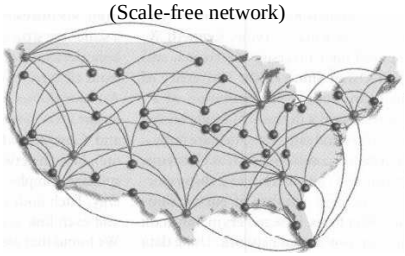
- Many mobile ad hoc network (MANET) studies are based on simulation (e.g. ns-2 and GloMoSim)
  - Mobility is one of important factors
  - Random mobility is taken for granted
- Nodes are assumed to be “randomly” located and to move “randomly”
  - At any instance, node connectivity can be modelled via Random networks
- But, real-life networks may be different
  - New graph models have emerged from studies in natural, technological and social networks, e.g. electric power grid or Internet connections
  - Small-world or Scale-free networks

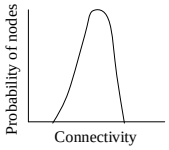
Random vs Scale-free Networks

US railroad network
(Random network)

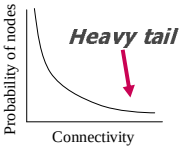


US airline network
(Scale-free network)





Bell-curve distribution of node connectivity



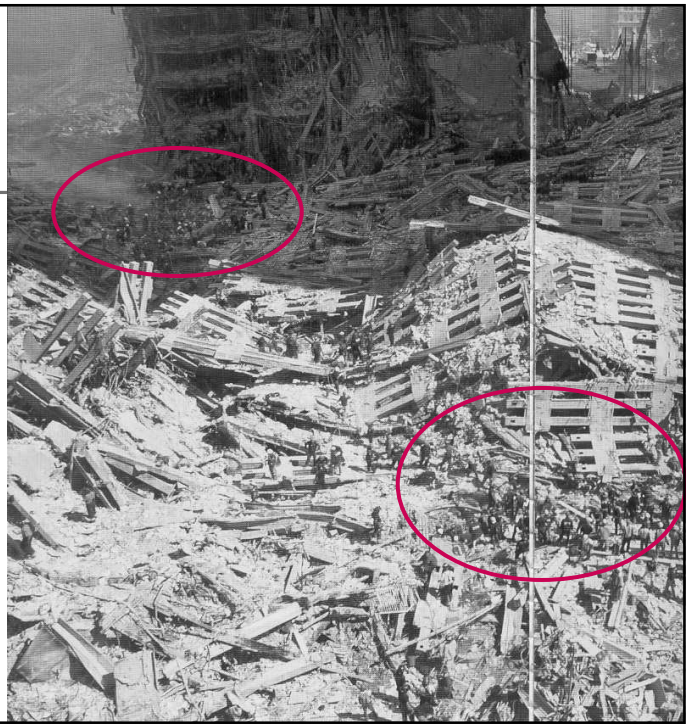
Power-law distribution of node connectivity

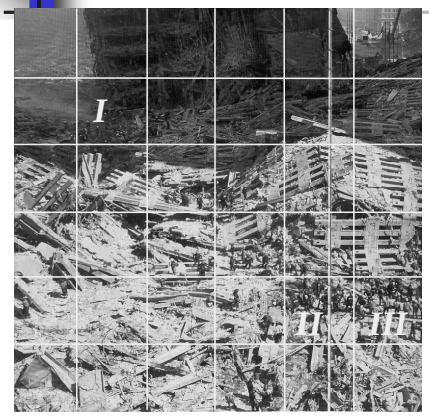
Scale-free networks, Albert-Laszlo Barabasi and Eric Bonabeau, Scientific American, May 2003

Typical MANET scenario: Disaster Relief

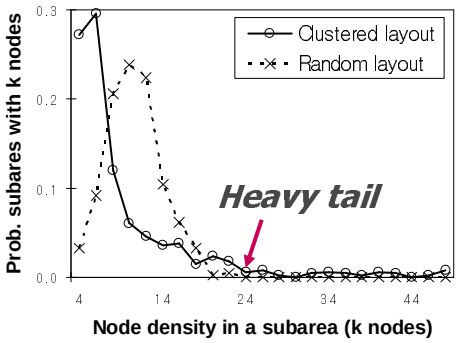
- Are they randomly distributed?
- Do they move randomly?

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





Rescue Team At Ground Zero

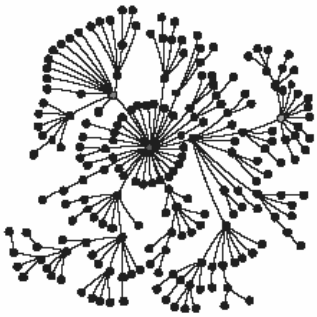


Node Density Distribution

Motivation: Scale-Free Wireless Networks

- Observations
  - In "some" mobile network applications, random graph does not correctly model the node mobility
  - Instead, nodes tend to move towards the crowd
  - Creates a few "clustered areas" or "hub nodes"
- This paper
  - Develops Clustered Mobility Model (CMM) to simulate such node mobility
  - It is based on scale-free network principles
  - And studies how it affects network capacity

Birth of Scale-free Network



- Network grows with new additional nodes, attaching to previously existing nodes. Incremental growth
- The probability of attachment is proportional to the connectivity of the target node. Preferential attachment
- Thus richly connected nodes tend to get richer, leading to the formation of hubs.

Exploring complex networks, Steven H. Strogatz, Nature, March 2001

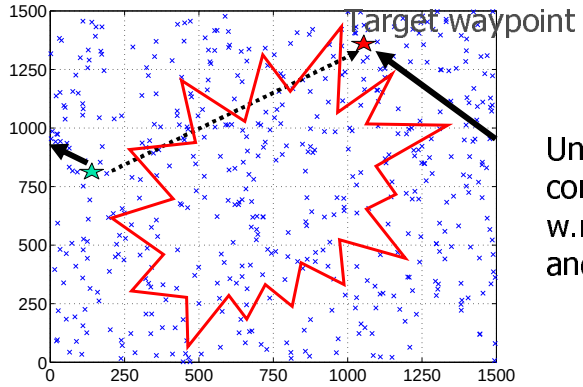
Clustered Mobility Model

- Models scale-free wireless networks (SFWN)
  - Exhibits power-law distribution of node connectivity
- Based on RWP (Random Waypoint) mobility model
- Exhibits steady-state mobility parameters (node speed, positions and density) unlike in RWP

CMM: Steady-State Mobility Parameters

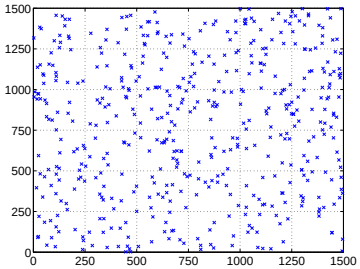
- RWP (Random Waypoint) mobility model
  - The most popular in simulation studies
  - Two parameters: Pause time and speed [0, V_{max}]
  - Pause ▸ Select a waypoint randomly ▸ Move toward it with speed between [0, V_{max}]
- Undesirable features of RWP
  - Average node speed is not $V_{max}/2$
  - Nodes are more concentrated at the center
- Approaches in CMM
  - Minimum speed is non-zero - [V_{min}, V_{max}]
  - Allows wrapping around at the boundaries (RWP_WRAP)

RWP_WRAP

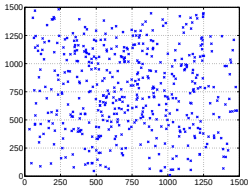


Unrealistic but offers correct measures w.r.t. node locations and concentrations

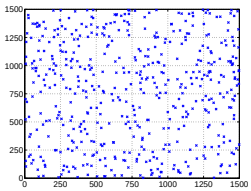
CMM: Steady-State Mobility Parameters



time = 0



RWP



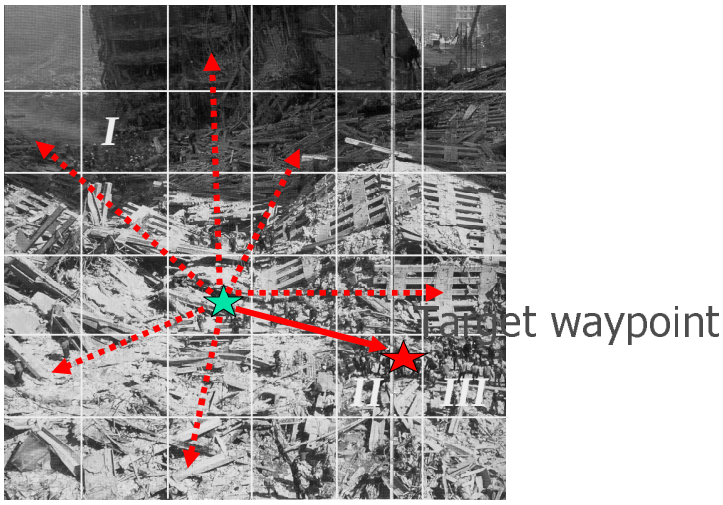
RWP_WRAP

time = 20,000

CMM: Scale-free Property

- Based on RWP (Random Waypoint) mobility model
  - The most popular in simulation studies
  - Two parameters: Pause time and speed [0, V_{max}]
  - Pause ▸ Select a waypoint randomly ▸ Move toward it with speed between [0, V_{max}]
- Exhibits power-law distribution of node connectivity
  - Initial layout (growth) & Induce mobility (rewiring)
  - Selection of waypoints (preferential attachment)

Selection of Waypoints



CMM: Growth

- Generate an initial layout of nodes
  - First, network area is divided into a number of square subareas (s_t)
  - A node is assigned a subarea based on their population (k_i)
  - Then, the node is randomly positioned within the subarea
  - The process ends when all the pre-determined number of nodes have been assigned subareas
- During the process,
  - Some subareas will have a higher probability than others "by chance" initially but "by preferential attachment" later
  - These areas will become hubs

CMM: Growth

/* when a new node joins in the network, */
for ($i = 0$; $i < s_t$; i ++) {
    /* calculate the popularity of subarea s_i */
    $k_i \leftarrow$ subarea population of s_i;
    $\varphi_i \leftarrow \frac{(k_i+1)^\alpha}{\Sigma_j (k_j+1)^\alpha}$;
}
choose a destination subarea using φ_j's;
choose a random position within the chosen subarea;

Clustering exponent

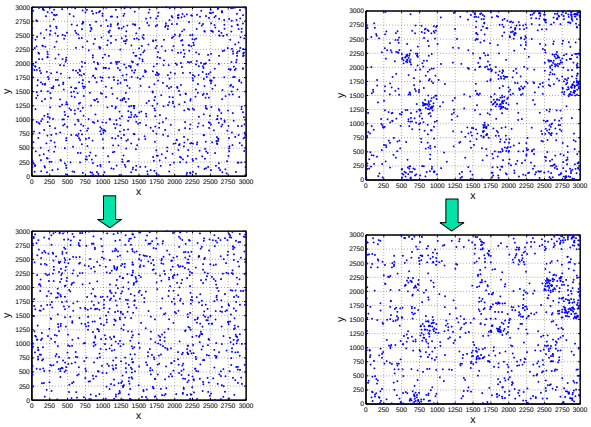
CMM: Rewiring

- Induced by mobility
- Each node is rewired from one subarea to another when it moves
  - A target waypoint is selected randomly in RWP
  - A target subarea is selected randomly but based on terminal subarea populations (φ_i's)
  - This implements the principle of preferential attachment

CMM: Growth & Rewiring

time = 0

time = 10,000



RWP_WRAP

CMM (α=1.2)

Level of clustering diminishes

Level of Clustering Varies Over Time

Selection of initial positions and waypoints are governed by preferential attachment (φ's).

But, during move, their locations are random !!!

If pause=0, entirely random
If pause=∞, entirely SF

Level of Clustering Varies Over Time

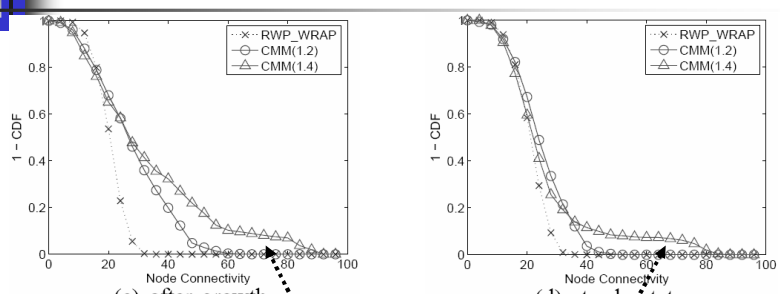
- Complications due to "mobility fraction" (ξ)
  - Nodes are located randomly for ξ and scale-free fashion for (1- ξ) of their lifetime
  - They'll reach steady-state ultimately but it takes a long simulation time to reach

/* when the network reaches the pre-determined number of nodes, */
for (each hub area s_i such that $k_i \gg \frac{n}{s_t}$) {
    /* calculate the steady-state population */
    $k'_i \leftarrow$ subarea population of s_i at steady-state $(k_i(1-\xi))$;
}
choose a destination subarea randomly for each of the excluded nodes;
choose a random position within the chosen subarea;

Performance Analysis

- Comparisons of node distributions
  - CMM (α = 1.2) and RWP_WRAP (equivalent to CMM, α = 0)
  - 1000 nodes in 3000x3000 m^2 network
  - Node speed is chosen from [5, 20] m/sec, and pause time = 106 seconds
  - Mobility fraction (ξ) = 50%
- Implications of scale-free wireless networks (SFWN) following CMM
  - Node connectivity
  - Physical (PHY), MAC and Network (NET) capacity

Node Connectivity



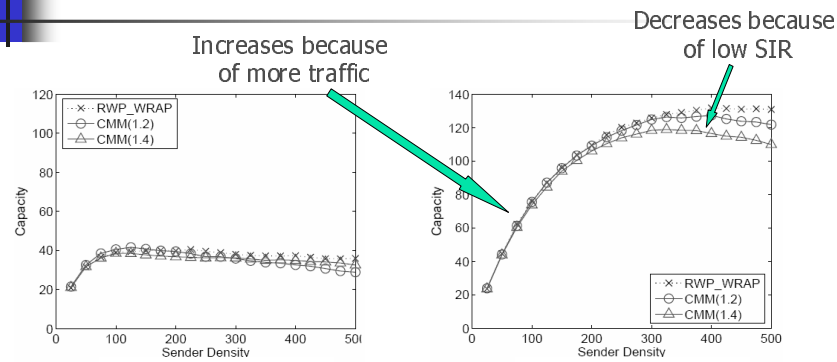
(c) after growth (d) steady state

CMM shows a heavy-tail,
which explains the existence
of hub subareas

PHY (nearest one-hop) Capacity

- Measures how much traffic the network can support
- Multiple communications can happen simultaneously as long as,
  - *Signal-to-interference ratio (SIR)* is larger than a certain threshold, called *capture ratio*
- Method
  - A node transmits to its nearest neighbor
  - A second node transmits to its nearest neighbor as long as SIR at the receiver is larger than the capture ratio
  - Repeats for all nodes
  - Summarize them

PHY (nearest one-hop) Capacities



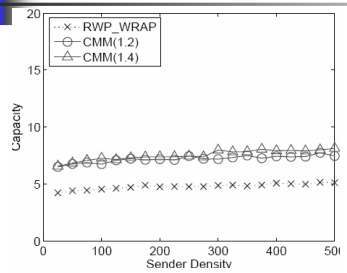
path loss exponent = 2 path loss exponent = 3

- The capture ratio is set to 6 dB
- CMM exhibits a comparable performance with RWP_WRAP except at high sender density

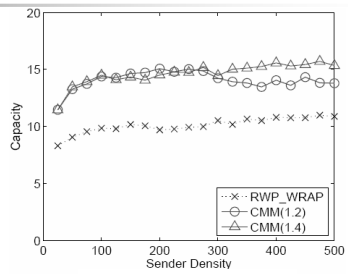
MAC (one-hop) Capacity

- Network layer protocols developed for multi-hop networks,
  - Favors the farthest neighbor along the direction of a final destination
- Measure the number of concurrent transmissions under this scenario
- Method
  - A node transmits to the farthest neighbor within its transmit range
  - A second node is allowed to transmit to its farthest neighbor as long as SIR at the receiver is higher than capture ratio
  - Repeats for all nodes and summarize them

MAC (one-hop) Capacities



path loss exponent = 2



path loss exponent = 3

- The capture ratio is set to 6 dB
- RWP_WRAP performs worse than CMM
- Both RWP_WRAP and CMM show consistent performance as the sender density increases

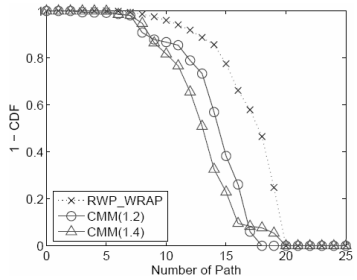
NET (multi-hop) Capacity

- Measure the robustness of multi-hop connections between a pair of nodes in the network
- Connectivity of $\kappa_{i,j}$ for node pair *i-j*
  - Number of disjoint multiple paths
  - A direct measure of the resilience of the pair to node failure or node mobility
- Use an approximation algorithm,
  - Finding the shortest path for a node pair
  - Finding the next shortest path using the unused nodes, and so on,
  - Until no further path exists for the node pair ***i*** and ***j***
  - Repeat for all node pairs to get the statistics

NET (multi-hop) Capacities

AVERAGE κ.

mobility	RWP_WRAP	CMM(1.2)	CMM(1.4)
κ	15.747626	12.799852	11.868478



- The average number of connectivity of a node pair
- RWP_WRAP has more number of paths than CMM

Conclusions

- Develop a new mobility model: clustered mobility model (CMM)
  - Simulates the non-homogeneity with the distribution of subarea population and mobility fraction (ξ),
  - Mobility parameters reach the steady state
- Define and evaluate network capacities at PHY, MAC, and NET layers
  - Scale-free wireless networks (SFWNs) exhibit lower NET capacity but achieve higher MAC and as high PHY capacity as conventional wireless networks

Future Works

- Investigate more on PHY, MAC and NET capacities
- Investigate the properties of the SFWNs that are likely to occur in a real deployment of wireless multi-hop and sensor networks
- Develop an optimized network protocols that take advantage of the special characteristics of SFWNs

Thank You !!