The Impacts of Physical Layer Parameters on the Connectivity of Ad-Hoc Networks

Javad Kazemitabar, Homayoun Yousefi'zadeh, Hamid Jafarkhani

University of California Irvine

[skazemit,hyousefi,hamidj]@uci.edu

Outline

- Background
- Ergodic SER Metric of Connectivity
- Performance results
- Conclusion

Outline

- Background

√ Ergodic SER Metric of Connectivity

√ Performance Results

√ Conclusions

Earlier Metrics of Connectivity

- Geometric disk model, Gilbert (1961):
  Distance less than the transmission range
  - No interference assumption
  - Node density more than a limit results in percolation, i.e., global connectivity
- SINR model, Gupta and Kumar (2000):
  Signal to Interference-Noise Ratio more than a threshold

Connectivity Reality

- A link between two nodes is a wireless channel
- A high-quality link is identified by:
  - A high capacity, and/or
  - A low symbol error rate
- New metrics of connectivity needed to capture the quantities

New Metrics of Connectivity

- SER metric, YJK (2005):
  - Outage probability of symbol error rates: $Pr(C_i < C_{out}) < \Delta_C$
  - Ergodic symbol error rate less than a threshold: $\overline{C}_i \geq C_{out}$
- Capacity metric, JYK (2005):
  - Outage connectivity: $Pr(SER_i > S_{out}) < \Delta_S$
  - Ergodic capacity more than a threshold: $\overline{SER}_i \leq S_{out}$

New Metrics of Connectivity cont'd

The new measure

- ↑Capture the reality of the physical layer

New Metrics of Connectivity cont'd

The new measure

- ↑Capture the reality of the physical layer
- ↑Outage and ergodic formulas are well known

New Metrics of Connectivity cont'd

The new measure

- ↑Capture the reality of the physical layer
- ↑Outage and ergodic formulas are well known
- ↓Have higher complexities compared to SINR and geometric disk models

New Metrics of Connectivity cont'd

The new measure

- ↑Capture the reality of the physical layer
- ↑Outage and ergodic formulas are well known
- ↓Have higher complexities compared to SINR and geometric disk models
- ↕What are the effects of physical layer variations on connectivity?

Outline

- √ Background
- Ergodic SER Metric of Connectivity
- √ Performance Results
- √ Conclusions

Ergodic SER Metric

- Two nodes forming a link i are considered connected if

$$\overline{SER}_i \leq S_{out}$$

(a) $\overline{SER}_i$ is the ergodic symbol error rate of link i and is calculated as a function of $\overline{SINR}_i$, number of transmit-receive antennas, coding, and modulation
(b) S_{out} is the threshold of connectivity and represents hardware sensitivity

Getting the Devil out ...

The Symbol Error Rate of link i with M_i transmit and N_i receive antennas utilizing BPSK is identified as

$$SER_i = Q\left(\sqrt{2\,\beta\,\Upsilon_i\,\overline{SINR_i}}\right)$$

where Q represents Marqum Q function, $\overline{SINR_i}$ is the average signal-to-interference-noise-ratio of link i, and Υ_i is defined as a function of fading factors F_{ii}

$$\Upsilon_i = \sum_{m=1}^{M_i}\sum_{n=1}^{N_i} F_{ii}(n,m)$$

Antenna-dependent values of β are shown below

	1×1	2×1	1×2	2×2
β	1	0.5	1	0.5

. . . of the Details

When facing an ergodic Rayleigh channel and utilizing L-PSK modulation, the average $\overline{SER}_i$ is specified as

$$\overline{SER}_i = \int_0^\infty \left(\frac{1}{\pi} \int_0^{(L_i-1)\pi/L_i} \exp\left(-\frac{2\,\beta\,\Upsilon_i\,\overline{SINR}_i}{2\sin^2\tau} \right) d\tau \right) p_\Upsilon(\Upsilon_i)\, d\Upsilon_i$$

The above integral has closed-form results for a number of antenna configurations and coding schemes, e.g., a 2×2 link utilizing Alamouti STBCs and BPSK modulation,

$$\overline{SER}_i = \frac{1}{2} - \frac{1}{2}\sqrt{\frac{\overline{SINR}_i}{2+\overline{SINR}_i}} \left(\sum_{j=0}^{3} \frac{\binom{2j}{j}}{[2(2+\overline{SINR}_i)]^j} \right)$$

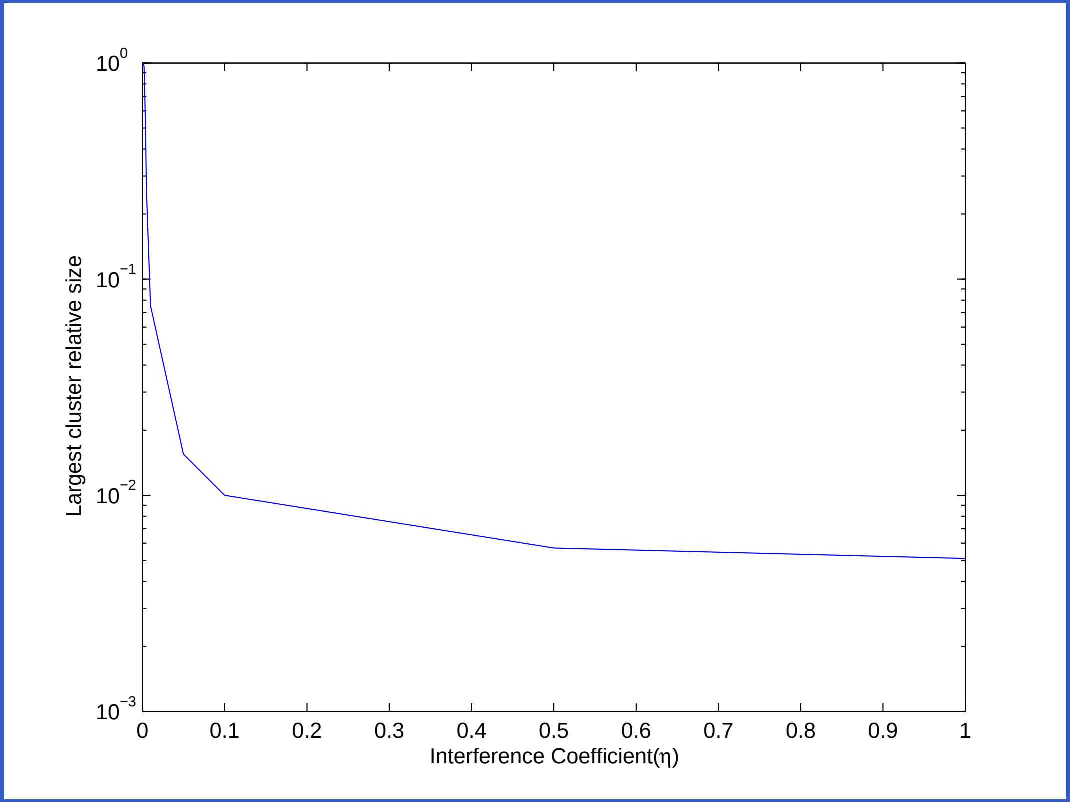
Outline

- √ Background
- √ Ergodic SER Metric of Connectivity
- Performance Results
- √ Conclusions

Experiment Settings

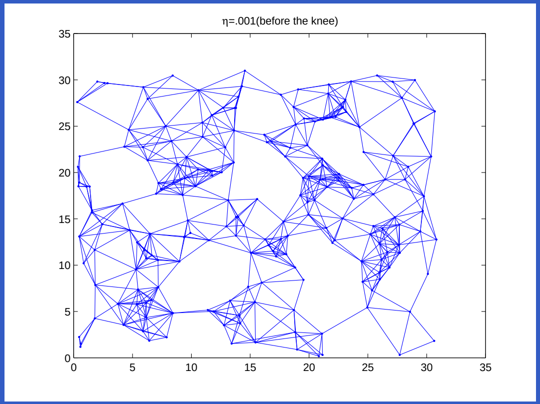
- Topology
  - A network with 200 nodes
  - An area of 1000 square meters
  - Nodes are distributed randomly
- Physical Layer Settings
  - BPSK modulation is used
  - Each node has two antennas
  - STBCs of Alamouti code is used when transmitting
  - MRC is used when receiving
- Communications Channel
  - Quasi-static flat Rayleigh fading
  - Transmit power of $1W$, noise power of $10\mu W$
  - Shadowing gains $G_{ii} = \frac{1}{d_{ii}^3}$, $G_{ij} = \frac{\eta}{d_{ij}^3}$

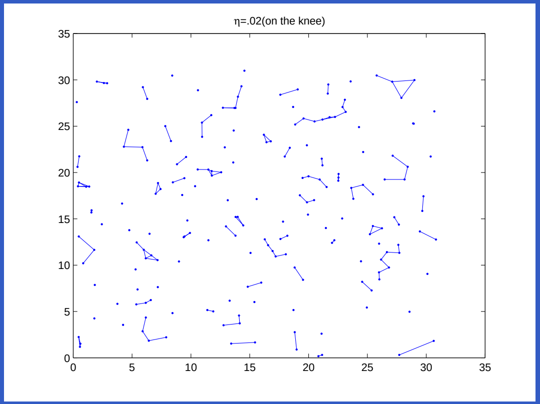
Interference Coefficient Effects

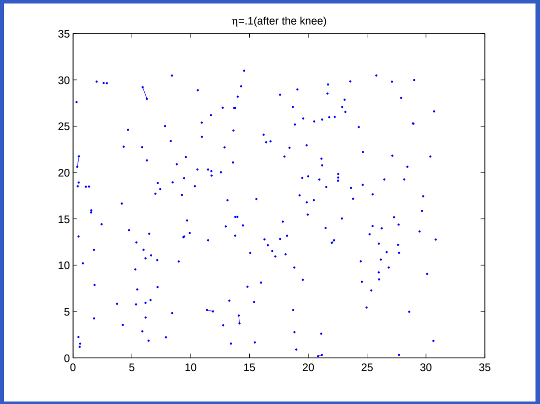


- Normalized size of the largest connected cluster versus the interference coefficient η for a connectivity threshold of $S_{out} = 0.001$

Interference Coefficient Effects (2)

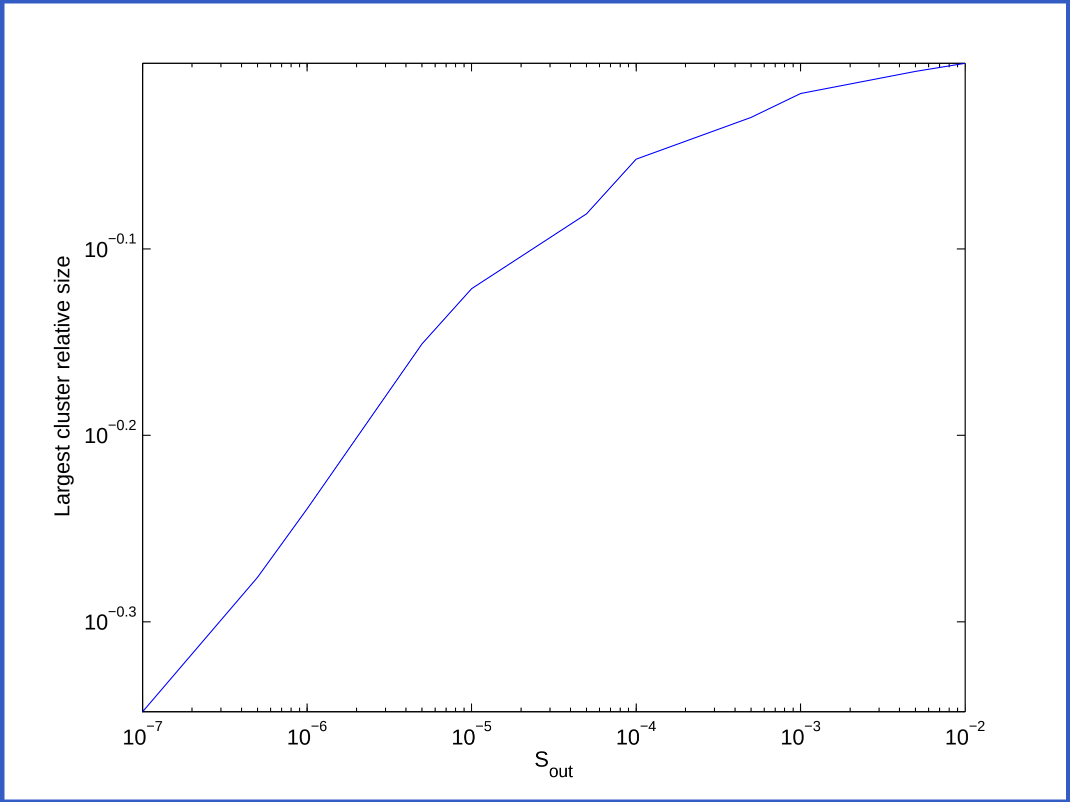






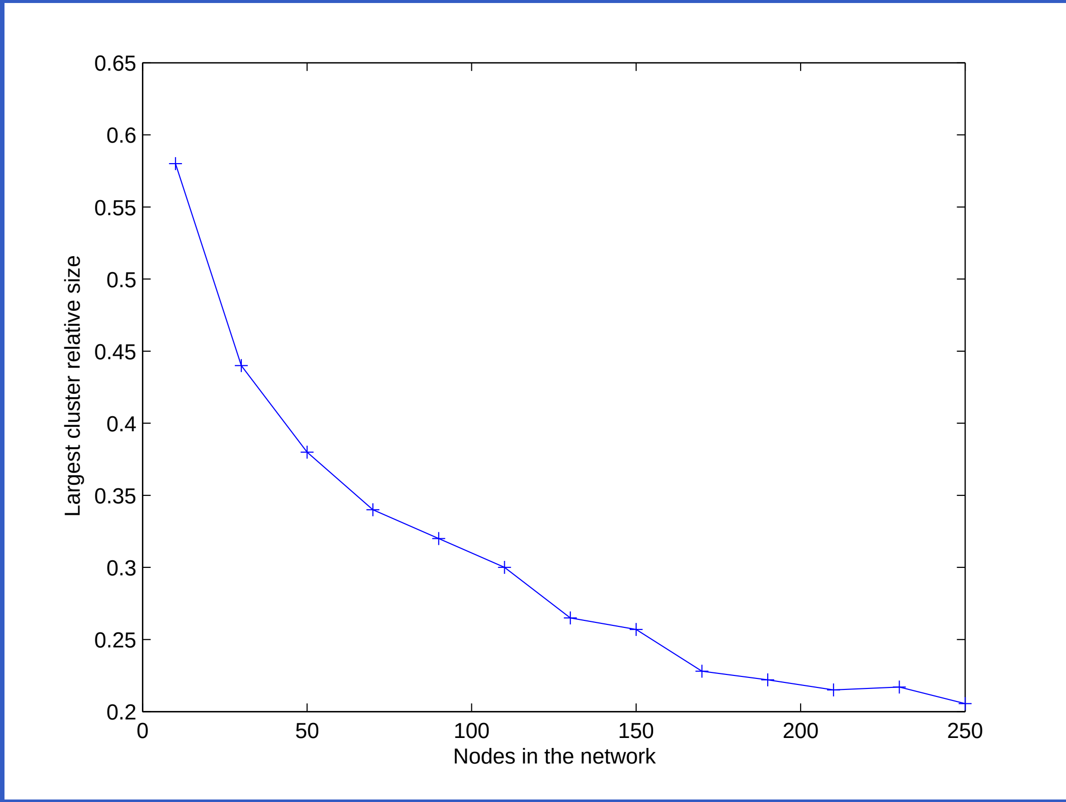
- Connectivity graphs associated with the three points before, at, and after the knee of the previous curve

Connectivity Threshold Effects



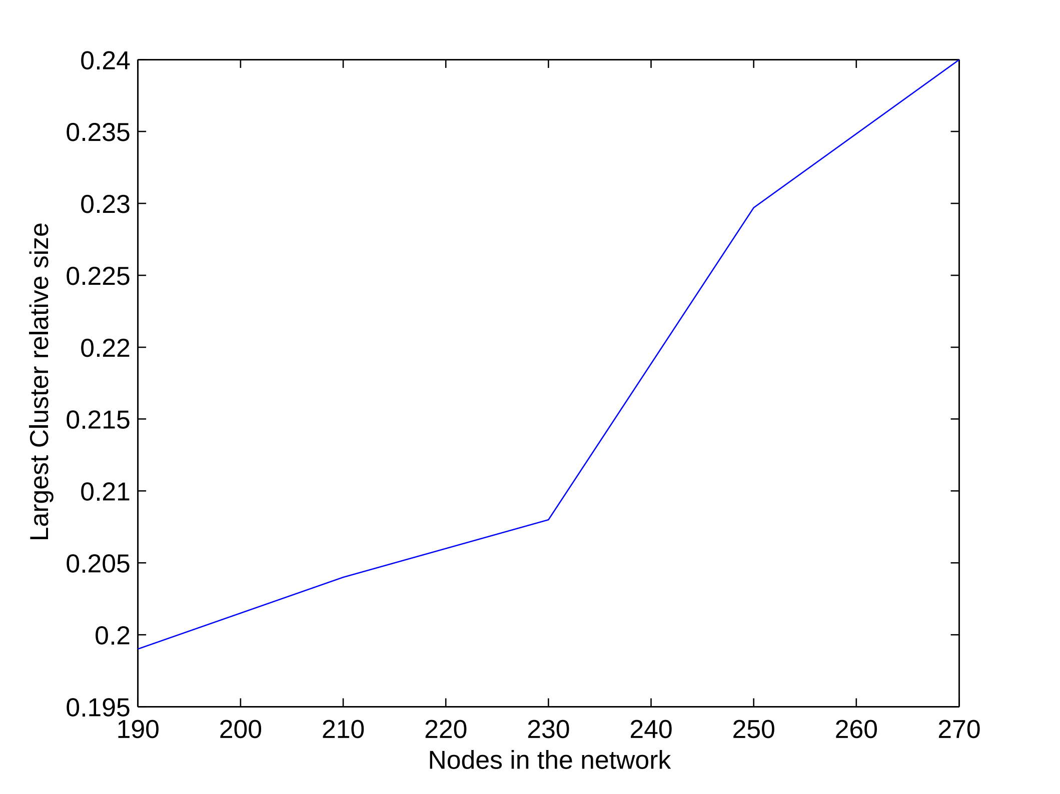
- Normalized size of the largest connected cluster versus the threshold of connectivity S_{out} for an interference coefficient $\eta = 0.002$

Node Density Effects



- Connectivity graphs with $S_{out} = 0.001$ and $\eta = 0.001$
- Connectivity decreases with the number of nodes in the network

Node Density Effects (2)



- Connectivity graphs with S_{out} =1e-6 and η =1e-5
- Connectivity decreases with the number of nodes in the network

Outline

- √ Background
- √ Ergodic SER Metric of Connectivity
- √ Performance Results
- Conclusions

Conclusions

- Interference coefficient poses percolation-like effects
- Connectivity threshold poses trivial effects
- Node density effects depend on interference and threshold values