Performance Comparison of Cellular and Multi-hop Wireless Networks: A Quantitative Study

Hung-Yun Hsieh and Raghupathy Sivakumar

The GNAN Research Group

http://www.ece.gatech.edu/research/GNAN

School of Electrical and Computer Engineering

Georgia Institute of Technology

June 19, 2001

Outline

- Introduction
- Performance comparisons
  - Simulation environment
  - Metrics
  - Results
- A hybrid wireless network model
- Conclusions

Wireless Data Networks

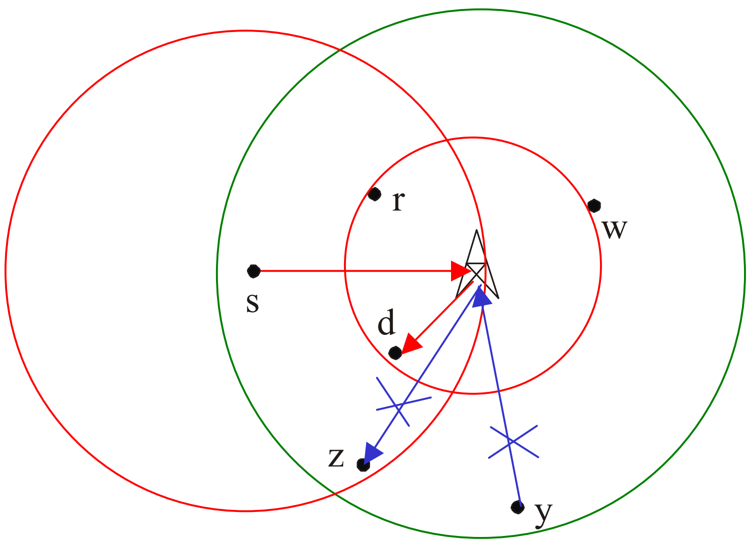
- Most wireless data networks are overlaid on cellular networks
- Channel data rate is limited
  - 3G wireless system

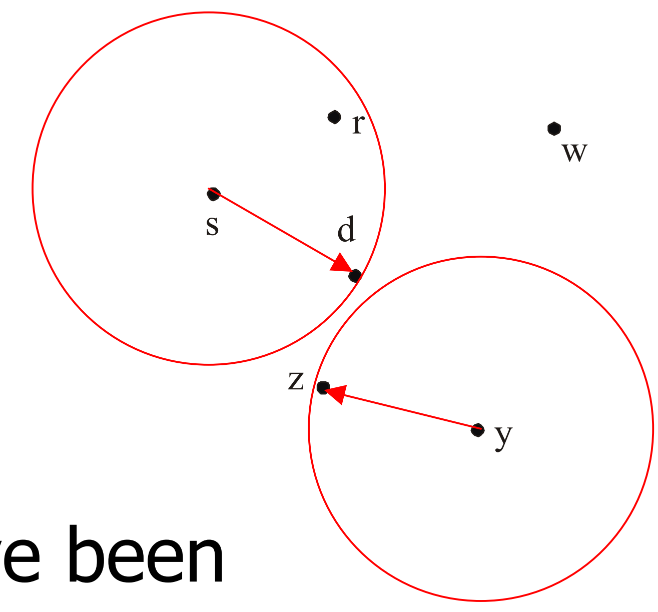
    144 kbps (outdoors/vehicle) – 2 Mbps (indoors)
- Bandwidth is shared by many users
  - Per-user throughput goes down as 1/n

✓ Capacity is an issue!

Ad-hoc Network Model

- Peer-to-peer communication provides better throughput because of spatial reuse [Gupta 2000, Lin 2000, Qiao 2000, Wu 2000]





✓ Not all trade-offs have been evaluated!

Progress

- Introduction
- Performance comparisons
  - Simulation environment
  - Metrics
  - Results
- A hybrid wireless network model
- Conclusions

Simulation Environment

- *ns-2* network simulator
- Physical layer
  - Single channel communication (2 Mbps)
  - Free space propagation and two-ray ground reflection channel models
- Medium access layer
  - Cellular model: IEEE 802.11 PCF (round-robin)
  - Ad-hoc model: IEEE 802.11 DCF / IFS / ILS
- Routing layer
  - Cellular model: no routing required
  - Ad-hoc model: DSR (dynamic source routing)

Simulation Environment

- Topology
  - 1500m by 1500m grid with randomly distributed nodes (50 – 400 nodes)
  - Transmission range
    - Cellular model: $750\sqrt{2}$ m
    - Ad-hoc model: variable (MIN to MAX)
- Mobility
  - Waypoint movement model
- Traffic generation
  - Every node acts as a CBR source with randomly chosen destination (light to heavy load)
  - Use TCP to transport CBR traffic

Metrics

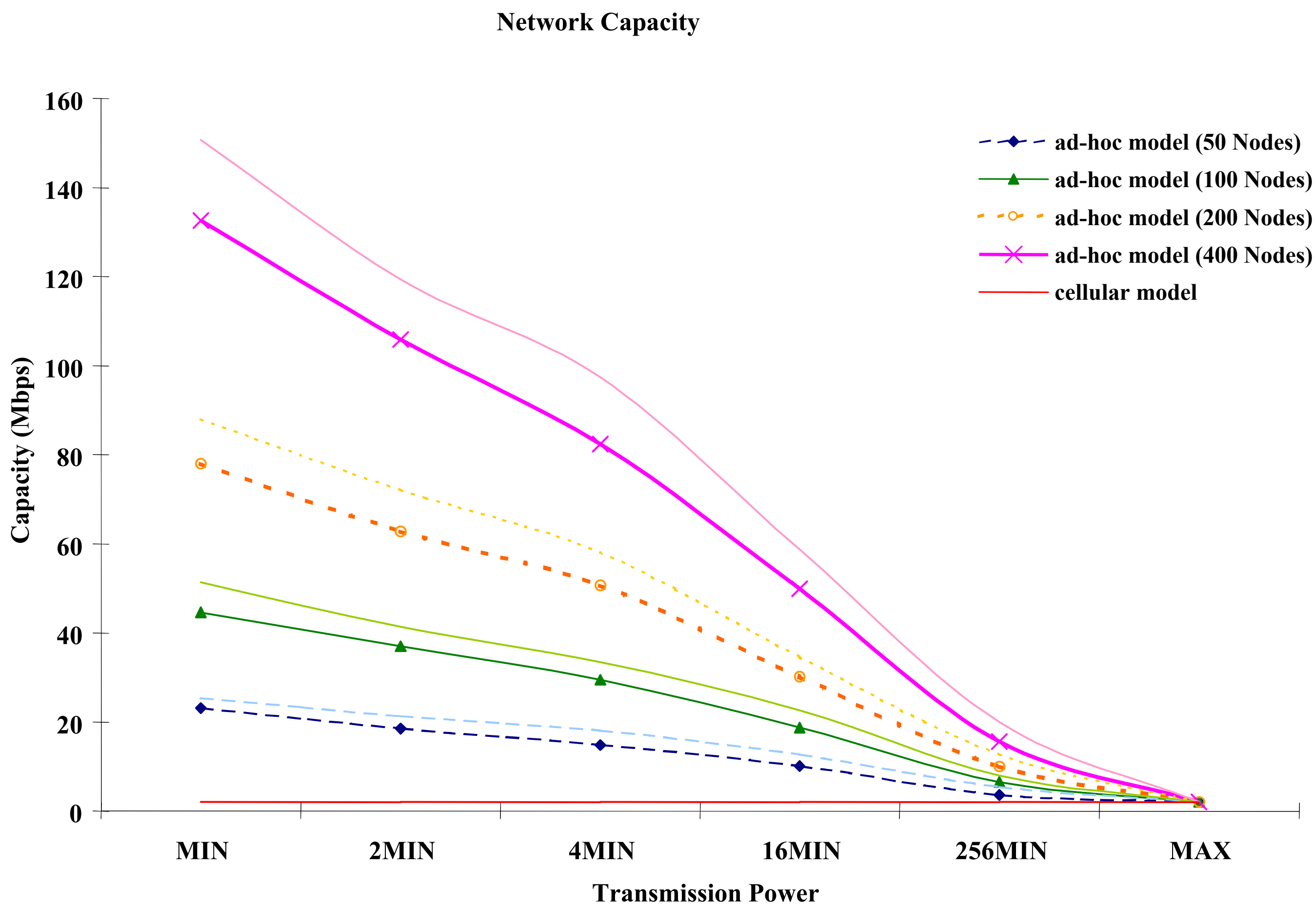
- Network capacity
- End-to-end throughput
- End-to-end delay
- Power consumption
- Fairness
- Impact of mobility

Network Capacity

- Network capacity
  - Proportional to the number of simultaneous transmissions (spatial reuse) and channel data rate
  - Destination is one-hop away from the source
  - Upper bound for instantaneous traffic
  - Unfair MAC vs. fair MAC

- Network capacity ~ O(Node number) = O(n)

Network Capacity

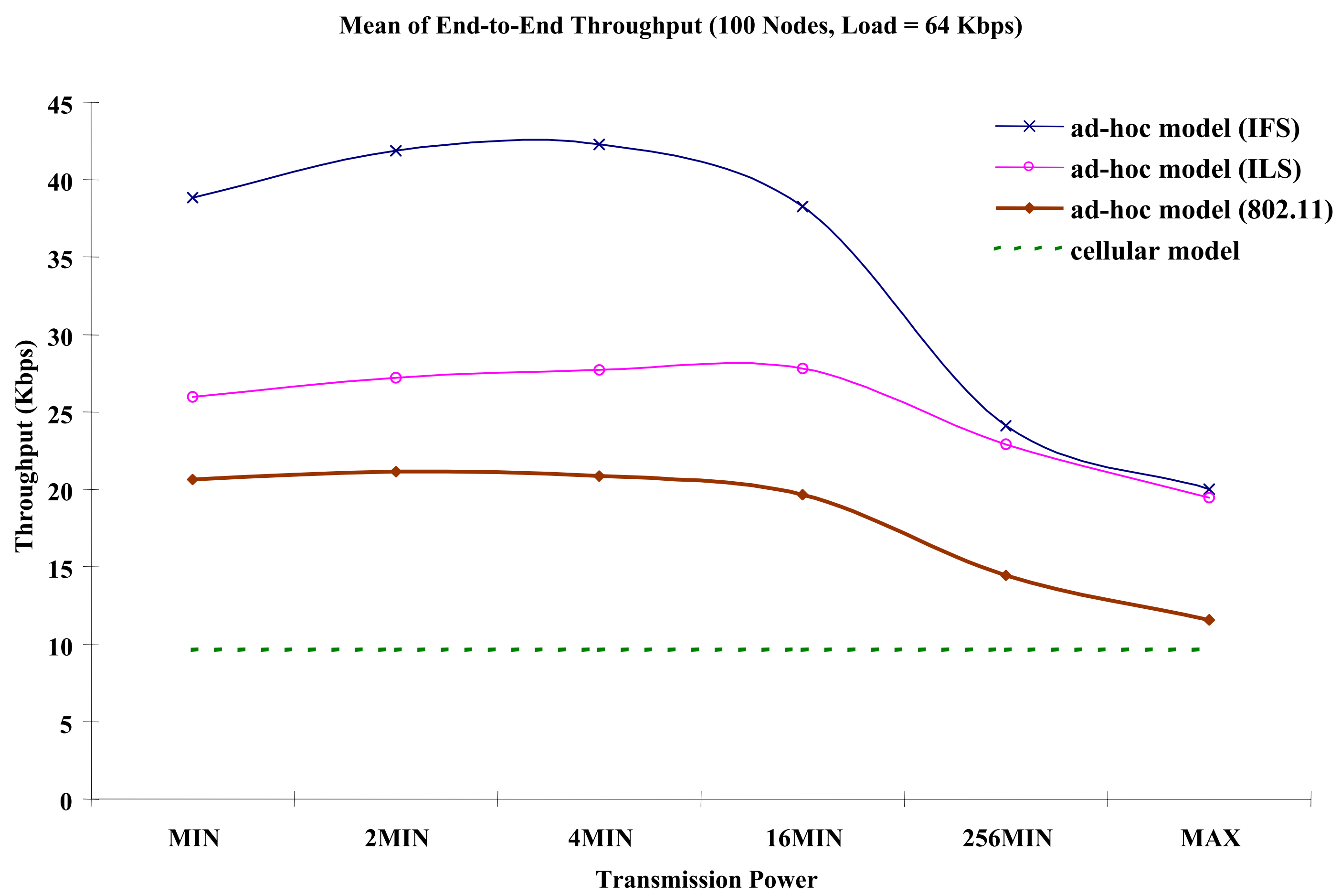


End-to-end Throughput

- End-to-end throughput
  - Performance measurement for end-to-end connections (flows)
  - Average for all flows in the network

- $$\text{E2E throughput} \sim O\left(\frac{\text{Network capacity}}{\text{Node num} * \text{Path length}}\right) = O\left(\frac{1}{\sqrt{n}}\right)$$
  - End-to-end throughput increases as the network capacity increases
  - End-to-end throughput decreases as the number of hops increases

End-to-end Throughput

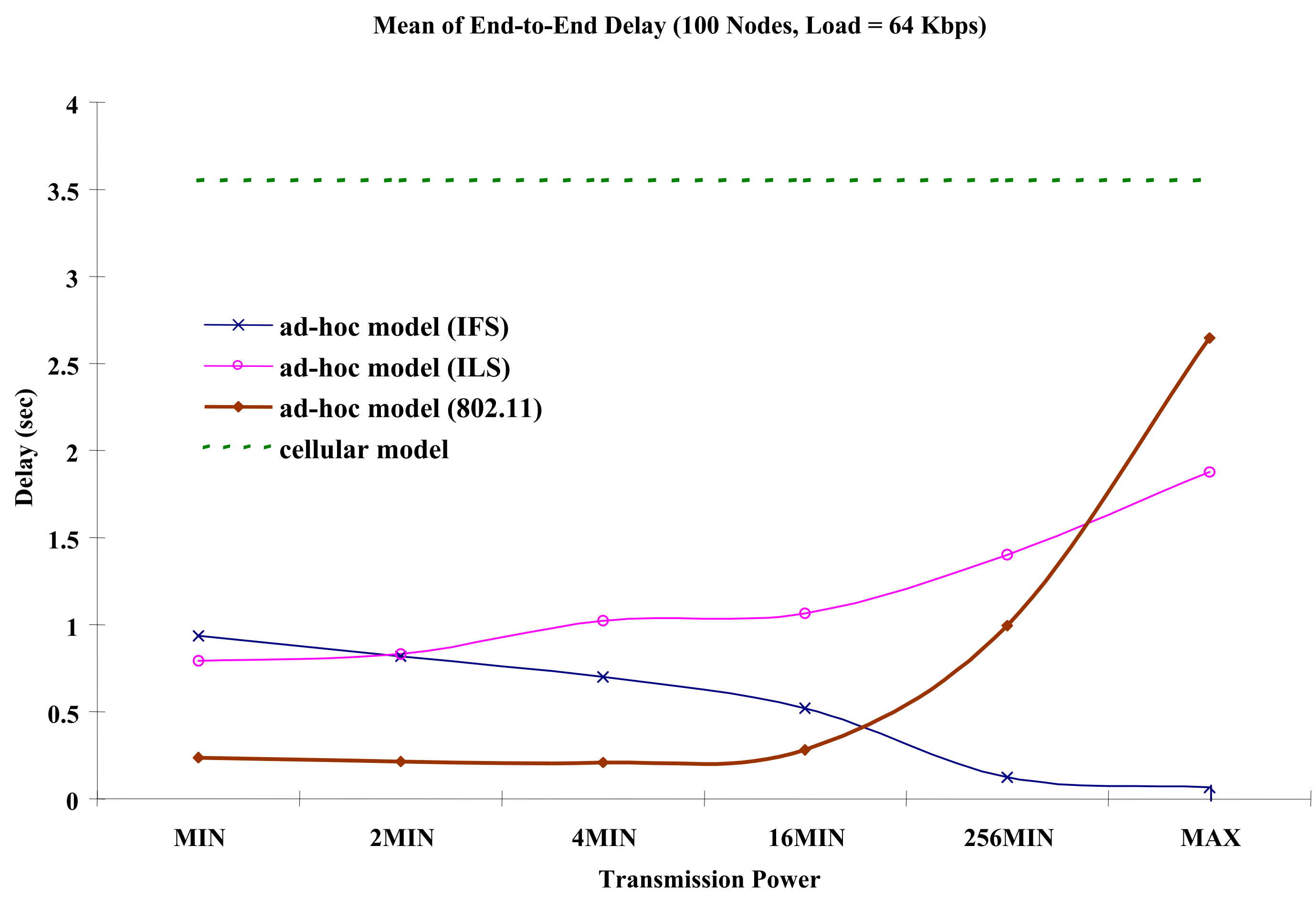


End-to-end Delay

- End-to-end delay
  - Measurement of network latency
  - Measured at the peer TCP layers

- $\text{E2E delay} \sim O\left(\dfrac{\text{Path length}}{\text{End-to-end throughput}}\right) = O(n)$
  - End-to-end delay decreases as the throughput increases
  - End-to-end delay increases as the number of hops increases

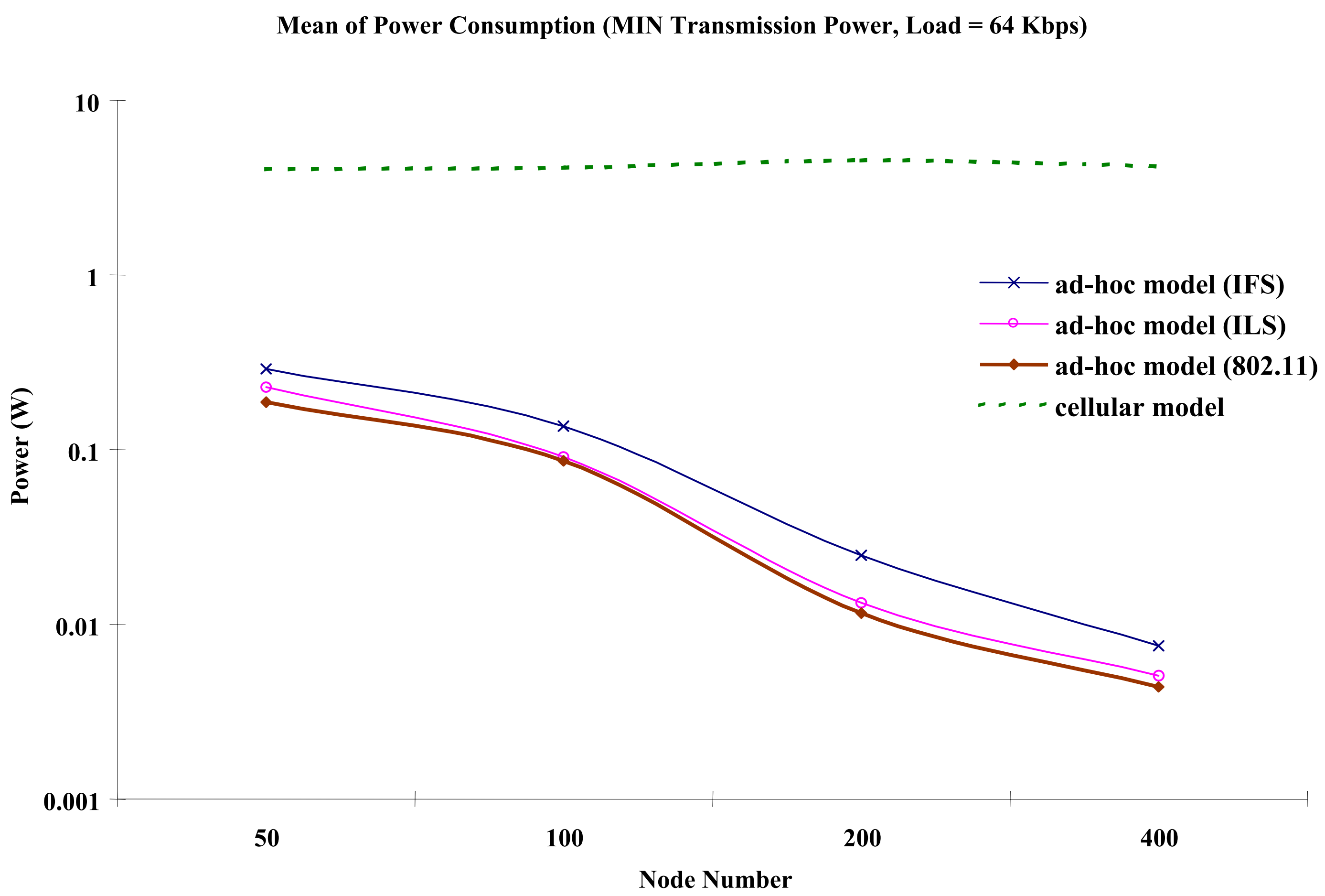
End-to-end Delay



Power Consumption

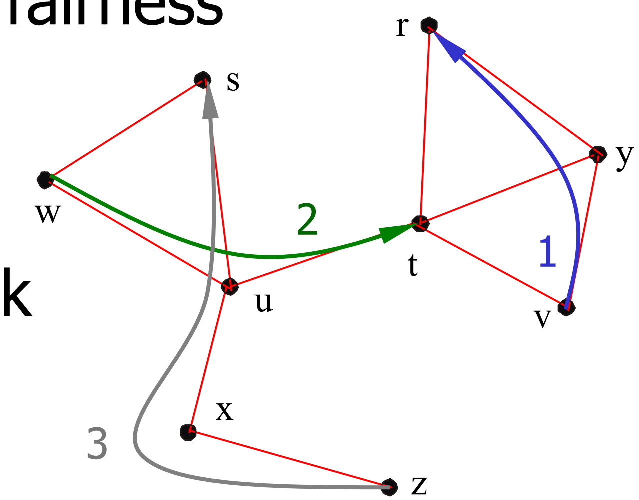
- Power consumption
  - Average power consumption for all nodes in the network
- $PC \sim O(\text{Path length} * \text{Radius}^4) \sim O(\frac{1}{n\sqrt{n}})$
  - Power consumption decreases as the transmission radius decreases
  - Power consumption increases as the number of hops increases

Power Consumption

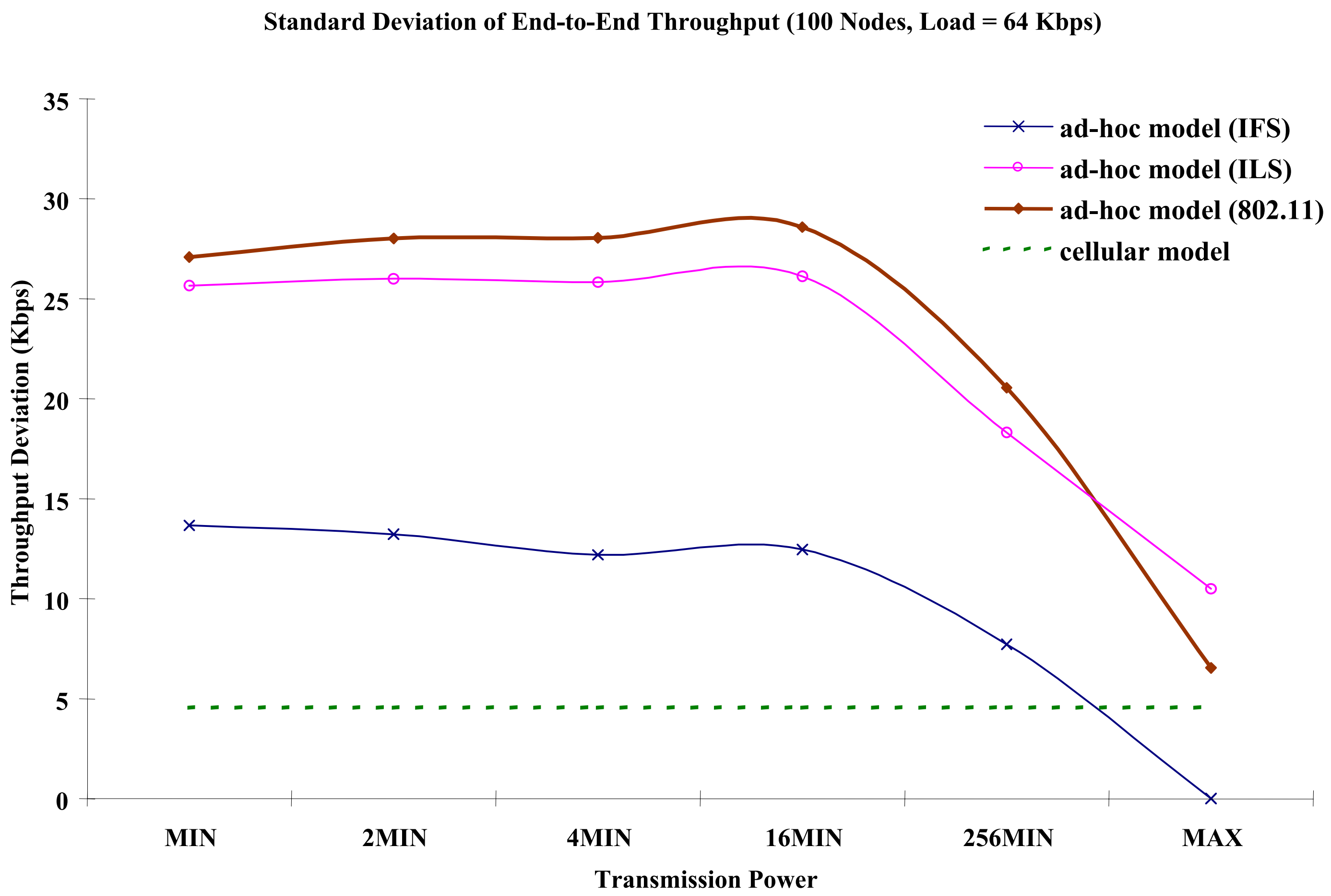


Fairness

- Fairness
  - Standard deviation of end-to-end throughput among all flows in the network
- Cellular network model
  - Round-robin polling ensures fairness
- Ad-hoc network model
  - Fairness is limited by network topology

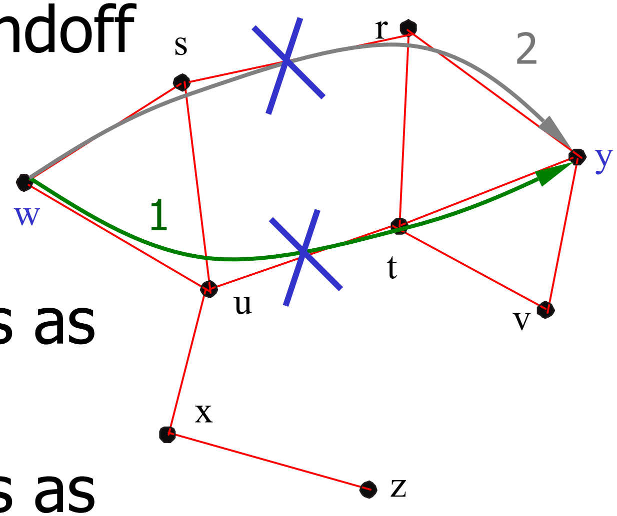


Fairness

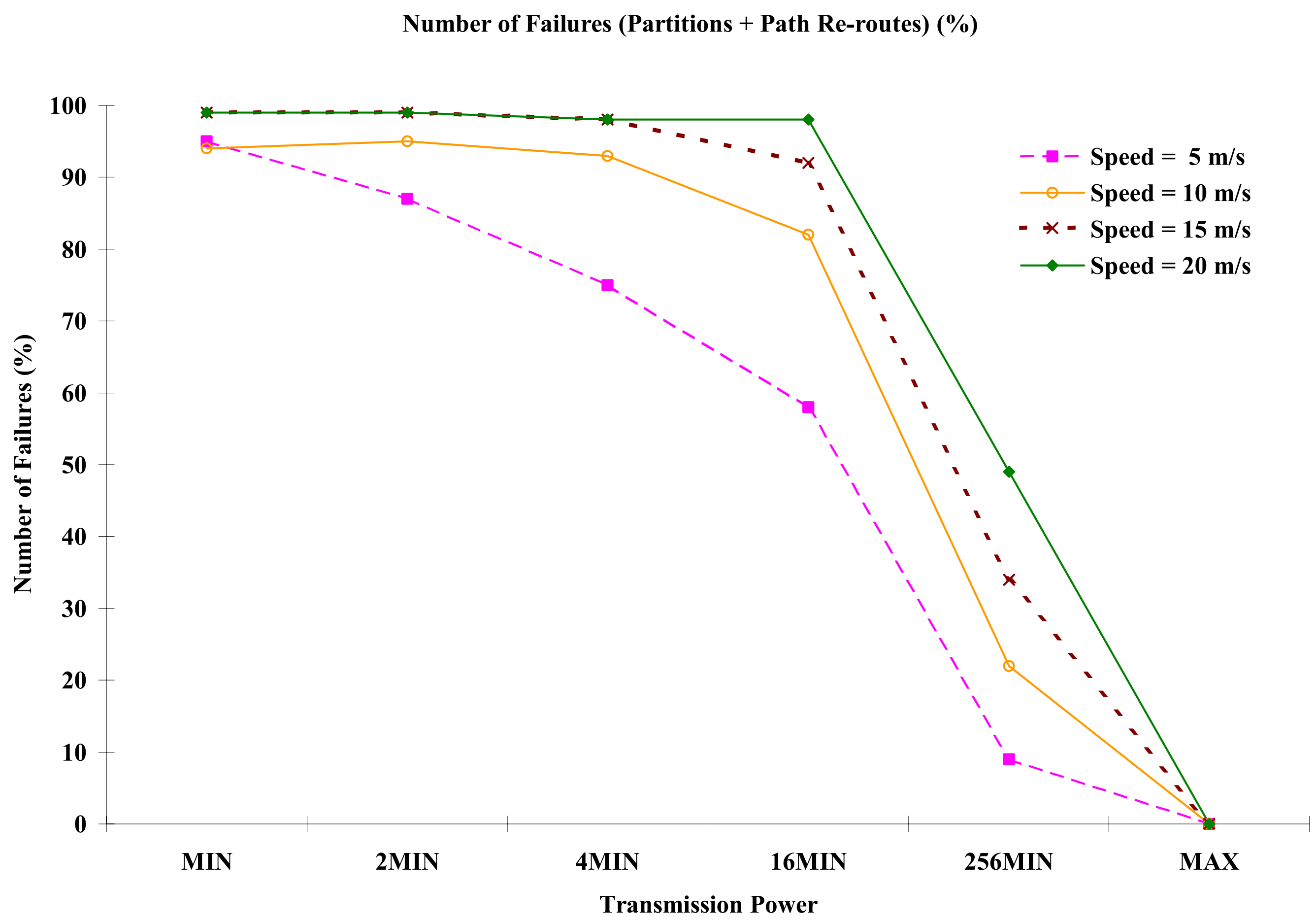

Standard Deviation of End-to-End Throughput (100 Nodes, Load = 64 Kbps)
Throughput Deviation (Kbps)
0
5
10
15
20
25
30
35
ad-hoc model (IFS)
ad-hoc model (ILS)
ad-hoc model (802.11)
cellular model
MIN
2MIN
4MIN
16MIN
256MIN
MAX
Transmission Power

Impact of Mobility

- Impact of mobility
  - Network failure is measured as the sum of path re-routes and network partitions
- Cellular network model
  - No impact without mobility handoff
- Ad-hoc network model
  - Frequency of failures increases as transmission power decreases
  - Frequency of failures increases as mobility increases



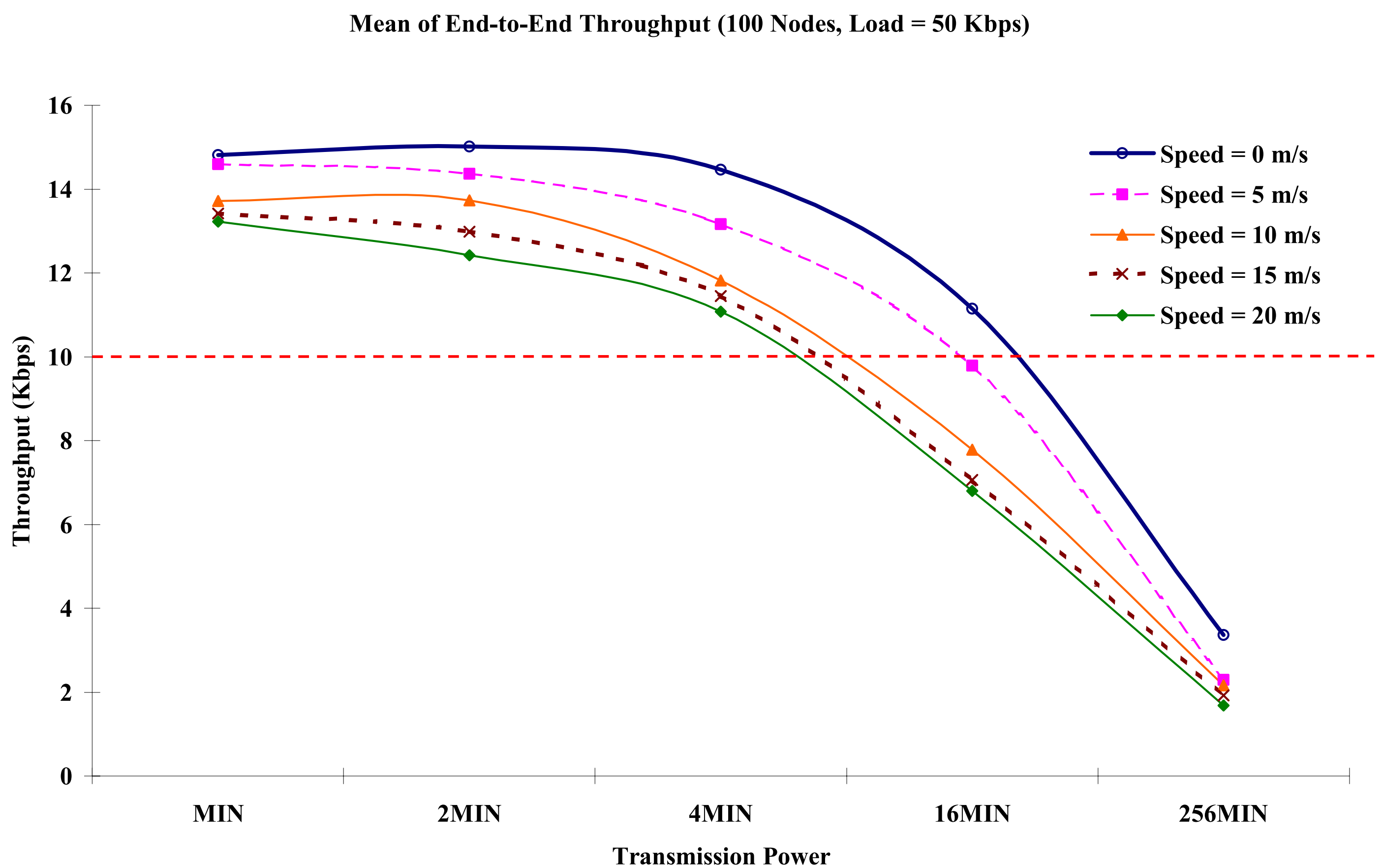
Impact of Mobility



Throughput Degradation

- End-to-end throughput degradation
  - Network failures (due to mobility) reduce network throughput
- Route failures cause packet loss and stall TCP transmission
- Route recovery process consumes network bandwidth

Throughput Degradation



Summary

- Ad-hoc network model performs better than cellular network model in terms of
  - End-to-end throughput
  - End-to-end delay
  - Power consumption
- Ad-hoc network model shows undesirable performance in terms of
  - Unfairness
  - Impact of mobility

Progress

- Introduction
- Performance comparisons
  - Simulation environment
  - Metrics
  - Results
- A hybrid wireless network model
- Conclusions

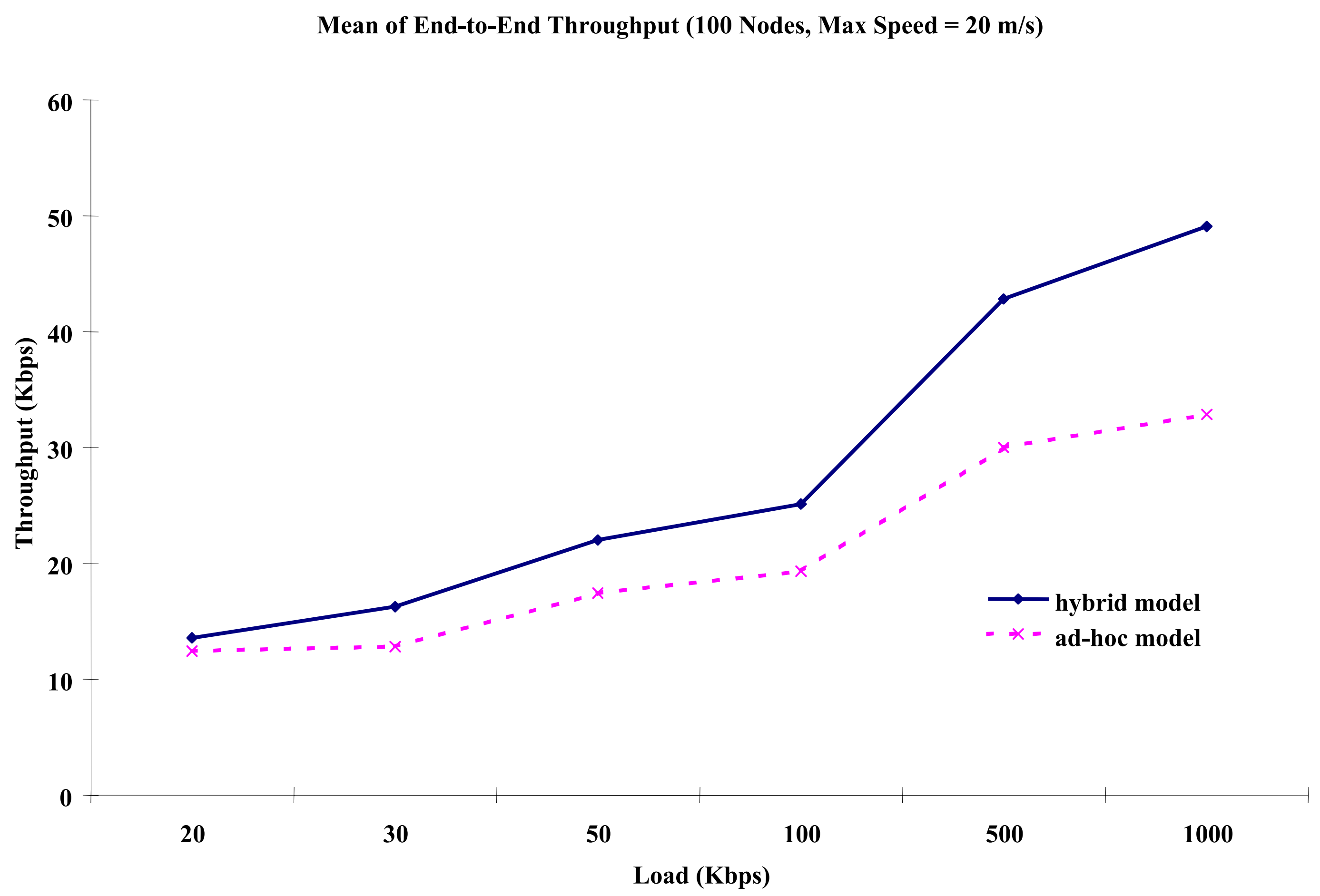
Hybrid Network Model

- Objectives
  - Combine advantages of ad-hoc network model with that of cellular network model
  - Address the mobility problem
- Architecture
  - Use network infrastructure as a cellular network model does
  - Mobile devices by default operate in multi-hop mode (peer-to-peer communication)

Hybrid Network Model

- Algorithm
  - Use a separate control channel
    - Upstream: location information and the observed throughput
    - Downstream: transmission power level and the mode of operation
  - Two-stage adaptation scheme
    - Base station tells the mobile devices to increase transmission power if network is partitioned
    - Mobile devices switch to cellular mode if the throughput falls below the cellular mode

Hybrid Network Model



Hybrid Network Model

- Issues
  - Unfairness
  - Traffic locality (destination out of the cell)
  - Adaptive transmission power
  - Ping-pong switching
  - Need for location information
  - Protocol complexity
  - Security, pricing and billing

Conclusions

- The performance trade-offs between the cellular and ad-hoc network model preclude the adoption of either as a clear solution for future wireless systems
- The proposed simple hybrid network model can combine advantages of both models and show better performance

- For more information, please go to http://www.ece.gatech.edu/research/GNAN