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

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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

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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 $\sim O(\text{Node number}) = O(n)$
Network Capacity

Network Capacity

Transmission Power

Capacity (Mbps)

- ad-hoc model (50 Nodes)
- ad-hoc model (100 Nodes)
- ad-hoc model (200 Nodes)
- ad-hoc model (400 Nodes)
- cellular model
End-to-end Throughput

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

- E2E throughput \( \sim O\left(\frac{\text{Network capacity}}{\text{Node num} \times \text{Path length}}\right) = O\left(\frac{1}{\sqrt{n}}\right) \)

- 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

Mean of End-to-End Throughput (100 Nodes, Load = 64 Kbps)

Transmission Power versus Throughput (Kbps)

- ad-hoc model (IFS)
- ad-hoc model (ILS)
- ad-hoc model (802.11)
- cellular model
End-to-end Delay

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

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

Mean of End-to-End Delay (100 Nodes, Load = 64 Kbps)

- ad-hoc model (IFS)
- ad-hoc model (ILS)
- ad-hoc model (802.11)
- cellular model
Power Consumption

- Power consumption
  - Average power consumption for all nodes in the network

- PC \sim O(\text{Path length} \times \text{Radius}^4) \sim O\left(\frac{1}{n\sqrt{n}}\right)
  - Power consumption decreases as the transmission radius decreases
  - Power consumption increases as the number of hops increases
Power Consumption

Mean of Power Consumption (MIN Transmission Power, Load = 64 Kbps)

- ad-hoc model (IFS)
- ad-hoc model (ILS)
- ad-hoc model (802.11)
- cellular model

Node Number

Power (W)
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
Standard Deviation of End-to-End Throughput (100 Nodes, Load = 64 Kbps)

- ad-hoc model (IFS)
- ad-hoc model (ILS)
- ad-hoc model (802.11)
- cellular model

Transmit Power: MIN, 2MIN, 4MIN, 16MIN, 256MIN, MAX

Throughput Deviation (Kbps): 0, 5, 10, 15, 20, 25, 30, 35

Fairness
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

Number of Failures (Partitions + Path Re-routes) (%)

- Speed = 5 m/s
- Speed = 10 m/s
- Speed = 15 m/s
- Speed = 20 m/s

Transmission Power

Number of Failures (%)

MIN 2MIN 4MIN 16MIN 256MIN MAX
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

Mean of End-to-End Throughput (100 Nodes, Load = 50 Kbps)

Throughput (Kbps)

Transmission Power

- Speed = 0 m/s
- Speed = 5 m/s
- Speed = 10 m/s
- Speed = 15 m/s
- Speed = 20 m/s
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
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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

Mean of End-to-End Throughput (100 Nodes, Max Speed = 20 m/s)

Throughput (Kbps) vs Load (Kbps)

- Hybrid model
- Ad-hoc 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.