A Performance Study of Deployment Factors in Wireless Mesh Networks

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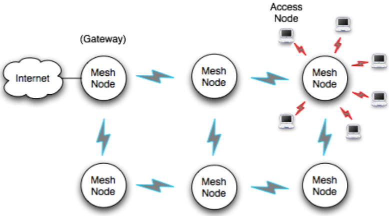
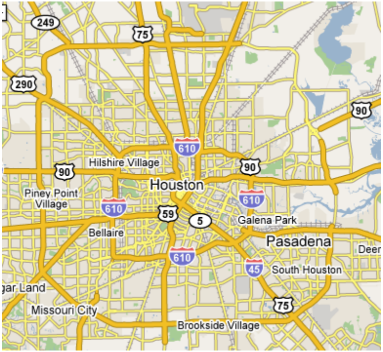
City-wide Wireless Deployments

Many new city-wide wireless mesh networks being planned or deployed: Two-tier mesh networks



Houston-wide Wireless Network

- 620 square miles of coverage:
  - 95% Outside
  - 90% Inside (window)
- Earthlink
- $50 million estimated cost
- 15k mesh nodes and 3k gateways
- Operational by 2009
- Miami-Dade Co. wants 2k sq. miles coverage



Deployment Strategies

State of the art deployment strategies

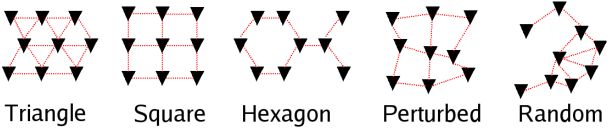
- Exhaustive survey (WLAN, cellular) costly
- Community networks do not cover efficiently
- *Rules of thumb* in practice

Problem: what deployment factors are important to mesh performance and why?

- For general network environments, not specific

Deployment Factors and Mesh Performance

We identify critical deployment factors and explore how they affect mesh performance



Topology and Architecture

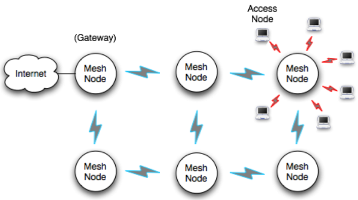
- Mesh topology structures
- Multiple radios for access and backhaul
- Number of wired gateways

Real-world limitations

- Placement perturbations
- Unplanned deployments

Three Mesh Performance Criteria

Goals for a high-performance mesh network?



Focus on each part of the mesh: access tier, backhaul tier, and gateway nodes

Three Mesh Performance Criteria

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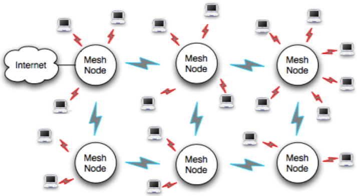

- Ubiquitous coverage

Three Mesh Performance Criteria

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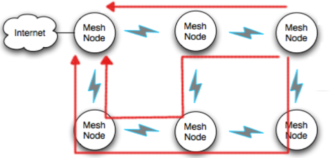

- Ubiquitous coverage
- High quality routes to a gateway

Three Mesh Performance Criteria

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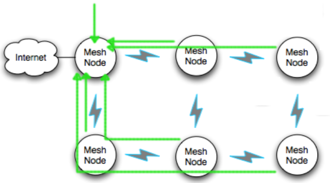


- Ubiquitous coverage
- High quality routes to a gateway
- Fairly support many simultaneous flows

Evaluating Mesh Performance

Three mesh performance metrics

1. Coverage Area
   - Does the access tier provide all-over coverage?
2. Connectivity
   - Are all mesh nodes connected to a gateway?
3. Fair Mesh Capacity
   - What fair rates can users in the network expect?

Identify and study the deployment factors that control each metric

Evaluation Methodology

Calculating each performance metric

- Compute performance of each mesh node and client location
- Use measurement data to drive study
- Monte Carlo simulations for topologies
- Infinite plane topology, no edge results reported
- Performance of single-link fundamental

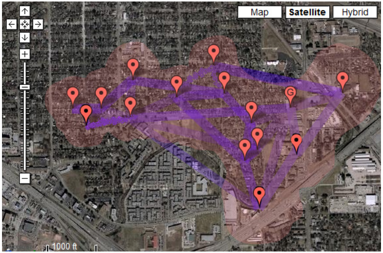
Well-known pathloss model

$$P_{dBm}(d) = P_{dBm}(d_0) - 10\alpha log_{10}(\frac{d}{d_0}) + \epsilon$$

Technology-For-All (TFA) Mesh Testbed

Operational mesh in pilot neighborhood in Houston's East End (Pecan Park)

- Status: 18 nodes with approximately 3 km^2 of coverage and 2,000 users
- Operational since May 2005
- More info at tfa.rice.edu
- Results presented use TFA measurements for pathloss*



* "Measurement Driven Deployment of a Two-Tier Urban Mesh Access Network" In Proceedings of MobiSys 2006.

Coverage Area

Coverage area is the expected fraction of client locations which connect to a mesh node above a threshold signal strength

- Threshold value is 2 Mbps
- Connect to *at least* one mesh node
- Uniform user distribution

Controlling topology factors: Mesh node density and configuration

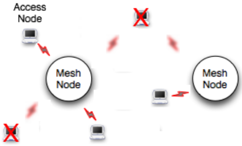
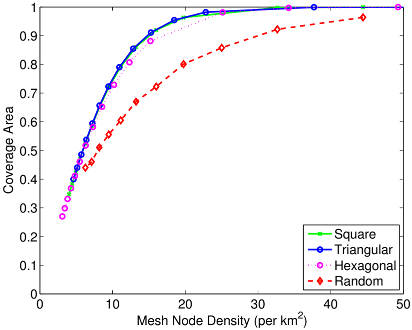


Figure: Two access nodes with poor coverage.

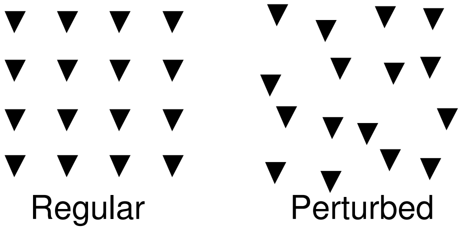
$$\text{Coverage} = 1 - \prod_{\forall i} (1 - Prob_{d_i}[X > T_{min}])$$

Coverage Area, Regular and Random



- Ideal grid placement and 2-d Poisson point process
- Compare mesh node densities, equivalent resources
- 95% coverage: random requires twice the density!

Perturbations from Ideal Grid Placement

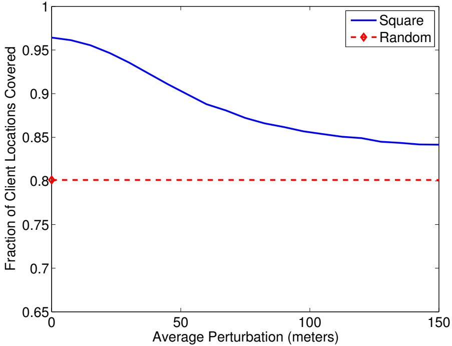


- Not usually possible to deploy a perfect grid
- Random angle and distance chosen from uniform distribution
- Results from averaging 100 trials

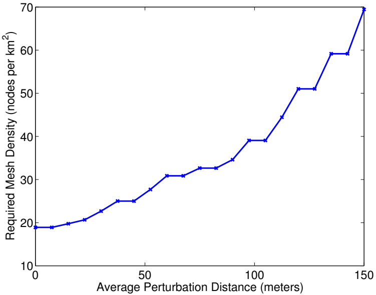
Mesh Node Perturbations

Fix average node density at 20 nodes per km^2

- Inter-node spacing for square grid is 225 meters
- Coverage declines only 3% up to $\frac{1}{5}$ of the inter-node spacing
- High perturbation better than coverage of random networks



Deploying with Perturbations



- Coverages declines because of increasing dead spots
- Resource demands for 95% coverage grow rapidly with perturbations above 40 meters
- Perturbations of $\frac{1}{5}$ inter-node distance correspond to 25% over-provisioning

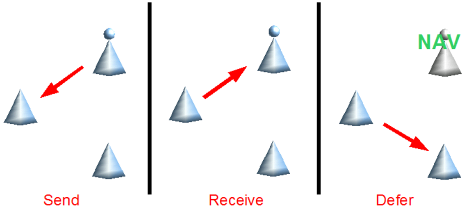
Fair Mesh Capacity

Model a gateway node as alternating between:

- Rx/Tx to one-hop neighbors
- Deferring to other neighbors within interference range

Capacity is then found by the percentage of time doing Rx/Tx

- All flows receive fair time shares
- Depends on gateway placement and routing



Calculating Fair Mesh Capacity

Find routes first, then Tx/Rx and Defer times

- Uniform distribution of clients
- Two-hop neighbors interfere
- Single-radio system
- Assume fair scheduling exists
- Longer routes add more defer time

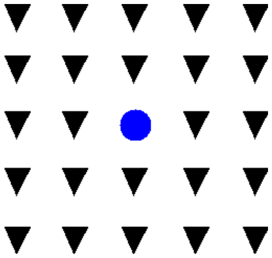


Figure: Square grid network with wire ratio of $\frac{1}{16}$

$$\delta = \frac{\text{Tx/Rx Time}}{\text{Tx/Rx Time} + \text{Defer Time}} = \frac{16}{46} = 35\%$$

Second Radio for the Access Tier

Architectural Feature: dedicated radios for access and backhaul links

- Client to Mesh transmissions do not interfere on wireless backhaul

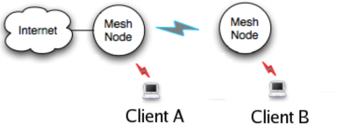
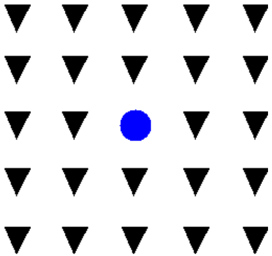


Figure: With two radios, fair share is $\frac{1}{2}$.

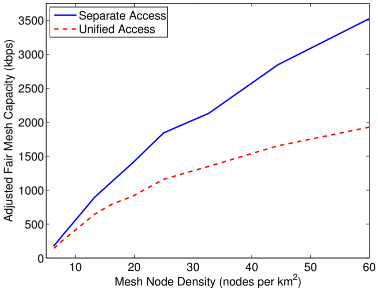
Calculating Capacity for Two Radios

$\delta = \frac{16}{33} = 48\%$



- Backhaul tier is 39% more efficient
- Expect fair mesh capacity to increase proportionally
- Spatial reuse decreases benefits

Fair Mesh Capacity Results



- Backhaul tier has more time available for useful transmissions
- Fair mesh capacity increases by factor of *almost* 2
- Adjusted capacity does not include the clients at a wired gateway

Summary and Contributions

Measurement-driven methodology for evaluating mesh network performance

- Coverage, connectivity, and capacity metrics
- Topology, architecture, deployment factors

Identified critical deployment factors and how they impact mesh performance, including

- Coverage Area: studies regular grids, random networks, and the impact of perturbations
- Connectivity: studied asymmetric links, redundant paths, and multiple backhaul radios
- Fair Mesh Capacity: studied regular grid topologies, random networks, and two-radio mesh architectures

Ongoing and Future Work

Continued Expansion of the TFA network

- Doubling the number of mesh nodes and gateways

Deployment issues

- Selecting gateway placements
- Optimal deployment strategies
- Increasing capacity with additional radios