Adding Capacity Points to a Wireless Mesh Network Using Local Search

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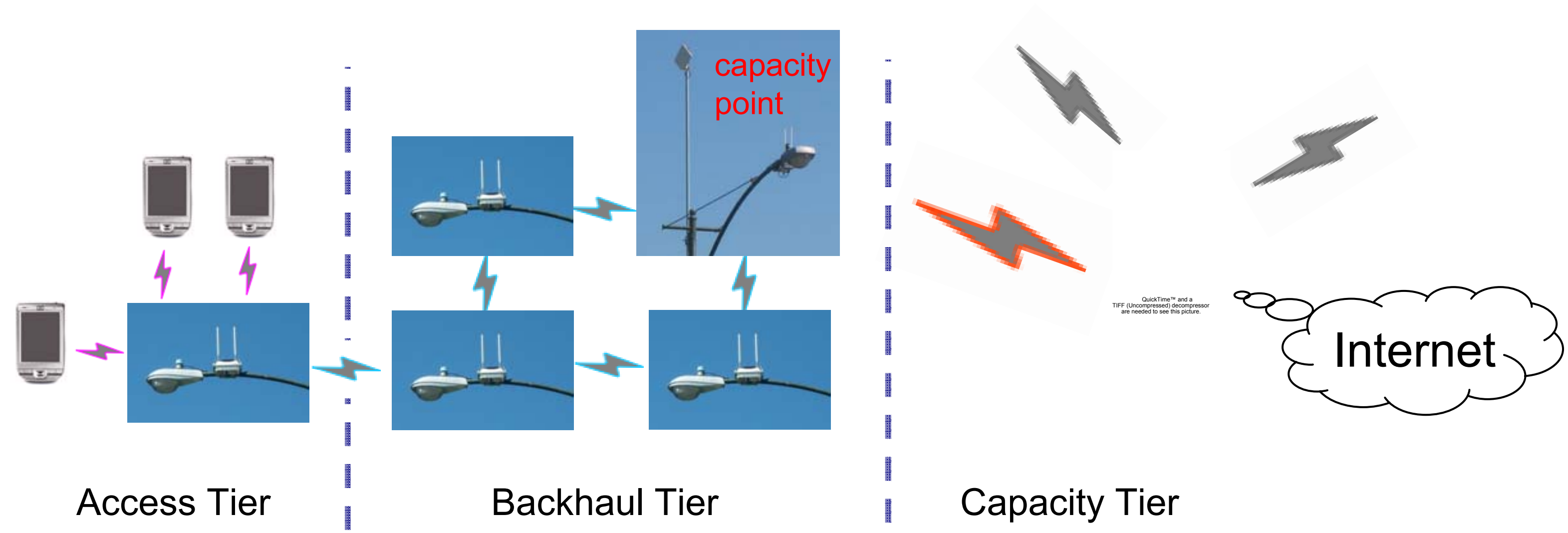
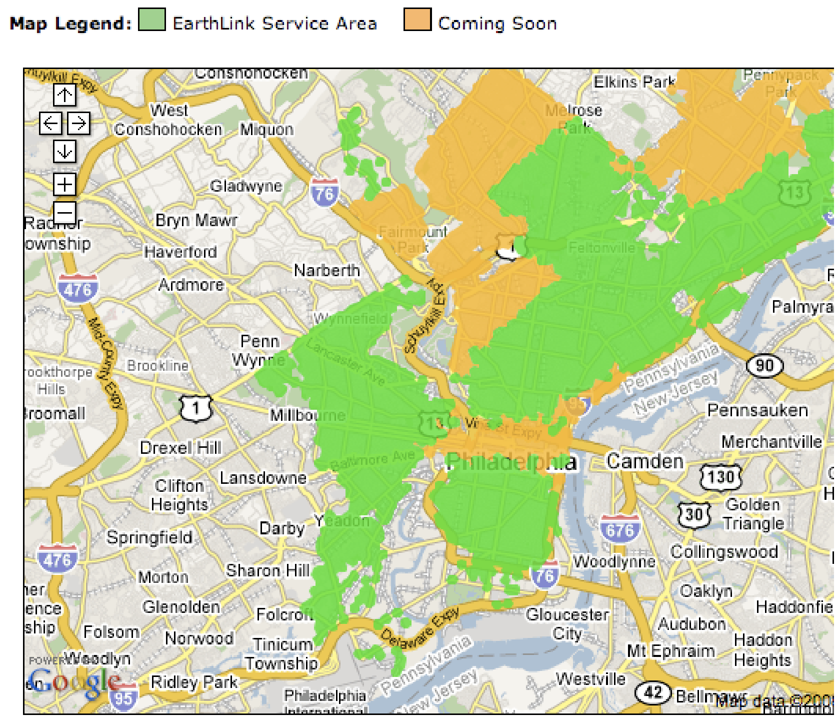
Multi-Tier Mesh Architecture



- Goal: provide Internet connections with low cost
  - Access tier: clients connect to a mesh node
  - Backhaul tier: mesh nodes multi-hop to a capacity point
  - Capacity tier: traffic aggregates to wired Internet
- Capacity tier utilizes directional wireless, WiMAX, or fibers
- Capacity points (gateways) co-located with mesh nodes

Wireless Network Evolution

- Network capacity needs to increase over time
  - New users, increasing traffic, changing usage patterns
- Increasing capacity of a mesh network
  - Nodes: increase coverage area of the network
  - Capacity points: increase overall throughput with Internet
  - Radios: increase throughput
- Our focus: incremental deployment of capacity points



Choosing Capacity Point Locations

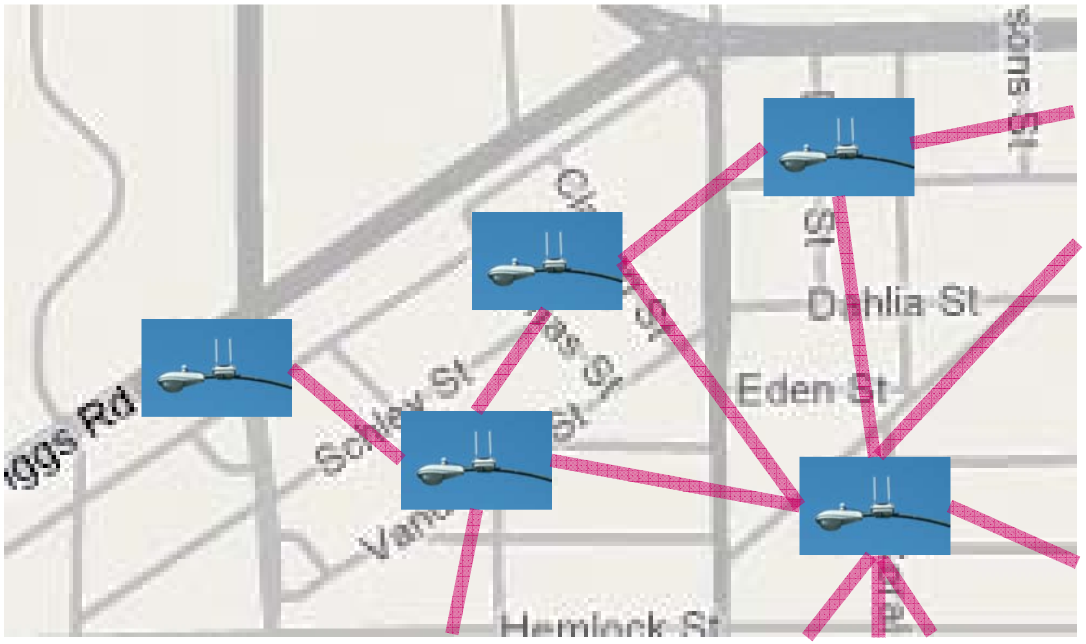
- *Capacity points*: mesh nodes connecting wireless mesh to the Internet

- Capacity point placement determines:
  - Path lengths of the wireless routes
  - Amount of wireless contention
  - Available bandwidth to/from Internet

- Two main challenges:
  1. How do we define and compute capacity?
  2. How do we best place new capacity points at a subset of the existing mesh nodes?

Formulation: For a given budget constraint, deploy new gateways to maximize the gain in network capacity

Capacity Term to Maximize?



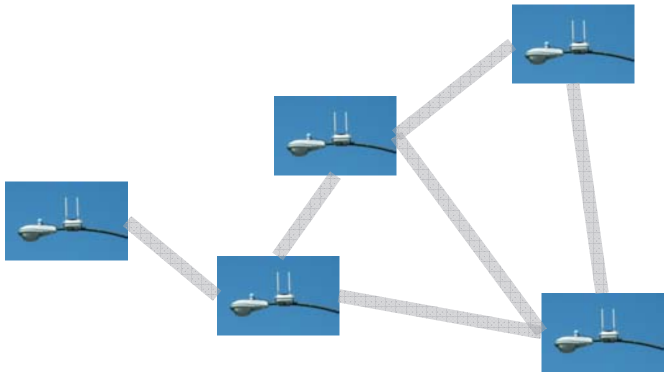
- <u>Need</u>: to compare potential placements
- Challenges: different link speeds, population density, and contention matrices
- Gateway-limited fair capacity is the aggregate rate at which data flows through capacity points

Gateway-limited Fair Capacity

- Wireless interfaces on gateways are bottleneck resource
  - We focus on access networks without peer traffic
  - Traffic aggregates to gateways
- Constraints on gateway interfaces
  - Per-user fairness ensures equal time for longer flows
  - Gateway airtime balances between tx/rx and defer
  - How often contending links are active --> gateway defer time
- We formalize efficient technique to calculate capacity which is suitable for local searching

Solving Gateway Placement

- To maximize network capacity
- Three coupled sub-problems:



Solving Gateway Placement

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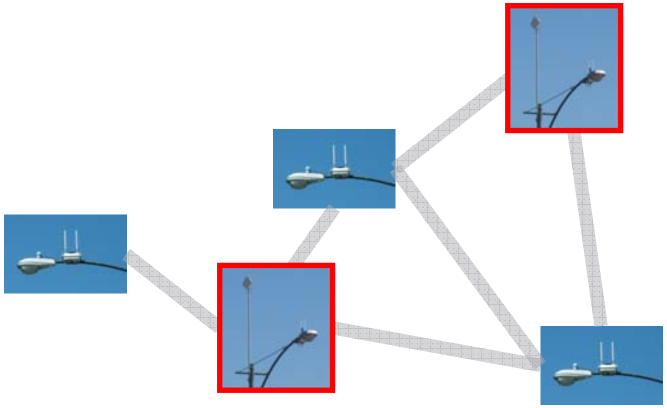

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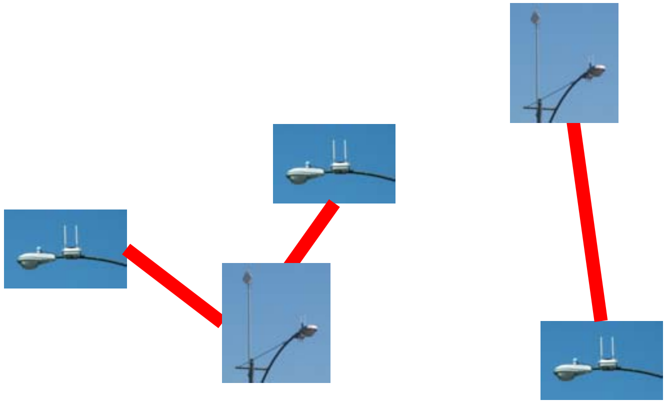
  2. Backhaul-tier routing choices



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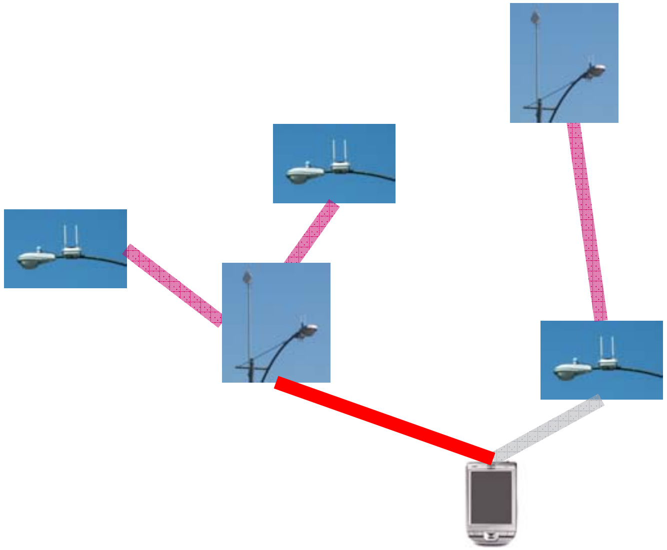

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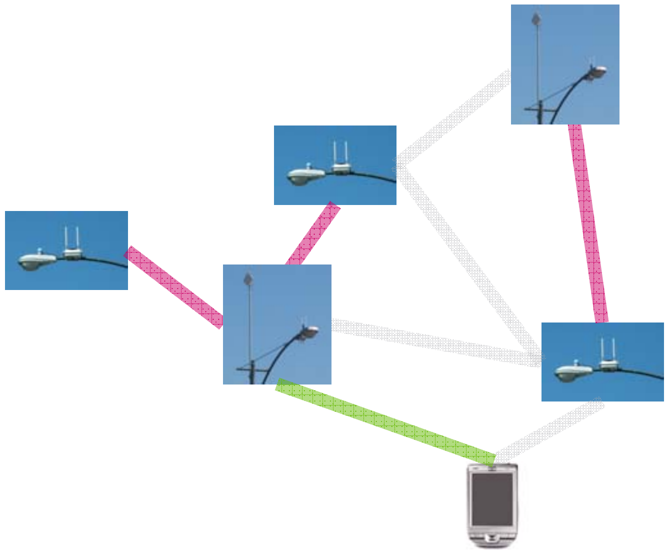

- Present two local search algorithms
  - Use local search to test good choices for (1)
  - Solves (2) and (3) as an assignment problem
  - Build on algorithms for Facility Location problems
  - Incorporate wireless contention effects

Gateway Placement and Facility Location

	Facility Location	Gateway Placement
Objective:	Choose facility locations to minimize sum of facility cost and service cost*	Choose gateway locations to maximize capacity or minimize gateway cost

* *k*-Median problem fixes number of facilities at *k*

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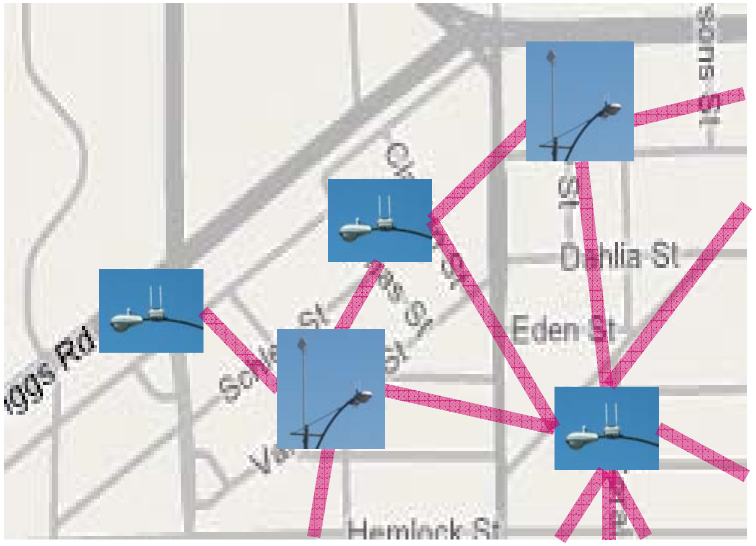
- Both problems are NP-hard
- Local search algorithms well-suited for facility location

Local Search Operation: Primitives

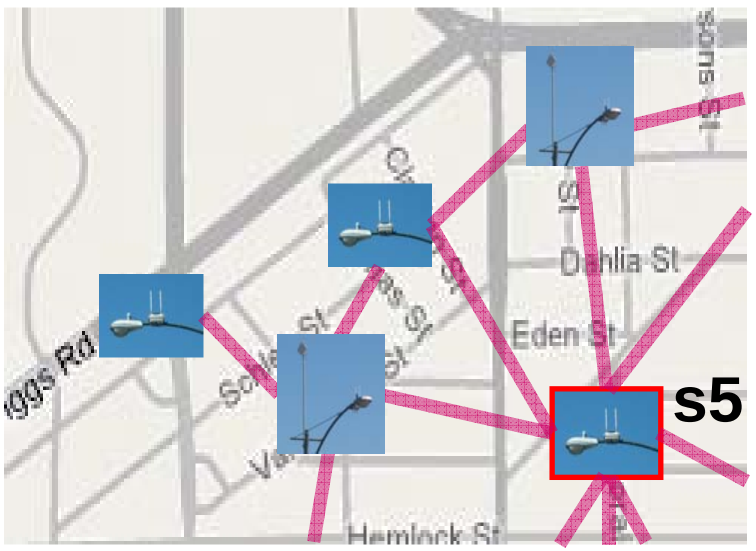


Current best placement

open(s,T) - open gateway at mesh node s and close gateways at mesh nodes in set *T*

add(s)
close(s,T)
swap(S,T)

Local Search Operation: Search

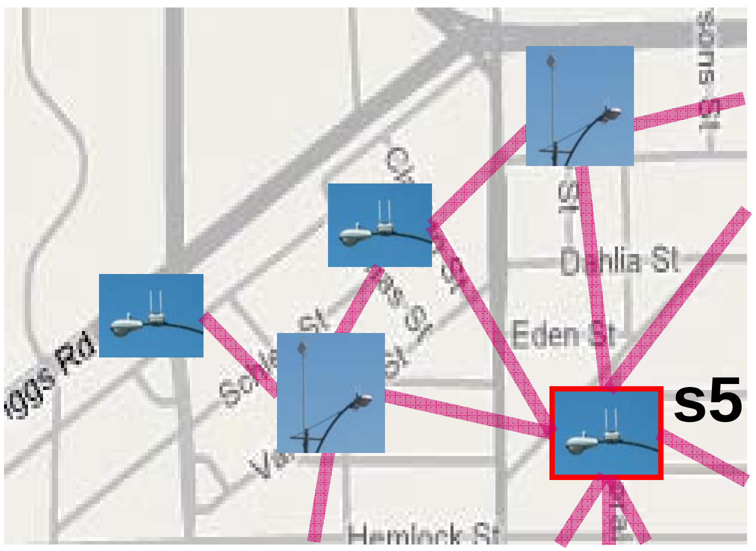


Current best placement

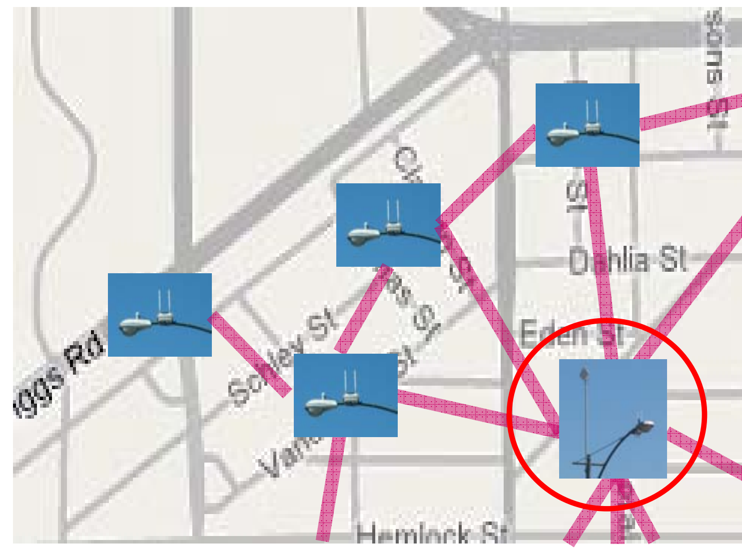
Search and evaluate:

add(s1)
add(s2)
add(s3)
add(s4)
add(s5)
open(s1,T)
open(s2,T)
open(s3,T)
open(s4,T)
open(s5,T) - Largest Gain!
close(s1,T)
close(s2,T)
close(s3,T)
close(s4,T)
close(s5,T)

Local Search Operation: Update



Current best placement



New best placement

And repeat….

MinHopCount Algorithm

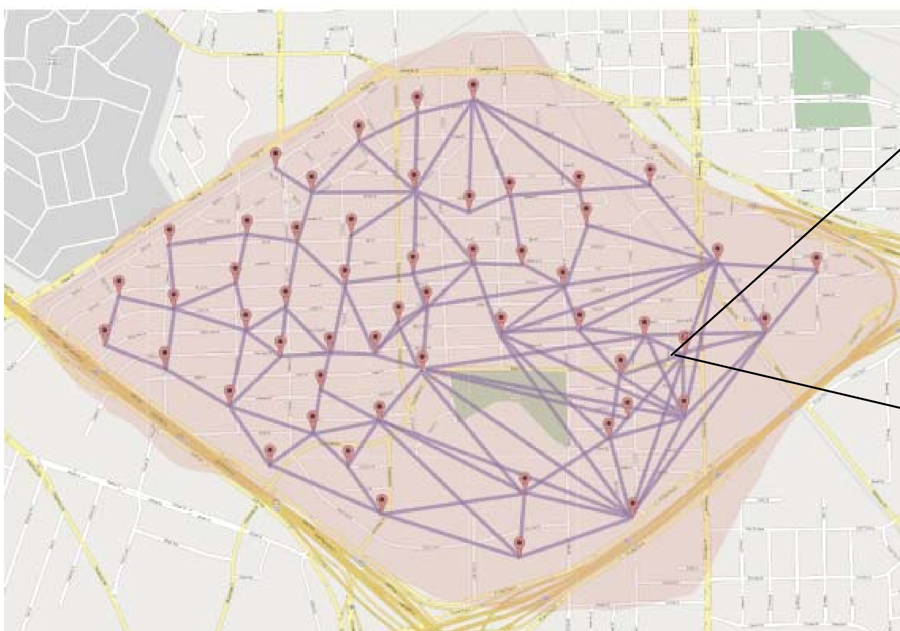
- Uses add(), open(), close() local operations to maximize capacity
- Challenge: metric service cost function
  - Exponential number of open(s,*T*) and close(s,*T*) operations
  - Use wireless hop count as cost function to find good values of T
  - Employs results on (9 + ϵ) algorithm by Pál et al (2001) for Capacitated Facility Location to find set *T*
- Configurations violating budget constraint not allowed
  - Makes the gateway placement problem *harder*
  - No provable optimality bounds
- Challenge: unknown gateway capacities
  - Iteratively improve estimate of gateway wireless capacities

MinContention Algorithm

- Uses swap() local operation to minimize network-wide contention
- Challenge: metric service cost function
  - Link weight as *contention* region size obeys triangle inequality
  - Exploits results on (3 + ε) algorithm by Arya et al (2001) from Uncapacitated *k*-Median problem
  - Minimizes the average size of contention regions for all nodes with constant-factor approximation

Houston Neighborhood Deployment

- Evaluate algorithms on Technology For All (TFA) network topology
- Multi-hop IEEE 802.11 wireless mesh network covering 40,000 residents, currently at 3 km^2
  - 18 nodes deployed, expansion to 53
  - tfa.rice.edu for more info



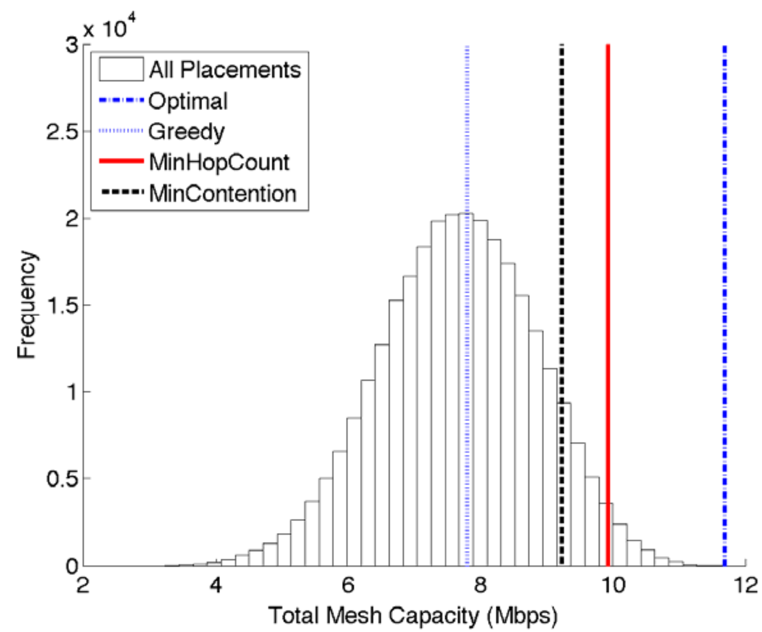
One wired aggregation point

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

Plus new virtual gateways

TFA Expansion Scenario

- Placing 4 new gateways in 53-node expanded network
- All placements evaluated via brute force
- MinHopCount performs better with smaller budgets
  - Inter-gateway contention limitation
- MinContention performs better in regular topologies
  - Irregular contention throughout network
- Up to 50% gains available from our algorithms



Conclusions

- We define an efficient technique for calculating gateway-limited fair capacity
- We present two polynomial-time local search algorithms for gateway deployment
  - Incorporating wireless contention effects

Questions?

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