Technology For All Wireless: Deployment, Measurements, and New Applications

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The Digital Divide Challenge

- Southeast Houston
  - 37% of children below poverty
  - 56% have < $25,000/year *household* income
- Goal: pervasive wireless and transformational applications

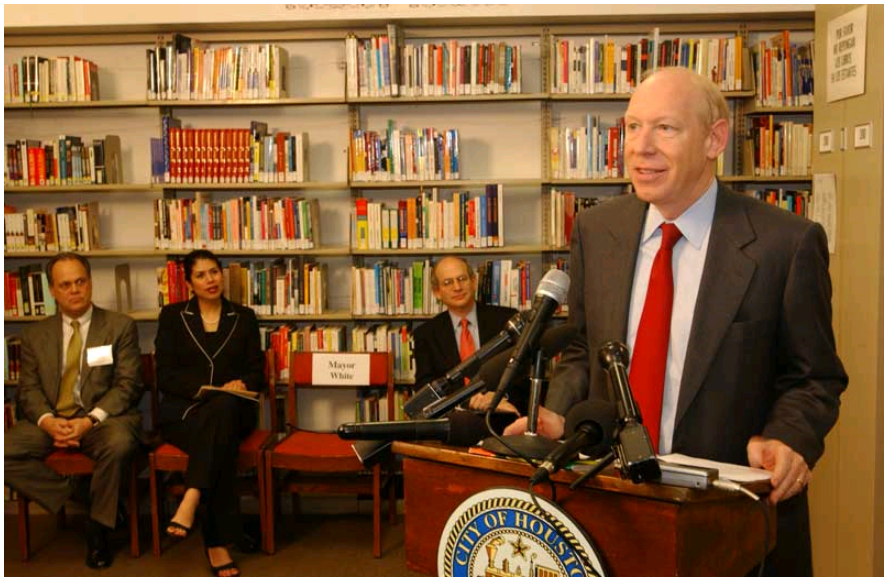
Technology For All/Rice Mesh Deployment

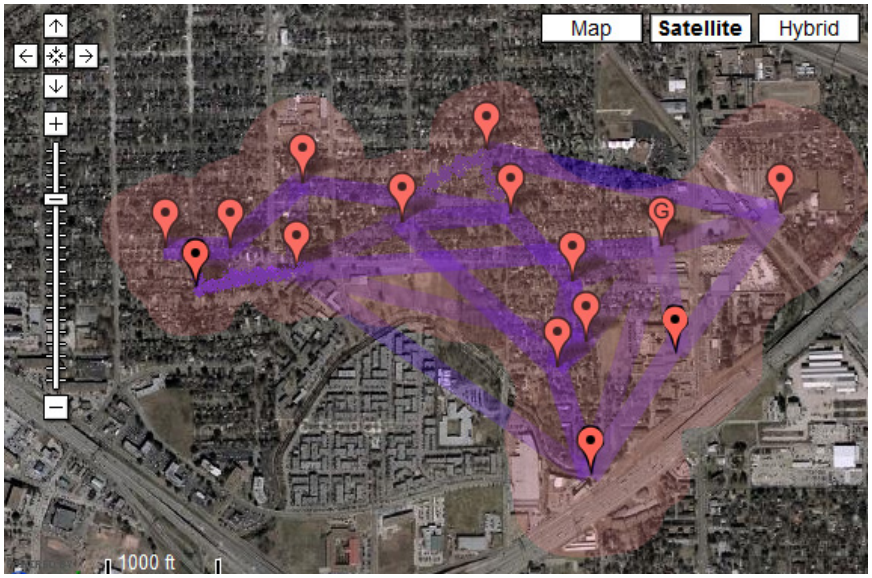
"Empower low income communities through technology"

- Pilot neighborhood: Houston's East End (Pecan Park)
- Status: approximately 3 km2 of coverage and 1,000 users
- Operational since late 2004

Applications

- Internet access, education, work-at-home, health care





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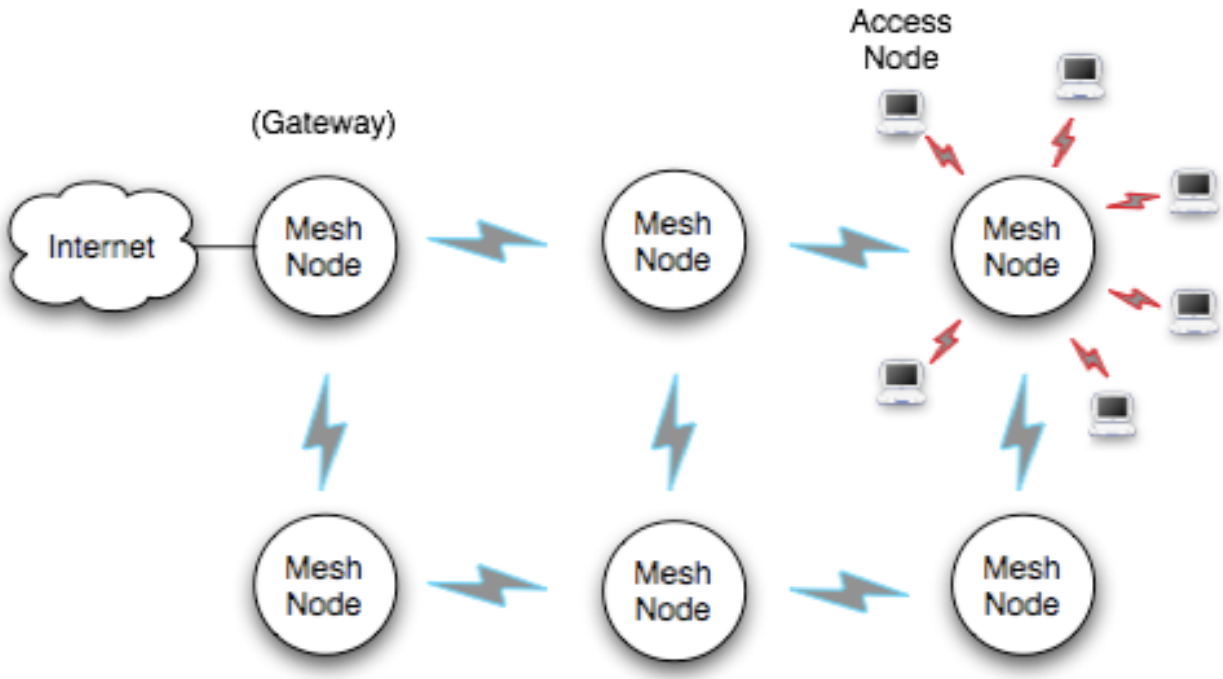
Outline

- Digital divide objectives
- Network architecture and platform
- Network planning, deployment, and measurements
- New applications and future work
- Challenges for Houston

Two-Tier Mesh Architecture



- Limited gateway nodes wired to Internet
- Mesh nodes wirelessly forward data
- Backhaul tier - mesh node to mesh node
- Access tier - mesh node to client node

Design Objectives/Constraints

- Single wireline gateway (burstable to 100 Mb/sec)
- $15k per square km ($100k typical for mesh)
- 99% coverage for entire neighborhood
  - contrasts with single-tier "community nets"
- 1 Mb/sec minimum access rate
- Programmable platform for protocol design and measurement

Commercial Technologies

Vendor	Product	Radios for client access	Radios for backhaul
BelAir Networks	BelAir 200	1 802.11b/g	Up to 3 proprietary 5GHz
Cisco	Aironet 1500	1 802.11b/g	1 802.11a
Firetide	HotPort 3203	1 802.11a/b/g	Same as for client access
Nortel	Wireless AP 7220	1 802.11b	1 802.11a
Strix Systems	OWS 3600	Up to 3 802.11b/g	Up to 3 802.11a
Tropos Networks	5210 MetroMesh Router	1 802.11b/g	Same as for client access

Source: Network World

- No programmability as required for research
- Wide range of cost and performance

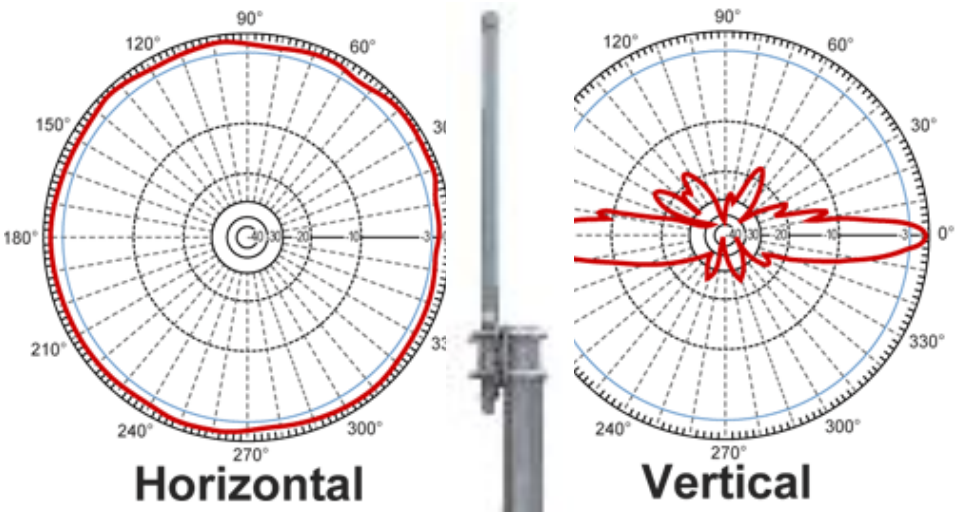
Backhaul/Mesh Node Hardware

Programmable, single-radio mesh node with storage

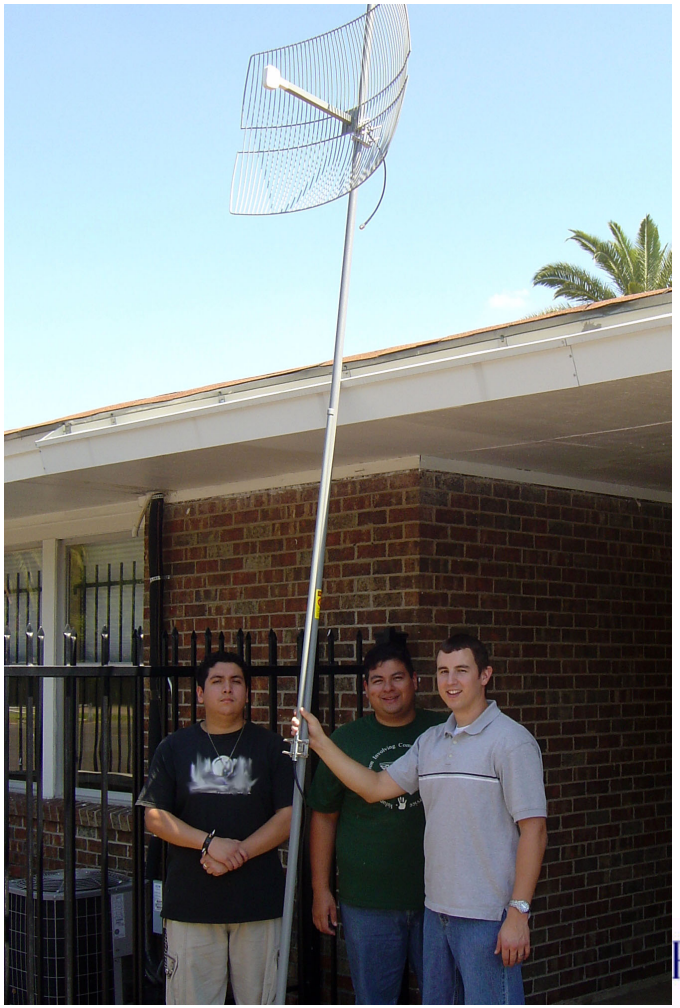
- 200 mW 802.11b
- LocustWorld Mesh SW
- VIA C3 1Ghz
- 5 GB Hard Drives
- 4 GB Flash to run Linux
- HostAP driver
- 15 dBi Omni-directional Antenna

Mesh Antennas

- Access and Backhaul links
  - High-gain 15 dBi omni-directional antenna at 10 meters
  - Serves access and backhaul
  - Attenuation primarily due to tree canopy



- Long distance links
  - Directional antennas as wire replacement



Access Node Hardware

Access inside homes is limited

Users must understand this is not like cellular

Expect to need a bridge, repeater, or directional or high-gain antenna near a window ($20 to $100 price)

Ethernet Bridge

USB WiFi

Directional antenna

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Network Planning Issues

- Density of mesh nodes
  - If large inter-node spacing…
    - reduces # nodes (costs) per square km
    - yet, results in coverage gaps
    - and, long distance links reduce throughput

- Number and placement of wires
  - If few wired gateways…
    - reduces costly wireline access and deployment fees
    - yet, throughput decreases with the number of wireless hops

What is the price-performance tradeoff?

Background in RF Propagation

- Pathloss
  - Average or large-scale signal attenuation
  - Exponential decay (pathloss exponent,)
  - Typically 2 to 5 in urban environments

$$P_R = \frac{P_T G_T G_R \lambda^2}{16\pi^2 d^\alpha L}$$

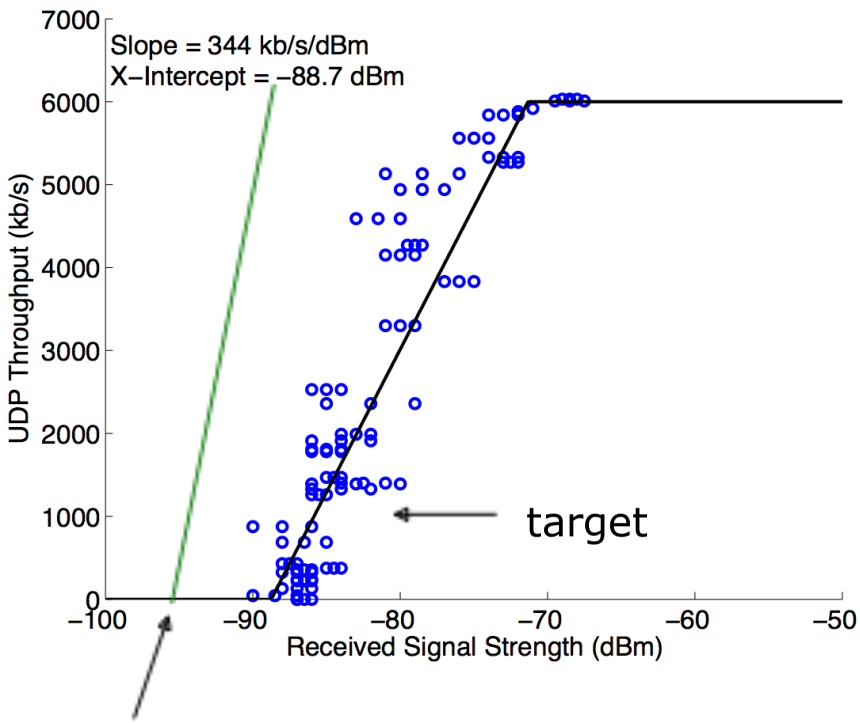
- Shadowing
  - Variation between points with similar pathloss
  - Typically 8 dB in urban environments

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

Translation

- Links get much slower (and eventually break) as distance increases
- The key parameter is the "path loss exponent"
- A particular environment is stuck with its exponent (can't change physics)
- Typical range: near 2 for near line-of-sight to 5 for numerous obstructions
- Shadowing: expect variations, even at one distance

Access Links: Throughput



Manufacturer specification

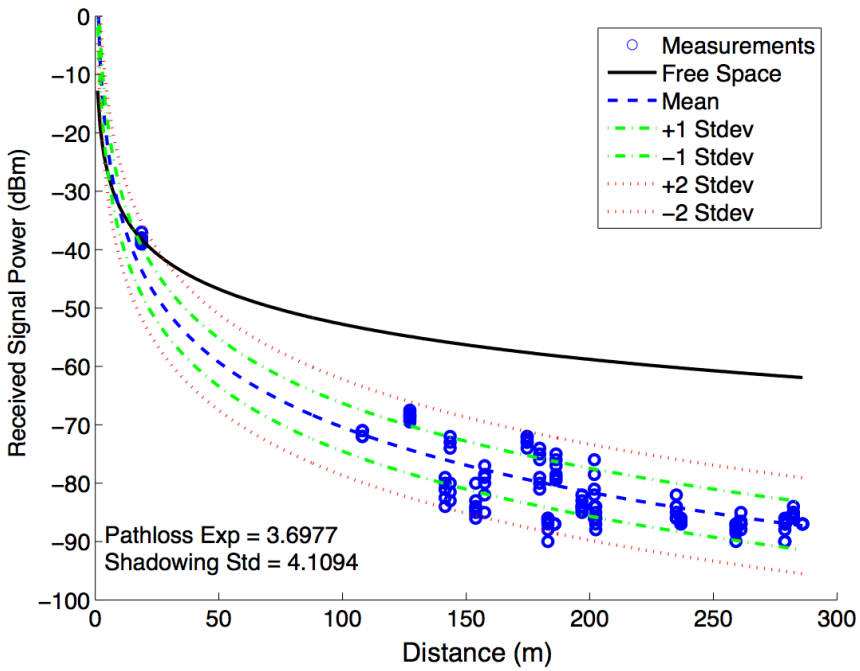
- Shannon Capacity

$$C = W \cdot log_2(1 + \frac{S}{N_0 W})$$

- Note: 1 Mbps at -86 dBm
  - Target throughput for access links
  - DSL and Cable Speed
- Manufacturer specification severely optimistic

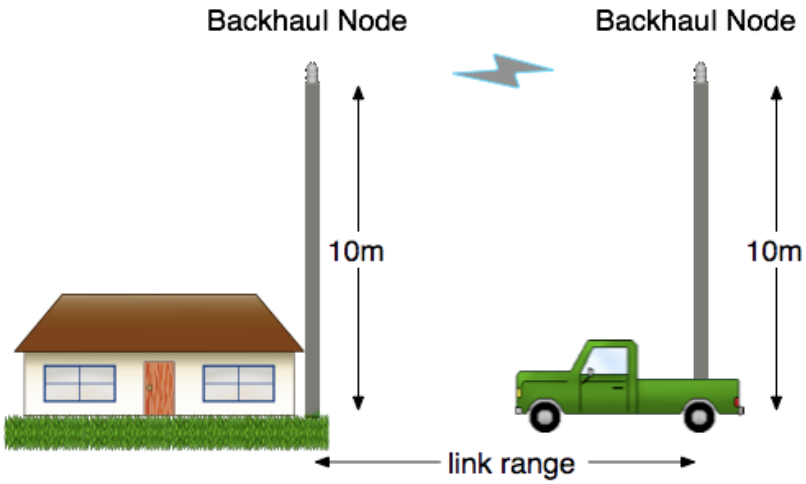
Access Links: Pathloss

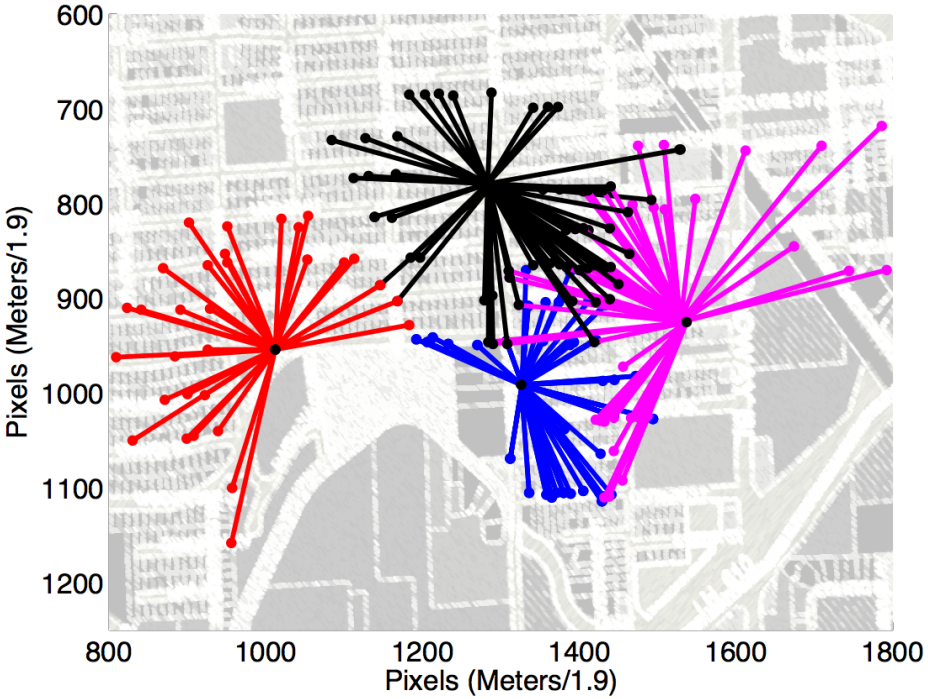
Given the path loss exponent and the node profiles, the distance-throughput tradeoff is revealed



- 150-200 meters
  - Mesh-client distance
  - For 1 Mbps/ -86 dBm deployment
- Pathloss = 3.7
  - Urban pathloss 2 to 5 [Rappaport]
  - Dense trees
  - Wooden framed homes
- Shadowing = 4.1

Backhaul Link Experiments





- Experiments yielded lower path-loss exponent of 3.3
  - Due to both antennas being at 10 meters and high-gain
- Permissible node spacing 200m to 250m for 3 Mb/sec links

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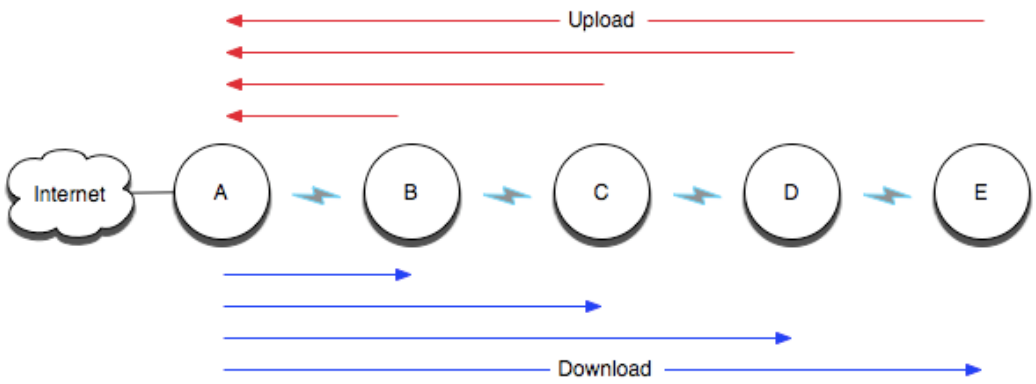
Single Hop Measurement Findings

- Accurate baseline physical measurements critical for effective deployment (measured = 3.3, models suggest 2 to 5)
  - 2 yields completely **disconnected** network
  - 3.5 yields overprovision factor of 55%
  - 4 yields overprovision factor of 330%
  - 5 yields **9 times overprovisioning**
- Accurate throughput-signal-strength function critical
  - manufacturer values over-estimate link range by 3 times yielding **disconnected** network
- Requires small number of measurements
  - 15 random measurements = std. dev. 3% about average
  - 50 random measurements = std. dev. 1.5% about average

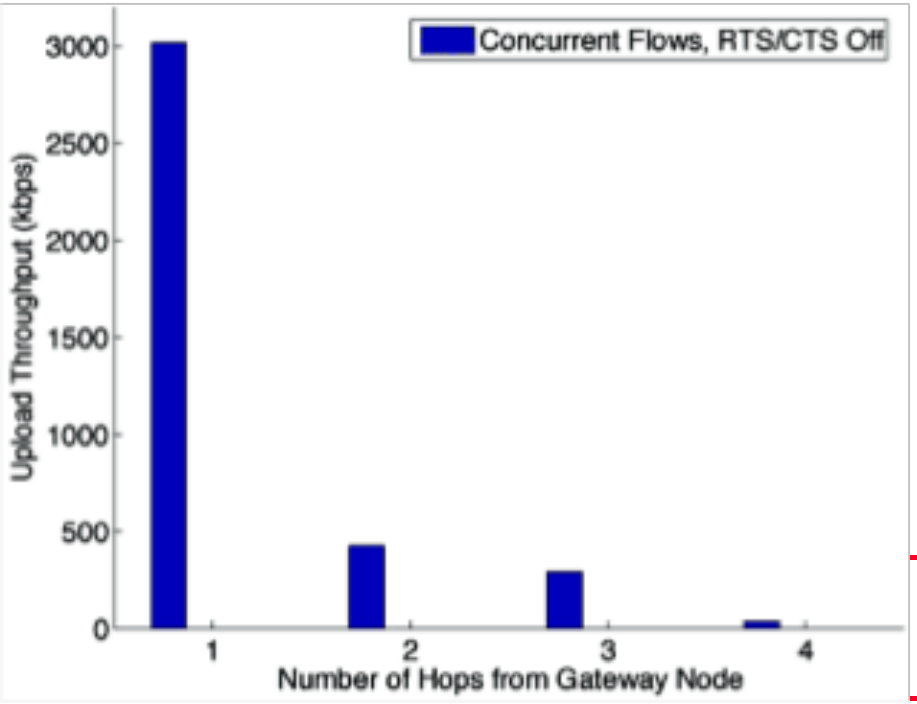
Multihop Experiments

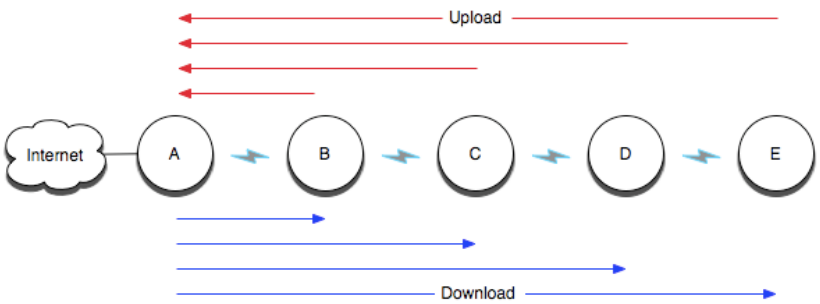
Issue: How does the number of wireless hops affect performance?

- The answer controls the required number of wired gateways
- Ideally, throughput is independent of spatial location



Bad News





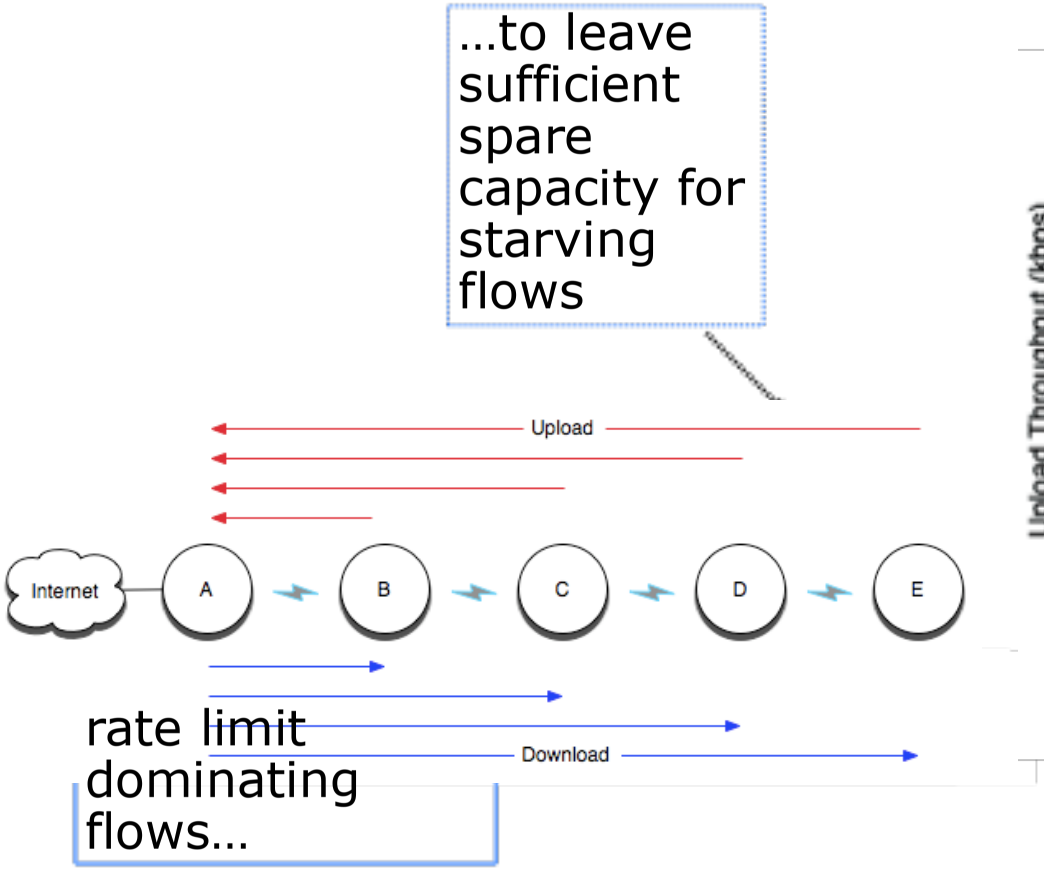
Scenario: large file uploads via FTP/TCP

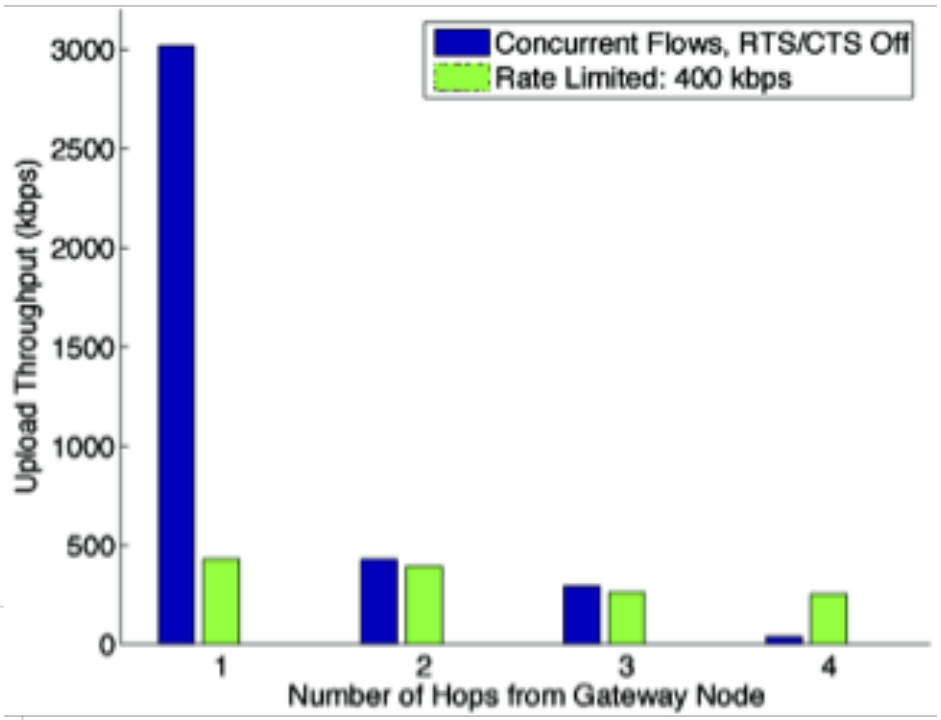
Nodes farther away nearly starve

- contend more times for more resources
- encounter asymmetric disadvantages in contention

Starvation Solution I: Rate Limiting

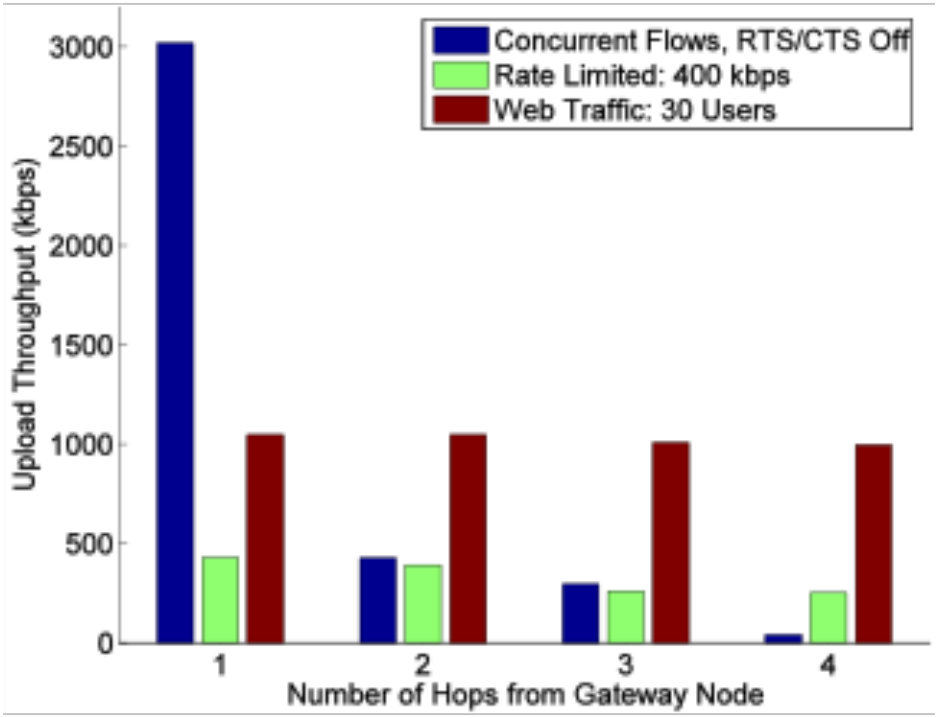
- Need to throttle dominating flows
  - Statically (as in current deployment) or dynamically according to congestion (via IEEE 802.11s)





Starvation Solution II: Exploit Statistical Multiplexing

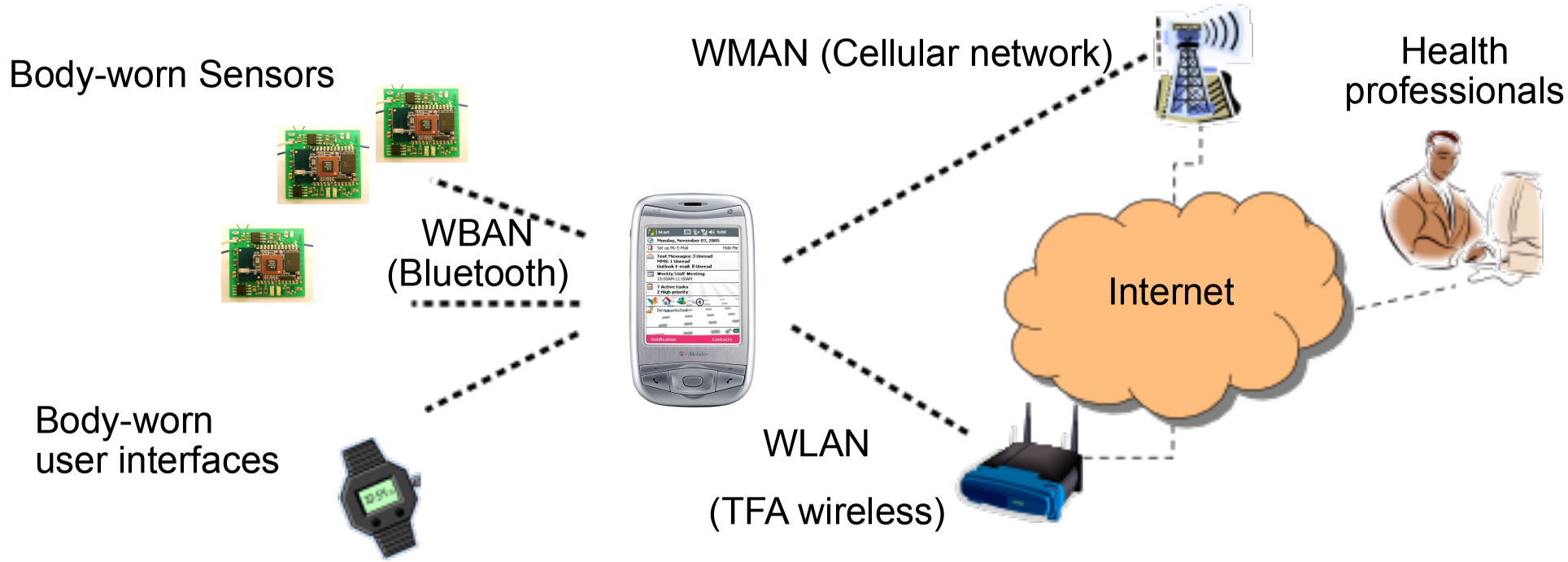
- Bursty traffic yields gaps in demand
  - on-off vs. greedy
  - alleviates spatial bias
- Can support approximately 30 web browsers per mesh node with minimal spatial bias



Multihop Measurement Findings

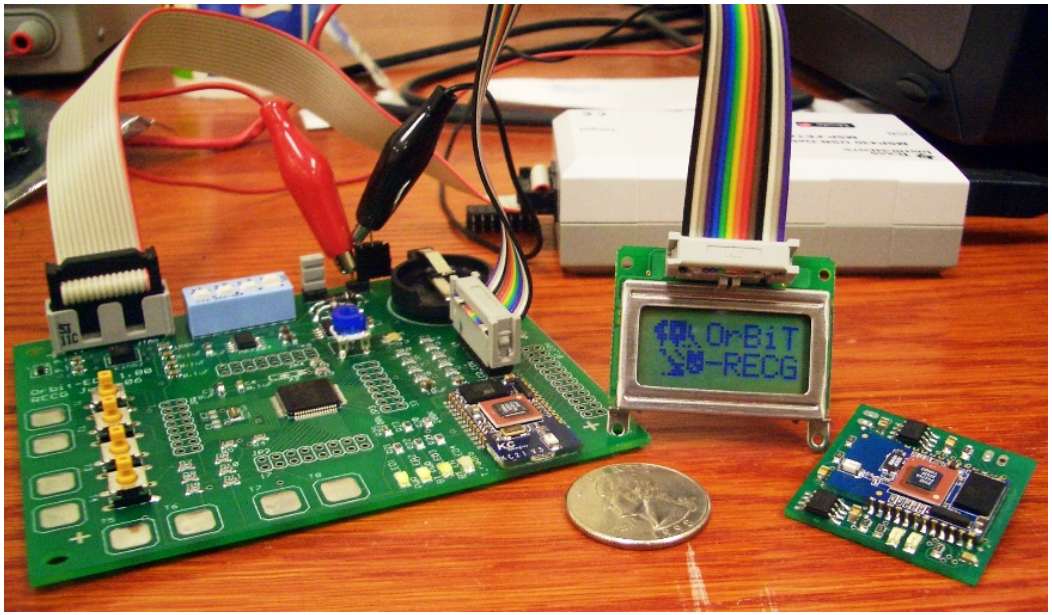
- Imperative to consider multiple multi-hop flows
  - Cannot "extrapolate" from link measurements as in wired nets
- Starvation in fully backlogged upload
  - Without additional mechanisms, severe problem with p2p-like traffic
- Proper rate limiting of flows alleviates starvation
  - Static or dynamic
- Web traffic and provisioning allows statistical multiplexing to alleviate starvation
  - Even without rate limiting

Healthcare Applications



- Pervasive health monitoring with body-worn health sensors
- Health information delivery through body-worn user interfaces
- Initial focus on obesity management and cardiovascular diseases
- Collaboration with health researchers
  - Baylor College of Medicine
  - Methodist Hospital
  - UT Health Science Center at Houston
- User and field studies in Houston neighborhood with TFA wireless coverage

Current Prototype (Lin Zhong)



- Left: Bluetooth wearable sensors for mobile system to connect health information: debugging and mini versions
- Right: Wrist-worn Bluetooth display for mobile system to deliver health promoting messages

Challenges for Houston

- Tempered expectations, especially indoors
  - Avoid Tempe-style complaints
- Heterogeneous propagation and usage environments
  - Downtown vs. treed urban vs. sparce
- Evolvable architecture
  - 802.11s will standardize, 802.16 will mature, MIMO will advance (802.11n), we will learn, etc.
- Balancing cost ($$/km2) and performance (Mb/sec/km2, %-coverage)
  - Lowest cost solution may sacrifice throughput and coverage
- Incorporating cost and performance implications of the number of wired gateway nodes
- Innovative applications beyond "access"

Conclusions

- Multi-hop wireless technology is cutting edge
- Most experience is not in public access
- Deployment and operational challenges ahead
- Opportunities for innovative applications

More information

- TFA website http://www.techforall.org
- Rice website http://www.ece.rice.edu/networks