Ultra-Low Cost Wireless Access: Lessons from the Field

Ed Knightly

Rice University

http://networks.rice.edu

Challenge for Urban U.S.

- Houston's East End
  - 37% of children below poverty
  - 56% have < $25,000/year *household* income
  - Milby High School: 36-43% graduation rate
  - Health care: increased chronic and acute disease rates

Ed Knightly

Unequal Access to IT Resources

- Fewer than 10% of households with income less than $20,000 per year have high-speed Internet access.
- Low-income children are 8 times less likely to use a computer at home than children in families earning at least $75,000
- PCs? Training? Internet access? Applications? Opportunity?

Project Goals

- Societal objective
  - "Empower under-resourced communities through technology"
- Technical objectives
  - Low-cost, high-performance, pervasive wireless
  - Applications providing new quality-of-life opportunities
    - Education and job-training
    - Work at home
    - Low cost health-care
  - Research platform: programmable and observable
    - Proof-of-concept for next generation protocols
    - Unique to demonstrate research advances "at scale"

Key Technical Challenge

- Today: have “fast wireless”
- The catch: each wireless AP has a WIRE.
  - Wires are expensive ($80k/linear mile)
- Challenge: can we serve large geographical areas with a single wire?
- Approach: multi-hop multi-tier wireless
  - Multi-hop: limit wires and counter path loss from long links
  - Multi-tier: inject capacity as traffic aggregates

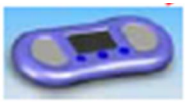
Technology For All Wireless Network

- Research platform: programmable and observable
- Wireless ISP for region since late 2004
- Over 4,000 users in 3 square kilometers
- Multi-tier architecture

Ed Knightly

Access Tier

- Clients (mobiles and residents) access mesh infrastructure
- Access Point density: approximately 7 Mesh AP's per km^2
- No DSL, cable modem, … at Access Point



Backhaul Tier

- Access nodes interconnected via backhaul tier
  - Access traffic forwarded to and from gateway
  - Omni directional 802.11 (b, g, or a)
  - Single fiber in region

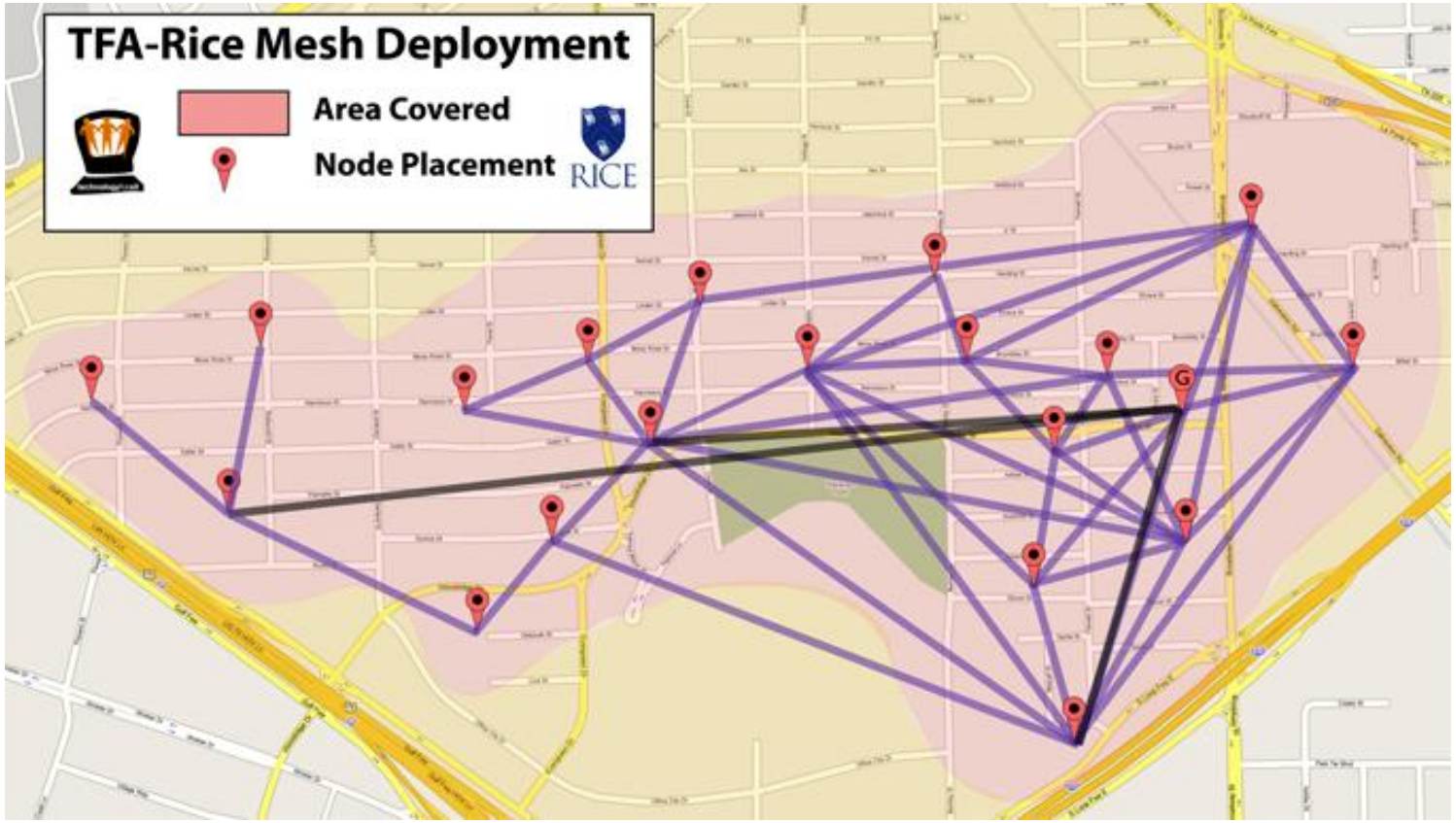




Capacity Points

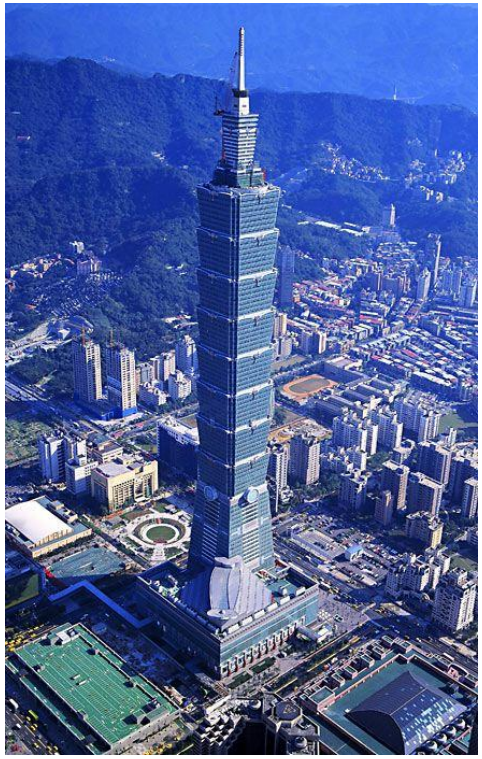
- Gateways inject capacity into backhaul tier
  - Injects capacity for sufficient Mb/sec/km^2
  - Continued multi-hopping would be too many users over too many hops

TFA Network Topology



- 802.11b access and backhaul, 802.11a capacity tier, 4,000+ users over 3 km^2
- One to five radios per node

Example Commercial Deployment: Taipei



- 52 square miles
- 10,000 mesh access points
- Nortel platform
  - 802.11b/g access
  - 802.11a backhaul
  - WiMAX capacity injection

- Lacks programmability and observability for research objectives

Lessons Learned

Initial Announcement: February 2005

Ed Knightly

Lesson 1: Not Everyone Likes Us

Good morning! PARTLY CLOUDY, HIGH 68, LOW 50 / PAGE B12 ROCKETS FALL SHORT AGAINST WIZARDS / PAGE C1

HOUSTON CHRONICLE

WWW.CHRON.COM THURSDAY, MARCH 3, 2005 ★ ★ ★ VOL. 104 · NO. 141 · 50 CEN

Wireless networks don't click with some

■ Telecom bill would ban free Internet access like that in model East End program

By ERIC BERGER
HOUSTON CHRONICLE

Will Reed envisions [illegible] computers, that is — and high-speed Internet connections for all. A wired community, he says, is an empowered one.

From his nonprofit group's East End offices, Reed is turning his vision into a reality. Although Pecan Park neighborhood residents may not realize it, e-mail, pictures and commerce now zip above their tree-lined streets. This high-speed, wireless Internet access is free for the taking.

TEN COMMANDMENTS

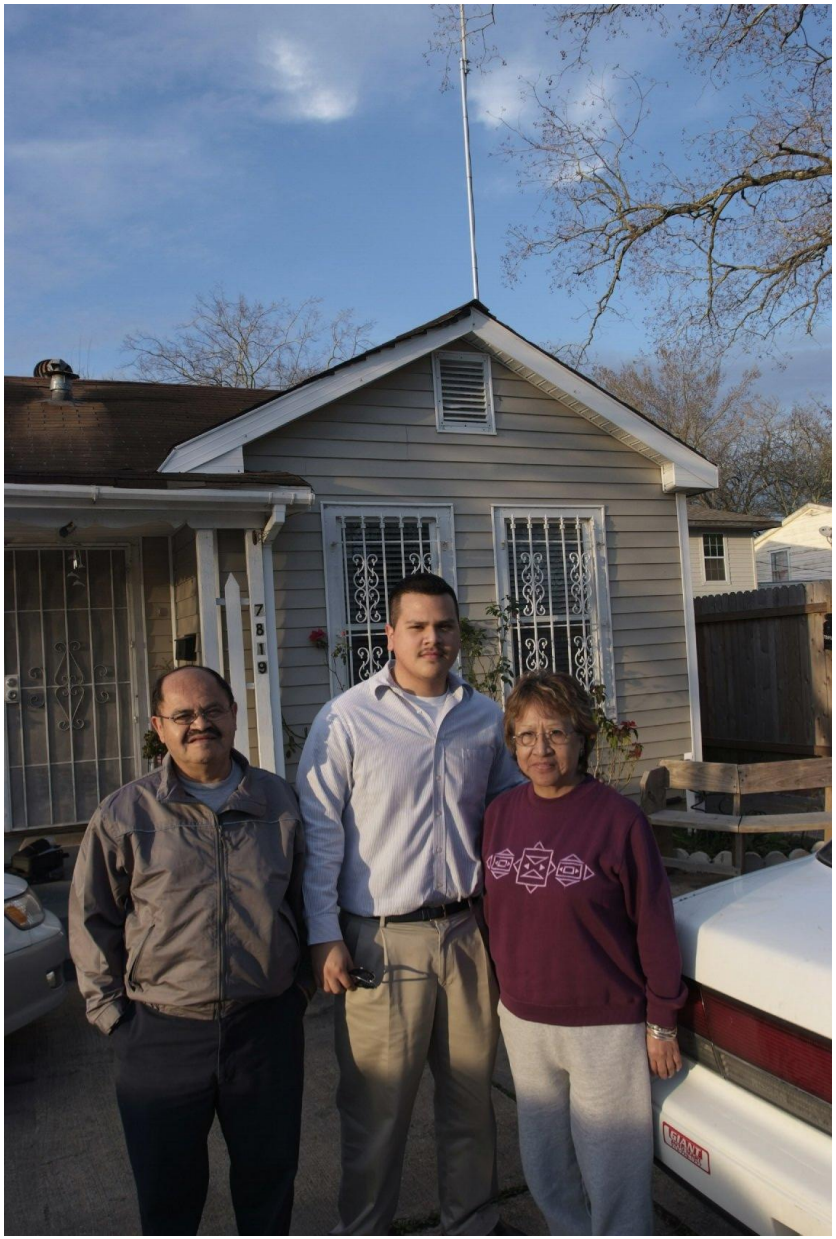
GERALD HERBERT : ASSOCIATED PRESS

HAND IN HAND: Christian ministers from Kentucky demonstrate outside of the Supreme Court while cases from Texas and Kentucky are heard. From left, the Rev. Ray Hines, the Rev. Henry Westerfield and the Rev. Gary Dull.

Texas case before high court could redefine church, state

Ed Knightly

Community and Technology Lessons...



Understanding Community

- Communicating technology objectives
  - Why are we there? Why do we keep driving around?
  - Fault origins
- Community values for technology
  - Availability and predictability (note: fault reporting)
  - Importance of training and content
- Community usage
  - Unexpected usage by police and truckers
  - High value and high usage apps: K-12 education, games, job search, health info, streaming soccer, home town news
  - Low usage apps: banking, skype

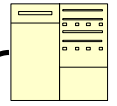
New Applications: Chronic Disease Management

wireless sensors + mobile phones + mesh + community
= self management➔reduced cost & improved health

Wireless body-area health sensor and user interfaces

TFA-Rice Mesh

Internet



Medical server

Bluetooth
Wibree

Cellular network

Wireless health peripherals

Community health worker

Bluebox

- CVD responsible for 40% of deaths in Texas
- Dacso's Hypothesis: repeated, long-term, inaccurate measurement can achieve predictive power close to in-hospital facilities
- Four cardiac output components
  - Systolic time interval, Pulse duration, R-R variability, impedance
- Self-management of Cardio-Vascular Disease

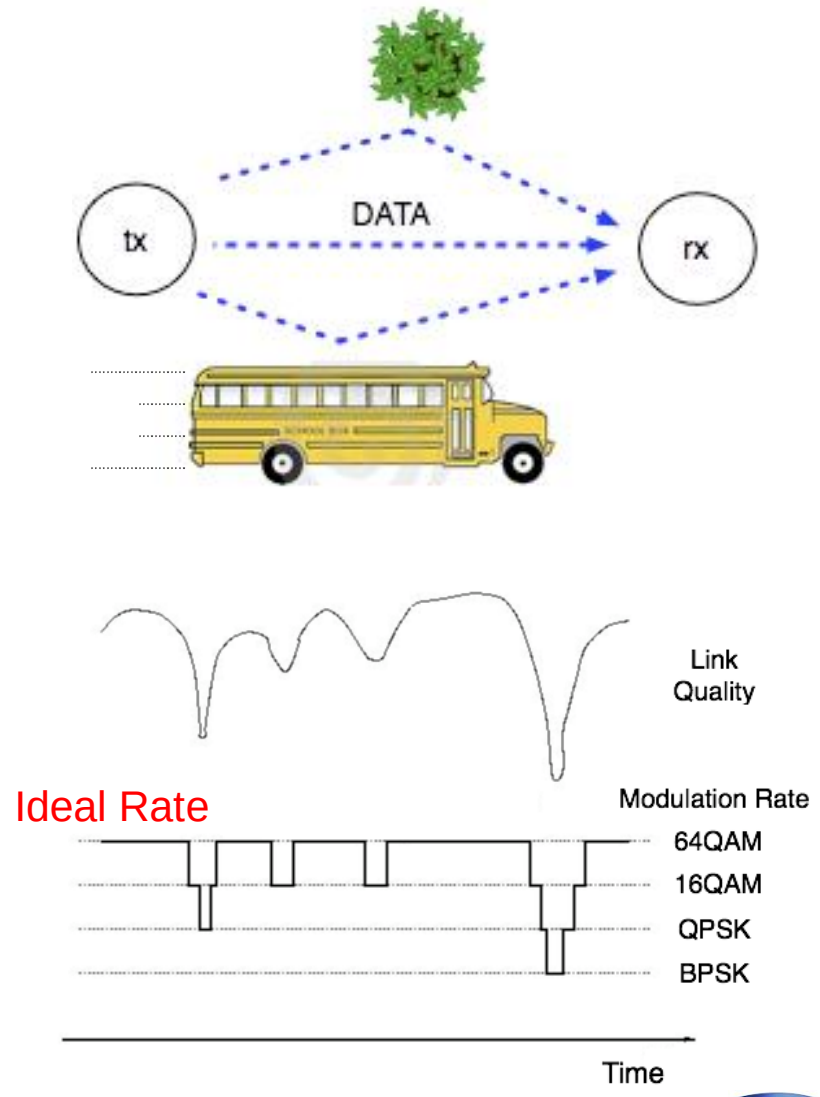
Ed Knightly

Lessons: Theory and Practice

- Carrier Sense – not what you think
- Collisions – winner take all
- Overhead – high cost of a byte
- Routing – no technique, commercial or research, can reliably select targeted route
- Multi-rate – no technique, commercial or research, can track modulation rate

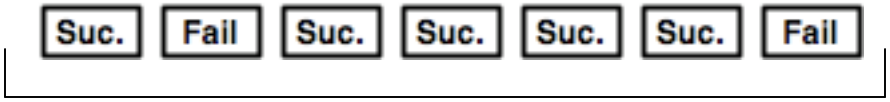
Background: Link Characteristics

- Time-varying link quality
  - mobility of sender, receiver, or obstacles
  - multiple paths
- Each channel condition has an ideal modulation rate
  - rate with highest throughput
- If the modulation rate is …
  - too high: packet loss
  - too low: wasted air time



Existing Rate Adaptation Protocols

- Averaging over a window
  - Transmitter uses packet statistics

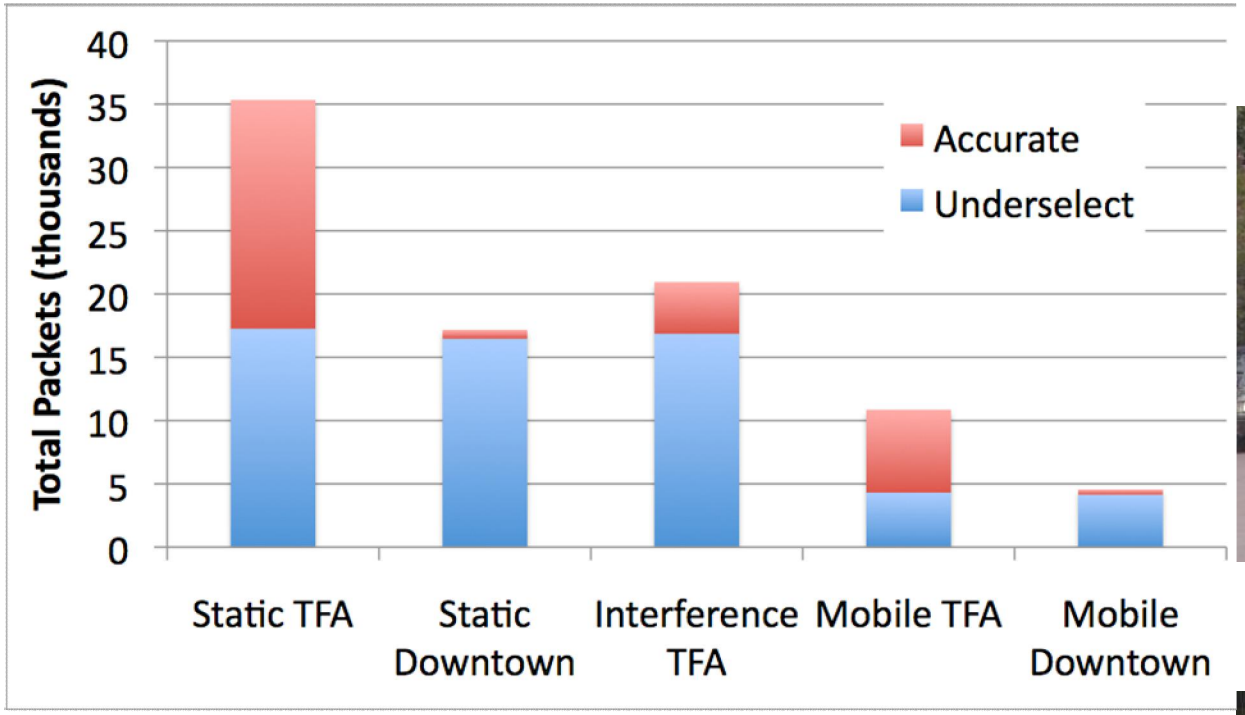


Window

- Modulation-Rate Adaptation
  - Loss: infer poor channel, lower rate
  - Success: infer quality channel, raise rate

- Widely deployed
  - Easy to implement

Poor Performance in Practice



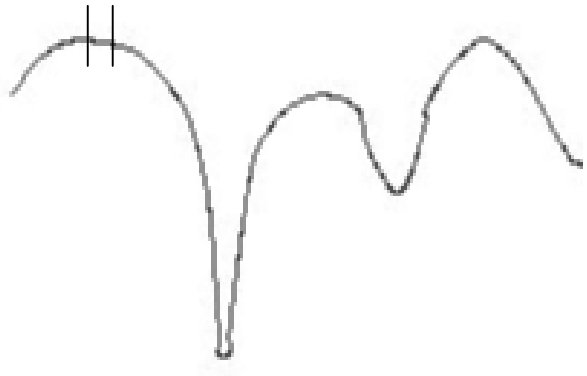
Residential Urban

Downtown Houston

- Loss-based protocols underselect in practical scenarios
  - Any failure trigger lower rate choice
  - Vast reasons and timescales for packet loss

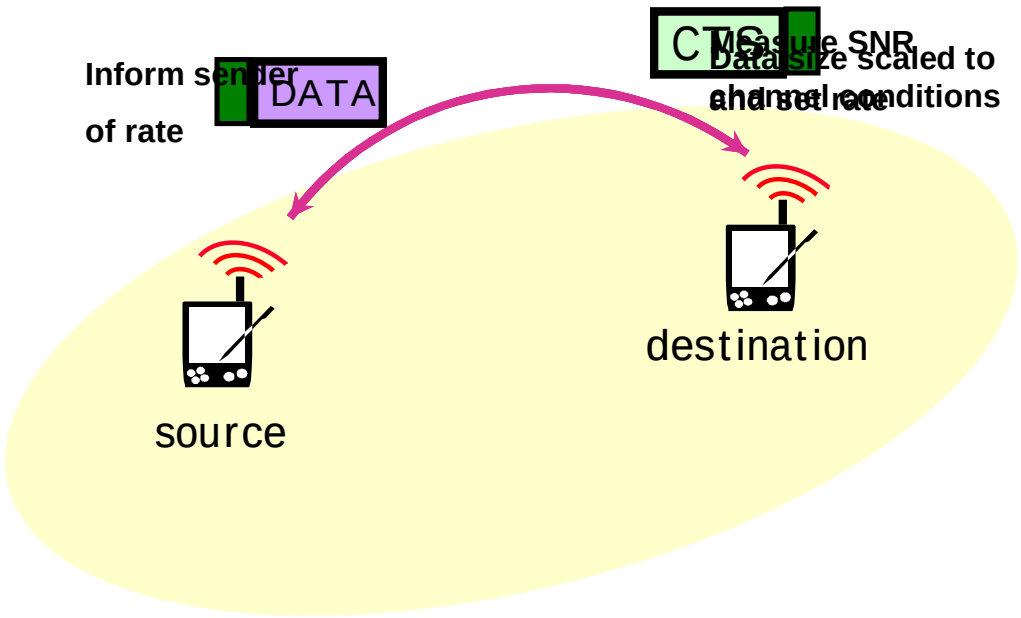
Different Approach: Measuring Link Quality

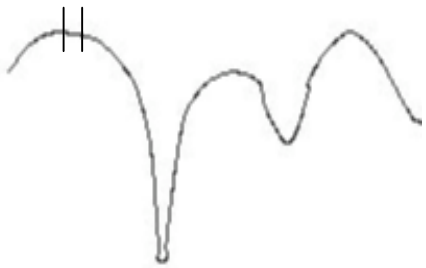
- SNR: signal to noise ratio
  - Ratio of desired signal to undesired signal (noise)
- Request/Grant optionally used prior to data packet
- RTS: **request** to send
- CTS: clear to send (**grant**)



Protocol: Opportunistic Autorate (OAR)

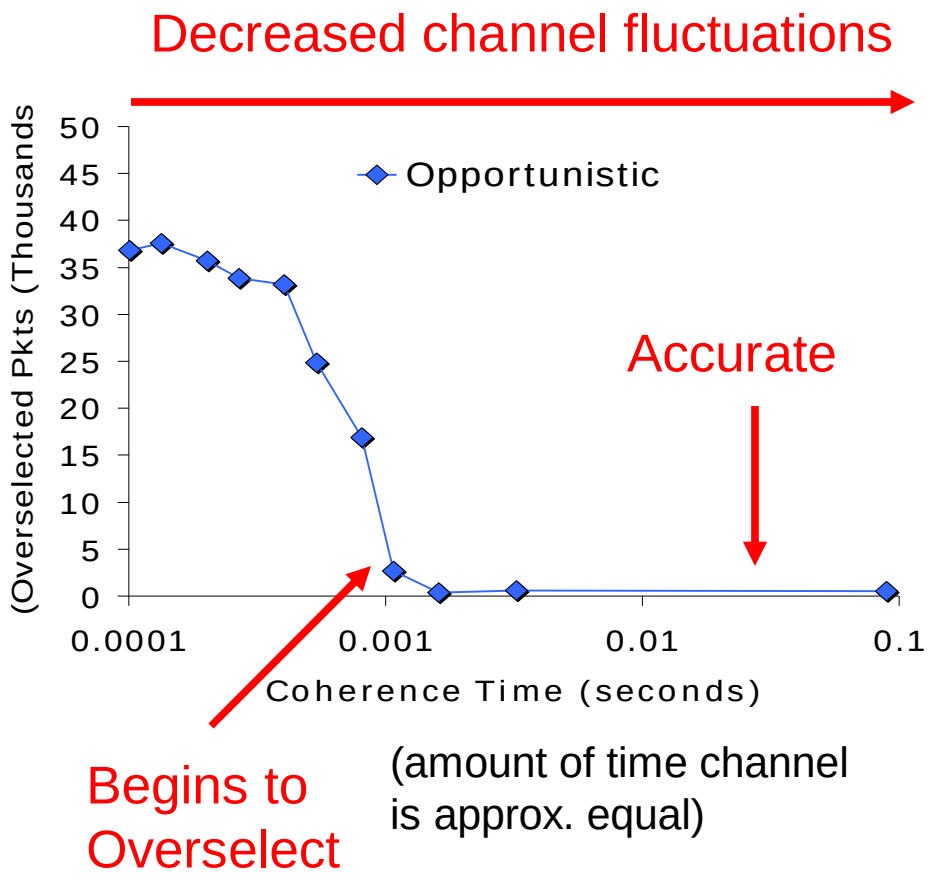
- OAR: measure and adapt rate for each packet
  - RTS/CTS hand-shake to measure SNR
  - Opportunistically send back-to-back packets in good channel conditions
  - Not previously implemented





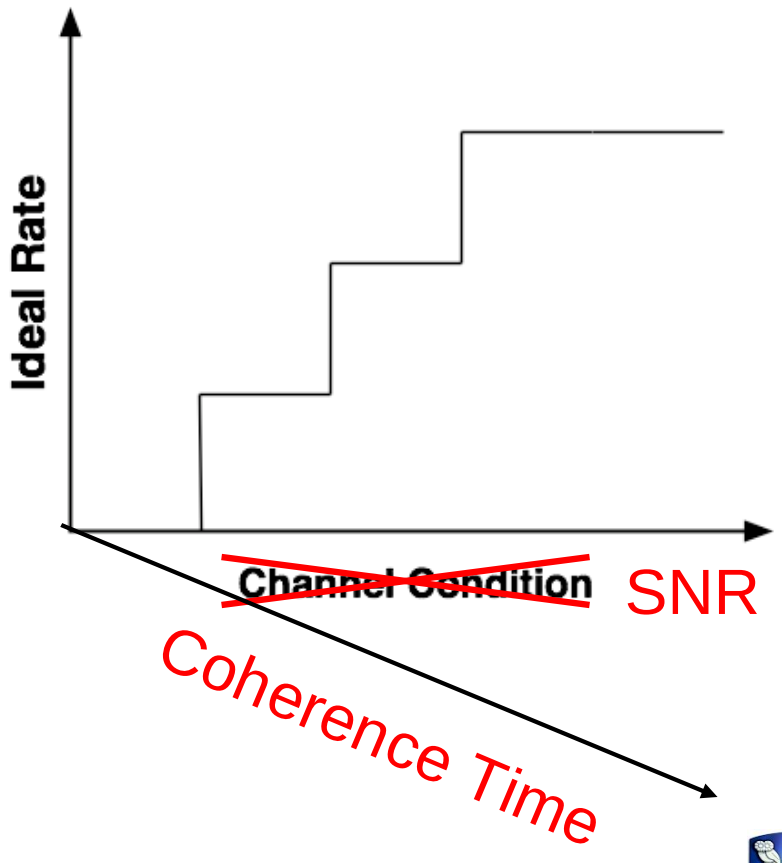
Problem: Over-selection for Short Coherence Times

- Rate selection is per-packet. Why still inaccurate?
- Fast to slow channel fading
  - Accurate at long coherence
  - Overselect at <1ms
- Overselection caused by coherence time sensitivity of SNR-rate relationship



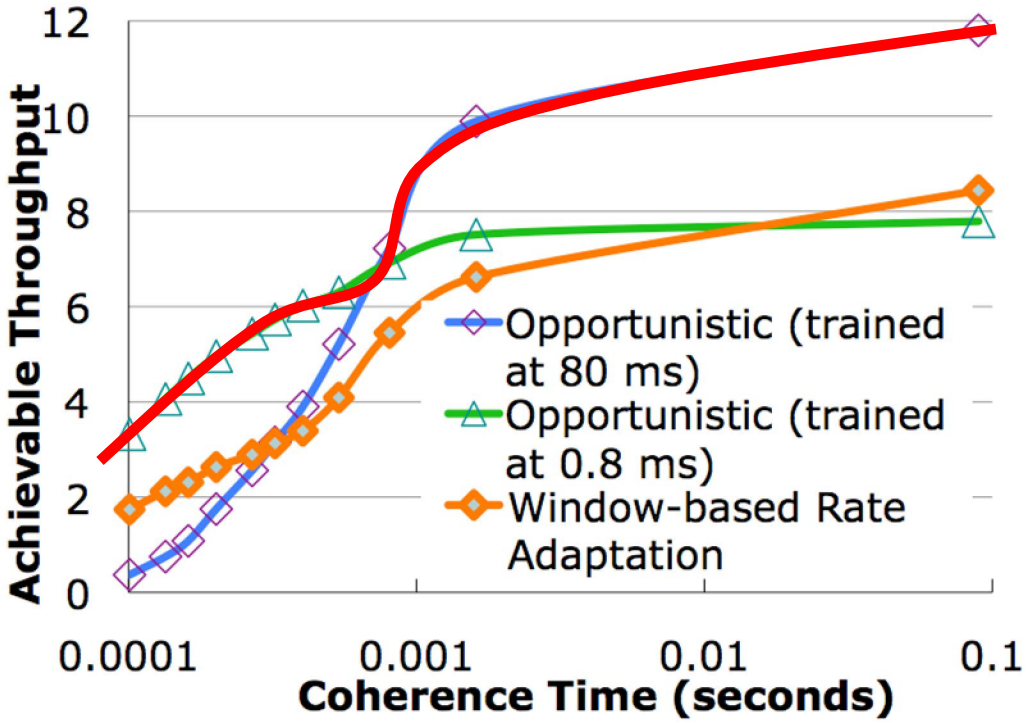
Joint Consideration of SNR and Coherence Time

- Consider different SNR thresholds according to coherence time
  - Ideal rate = f(SNR, CT)



Joint Consideration of SNR and Coherence Time

- Consider different SNR thresholds according to coherence time
  - Ideal rate = f(SNR, CT)
- Retrain SNR-based decision (for the same protocol)
- Joint consideration of SNR and coherence time provides large gains



Summary

- Wireless networking by the people, for the people
- Challenges ensuring
  - High bandwidth, resilient, secure, reliable, ultra-low cost, …
- New protocol designs
  - Track channel fluctuations in diverse operating conditions
  - First-ever implementation of 802.11 SNR-based adaptation
  - Explored joint role of SNR and coherence time
- Implement protocols at your own risk

Ongoing Research Topics

- Wireless networking theory
  - Models for understanding and “what if” queries
- Algorithm and protocol design
  - Mobility, routing, MAC, traffic management, …
- Users and applications
  - Anthropologists and sociologists to study societal impact
  - M.D.s to explore health sensing applications
- Experimental validation “at scale”

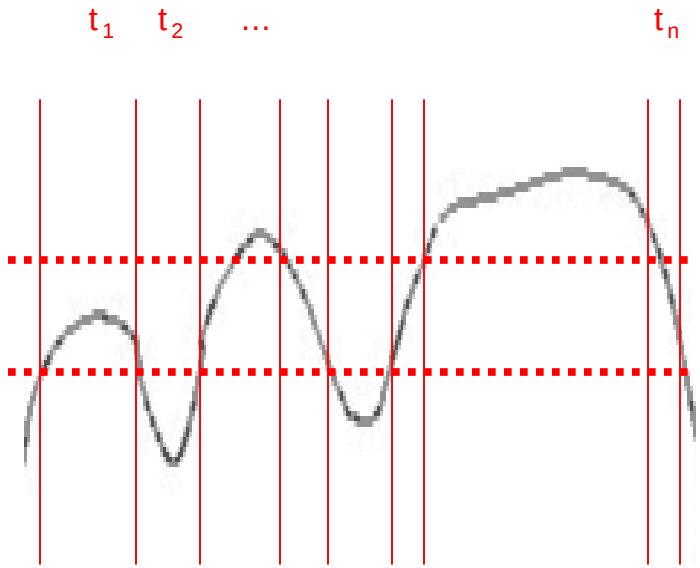
Acknowledgements

- Sponsors

- Collaborators at Rice, TFA, and Methodist Hospital
- Students, postdocs, and staff
- More information:
  - http://networks.rice.edu
  - http://tfa.rice.edu

Measuring Coherence Time

- SNR computation
  - From Automatic Gain Control
  - Per-packet
- Shortest Granularity
  - Zero-payload packets, back-to-back
  - Forms SNR curve



- Thresholds for rate changes
  - Mean channel quality ideal for middle modulation rate
- Average duration between idealized rate changes