TAP Networks: Challenges in Multi-Hop Wireless

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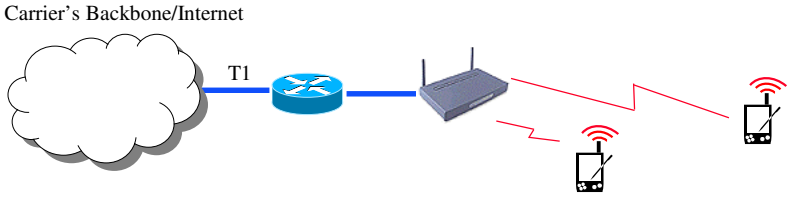
Wireless Utopia

- Widely deployed wireless Internet access to hot spots, residences, and public places
  - High Performance
  - Scalable
  - Cost Effective

- Why?
  - Broadband to the home and public places
  - Enabling new applications

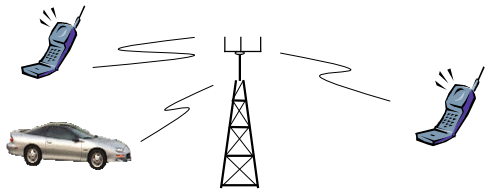
WiFi Hot Spots?

- 11–54 Mb/sec, free spectrum, inexpensive APs/NICs



- Problems?
  - Poor economics
    - High costs of wired infrastructure ($10k + $500/month)
    - Pricing: $3 for 15 minutes, $6M U.S. revenue in 2002
    - Dismal coverage averaging 0.6 km^2 per 50 metro areas
  - Poor performance scaling in dense environments
    - A few residential and ISP APs = starvation

3G Cellular? Fixed Wireless?



- 3G Cellular
  - Coverage, mobility, video phone, …
  - Expensive: spectral fees and high infrastructure costs
  - Slow: 100's of kb/sec
  - Scaling unproven

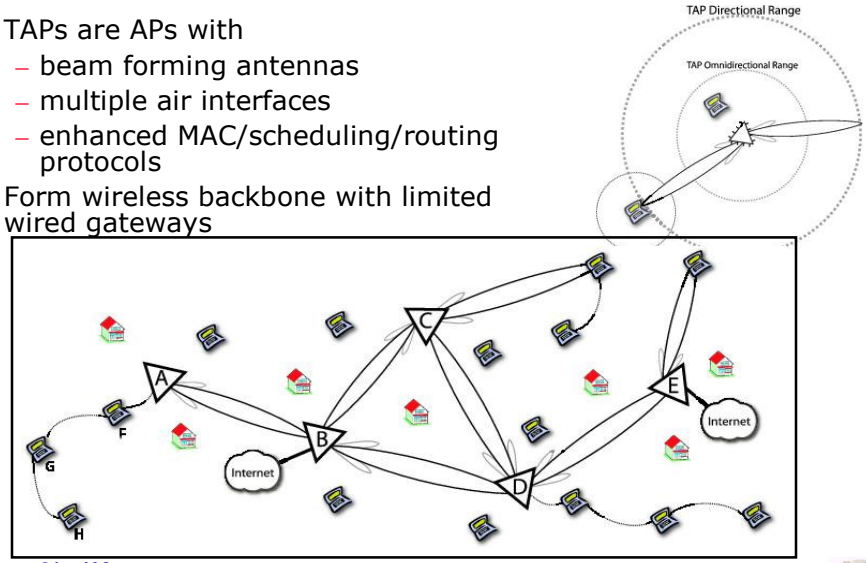
- LMDS (Local Multipoint Distribution System)
  - High bandwidth
  - Large, expensive, line-of-sight transceivers (no portability)

Grand Challenges

- Multi-hop WiFi Wireless Architecture
  - Infrastructure costs (few wires/free spectrum)
- Scheduling and Media Access
  - Goals: ensure scalability, fairness, and QoS
  - Challenge: opportunistically exploit all available resources
  - Class of distributed scheduling problems
  - Class of multi-channel MAC design problems
- Control Protocols
  - Route to nearest wire
  - Fairness: eliminate spatial throughput bias
- Proof of concept testbeds and deployments

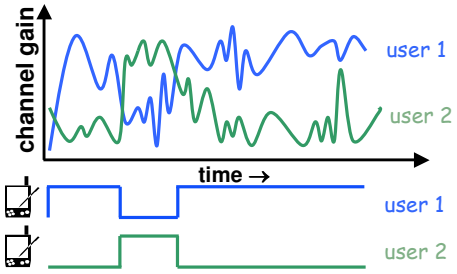
Transit Access Points (TAPs): a multi-hop architecture for scalable, deployable high-speed wireless

- TAPs are APs with
  - beam forming antennas
  - multiple air interfaces
  - enhanced MAC/scheduling/routing protocols
- Form wireless backbone with limited wired gateways



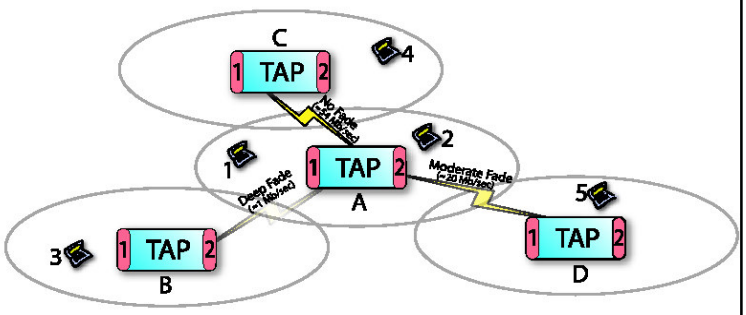
Background: Downlink MAC/Scheduling

- Problem Formulation
  - N backlogged users and M channels
  - Select users with best channel conditions subject to capacity and fairness/delay constraints
- Solution [LK03]: formulate as multi-dimensional control problem



TAP Media Access and Scheduling

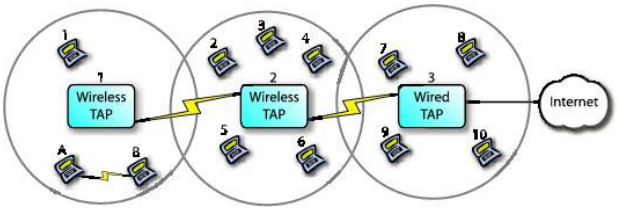
- Challenge: distributed scheduling
  - Others' channel states, priority, & backlog condition unknown
    - Ex. TAP A's best recv'r may be transmitting elsewhere
    - Ex. Traffic to be recv'd may be higher priority than that to be sent
  - Traffic dynamics preclude scheduled cycles
  - Modulate aggressiveness according to overheard information



Multi-Destination Routing/Scheduling

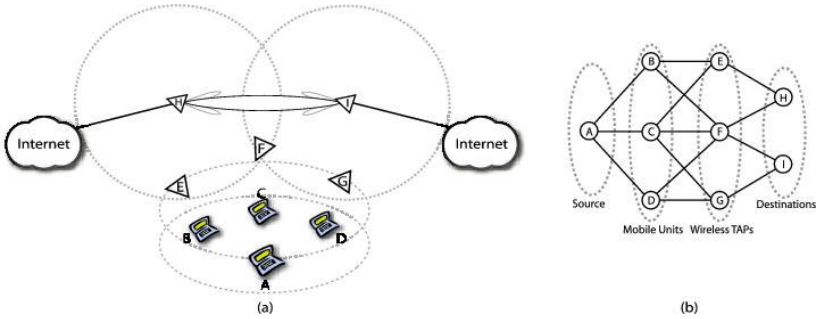
- Most data sources or sinks at a wire
- Routing protocols for any wire abstraction
- Scheduling
  - At fast time scales, which path is best (channels, contention, …) now?
  - Can delay/throughput gains be realized despite TCP?

Distributed Traffic Control



- Distributed resource management: how to throttle flows to their system-wide fair rate?
  - TCP cannot achieve it (too slow and RTT biased)
  - Throttle traffic "near-the-wire" to ensure fairness and high spatial reuse
  - Incorporate channel conditions as well as traffic demands

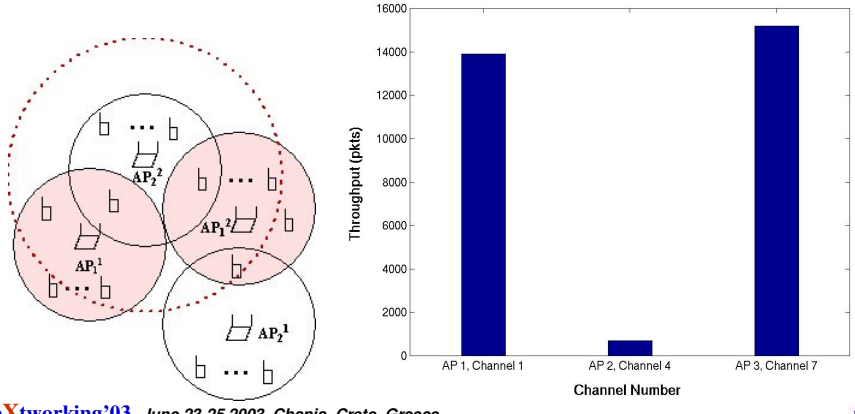
Capacity Driven Protocol Design
Protocol Driven Capacity Analysis



- Traditional view of network capacity assumes zero protocol overhead (no routing overhead, contention, etc.)
- Protocols themselves require capacity
- A new holistic system view: "the network is the channel"
  - Incorporate overhead in discovering/measuring the resource
  - Explore capacity limits under real-world protocols

Problem: Multiple APs/TAPs/… within Radio Range

- PHY Interference has disproportionate throughput degradation at MAC layer
- Interference can lead to severe scaling limitations and starvation (worse than zero-sum game)



Opportunistic Channel Skipping

- Observe: Channel characteristics are largely independent
- Protocol: Multi-channel OAR, opportunistically exploit multiple best channels
  - If a channel is poor quality (due to other APs or fading), SKIP it
  - Key question: when to stop skipping
    - Balance incurred overhead with throughput gain of discovering a better channel
    - Analogous to house selling problem

Prototype and Testbed Deployment

- FPGA implementation of enhanced opportunistic, beamforming, multi-channel, QoS MAC
- Build prototypes and deploy on Rice campus and nearby neighborhoods
- Measurement study from channel conditions to traffic patterns

Summary

- WiFi "footprint" is dismal
- Removing wires is the key for economic viability
- Open challenges in architecture, protocols, and capacity limits