Modulation Rate Adaptation in Urban and Vehicular Environments:

Cross-Layer Implementation and Experimental Evaluation

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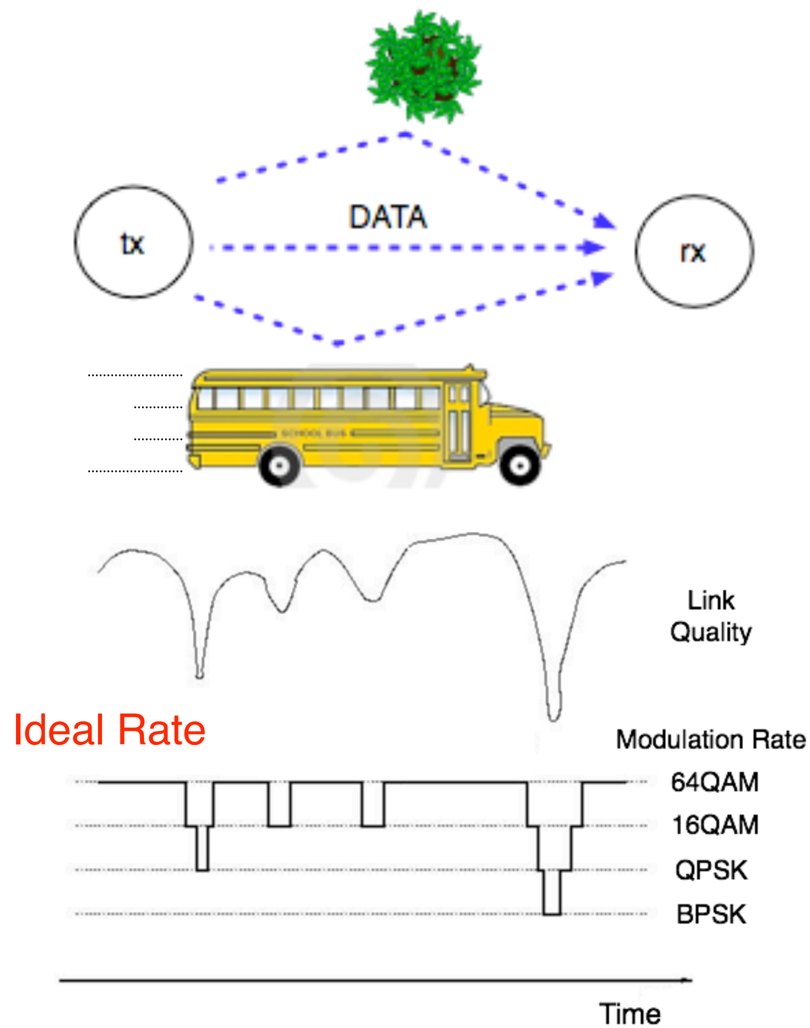
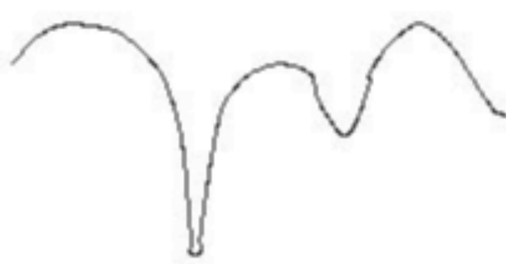
Background: Link Characteristics

- Time-varying link quality
  - Mobility of sender, receiver, or obstacles
  - Multiple paths existing
- Ideal modulation rate for channel condition
  - Modulation rate with **highest throughput** for channel condition

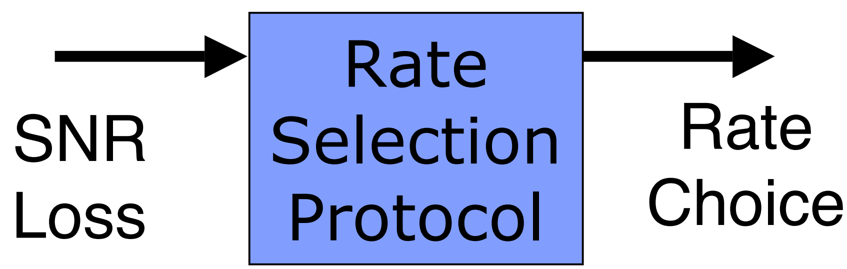


Goal of Protocol Designer

- Use available information (loss, SNR, …) to track ideal modulation rate
- Many protocols have been invented
  - ARF, RBAR, OAR, RRAA, CARA, ONOE, …



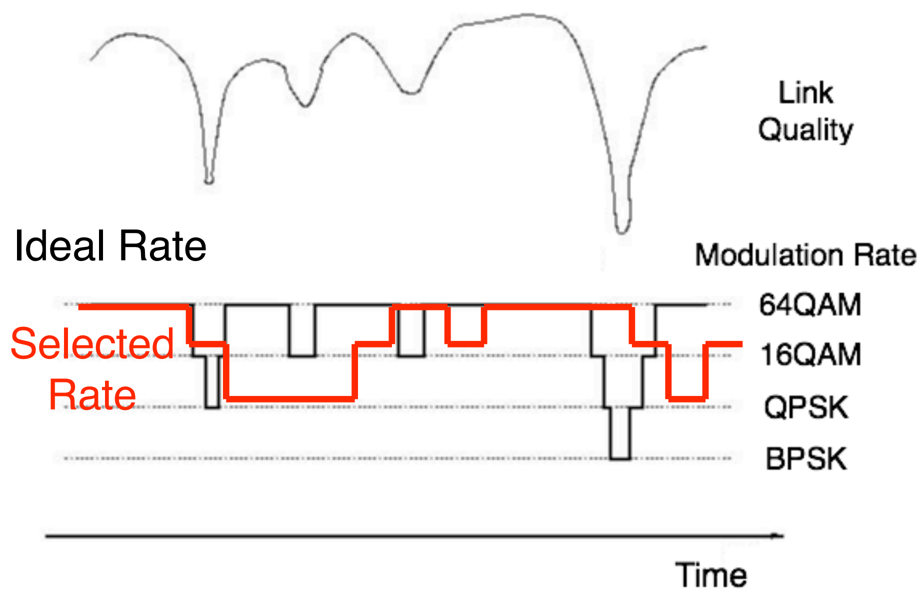
Ground Truth



Real System

Problem

- ALL existing rate adaptation algorithms **fail** to track the ideal rate
  - Urban propagation environment
  - Even with non-mobile sender and receiver
  - Result = loss and under-utilization



Objective

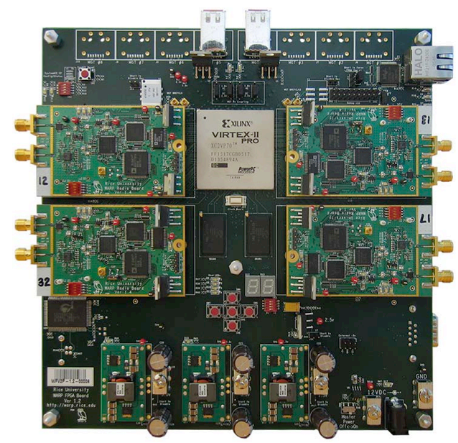
- Understand the origins of the failure to track link variation
- Identify core mechanisms needed to succeed in urban channels

Methodology

- Unified Implementation Platform
  - Implement multiple algorithms on a common platform
  - First implementation of SNR-based protocols
- Extract General Rate Adaptation Principles
  - Evaluate rate selection accuracy *packet-by-packet*
    - Compare against ideal rate found via exhaustive search
  - Use *repeatable* controlled channels and
  - Accurately *measured outdoor* channels
- Design core mechanisms to track real-world link variation

Wireless Open-Access Research Platform (WARP)

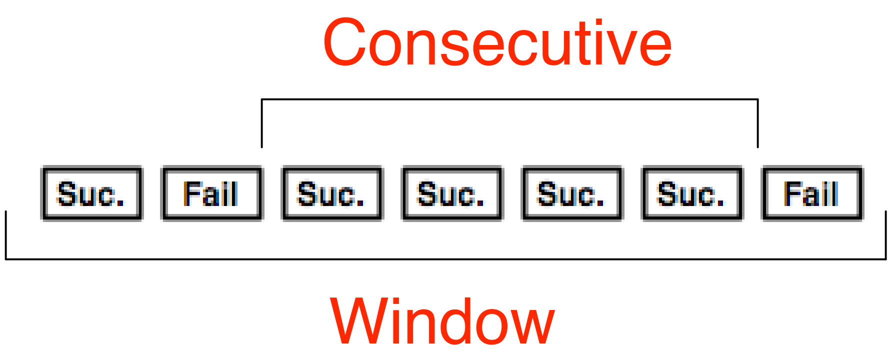
- Limits of Off-the-shelf platforms
  - Programmability and observability
- WARP is clean-slate MAC and PHY, needed to implement:
  - CSMA/CA (802.11-like MAC)
- Cross-layer rate adaptation framework
  - Core mechanisms for rate selection protocols
  - Channel measurements
  - Evaluation of selected rate versus ideal rate



Virtex-II Pro FPGA

Core Mechanisms for Rate Adaptation

- Loss-based
  - Averaging over window
    - Consecutive
  - Collision/Fading Differentiation



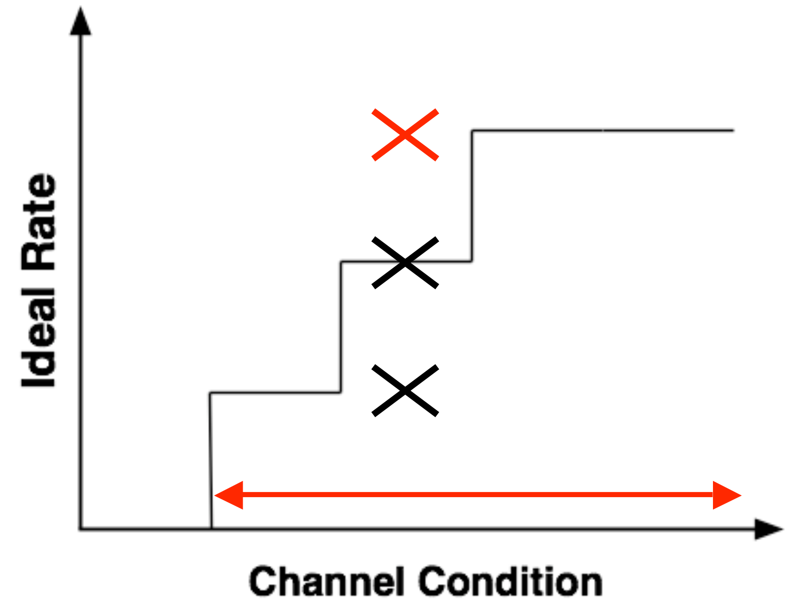
First to implement

- SNR-based
  - Measure SNR per data packet
  - Opportunistic
    - Better channel

Goal to track ideal, why not measure?

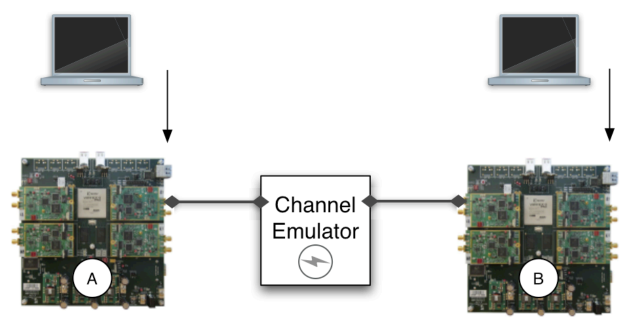
Rate Adaptation Accuracy

- Ideal rate found via exhaustive search of channel condition
- Consider case where at least one modulation rate succeeds
- Rate Selection Accuracy Categories
  - Over-selection (loss)
  - Accurate (achieving optimal rate)
  - Under-selection (under-utilization)

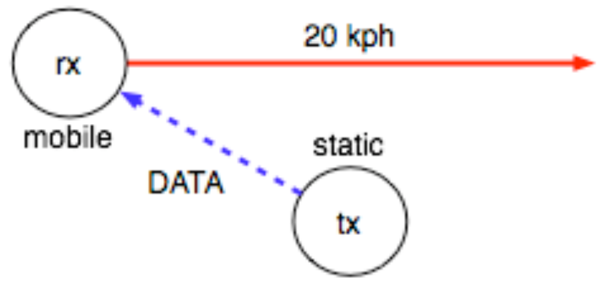


Experimental Design

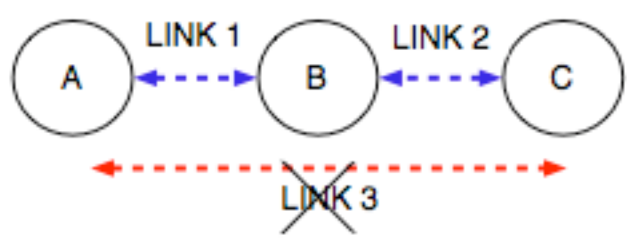
- Repeatable channels
  - Mean channel quality
  - Channel fading/coherence time
  - Multipath effect and interference



- Accurately measured urban channels
  - Residential and downtown scenarios
  - Measure coherence time
  - Static and Vehicular Topologies

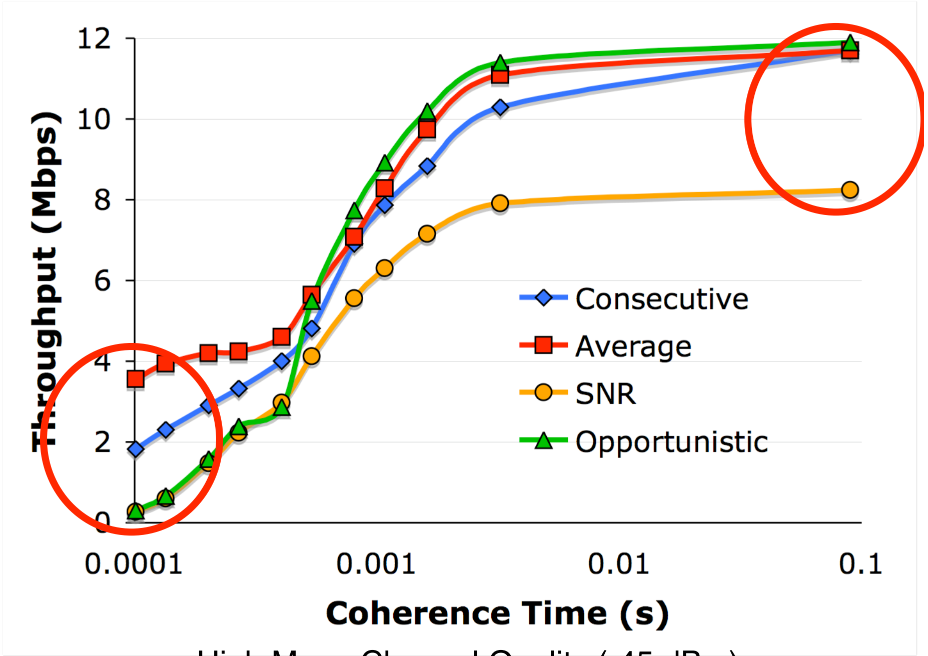


- Competing links (in paper)
  - Indoor, controlled environment
  - Urban environment



Impact of Coherence Time

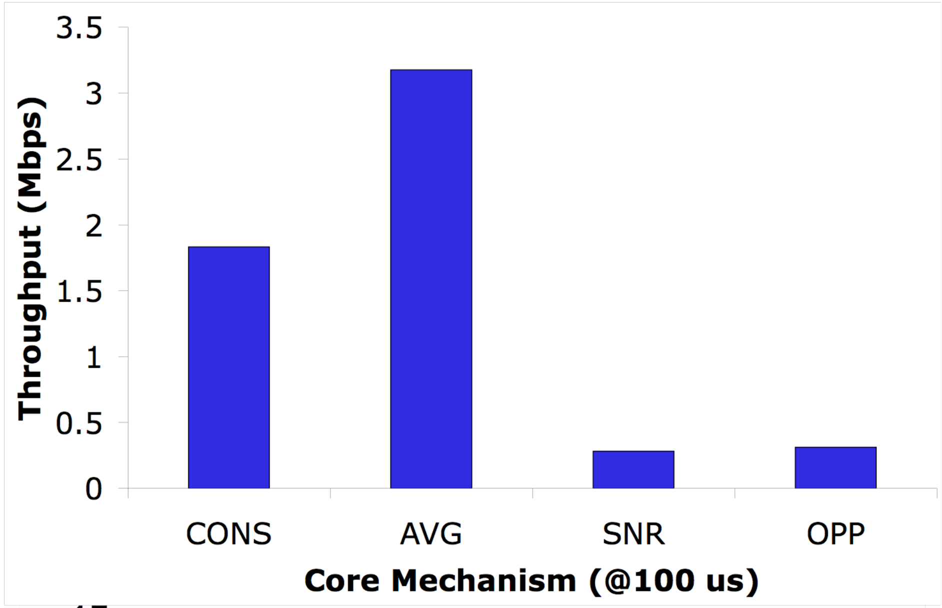
- Issue: Increase fading of the channel to evaluate if rate adaptation can track
- Similar performance with long coherence of channel
  - SNR: high overhead penalty (contrasts result of protocol designer)
  - Opportunistic: overcomes RTS/CTS overhead penalty
- Dissimilar performance at short coherence of channel

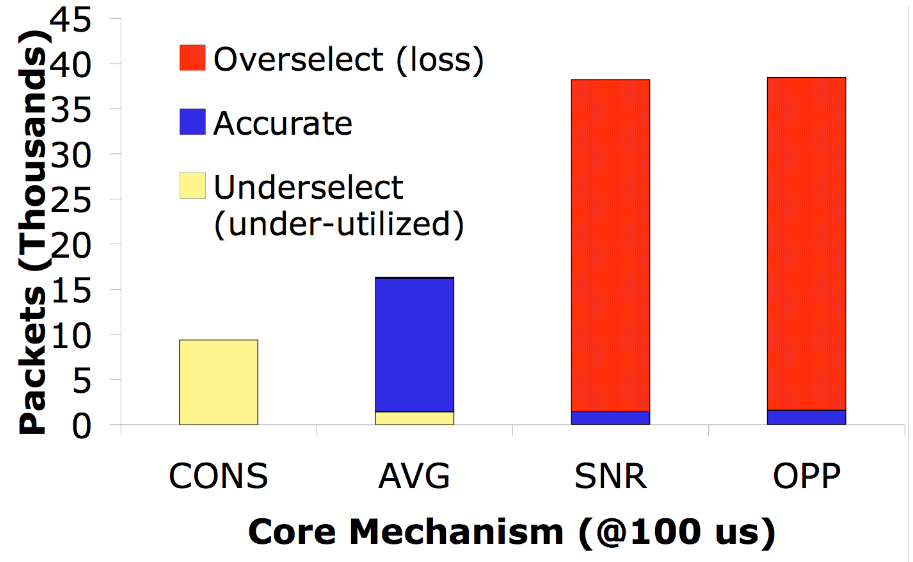


High Mean Channel Quality (-45 dBm), Single Rayleigh Fading Channel

Opposite Rate Choice Inaccuracies

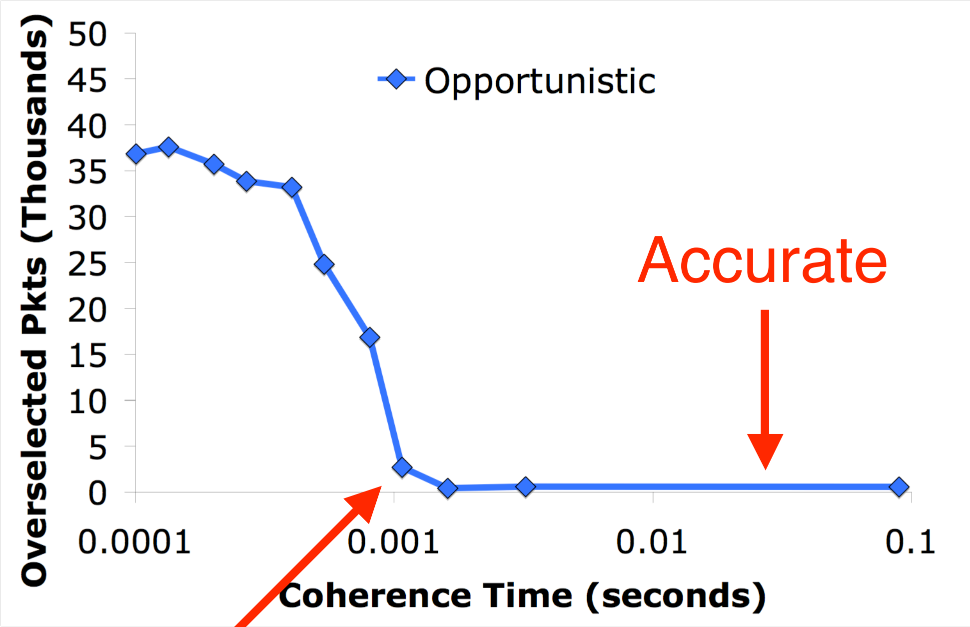
- Issue: Packet-by-packet accuracy to reveal why throughput is low
- Average vs. consecutive mechanisms
  - Consecutive low due to **under**selection
- SNR: extremely low throughput
  - Due to **over**selection (loss)
- Per-packet analysis needed to show poor rate adaptation behavior





SNR-based Coherence Time Sensitivity

- Issue: SNR rate selection is per-packet (should track fading), why inaccurate?
- Fast to slow channel fading
  - Accurate at long coherence
  - Overselect at <1ms
- Overselection caused by coherence time sensitivity of SNR-rate relationship

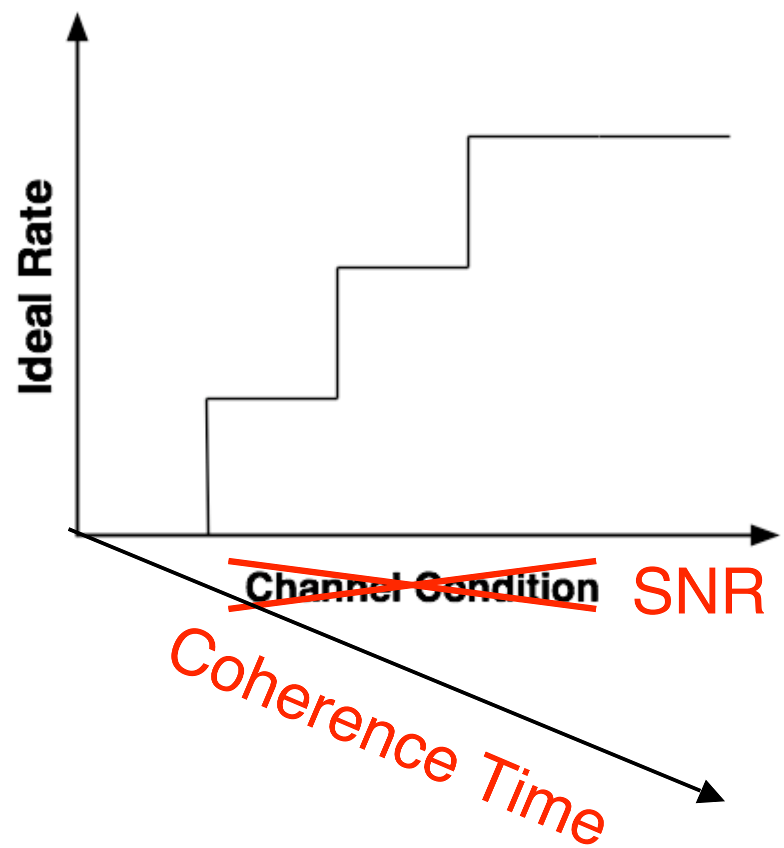


Accurate

Begins to Overselect

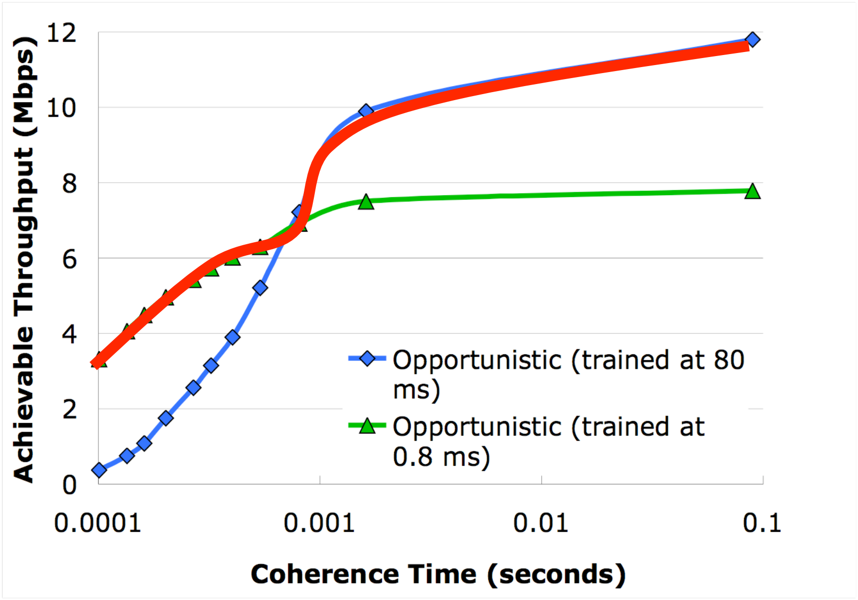
Joint Consideration of SNR and Coherence Time

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



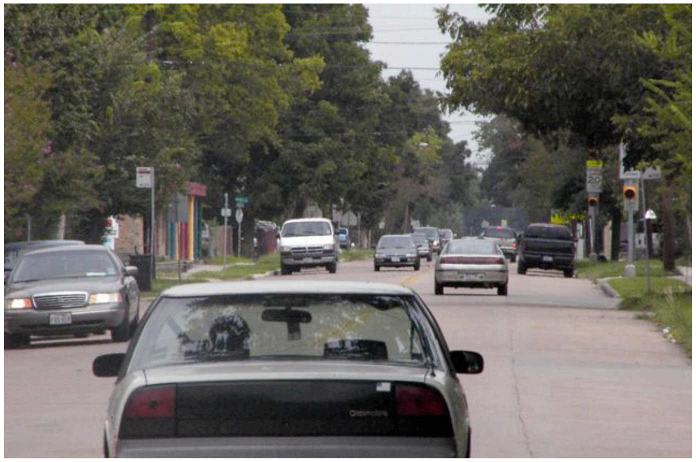
Joint Consideration of SNR and Coherence Time

- 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



Scenarios and Channel Measurements

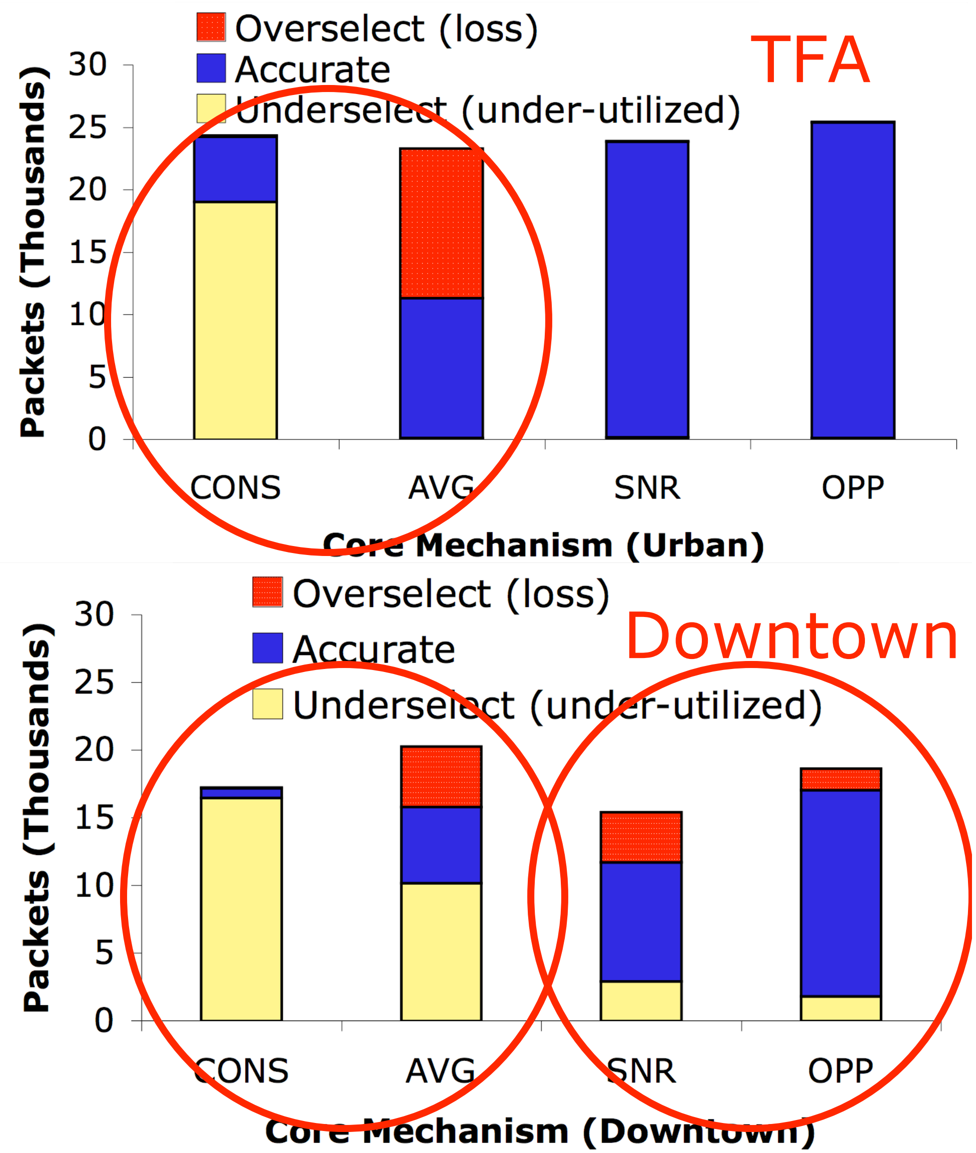
- Residential Urban (TFA)
  - Single-family residential, dense foliage
  - Coherence Time: 100 ms on average
  - Driven to 15 ms with mobility of scatterers (in static topology)



- Downtown Houston
  - Both sides of street lined with tall buildings (strong multipath)
  - Coherence Time: 80 ms on average
  - Driven to 300 usec with mobility of scatterers (in static topology)

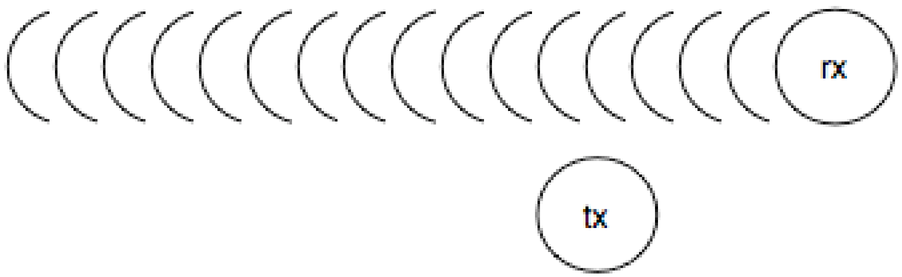
Outdoor Static Topologies

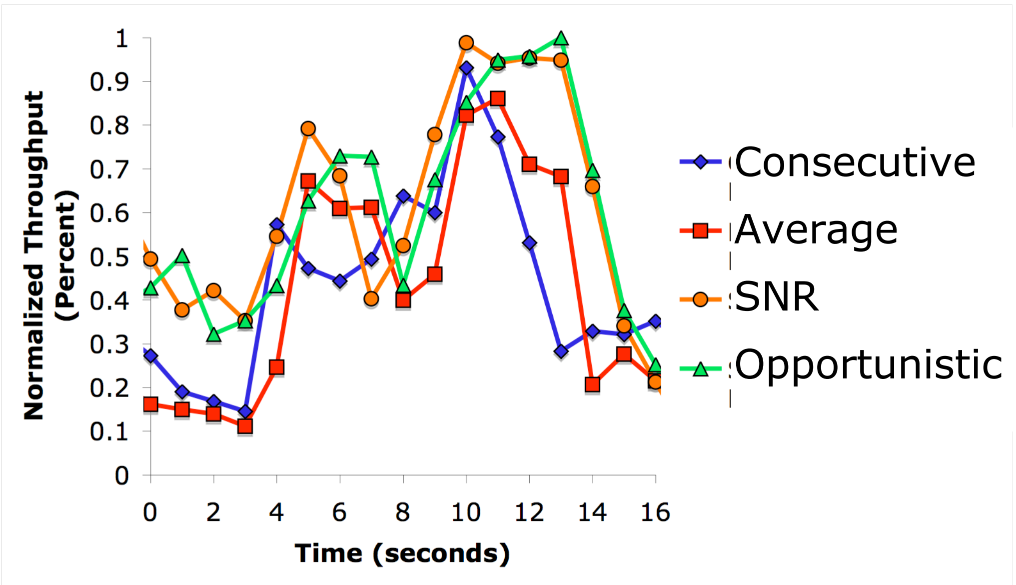
- Issue: Evaluate rate adaptation accuracy in outdoor scenarios
- Consecutive and average: inaccurate in outdoor settings
- Downtown (strong multipath)
  - Force loss-based to underselect
  - SNR: over and underselect with low coherence time
- No long coherence times and equal performance as in lab



Static Sender to Mobile Receiver (Urban)

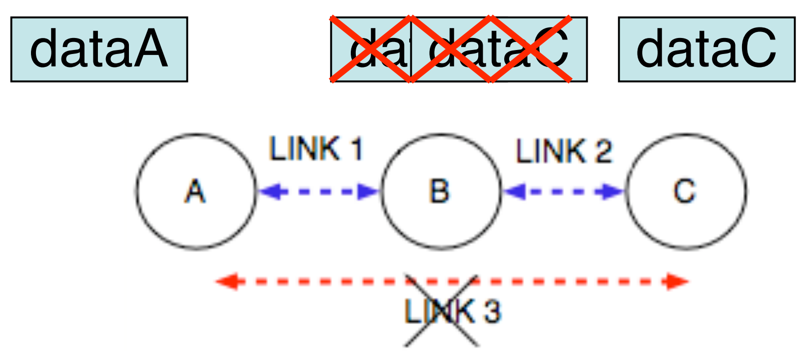
- Issue: Evaluate rate adaptation ability to track with mobility
- SNR protocols are able to plateau for >4 sec
  - Per-packet decision
- Loss-based protocols are only able to spike to suboptimal rate choices
  - Loss sensitivity prevents protocol from tracking
- Loss-based protocols are unable to track with mobility





Heterogeneous Competing Links (in paper)

- Lack of loss distinction
  - Causes underselection
- Collision/Fading differentiation able to overcome with equal links
  - Large imbalances for **slight** differences in competing links
- Residential Urban Scenario
  - Competing links with vehicular mobility



In Summary

- Implementation of multiple and previously unimplemented rate adaptation mechanisms and found via per-packet inspection:

- Loss-based core mechanisms **underselect** with
  - Fast-fading, interference, competing links (even with collision/fading differentiation), and mobile environments
- SNR-based mechanisms **overselect** with fast-fading but have
  - Large gains from considering SNR and coherence time jointly
  - **Robustness** to interference, competing links, and mobility
- Despite use of 4-way handshake, SNR-based protocols **outperform** loss-based protocols in practical environments

WARP: http://warp.rice.edu
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