WIRELESS NETWORK CONTROL

OVERVIEW AND CHALLENGES FOR LOW LATENCY NETWORKS

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SETTING AND MOVING FORWARD

- Current State
  - Cellular: Large cells with tens of users per sector/cell
  - Cellular: Time-scale separation between scheduling and mobile-to-cell association
  - Unlicensed: Dominated by WiFi
- Moving Forward
  - Many small cells with few(er) users per cell; fast(er) transitions between cells
  - Heterogeneous capabilities
  - Mixture of cellular and D2D traffic over shared spectrum
  - Much smaller slot timescales (100s of microsecs instead of milliseconds)
  - Much larger bandwidth

STATE OF THE ART: CONTROL ALGORITHMS

STATE OF THE ART: QUEUE BASED CONTROL

- Queue length (and variants such as HOL delay) the key weighting function for resource allocation
- Has been shown to be "universally" useful
  - Downlink scheduling, multi-hop scheduling, distributed scheduling (CSMA), ...
- Useful for stability, performance (delay), utility maximization
- Impact: Standard LTE Base Stations have incorporated queues into the scheduler
- Algorithms and systems for distributed resource allocation incorporate queues into control

STATE OF THE ART: STATISTICS-FREE CONTROL ALGORITHMS

- Myopic/greedy algorithms that use only instantaneous state

- Use weighted mixtures of current state (channel / queue / topology)
- Does not rely on past history
- Nevertheless has great optimality properties

STATE OF THE ART: MATHEMATICAL METHODS FOR PERFORMANCE ANALYSIS

STATE OF THE ART: LYAPUNOV ANALYSIS FOR NETWORKS

- Has proved to be powerful for both design and analysis
- New proof ideas leading to explicit bounds on performance
- New queueing structures for tracking and combining multiple (non packet) objectives
- Various extensions developed for wireless networks
  - Stability analysis
  - Delay Bounds
  - Utility optimization
  - Design and analyze trade-offs between multiple objectives

STATE OF THE ART: NETWORK DELAY ANALYSIS

- Several new techniques over the last decade
- Large deviations tools for queue-lengths/delay
- Sample-path large deviations for wireless channels
  - Characterize the performance and optimality of algorithms as queues become large
- Many channels large deviations
  - Characterize the performance and optimality of algorithms as number of channels become large
- Mean delay analysis
  - New methods for bounding end-to-end delay with multi-hop

STATE-OF-THE-ART: DISTRIBUTED SCHEDULING TOOLS

- New tools for stability properties of distributed (CSMA-like) schedulers
- Rigorous methods inspired by statistical physics
  - Idea is to allow queues to evolve "slowly"
  - Leads to a time-scale decomposition
  - "Temporally local" solutions with fixed queues solve hard independent set scheduling
  - Queues evolve on an outer time-scale to result in stability/ optimality properties

LOOKING AHEAD TOWARD LOW LATENCY NETWORKS

LOOKING AHEAD: QUEUE BASED CONTROL

- Small delay means that most queues (and HOL delays) ideally very small
- Weighting with queues potentially not very informative in most cases

- Users transition between cells at a faster time-scale
  - Number of users per cell smaller
  - Time-scale separation between scheduling and association unclear
- Scheduling resource allocation decisions not only for selecting user but also which access point/BS

LOOKING AHEAD: HIERARCHICAL RESOURCE ALLOCATION

- Time-scales with each BS/AN very short — not clear that queues will "converge"
- Need to leverage the cellular data center — vast statistics available
  - Traditionally, queues "encode" statistics
  - Will the data center "replace" the queues?
- Globally track arrival statistics; channel statistics

- Share statistics across network for coordinate decision making
- Resource allocation and control based on local state + global statistics

LOOKING AHEAD: SAMPLING AND INFORMATION COSTS

- State of the Art: Channel probing mechanisms in cognitive radio settings
- Looking Ahead: Bandit-like algorithms more important in cellular contexts
- Exploit for mobile user's benefit; explore (probe/ learn) for the system's benefit