Building Cooperative Heterogeneous Wireless Networks With Re-Configurable Devices

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Outline

- Introduction
  - Towards cooperative wireless networks
  - Towards heterogeneous wireless system
  - Towards re-configurable devices
  - Problem domain and motivations
- Background
  - Scheduling, fairness
- Project Goals and Accomplishments
- Conclusions and Future Work

Let's Digress

- Top three ways you know you had a good visit in Maui:

3 For your next conference located in Hawaii, you now know the only suit you need is a bathing suit

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- Top three ways you know you had a good visit in Maui:

2 You now understand the Hawaiin Pizza

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Let's Digress

- Top three ways you know you had a good visit in Maui:

1 Once you are home, you try to teach the local birds how to sing like a Myna.

2 You now understand the Hawaiin Pizza

3 For your next conference located in Hawaii, you now know the only suit you need is a bathing suit



Introduction: Towards Cooperative Networks

- Cooperative wireless networking concepts are seen at all layers:
  - Physical Layer such as dynamic spectrum management or cognitive devices that sense how spectrum is being used and adapt to improve local or global performance
  - MAC/PHY layer to address interference issues resulting from picocells or femtocells
  - Network Layer such as large cellular, WiMAX, and WiFi where the base stations must coordinate

Assumption #1: Resource allocation is typically performed at the local level (i.e., by each base station). It is well understood that some level of coordination across networks (i.e., at the global level) will improve system spectral efficiency. This becomes even more important in heterogeneous systems.

Introduction: Towards Heterogeneous Wireless Networks

- A heterogeneous wireless network is a wireless system that provides the appearance to users of a single network but in actuality it is composed of more than one radio access technology (RAT).
- Tremendous amount of related work:
  - Handoff techniques
  - Standards-based frameworks
    - IEEE 802.21 and 3GPP
  - Extending the Macrocell network
    - Picocell, femtocell
  - Resource allocation, system optimization, network selection

Introduction: Toward Reconfigurable Devices

- Let's look at a 3G device (the iPhone 4):
  - GSM model: UMTS/HSDPA/HSUPA (850, 900, 1900, 2100 MHz), GSM/ EDGE (850, 900, 1800, 1900 MHz)
  - CDMA model: CDMA EV-DO Rev. A (800, 1900 MHz)
  - 802.11b/g/n Wi-Fi (802.11n 2.4GHz only)
  - Bluetooth 2.1 + EDR wireless technology
- Issues:
  - Multiple versions of phones are required for different carriers
  - To minimize power, low power ASIC technology provides circuitry for all supported modalities

Assumption #2: We assume future devices will become reconfigurable AND able to operate over multiple radios concurrently. Power is the issue today, This will change as reconfigurable fabrics become less power hungry AND bandwidth/spectrum limitations become more evident.

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Introduction

- Case study: WiFi Offload (‘the Starbucks Problem”)

Introduction

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  - Case 1: Starbucks hires AT&T to provide a managed WiFi service
  - Case 2: Starbucks provides an open WiFi network





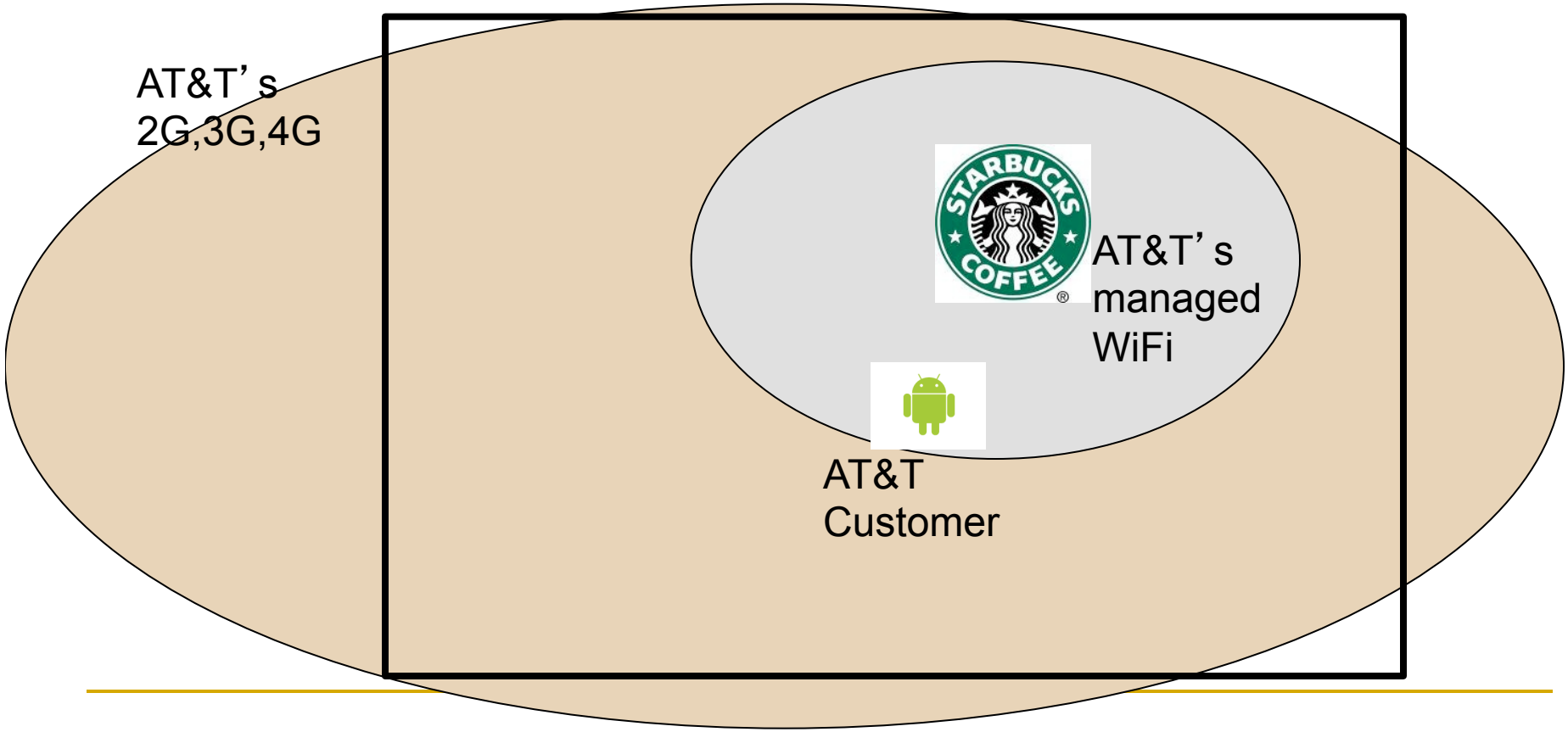
Introduction

- Case 1: Verizon's customer limited to cellular connectivity



Introduction

- Case 1: AT&T customers can switch to WiFi. Methods include use ‘on-the-spot’ offloading, ‘delayed offloading’, and in the future, ‘centralized assisted‘ offloading.



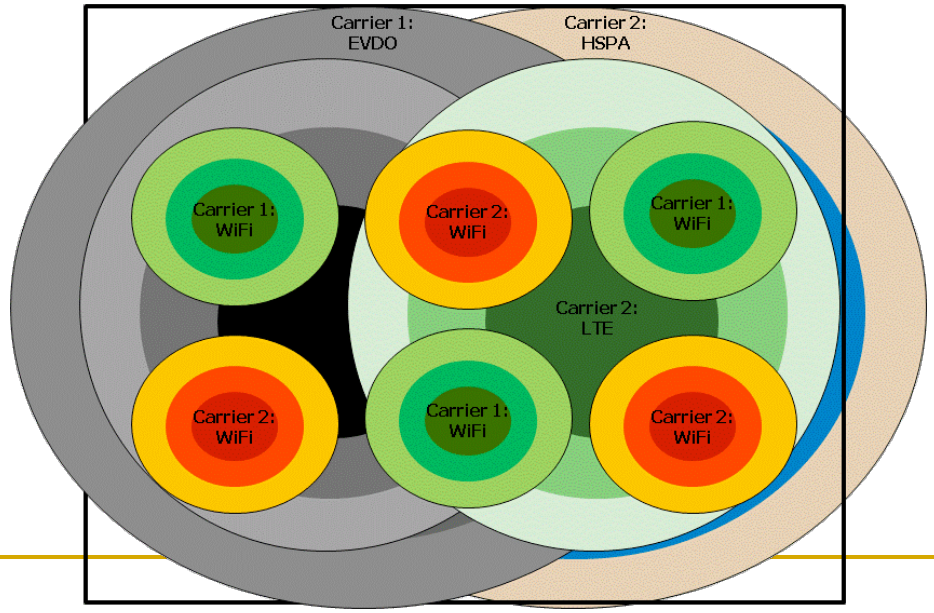
Introduction

- Let's say it's an open WiFi network at starbucks. Problem is how can that open WiFi network best support AT&T, Verizon, and any other devices?
- Many interesting problems:
  - How should open spectrum be managed to provide fair access while providing economic incentives to providers to make use of the spectrum?
  - How/who should decide when a device is to begin using a new RAT ?

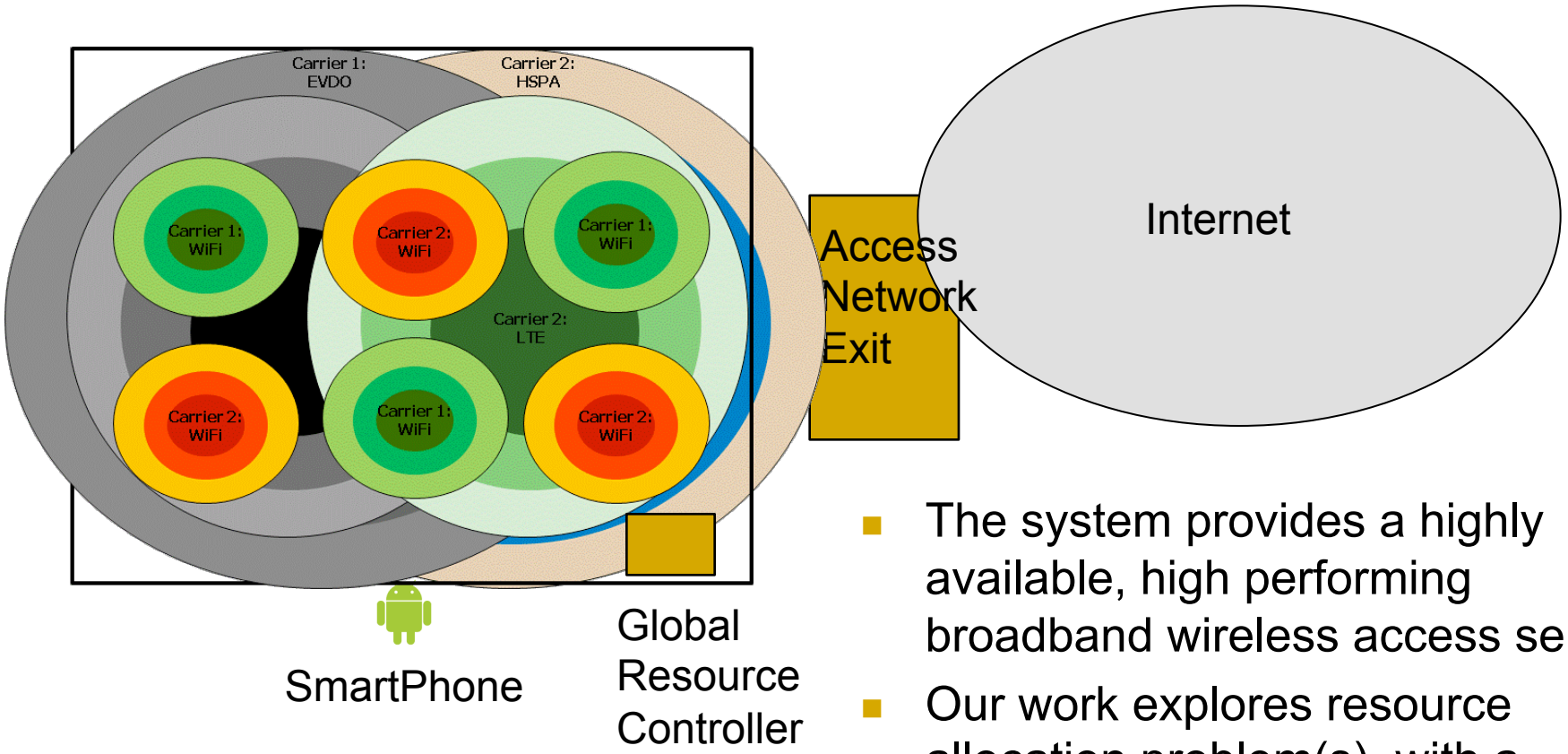
Assumption #3: We assume that economic barriers will be overcome and that eventually standards-based, Internet services will be widely deployed that provide dynamic spectrum management.

Introduction: Problem Domain and Motivations

- Back to our ‘Starbucks Problem’ example, what if both carriers could control how their users might use the open network?
- Let’s extrapolate and say the WiFi network can be any ‘open spectrum’ that might be sensed by cognitive devices that interact with a spectrum management entity.
- And perhaps carriers reach ‘spectrum sharing’ peering agreements….



Introduction: Problem Domain and Motivations



- The system provides a highly available, high performing broadband wireless access service
- Our work explores resource allocation problem(s), with a particular focus on reconfigurable devices

Background

- Resource allocation is the process by which network capacity is apportioned. Two primary factors of interest:
  - Fairness across users of similar types
  - Maximized bandwidth utilization
- Time scales of interest:
  - Microseconds (packet scheduling)
  - Minutes or Hours (optimizing resource utilization)
  - Days or weeks (adding capacity and equipment)
- Online vs Offline algorithms
  - Online
    - Must deal with events as they arrive (no knowledge of future events)
  - Offline
    - Have knowledge of all future events

Background

- Fairness: provides a ‘criteria’ or a basis for an allocation strategy.
  - Max-min fairness: Gives the maximum possible bandwidth to the source receiving the least among competing flows at the bottleneck
    - Smallest allocation as large as possible, next smallest as large as possible, …
    - Packet-based approximations of Generalized Processor Sharing (GPS) , PGPS or weighted fair queueing (WFQ), provides max-min fairness over a single wired channel bottleneck
    - Methods such as waterfilling can achieve max-min fair allocation over multihop paths
  - Proportional fairness (PF): takes advantage of multiuser diversity while maintaining fairness over long time periods

Project Goals and Accomplishments

- Broad goal:
  - Explore resource allocation problems in heterogeneous wireless systems with a focus on reconfigurable devices
- Problems/Steps:
  - Reconfigurable fabrics and devices
  - Develop and model a system that we can use to evaluate our ideas
  - Resource allocation

Project Goals and Accomplishments

- Reconfigurable fabrics and devices:
  - Hybrid ASIC+FPGA platform
    - Tradeoff is number of modalities versus power consumption
    - "Energy Aware Task Mapping Algorithm For Heterogeneous MPSoC Based Architectures" accepted as a poster at IEEE ICCD 2011 conference.
  - Model the 'impacts' of reconfiguration
    - Estimate the communications downtime time and the spike in power the device suffers for each reconfiguration operation

Project Goals and Accomplishments

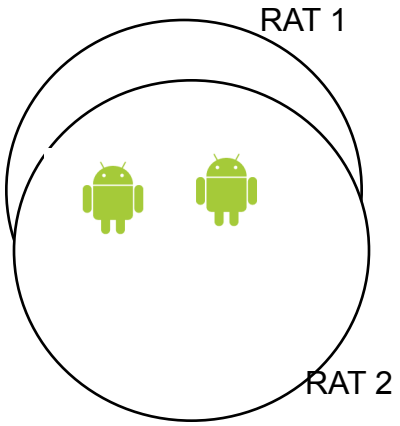
- We have developed a MATLAB simulation modell
- 2 * 2 km^2 grid modeling two wireless carriers:
  - EVDO (3G), WiMAX (4G), IEEE 802.11g (Wi-Fi)
  - HSPA (3G), LTE (4G), IEEE 802.11g (Wi-Fi)
- Cellular base-stations (3G/4G) placed near the center of the grid, Wi-Fi APs are spread throughout the topology
- Each technology supports adaptive Modulation and Coding Scheme (MCS)
- MCS mapping for each user is determined based on distance of the user from the Base-Station
- 100 users, different mix of nomadic and mobile users, random waypoint mobility model
- Experimental Parameters
  - Network Outage: Varied between 0-25%
  - Impact of Reconfiguration: Increased Power Consumption and Communications Downtime multiplied by a scalar $\in [0,1]$

Project Goals and Accomplishments

- We formulate use cases that assume presence of 2 major cellular carriers in a given area
  - Use Case 1
    - No co-operation between the two carriers
    - Users use multiple static radios that can connect to its own carrier's access technologies
  - Use Case 2
    - Co-operation exists between the two carriers
    - Reconfigurable radios are used to support access technologies implemented by the other carrier
- Results
  - Depends on system parameters
  - One data point shows an increase in spectral efficiency (defined in bits/second/Hz) of 75% between Use Case 1 and 2 at a cost of twice the power consumption

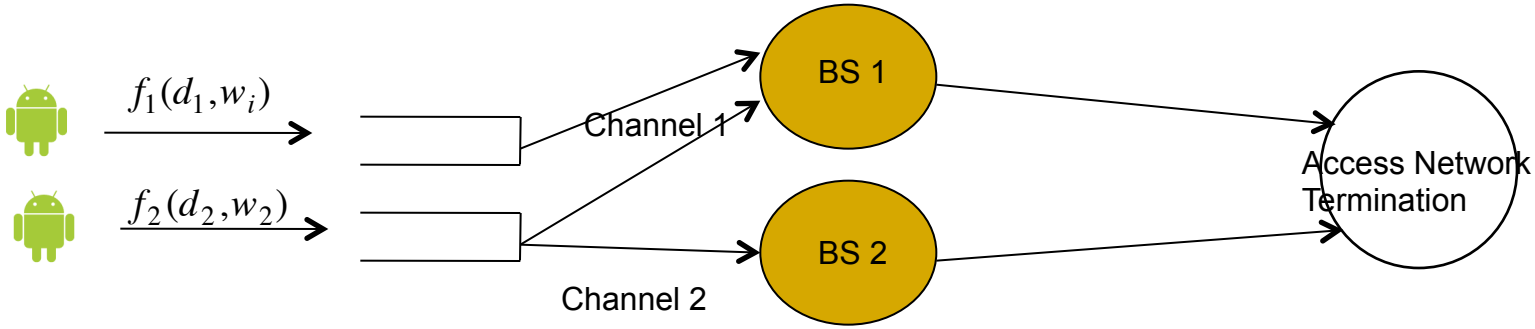
Project Goals and Accomplishments

- Resource Allocation
  - Start with a simple toy example
  - Two RATs, Two smartphones
    - Smartphone 1: demand 10 Mbps, Link to RAT1
    - Smartphone 2: demand 10 Mbps, Link to RAT1 and RAT2
  - For simplicity let's assume all radio links obtain a data rate of 10 Mbps



Project Goals and Accomplishments

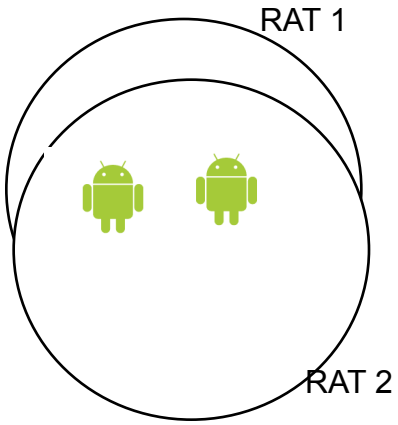
- In a real system, each device is making its own sending decisions
- In our model, we assume an ideal, global scheduler.



- The max-min fair allocation should cause f1 and f2 to each get 10 Mbps. But even in this toy example, implementing fair queueing is challenging
  - Round-robin based algorithms (e.g., DRR), will not work in all situations
  - Timestamp-based algorithms appear to work in more situations, but not all

Project Goals and Accomplishments

- Our model allows any number of devices, RATs, and radios/device.
- The global resource allocator will determine device RAT assignments and the amount of bandwidth that can be consumed in each scheduling period.
- This online scheduling algorithm uses a set of heuristics that provides a ‘tuning knob’ to adjust the balance between fairness and maximizing spectral efficiency
- We use a set of offline algorithms to calculate max-min and PF allocations giving us a reference point



Concluding Remarks
Future Efforts

- Reconfigurable devices are a crucial component to dynamic spectrum management.
- Our work has demonstrated how a large scale heterogeneous wireless system might utilize devices with this capability.
- Future work includes:
  - Evaluate the schedulers to take into account more realistic mobility patterns AND realistic channel models
  - Explore the ‘law of diminishing returns’ that can be observed as the number of radios/node increases
  - Develop a hybrid approach that utilizes a combination of packet scheduling and periodic system optimization adjustments to maintain system performance objectives

Questions



Appendix

Project Goals and Accomplishments

- Power Consumption Model:

$$P_{total} = \propto_{run} P_{dyn} + \propto_{rec} P_{rec}$$

where:

P_{dyn} represents running power

P_{rec} represents reconfiguration power

$\propto_{run}$ represents percentage of time system operates in regular mode

$\propto_{rec}$ represents percentage of time system operates in reconfig. mode

- P_{dyn} and P_{rec} values are estimated based on current FPGA implementations
- Worst Case: For 25% network outage and impact of reconfiguration equal to 1, the average power consumption per node for use case 2 (6 Watts) doubles when compared to use case 1 (3 Watts)

Background

- Bottom-Up approaches for cooperative, heterogeneous wireless systems:
  - Dynamic Spectrum Access
    - Requires devices to be frequency agile giving rise to software defined radios (SDRs) and Cognitive radios as possible implementations
  - Cognitive Networking:
    - A network that can perceive current network conditions and then plan, decide and act on those conditions
  - Symbiotic Networking:
    - Cross-layer design applied to the network level through co-operation across all layers and network boundaries

Background

- Top-down approaches for cooperative, heterogeneous wireless systems
  - IEEE Heterogeneous Wireless Frameworks:
    - 802.21 – Seamless mobility through networks based on different radio access technologies (RATs)
    - P1900.4 – Co-ordinated network-device decision making to aid in the optimization of radio resource usage, including spectrum access control
  - 3GPP Heterogeneous Wireless Frameworks:
    - Common Radio Resource Management, Joint Radio Resource Management, Multi-access Radio Resource Management
      - Local resource managers of different wireless technologies interact with a centralized entity to jointly optimize the process of resource allocation

Background
Scheduling Disciplines

- An alternative to round robin based is time stamp based scheduling

- General Processor Sharing (GPS)
  - Represents the "ideal" weighted fair share model
  - Services an infinitely small quanta from all flows simultaneously
  - Does not deal with packets, or that only one queue can be serviced at a time
  - Defines a theoretical metric to measure real implementations against

- Several approximations exist to simulate GPS in a packet based system
  - Most common are: Weighted Fair Queuing (WFQ) and Worst-Case Fair Weighted Fair Queuing (WF^2Q)
  - Finish times of packets are based on when a packet would finish service in GPS
  - Disadvantage is computational complexity

Background
Scheduling Disciplines

- Variations have been proposed that tradeoff complexity for reduced scheduling accuracy.

- One common example is Self Clocked Fair Queuing (SCFQ)
  - An internally generated clock (virtual time) is used instead of the simulated GPS clock as in WFQ
  - The service tag (finish time) of a packet is equal to the total normalized service for the flow up to that time
  - Service tags are calculated as:

    $F_k^i = L_k^i / r_k + \max(F_k^{i-1} , v(a_k^i))$
  - The packet transmission time of the previous packet is added to the max of the finish time of the previous packet, or the finish time of the current packet in service