NSF EAGER Collaborative Research Project: Towards a Unified Wireless Network Involving Reconfigurable Devices

Project Overview and Status

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Overview

- Project Overview
- Background
- Research Objectives
- Related Work
- System Discussion
- Technical Challenges

Project Overview

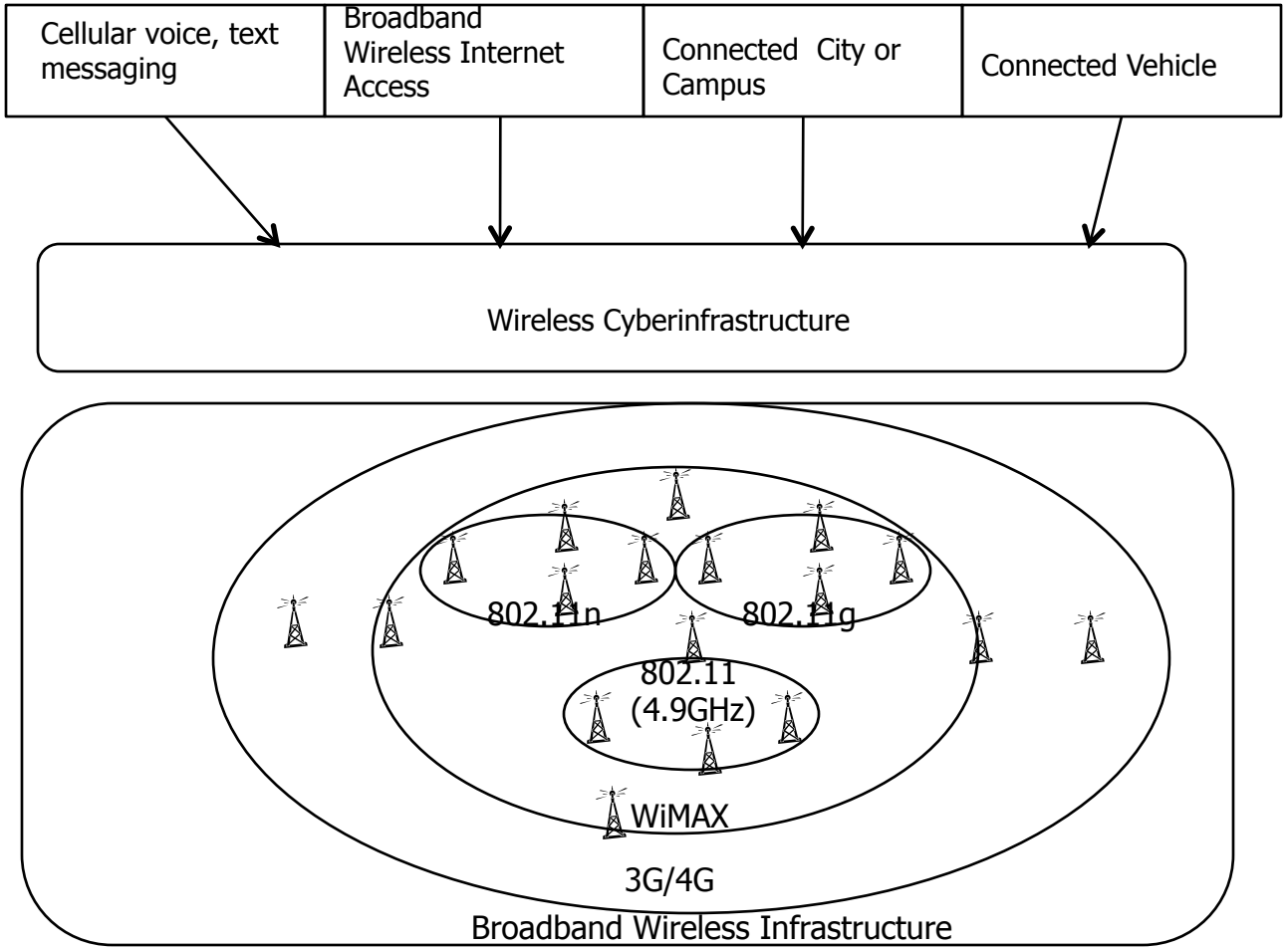
- Project sponsorship
  - NSF Electrical, Communications and Cyber Systems Division Electrical
    - Director: Andreas Weisshaar (aweissh@nsf.gov)
    - Acting PM: Lawrence Goldberg (lgoldber@nsf.gov)
- Project Duration
  - Start: 9/15/2009
  - End: 9/15/2011
- Summary of project: To define and explore challenges in next generation wireless systems based on heterogeneous wireless networks and highly reconfigurable handsets.

Background

- Trends:
  - Cellular voice and broadband wireless is converging- final destination is a ubiquitous, unified, broadband wireless network
  - Wireless technology at the handset and within the network is advancing rapidly
- Impediments:
  - Established practices, economic models, current spectrum allocations



Background


Cellular voice, text messaging
Broadband Wireless Internet Access
Connected City or Campus
Connected Vehicle
Wireless Cyberinfrastructure
802.11n
802.11g
802.11 (4.9GHz)
WiMAX
3G/4G
Broadband Wireless Infrastructure

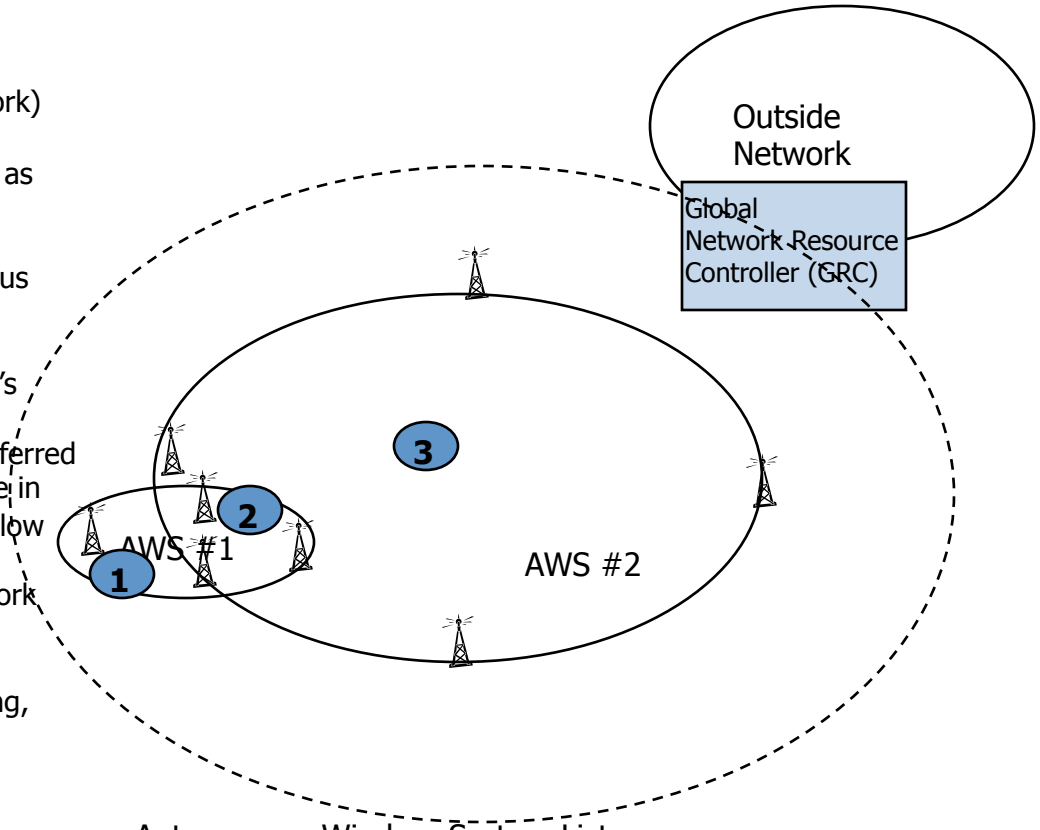
Research Objectives

The proposed research will focus on the following problems:

- Exploring the roles and impacts that next generation software defined radio architectures will have on future wireless systems. An important result of this research will be a device model that accurately captures the capabilities and limitations of emerging agile radios.
- Develop new methods and techniques for managing bandwidth in future unified wireless networks. An important result of this research will be the formulation and validation of an approach for managing resources in a heterogeneous wireless infrastructure taking into account the capabilities and limitations of software defined radios.

System Description: Requirements

- Unified network presented to users (referred to as the network)
- Users device can operate over one channel at a time
- The unified network provides a simple data service specified as best effort with an agreed upon downstream service rate and upstream service rate
- Within the network are a number of independent autonomous wireless systems (referred to as AWS)
    - User 1 has connectivity to a single channel AWS #1
    - User 2 can connect to a channel in either of the AWS's
    - User 3 can connect only to one channel in AWS #2
- The system requires a global network resource controller (referred to as the global resource controller or GRC). Devices must be in periodic contact with the GRC otherwise the system will not allow the device access to any AWS. Devices send status update information periodically to the GRC, and the GRC sends network level status and/or resource management control information periodically to devices.
    - The GRC must optionally provide packet resequencing, error recovery using ARQ and/or FEC.



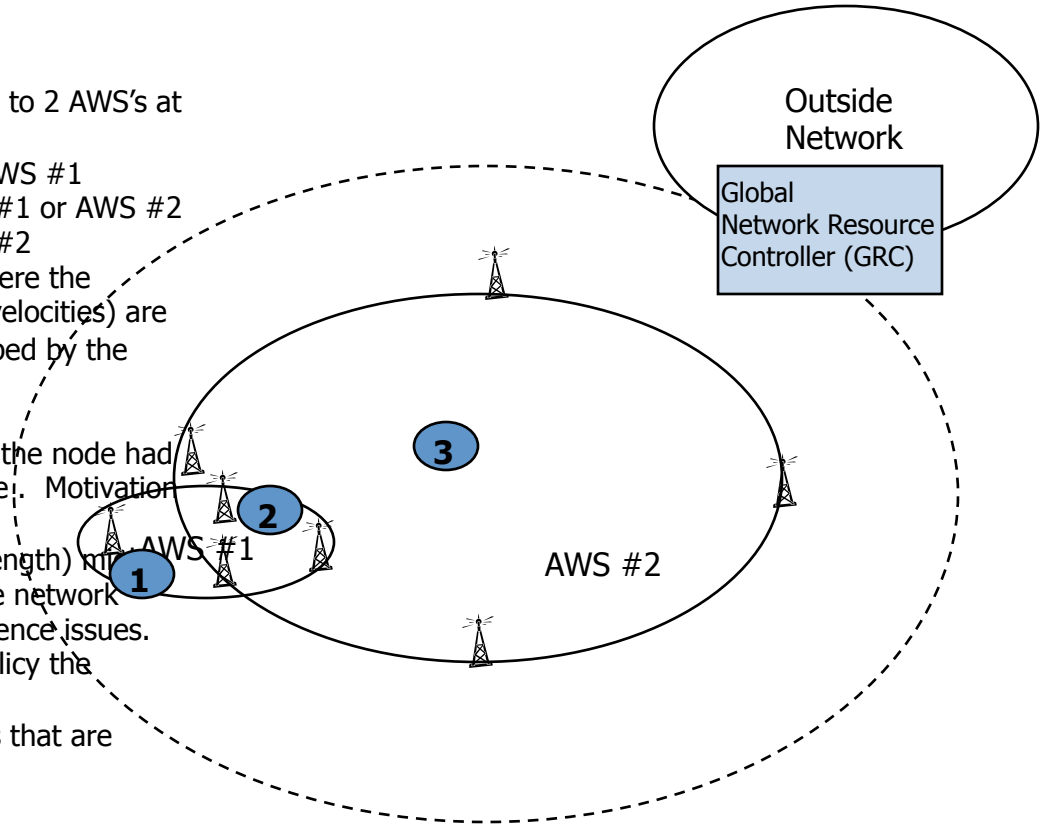
Autonomous Wireless System List

- AWS #1: 802.11n with 2 20MHz channels
- AWS #2: 3G network with a single 10 MHz channel

System Description: Requirements

• More complicated case if User's devices can connect with up to 2 AWS's at any given time.
  • User 1 has connectivity with up to two channels in AWS #1
  • User 2 can connect with up to two channels in AWS #1 or AWS #2
  • User 3 can connect with up to two channels in AWS #2
• Users are mobile. They can roam throughput the region where the network offers connectivitiy. User behaviors (i.e., paths and velocities) are expected to be similar to established mobility models developed by the wireless community.

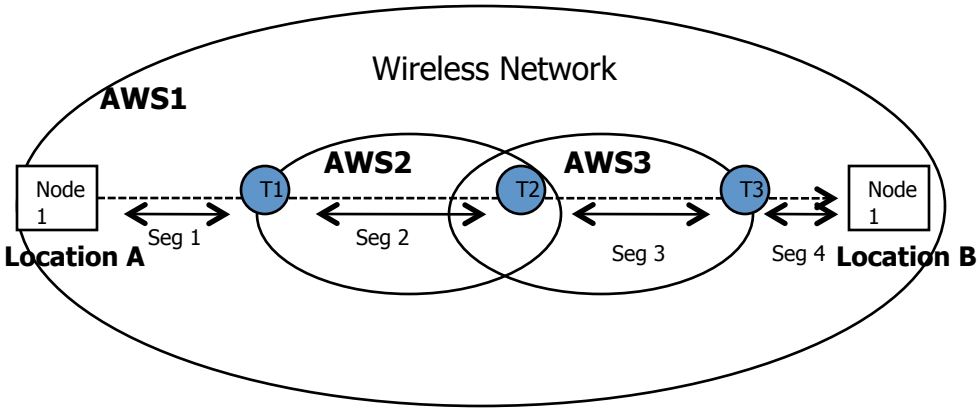
• Consider if User 2 was in coverage of 6 different AWSs AND the node had resources to communicate over 1 or 2 AWSs at any given time. Motivation for central allocation:
  • A decision made on local knowledge (e.g., signal strength) might not lead to the best resource allocation decision as the network might be congested or there might be unseen interference issues.
  • Local allocation decisions might not affect current policy the service provider would like to impose.
  • A node might not be able to detect all possible AWSs that are available.



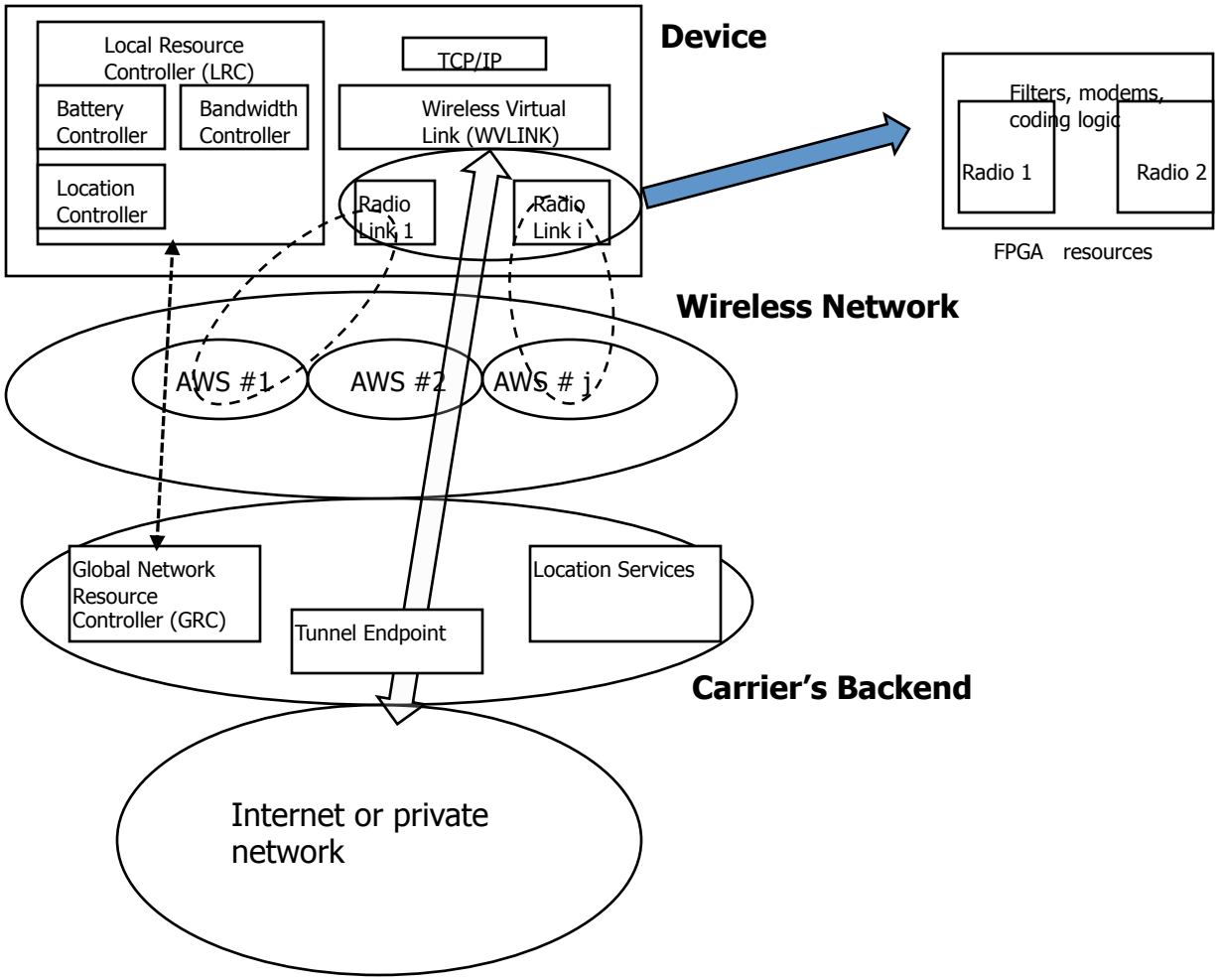
System Design: reconfiguration handoff example

•Node 1 has 2 reconfigurable radios
•Locations T1, T2, T3 represent transition points where reconfigurations might occur
•Seg 1: node has radio 1 tuned to AWS1
•At T1, the GRC tells the node to reconfigure so it can connect with AWS2
•At T2, the GRC tells the node to reconfigure so it can connect with AWS3
•At T3, if the GRC does NOT tell the node to power down its radio, its radio might scan for AWS3 forever.

•Approach requires the GRC to track the location of nodes.
•To make this scalable, the AWSC should participate in routing and handoff management. The AWSC will need to participate in reconfiguration handoffs.



System Model (Carrier-model)



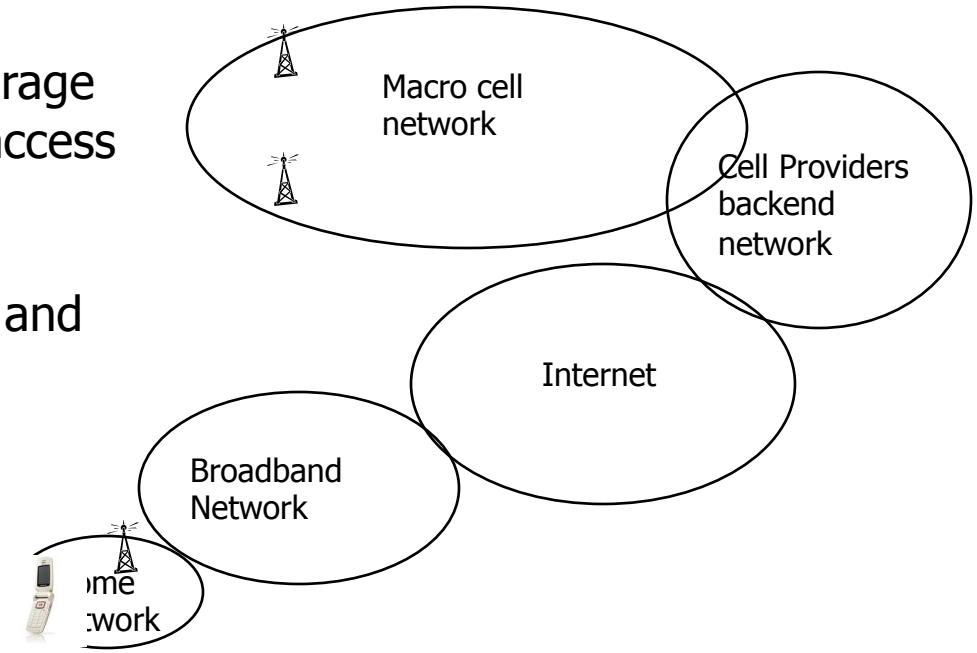
Related Work

- Femtocells:
- Dynamic spectrum management:
- Cognitive radio:
- Relay networks:
- Heterogeneous networks:
  - 3GPP
  - 802.21
  - European R&D
  - IEEE P9000.4

Related Work

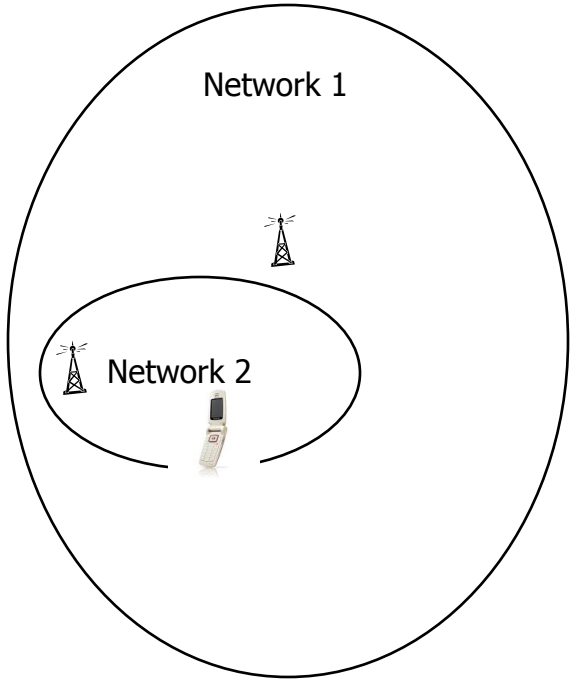
- Femtocells: small cellular base stations that augment the coverage and/or capacity of a macrocell network.

•Add technology to the network, keep device access unchanged
•Benefits end user by improving coverage
•Benefits cell provider by offloading access from macro cell network
•Problems:
  - •Interference between femtocell and macro/micro cells
  - •Does not take advantage of multimodal devices



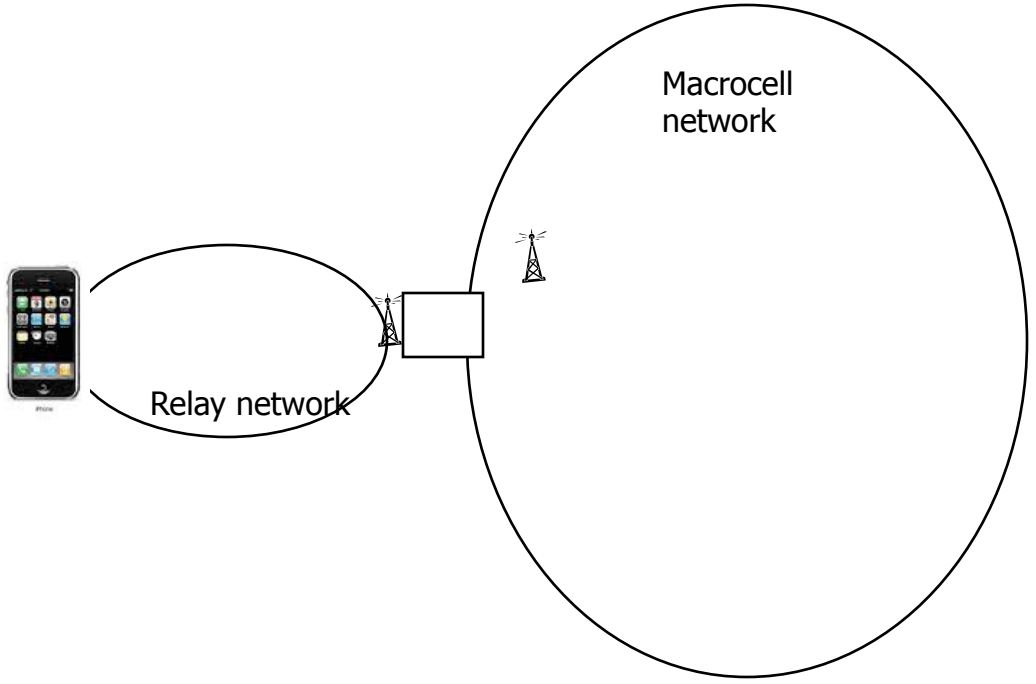
Related Work

- Dynamic Spectrum management/cognitive radio: Adapts the use of spectrum based on local information and policy.
- This addresses the issue of deciding when to do a *'reconfiguration handoff'*



Related Work

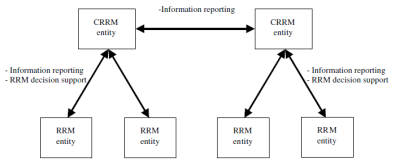
- Relay Networks – extend coverage or increase capacity.

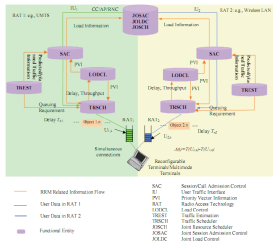


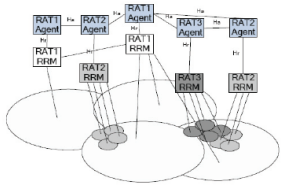
Radio Resource Management

Optimizing the overall usage of available radio resources

Radio Resource Management Frameworks provided by 3GPP and related European Projects

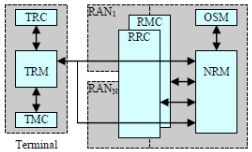




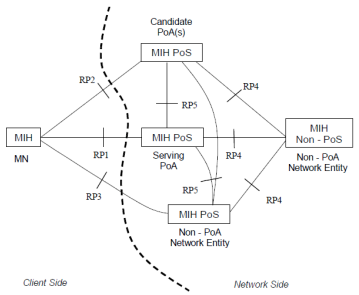


- CRRM, JRRM, MRRM
- Centralized vs. distributed architecture
- Coupling schemes driven by economic factors

Relevant standards introduced by IEEE

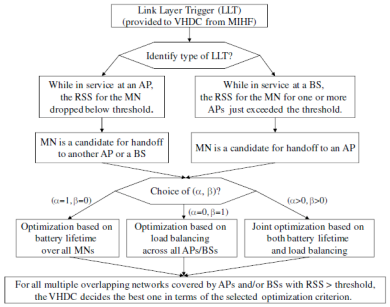


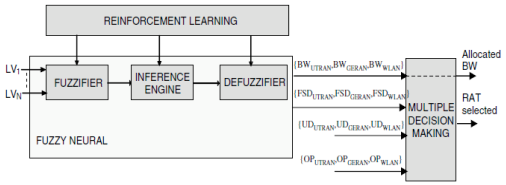
TRC – Terminal Reconfiguration Controller
TRM – Terminal Reconfiguration Manager
TMC – Terminal Measurement Collector
RMC – RAN Measurement Collector
RRC – RAN Reconfiguration Controller
OSM – Operator Spectrum Manager
NRM – Network Reconfiguration Manager
RAN – radio access network



- IEEE P1900.4, 802.21
- Building blocks for network-terminal distributed optimization
- Standard specific measurement parameters

Optimization algorithms





- Policy based algorithms
- Joint optimization using weighted-sum approach
- Fuzzy-Neural algorithms

Related Work: 802.21

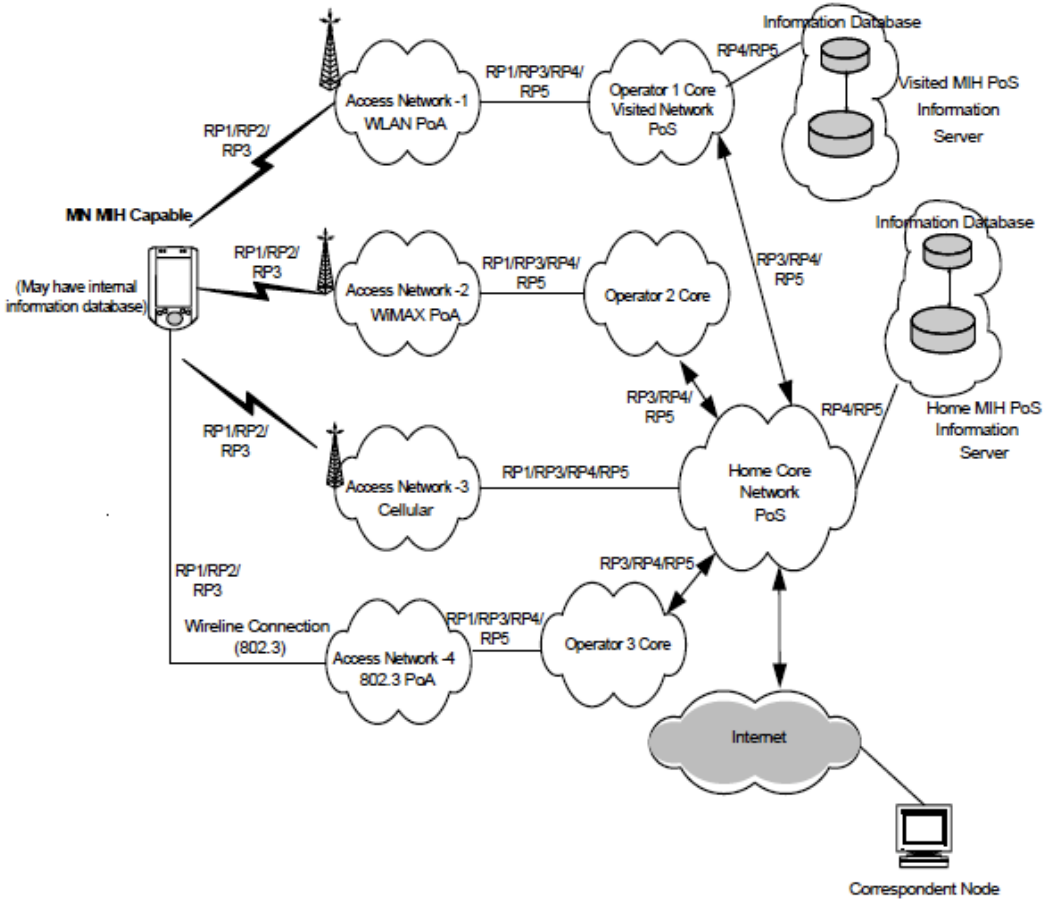
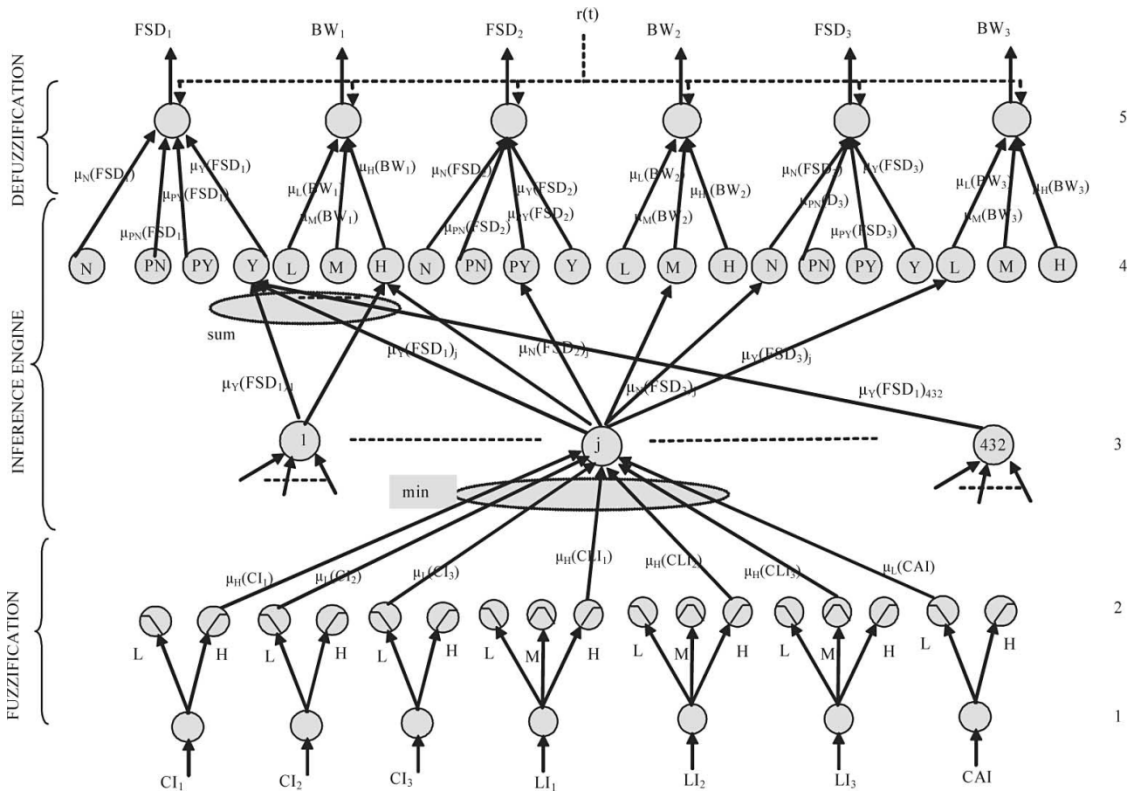


Figure 3—Example of network model with MIH services

Joint optimization using weighted-sum

- Optimization parameters: battery lifetime, network load
- Optimization equation: $G(\mathbf{X},\alpha,\beta)=\alpha\sum_{u_j\in U} lt_j(\mathbf{X})-\beta\sum_{1\le i\le N+M} w(i)\left(\frac{\rho_i+\gamma_i(\mathbf{X})}{z_i}\right)^2$
  - X: association matrix that maps each terminal j to one AP i
- Battery lifetime assumptions: $l_{ij}=\frac{p_j}{p_{ij}}$
  - lij: battery life of terminal j if connected to AP i
  - pj: available battery power for terminal j
  - pij: power consumption rate per unit time for terminal j when connected to AP i
- Network load assumptions:
  - zi: maximum bandwidth supported by AP i
  - ρi: current load at AP i
  - γi: requested data rate on AP i
- Relatively easy to measure network load statistics. Simplified assumptions made on battery lifetime statistics in this study. Battery lifetime depends on various dynamic factors such as: modulation and coding, traffic pattern (active/inactive time) etc.

Fuzzy-Neural Algorithm



- Three steps:
  - Fuzzification
  - Inference Engine
  - Defuzzification
- Fuzzification: Assigns unrelated inputs a degree of membership to a given fuzzy subset
- Inference Engine: For each combination of fuzzy subsets, makes use of some predefined rules to reach a fuzzy decision
- Defuzzification: Converts the outputs of inference engine into a number that represents final decision in terms of achieving some objective
- This 3-step process effectively does the job of normalizing and using parameters (from different technologies) that might be unrelated in a decision engine

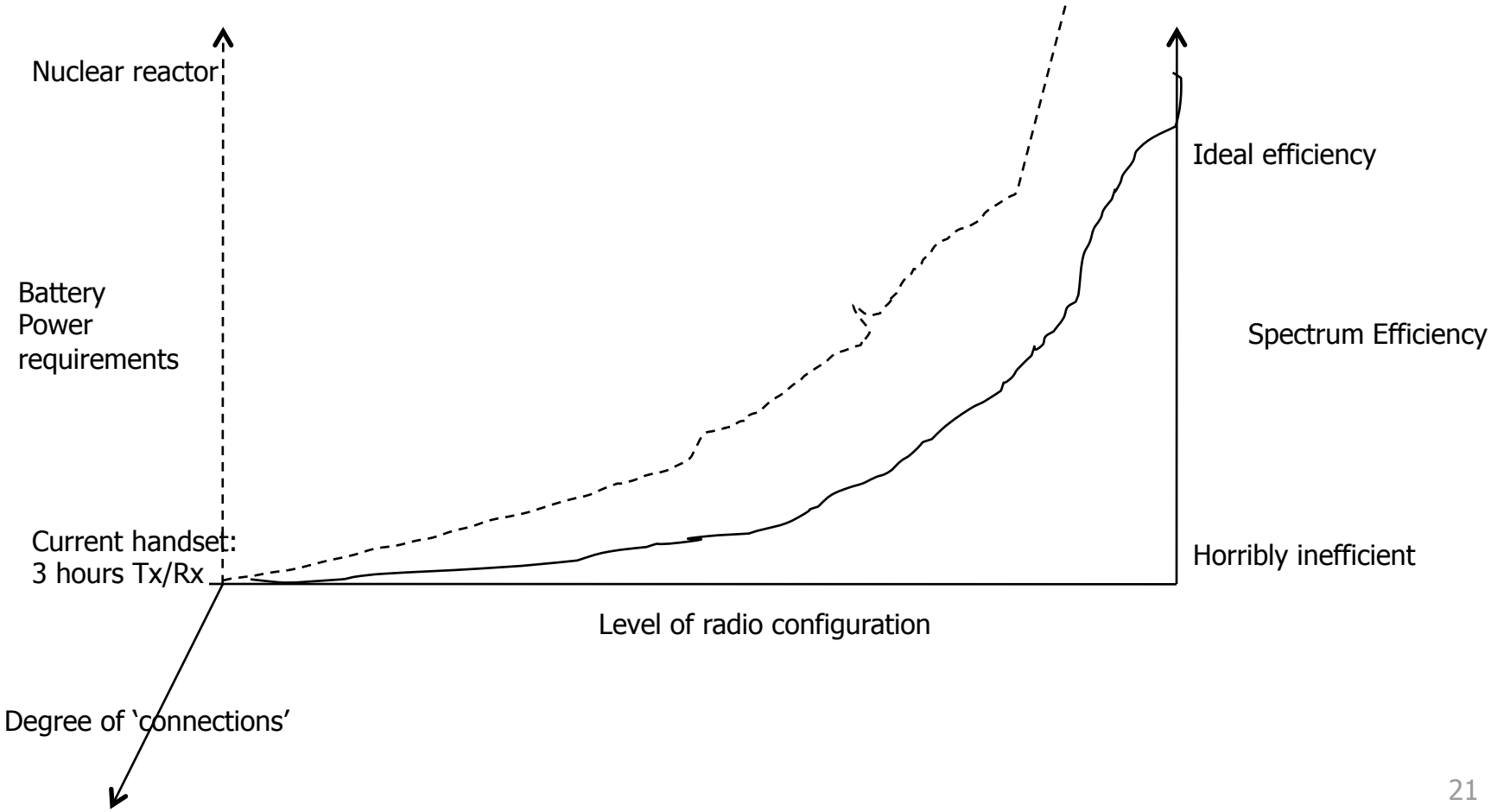
Positioning of our Work

- Our work is at the intersection of 4G cellular systems and IP-based heterogeneous systems. We differ in two assumptions:
  - We assume a wide range of wireless networks and infrastructure will exist and that the most flexible, unified system can only be derived when the devices are multimodal and highly reconfigurable.
  - We assume network-wide resource allocation is required. For simplicity, our initial path is to assume a single carrier model, however the ultimate vision is a wireless Internet model where devices at any given time might have many connectivity choices and a set of distributed services exist to allow the device to use the available resources in a manner that achieves some understood and agreed upon compromise between fairness and system resources.
- We would like to use the models/APIs/Frameworks being developed by IEEE.
- We are perhaps most interested in how others have gone from 4G requirements to mathematical models appropriate for optimization

Technical Challenges

1. Quantify/illustrate the tradeoffs between: power, degree of reconfigurability, channel depth, and spectrum efficiency
2. When many connectivity options are possible to users and service flows, how should resources be allocated?
    1. Is there an acceptable compromise between fairness and system efficiency?
3. Can a combination of an FPGA-like fabric with a RISC processor in an MPSoC framework be considered as an ideal SDR platform in terms of power consumption, programming model and scalability?
    1. Can partial reconfiguration lead to a minimization of the active parts on the MPSoC?
    2. Can partial reconfiguration minimize the impact to applications caused by the reconfiguration handoff?
4. What is the best approach for cross layer optimization that adapts the behavior of ARQ and coding (that operates over the wireless overlay) with research allocation and in particular with the reconfiguration decisions.
5. Ubiquitous Location service that works in a heterogeneous network (can assume gps outdoors, but indoors will need 802.11 location ? How to normalize the results?)
6. Is there a system architecture that is flexible enough to support a carrier model and also an Internet model?

Technical Challenge 1



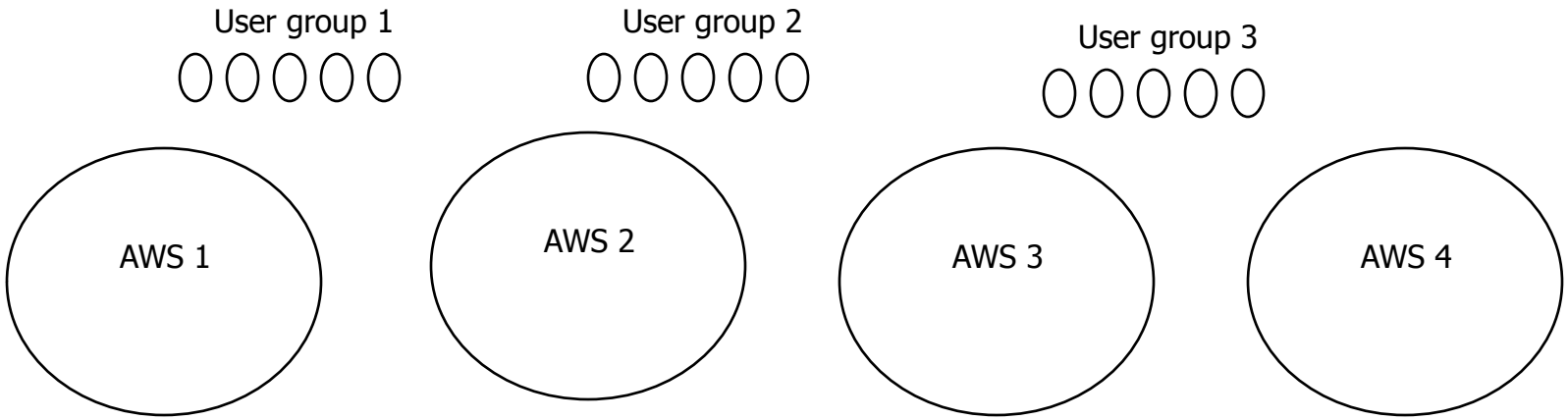
Technical Challenge 1: Parameter space

- Battery power requirements: Nodes have a simple battery power model: The battery holds so much power. Each radio consumes power in unique ways with each Tx/Rx related operation. Some sleep-mode behavior is assumed.
- Level of radio configuration: A node has one or more radios, each with a configuration capacity.
  - The minimum level is a radio that is dedicated to a single block of spectrum.
  - The next level is a radio that can adapt to different channels within the block.
  - Higher levels allow a radio to be moved to any block of spectrum

Technical Challenge 1: Parameter space

- Spectrum efficiency: A given node will have its radios assigned to a channel and configured in a particular way (e.g., a particular technology and possible waveform). A normalized throughput for all nodes can be computed at any given time in units of b/s/hz. This is then normalized by ideal capacity given by Shannon's theorem.
- Degree of 'connections': The number of possible wireless networks that are available to a node at any given location. In effect, it is a spectrum map.

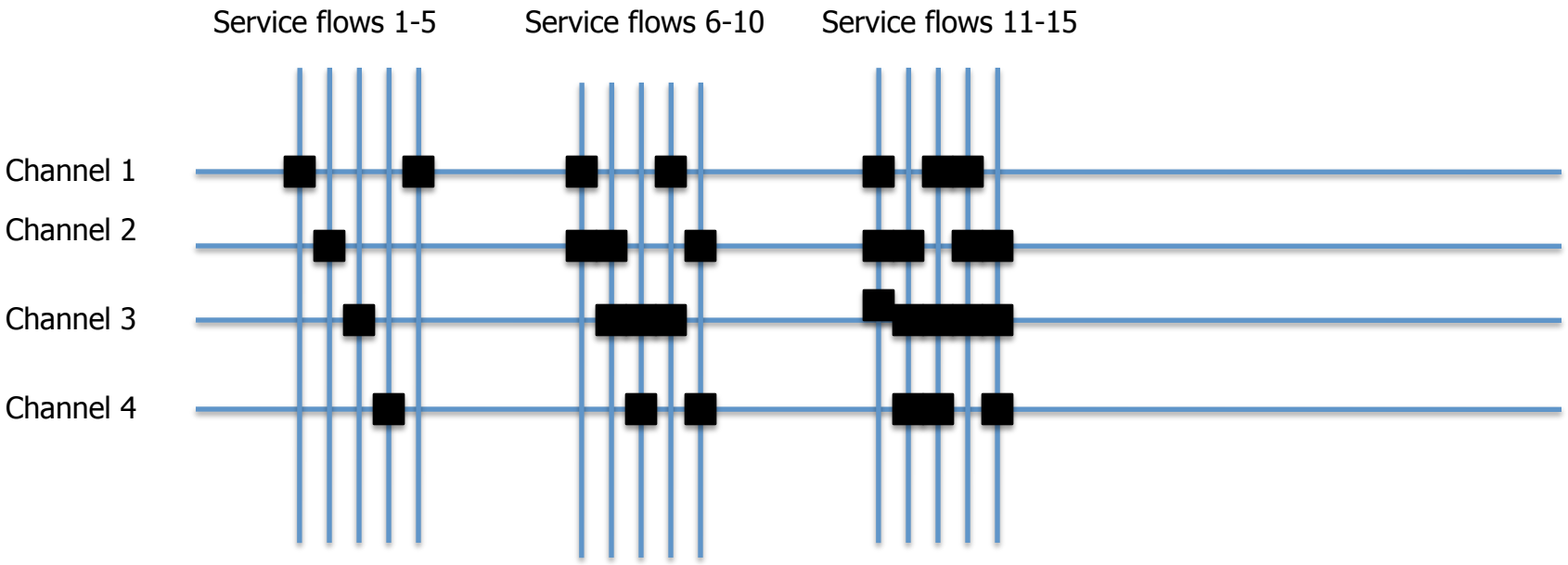
Technical Challenge 2



- Three sets of users : group 1 has 1 radio, group 2 has 2 radios, group 3 have 3 radios
- Users are stationary
- All users are in coverage area of any AWS

Technical Challenge 2

- Model each user as a ‘service flow’ parameterized by a desired sending rate
- Model an AWS as a channel that can be shared by all nodes with a radio tuned to the channel



Technical Challenge 2:

- Represent as a graph, assume all service flows have a known, constant sending rate, apply standard allocation algorithm based on maximal flow, max/min fair
- [Jaffe] extends fairness to include different users operating over different links. A given allocation is fair if:
  - Each user's throughput is at least as large as all other users sharing the same bottleneck link, and
  - The only factor preventing a user from obtaining a higher throughput is the bottleneck link
- The essence of max-min:
  - 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, etc.