Wireless Networking Systems Research

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Outline

- Themes and problems
- Research issues
- Impact of innovations in wireless networking

Recent Wireless Themes

End-user interest in mobile access to information

Recognition that spectrum is woefully under-utilized

Requirements of national defense and homeland security

Proposals to dramatically re-architect the modes & mechanisms for using radio frequencies

Applications

Policy

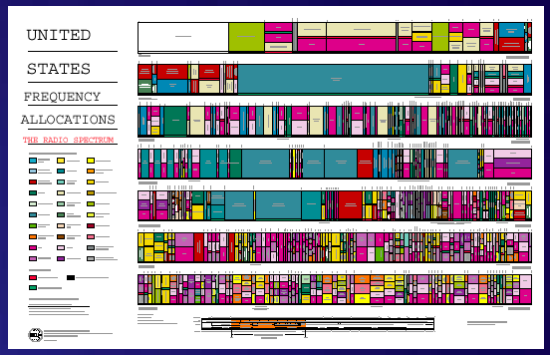
Opportunity - Wireless Networks That Exploit Flexibility

Advances in radio system engineering – flexible radios are just becoming available

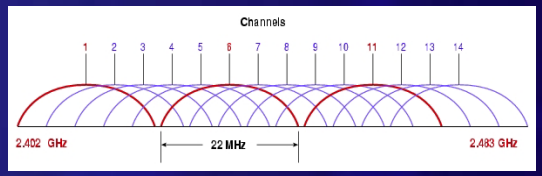
Technology

State of Wireless Networking

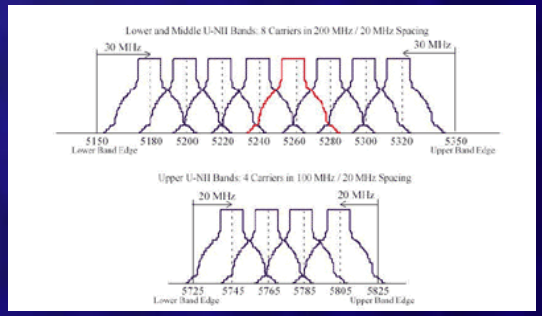
- Wireless systems today
  - Inflexible, wasteful static spectrum allocations
  - Fixed radio functions
  - Limited network and systems coordination
- Implications
  - Proliferation of standards, such as Wi-Fi/802.11, Bluetooth, 3G, 4G, CDMA, GSM
  - Encourages stovepipe architectures and services
  - Discourages innovation and growth



Source: FCC



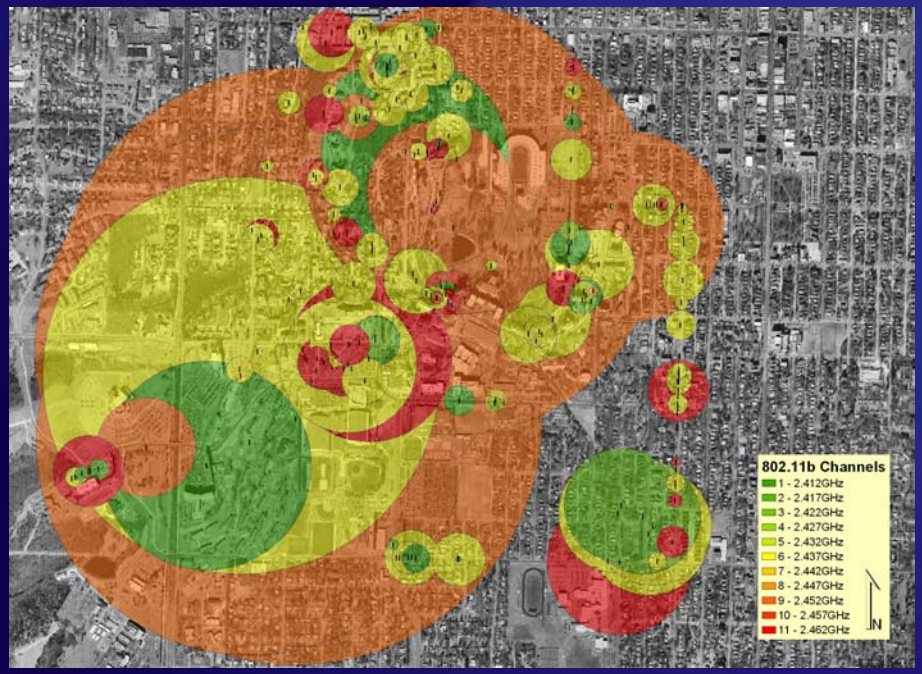
Source: Cisco



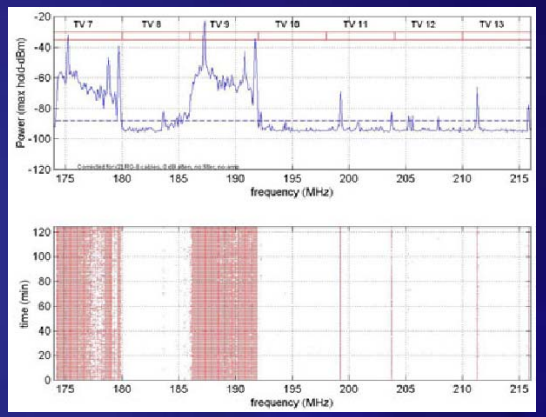
Source: Linksys

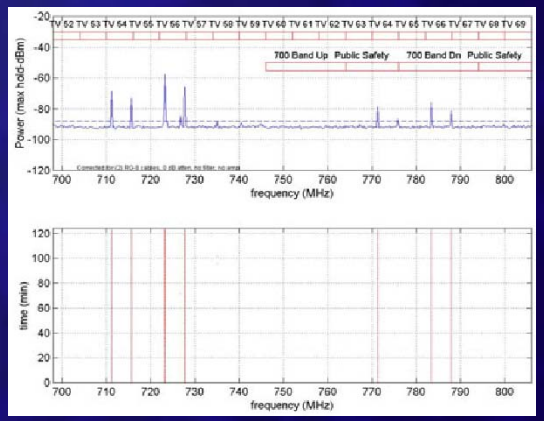
Critical Problems

- Interference in unlicensed bands
- Underutilization in many other bands



Source: B. Becker



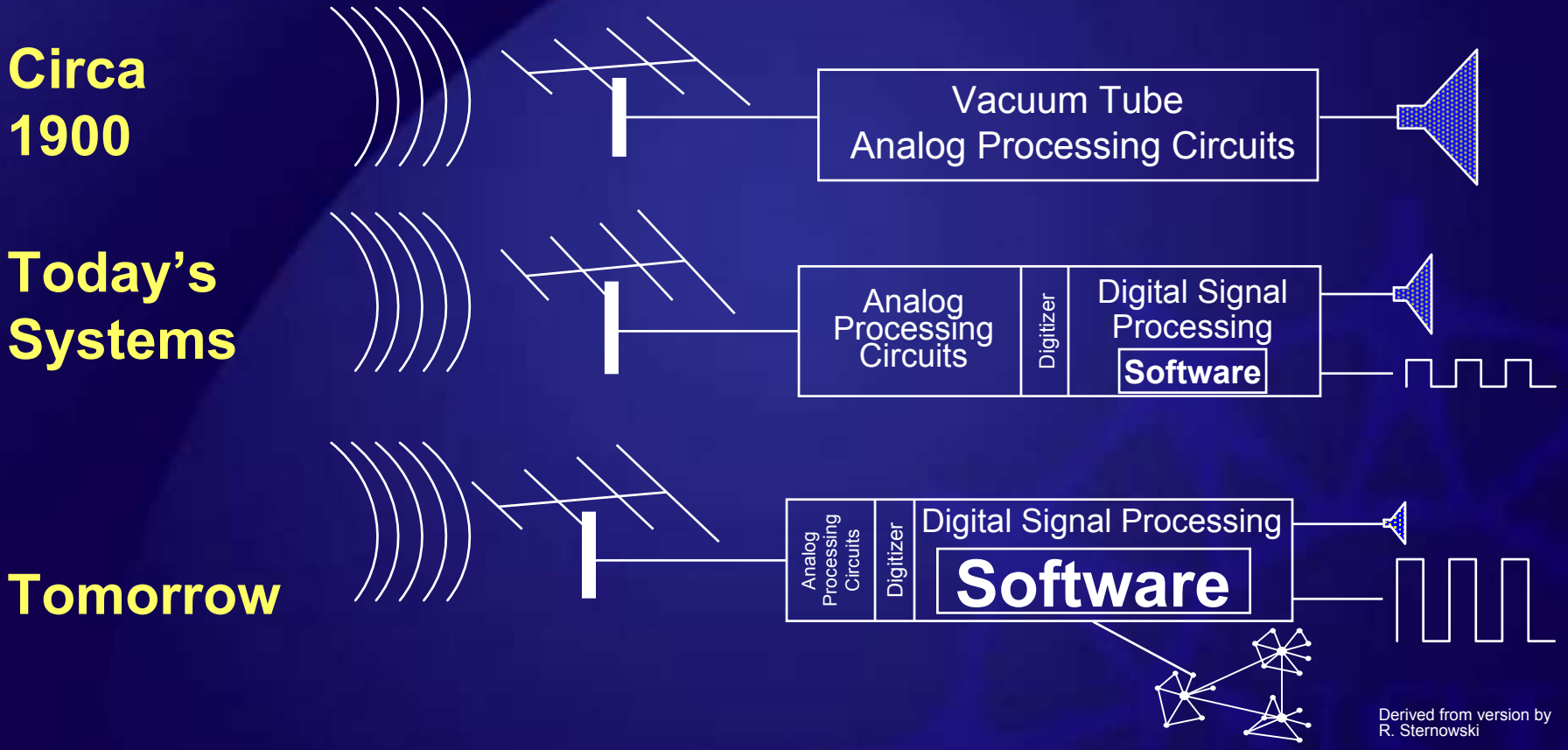


Source: M. McHenry

Evolution of Wireless Systems

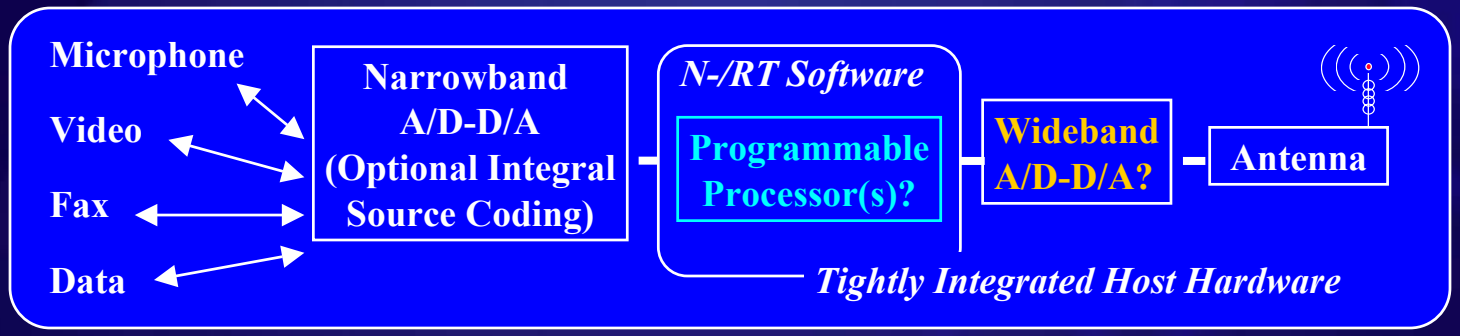
Receive → *Capture radio waves* → *Extract information from radio waves* → *Present information to user*

Transmit ← *Generate radio waves* ← *Implant information into radio waves* ← *Accept information from user*



Advances in Radios

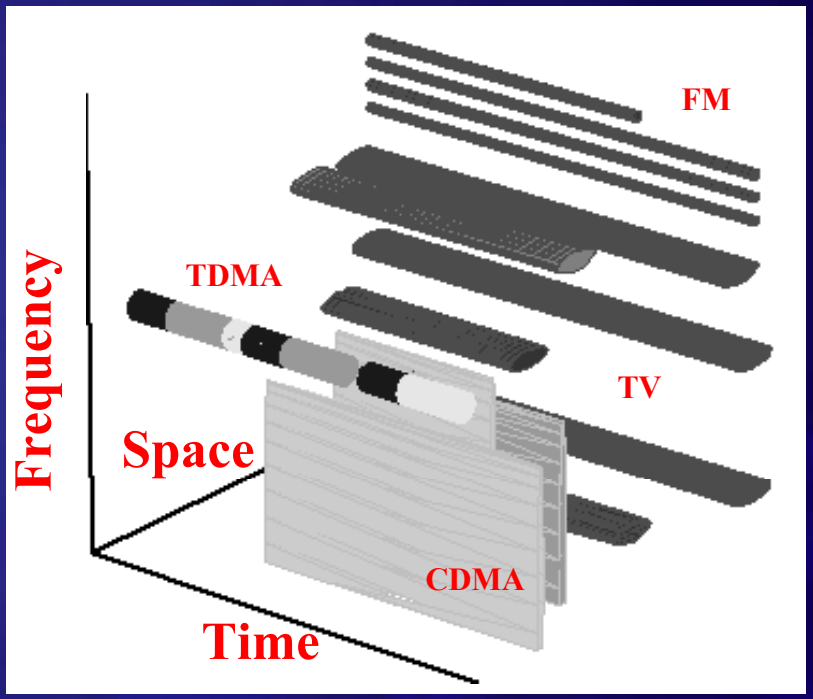
- Software Radio
  - Wide operational frequency supports use of multiple bands
  - Multiple waveforms in a single hardware unit provides interoperability
- Impact
  - Dynamic spectrum management helps prevent interference
  - Adaptable to local & current situation; flexible frequency use provides opportunities for quality of service
  - Rapid deployment and service creation
  - Enables new network architectures through flexible & dynamic connectivity



- Systems and networking issues remain unexplored and unexploited!

Spectrum Resources

- The spectrum resource space consists of
  - Frequency – the radio frequencies used to carry a signal
  - Time – the time duration a signal is transmitted
  - Space – the volume over which the signal transmission is effectively communicated or causes interference
  - Signal format – the manner in which information is encoded on the radio frequency signal

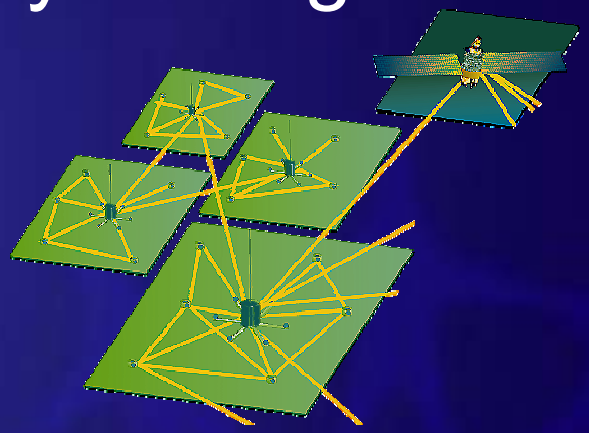


Source: G. Minden

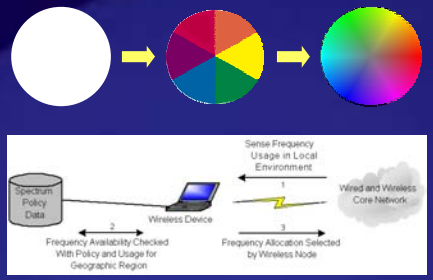
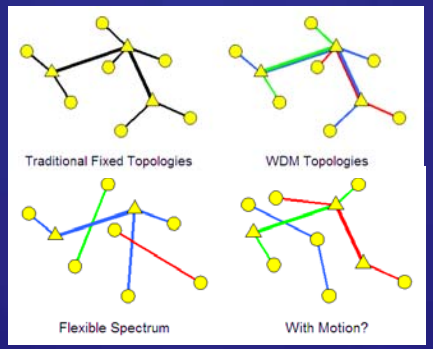
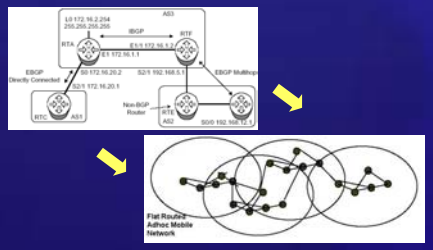
RF resources illustrating a few signals in time, frequency, and space

Programmable Wireless Networks

- Route messages through network and interoperate with larger Internet
- Dynamically and cooperatively manage spectrum resources
- Self-organize with rapid initial configuration
- Provide for mobility
- Support variety of network services
- Use adaptation to assure quality of service
- Support multiple users & domains



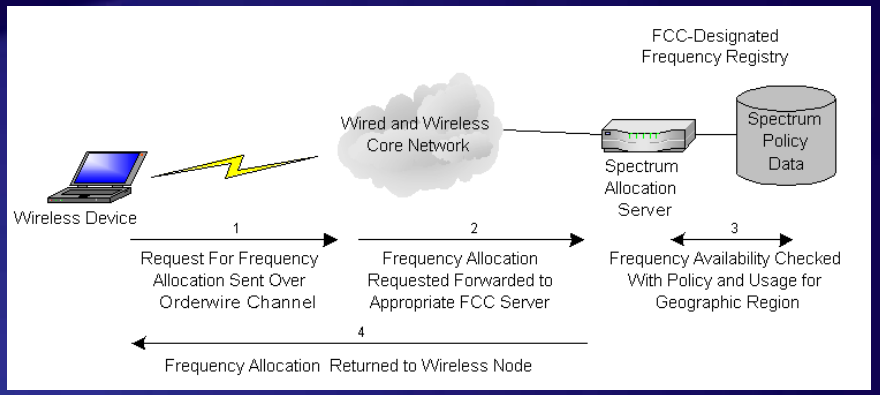
Programmable Wireless Focus

Research Area	Changes	Needs
Dynamic spectrum management architectures and techniques		Architectures that are secure & robust, with quality of service and policy enforcement
Topology discovery, optimization and network self-configuration		How to choose among possible topologies, and evaluate novel network architectures
Interaction between routing & topology optimization		Which approaches for diverse applications, communication modes, security & policy domains

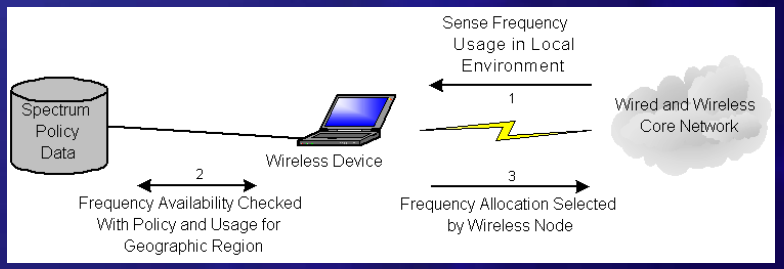
Source: H. Rajan

Dynamic Spectrum Management

- Architectures
  - Broker-based and/or sensing-based
- Issues
  - Secure and robust
  - Quality of service
  - "Contract" enforcement
- Evaluation and innovation needed



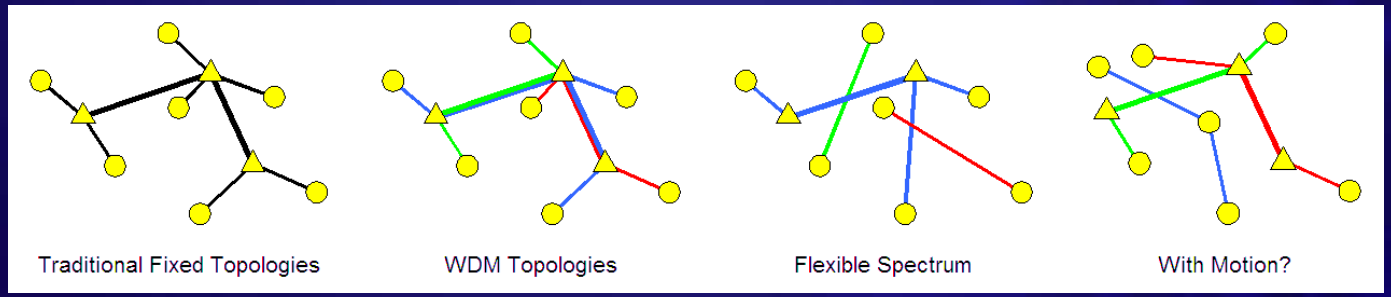
Obtaining Frequencies for Programmable Wireless via Broker



Obtaining Frequencies for Programmable Radio via Sensing

Towards Flexible Topologies

- Flexible topologies enabled by multiple simultaneous frequencies to multiple adjacent nodes
  - Novel network architectures possible
  - Significant service and performance improvements possible, including enhanced reliability and immunity
  - Need to determine how to choose among possible topologies, and evaluate network architectures
- Creates substantial security challenges
  - Already have very hard problems to solve, and flexibility makes these worse
  - Which associations are appropriate and trusted?

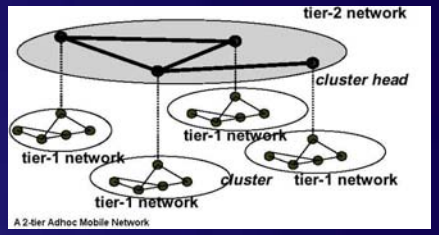


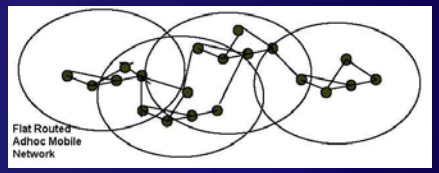
Topology & Interlayer Awareness

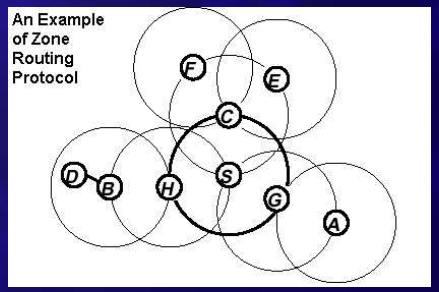
- Flexible topology requires inter-layer and inter-plane awareness
- Dials to observe
  - Traffic characteristics measured at network layer
  - Error rate & characteristics (BER and distribution)
    - MAC layer per packet error information
    - Network and transport layer per flow correlations
  - Receive characteristics
    - Physical layer – signal strength, interfering signals, background noise
    - MAC layer – transmit power, antenna in use
- Knobs to influence
  - Physical layer
    - Frequency & bandwidth
    - Transmit power
    - Beam width & direction
    - Data rate, code, & chipping rate
  - MAC protocol
    - FEC strength
    - Retransmit scheme
    - MTU size
    - Encryption & parameters
  - Network layer
    - Routing protocol
    - Addressing plan(s)
    - ACLs
- Interface framework needed to allow interoperation, with a flexible, usable set of scalable parameters

Programmable Wireless Routing

- Interaction between routing and flexible topology provides additional opportunities
- Different routing protocols have different models and assumptions, as well as strengths and weaknesses
  - On-demand (local distributed) vs. proactive; also hybrid
  - Distance vector (simple) vs. link state (QoS)
  - Flat (simple) vs. hierarchical (scalable)
  - Table driven vs. source route
  - Eventual stability (convergence) vs. eventual connectivity
  - Specialized protocols and algorithms, e.g., trajectory, spray, magnetic routing
- Need to understand which approaches are appropriate for diverse applications with different needs and communication modes



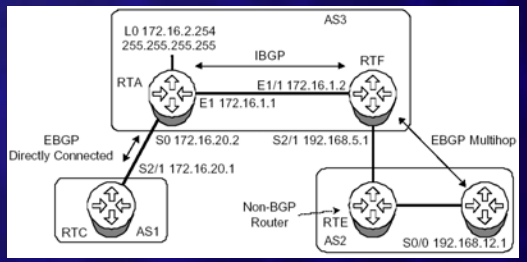




Source: H. Rajan

Programmable Wireless Routing

- Flexible wireless topologies implies more opportunity for connectivity with a larger set of other nodes from different administrative domains
- Policy & its implementation will be critical
  - BGP currently the only multi-domain option, with static policies tuned to particular peerings
  - Needs to be more automatic
  - Policy and security framework needs to be integrated



BGP Routing Complexities

Some Desirable Radio Attributes

- Flexible in RF carrier frequency (~0 - 6 GHz)
- Flexible in bandwidth (several 10's MHz)
- Flexible in waveform
  - Generally A/D and D/A driven
  - Generated/processed by programmable DSP and/or FPGAs
- DoD's Joint Tactical Radio System (JTRS) is an example
  - Waveforms and network control all in software
  - Significant general and signal processing
  - Possibly available for experimentation by community

Federal Research & Development

- Recent NSF efforts
  - Measurements of spectrum for scientific basis
  - Testbeds, preliminary flexible radio, workshops
- Ongoing DoD wireless efforts
  - DARPA
    - Mobile Network MIMO (MNM)
    - Connectionless Networks (CN) – cross-layer protocols for power conservation
    - Future Combat Systems - Comms (FCS-C) – beamforming and ad hoc routing
    - XG – spectrum management, with a data link layer focus
  - Joint Tactical Radio System (JTRS)
    - Focus on legacy systems – waveforms and lower-layer protocols
- NASA
  - Investigating software defined radio for space applications including inter-satellite links; research prototypes include ITT Low Power Transceiver (LPT) and SSP SDR-3000

DARPA GloMo Transceiver
- 20-2500 MHz
- Up to 10 MHz BW
- 1 Hz tune step
- 100 µs tune time
- 1 watt output
- Software radio
- 20 cubic inches

Source: R. Sternowski

Source: J. Freebersyer

Source: P. Marshall

Source: DoD

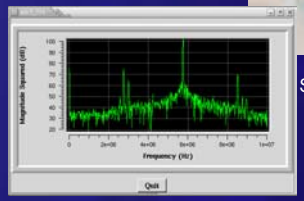
ITT Low Power Transceiver

Industry and Community R & D

- Vanu, Inc. software radio systems
  - Focus on integrating legacy systems
  - Currently low bandwidth services
  - Partially supported by NSF SBIR

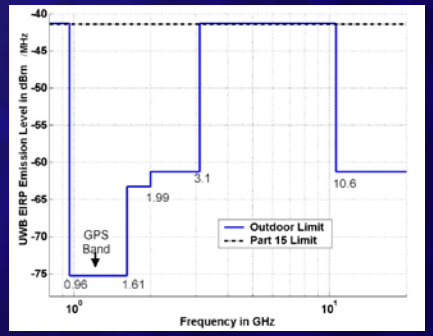
Source: Vanu, Inc.

- GNU Radio
  - Similar to Vanu efforts in technical concept and capabilities
  - Provide publicly-available platforms for development and fielding of more flexible radios



Source: GNU Radio

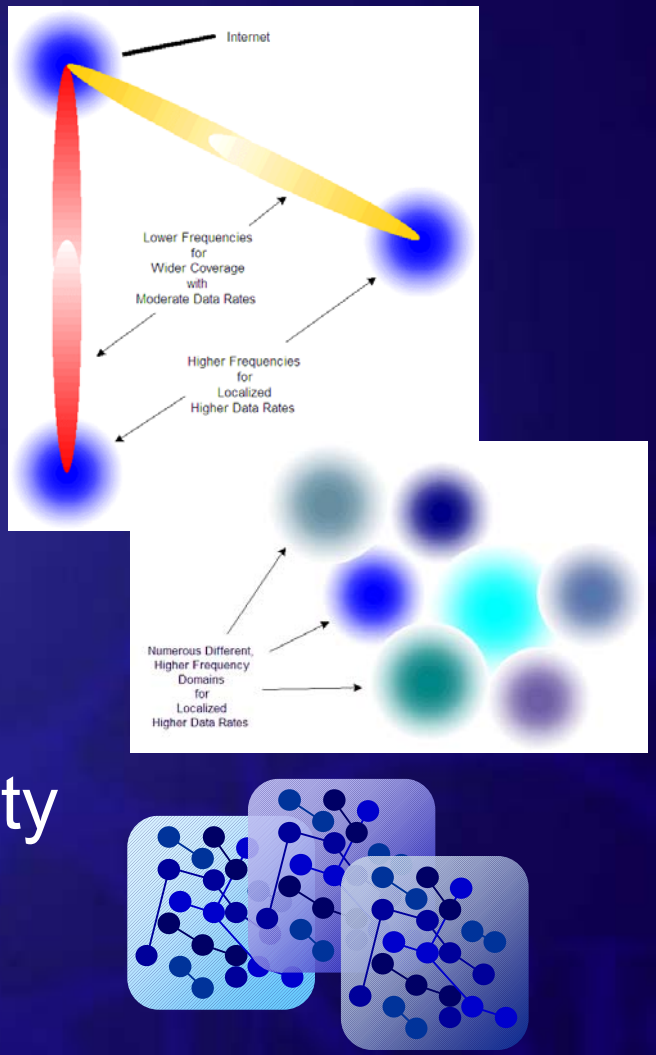
- Various UWB efforts focusing on physical layer under FCC constraints



Source: FCC

Impact of Programmable Wireless Networks

- Vastly improved connectivity
  - Remote areas → use more power and better frequencies where utilization relatively low
  - Urban areas → provide more capacity where utilization is relatively high
- More opportunities for networking devices such as sensors and controllers by providing capacity & adaptability
- More efficient use of a shared national resource



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