Agile Radio Systems and A National Radio Networking Research Testbed

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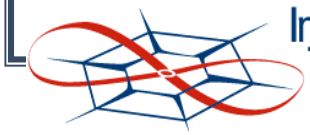


Mobile Networking Research

- **Agile Radios**
- **Flexible Wireless Systems for Rapid Network Evolution**
- **A National Radio Networking Research Testbed**

Agile Radios

- Flexible in RF carrier frequency (~0 - 3 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
- Joint Tactical Radio System (JTRS) and 3G cellular phones are prime examples

Agile Radios Enable

- **Dynamic service access**
  - **WiFi, AMPS, CDMA, GSM, FM radio, TV, land-mobile, …**
- **Dynamic spectrum access**
  - **Sense use of the spectrum, use if unused**
  - **Spectrum markets**
- **Innovative Radio System architectures**
  - **Current: Broadcast, point-to-point, cellular**
  - **Future: Mesh relays…**
- **Rapid service creation**

Agile Radio Challenges

- U.S. Government policy
  - FCC, NTIA, State, and international forums
  - National defense and national economic needs
- Brokering protocols
  - Secured and robust
  - 'Contract' enforcement
- Community rules
  - Challenged by UWB, DSS, FH
  - Various levels of interference impact
    - RF level, combinations, and throughput
- Robust communications
  - Urban environments, coordination, covert, anti-jam
  - Traditional defense requirements
- Exploitation of signal processing power
  - BLAST, STEP, STORM, …
  - Push toward Shannon limit

Agile Radio Investment Direction

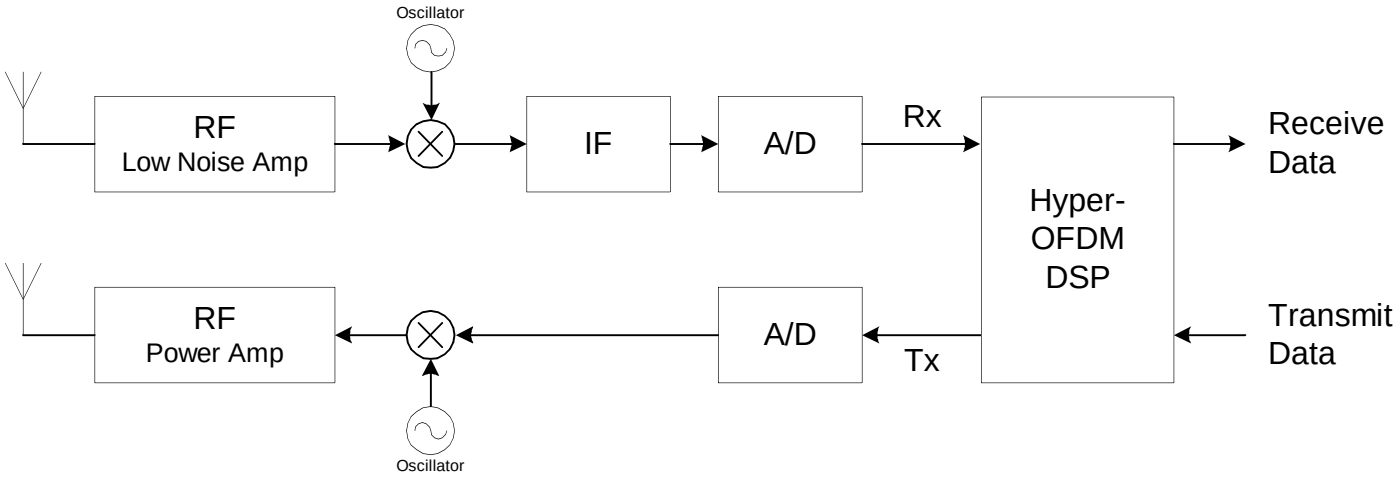
- **Radio technology, signal processing, protocols, mesh networks, self-organization, adaptability, disconnected operation, management structures, enforcement…**
- **New policies to allow agile radio deployment**
- **Development, experimental, and evaluation testbed**

Flexible Wireless Systems for Rapid Network Evolution

Flexible Wireless Objectives

- Develop and demonstrate high-performance digital signal processing (DSP) algorithms and components to generate and detect H-OFDM signals
- Develop and demonstrate ultra-wideband radio frequency transmitters and receivers
- Develop and demonstrate ultra-wideband antennas, power amplifiers, and low-noise receivers to support the H-OFDM system
- Analyze, implement, and evaluate H-OFDM for communication systems
- Determine how to recognize and organize H-OFDM systems into communications networks

Typical Agile Radio



Illustrates digitally controlled agile radio

Technical Approach

- Analyze Hyper-Orthogonal Frequency Division Multiplexing
- Adapt existing transmitter and receiver designs to wideband operation
- Implement high performance A/D and D/A converters
- Interface RF/digital sections to FPGAs and general purpose computers
- Implement protocols for resource allocation and coordination

National Radio Networking Research Testbed

A National Radio Networking Research Testbed (NRNRT)

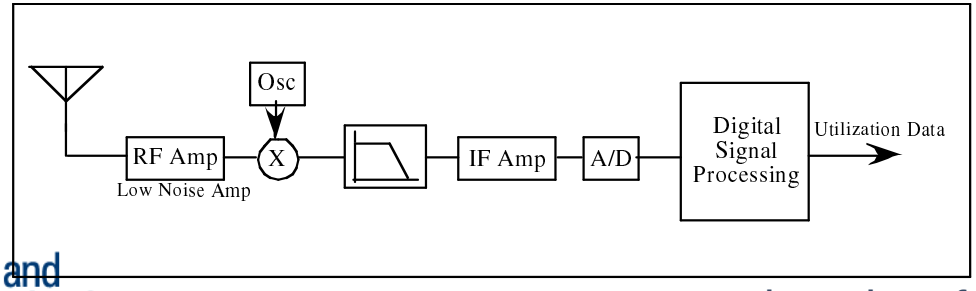
- A field deployed measurement and evaluation system
  - Long term radio frequency data collection
  - Facility for testing and evaluating new radios,
- An accurate emulation/simulation system
  - Incorporate long-term field measurements for evaluating new wireless network architectures, policies, and network protocols, and
- Experiments
  - Innovative wireless networks
  - Integrated analysis, emulation/simulation, and field measurements.

NRNRT Research Questions

- What are the characteristics of the wireless environment over a long time period and broad range of frequencies?
- How should sensor networks be built and deployed to best measure the wireless environment?
- How can the RF environment be sounded over a wide range of frequencies without interference and remaining within the constraints of government regulations?
- How can the wireless measurements be mapped to accurate network-level simulation models?
- How can the characterized RF environment be used for testing and evaluation of novel wireless systems?

NRNRT RF Data Collection

- **Long-term measurement of RF utilization**
  - **Noise floor levels ('Interference Temperature')**
  - **~2 MHz - 6 GHz**
- **Channel Sounding**
  - **Develop 'quiet sounding' using long, low-power density signals and signal processing techniques**
- **Test and evaluation range**
  - **Measure behavior of actual prototype radios**



NRNRT Accurate Analysis

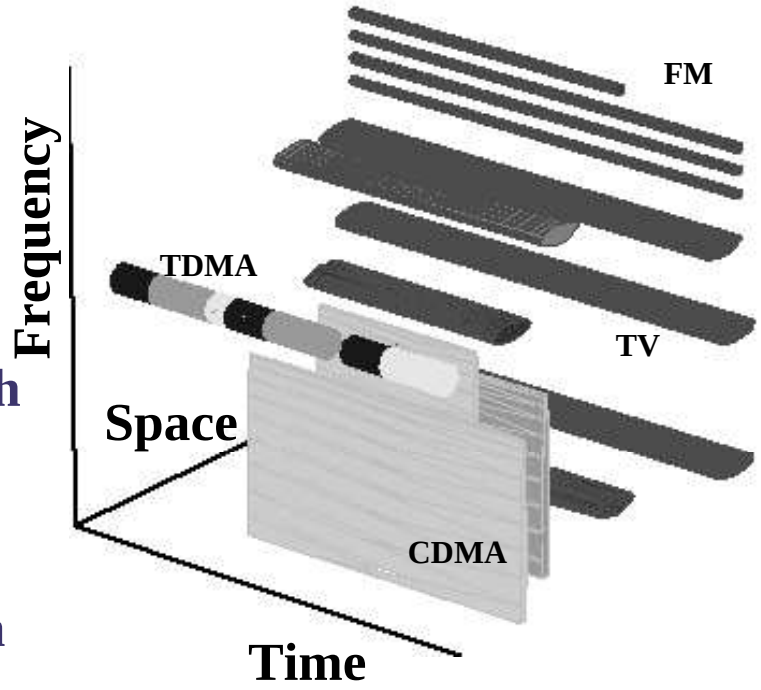
- **Integrate RF measurements into emulation/simulation systems**
  - **Better then simple power levels and BER**
  - **Simpler than detailed propagation effects**
- **Build on RDRN and SBI emulation systems**

NRNRT Experiments

- **Spectrum brokering radio network**
- **Mesh Multi-Relay**
- **Innovative services**
  - **Today: Broadcast, point-to-point, cellular**
  - **Future: Integrated Wired/Radio services, e.g. Wireless to access point, wired long-haul, re-transmit at remote access point**

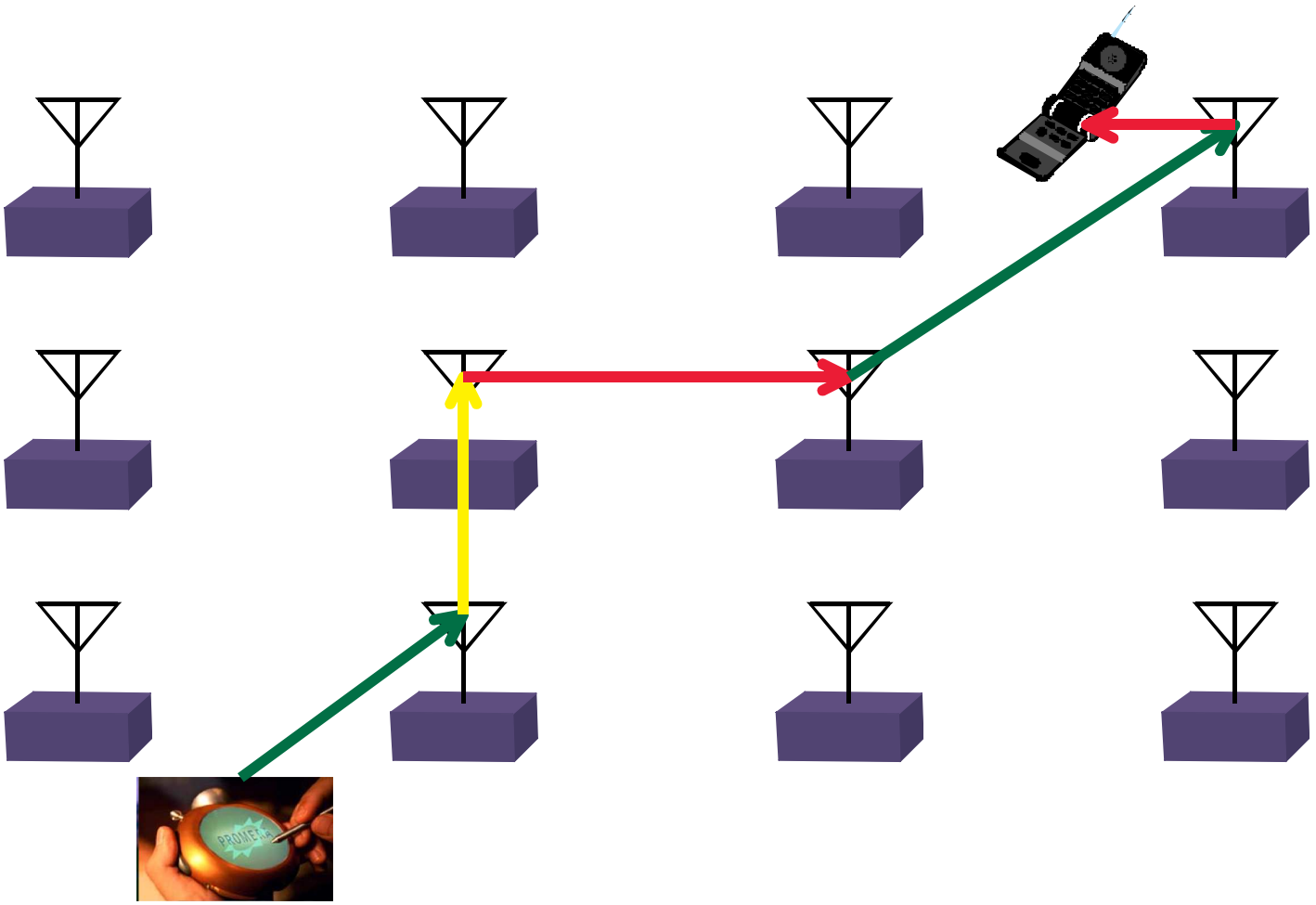
The ElectroSpace

- ElectroSpace 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

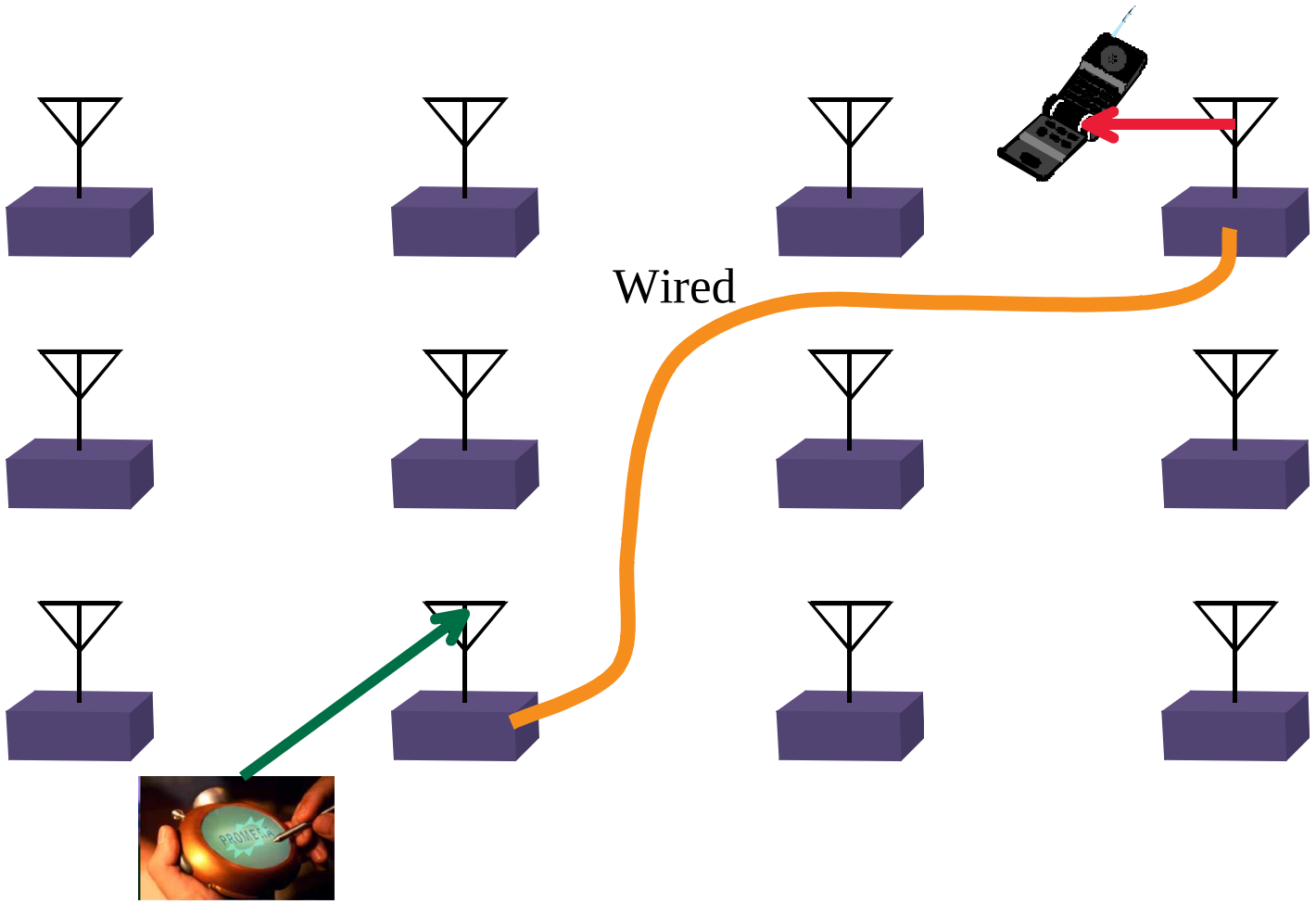


ElectroSpace illustrating a few signals in time, frequency, and space.

RF Mesh Networks



Integrated Wired/Radio services



Agile Radio Systems

- **Exciting confluence of technology, policy, economics, and management organization…**
- **Significant opportunity to influence future radio systems at the national level…**
- **Lead to innovative wireless services.**

Agile Wireless Systems

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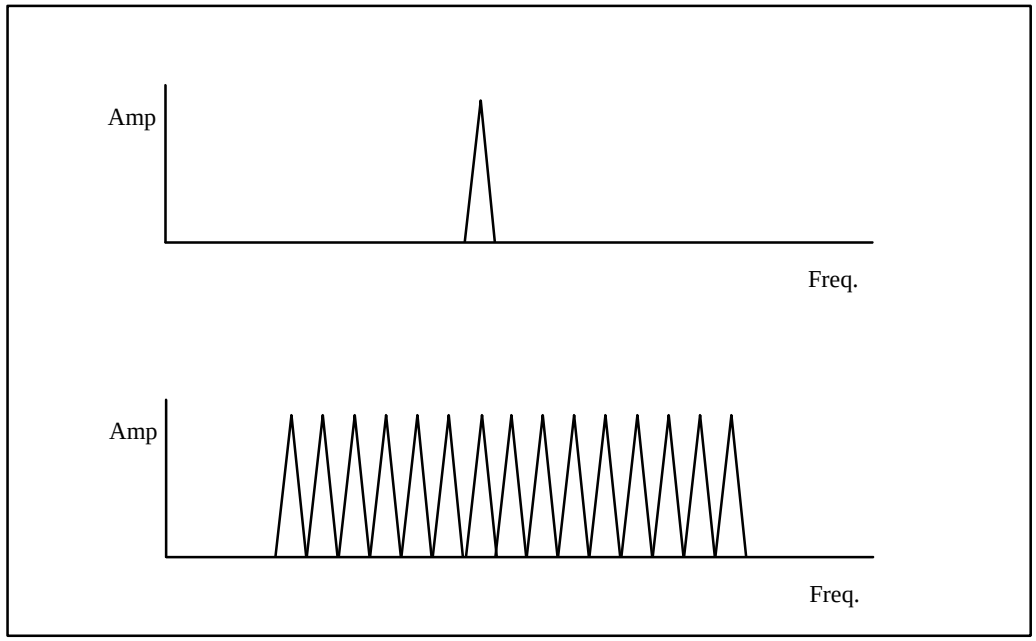
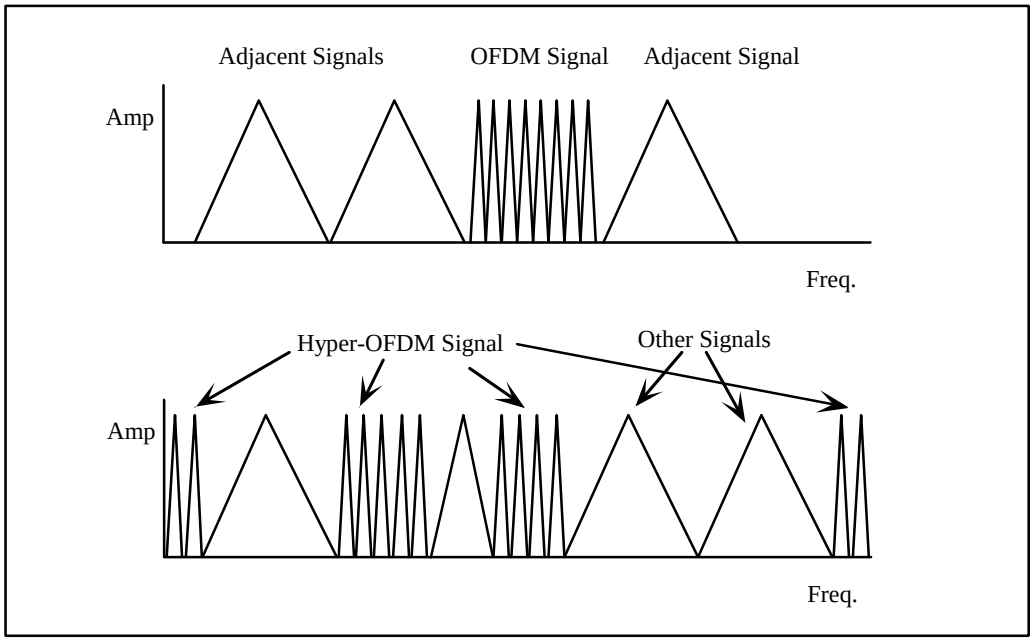
Backup Slides

Typical Narrowband/OFDM



Illustrates typical narrow-band signal and ‘compacted’ OFDM signal

Proposed Hyper-OFDM



Illustrates typical OFDM carrier placement and our proposed Hyper-OFDM carrier placement

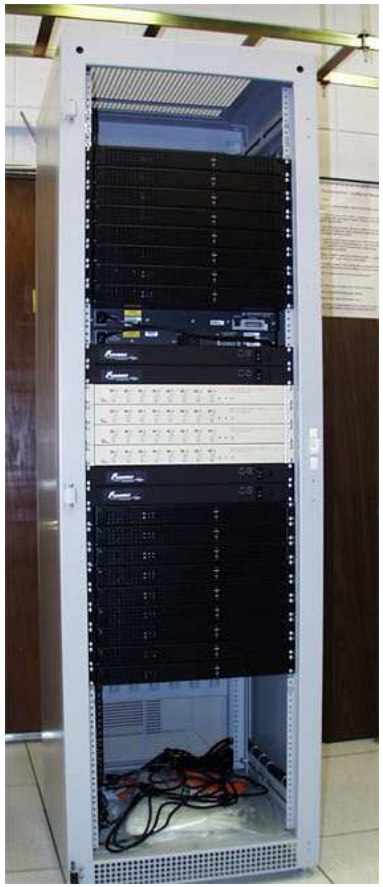
Why Hyper-OFDM

- OFDM offers rapid equalization of RF channel
- OFDM allows approaching band limits and utilization of narrow available spectrum
- Signals are easy to generate (a sine-wave generator), combine, and detect
- OFDM enables flexible frequency selection and utilization

Emulation/Simulation Tradeoffs

	Mathematical Analysis	Simulation	Emulation	Field Trials
Match to physical system	Weak	Weak	Very Good	The real McCoy
Scalability	Difficult	Very good	Good with reasonable cost	Good with high cost
Repeatability	Excellent	Very good	Very good	Poor
System time to real time	Much slower than real time	Better than real time to much poorer than real time	Real time	Real time
Support for actual applications	Poor	Poor	Very good	Very good
Cost	Relatively Low	Relatively Low	Relatively Low	Expensive
Time to implement	Medium	Relatively short	Relatively short	Long
Insight	High	Low	Low	Medium

Emulation System



- **Module contains**
  - **16 SBI nodes (Max 28) and one Emulation Manager processor**
  - **Linux OS on all nodes**
  - **Two Ethernet switched networks (management and data)**
  - **Two external 1 Gbps Ethernet ports**
  - **KVM switch**
  - **Portable Emulation System**
- **Features**
  - **Spatial models (terrain, space)**
  - **Communications models (CBR, delay, BER)**
  - **Emulation management**

Wireless Research Institute Idea

- **Intersection of communities**
  - **Federal, Commercial, Services, Academic**
- **Intersection of technologies**
  - **RF, DSP, Networks, Security, Protocols…**
- **Experiments and Instrumentation**
- **Policy Forum**
  - **Organization: FCC, NTIA, State**
  - **Policy: National defense, Law enforcement, Federal operations, Commercial/Economic innovation and development**
  - **Management: Organizing allocations, allowing innovation, …**

Implementing Flexible Radios

- **Adapt DARPA sponsored RDRN-II Tx/Rx modules to wideband use**
- **Adapt DARPA sponsored Adaptive Computational Systems results to OFDM**
- **Build and test**

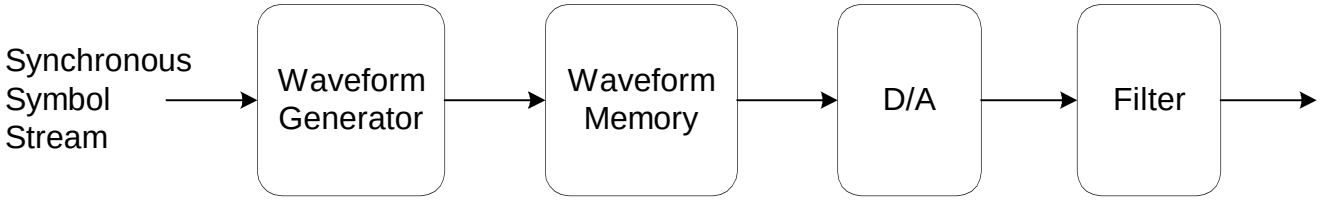
RDRN II 5.3 GHz Tx/Rx Radio

Illustrates RDRN-II Tx/Rx Module

Example Tx/Rx Antenna Patch

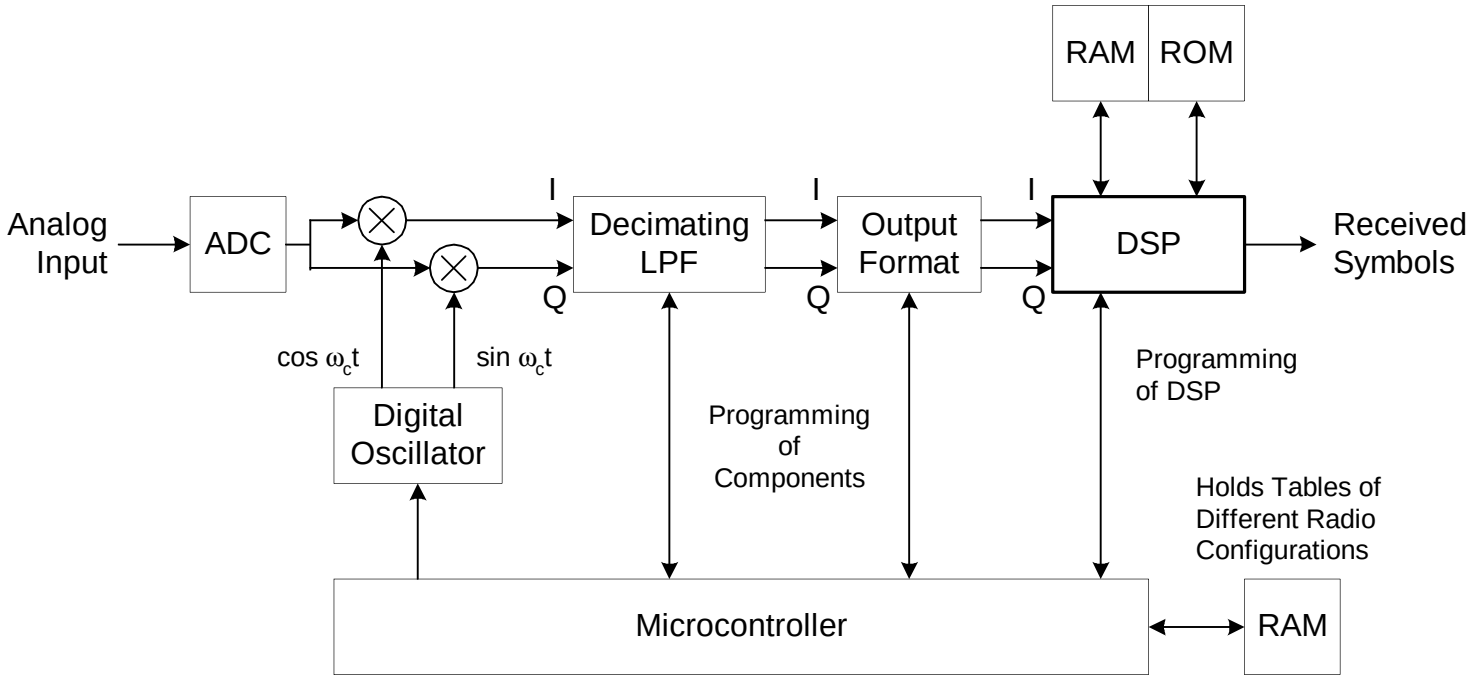
RDRN Receiver Patch is an integrated antenna with a low noise amplifier - the patch provides a 6 dBi gain and the LNA provides 18 dB gain

Proposed OFDM Modulator



Block diagram for the proposed Hyper-OFDM waveform modulator

Proposed OFDM Receiver



Block diagram for the proposed Hyper-OFDM receiver

Statement of Work

- Task 1 – Ultra-wideband Radios
- Task 2 – Ultra-wideband Antenna
- Task 3 – Ultra-wideband DSP
- Task 4 – Evaluation of Flexible Ultra-wideband Systems
- Task 5 – Network Control & Management for Flexible Ultra-wideband Systems
- Task 6 – Development of Flexible Ultra-wideband System Experiment Kits

Tentative Schedule