Academic Research in Public Safety Communications

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Research Scientist
Wireless @ Virginia Tech

SDR Forum Public Safety Workshop
November 30, 2010

Outline

Wireless @ Virginia Tech

SDR Technology

- Multiband Multimode Radio
- Antenna System

Cognitive Radio Technology

- Public Safety Cognitive Radio
- Embedded System

New Technology

- Wireless Distributed Computing
- Cognitive Radio Network Testbed

Acknowledgement

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Dr. Steven Ellingson
& his group

Dr. Charles Bostian
& his group

National Institute of Justice
The Research, Development, and Evaluation Agency of the U.S. Department of Justice

AIR FORCE RESEARCH LABORATORY

DEPARTMENT OF THE NAVY
USN ONR Science & Technology

National Science Foundation
WHERE DISCOVERIES BEGIN

MOTOROLA

DARPA

SDR Technology

Multiband Multimode Radio Project

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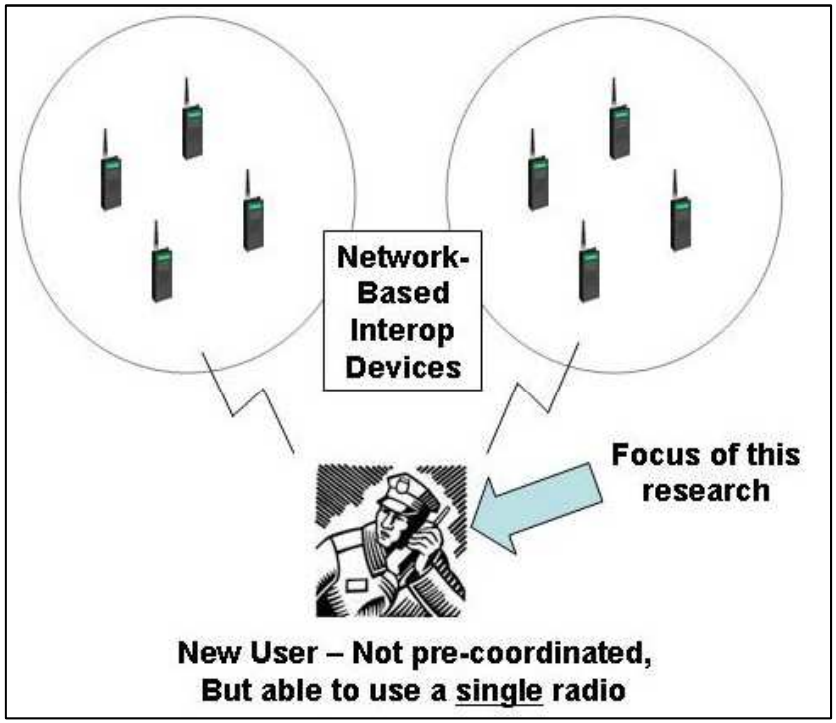
- To develop and demonstrate a radio which can operate in **all bands and all modes relevant to public safety** operation in U.S.
- The developed radio should be able to operate on **multiple channels simultaneously**, even across bands & modes.
- The explicit implementation of analog half-duplex (PTT), Narrowband FM voice, P.25 digital voice mode, and Rudimentary (PHY-only) 802.11b.
- Can we do it **using a one single** antenna?



VT Public Safety Radio Prototype

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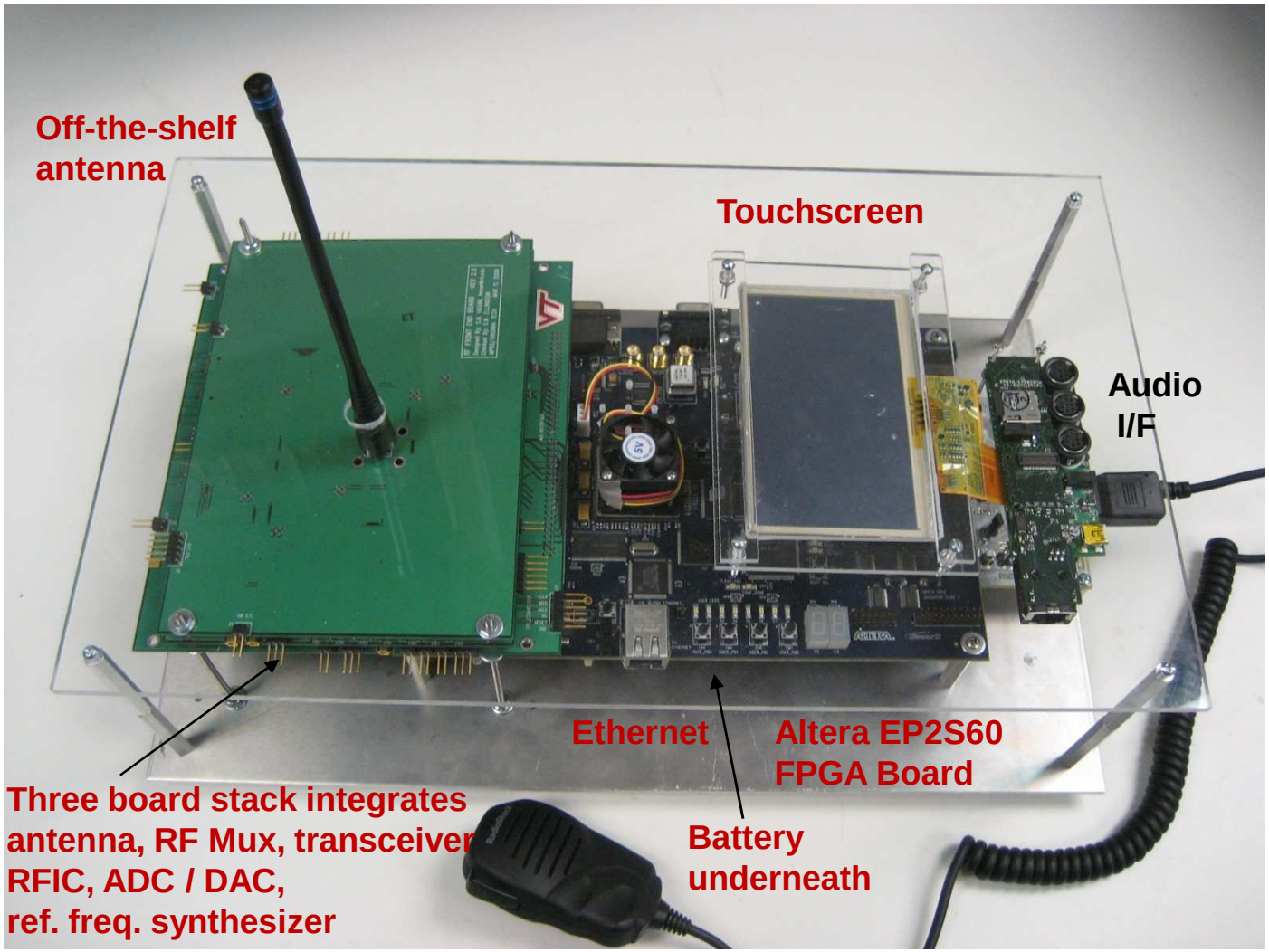


138-174 MHz
220-222 MHz
406-512 MHz
764-900 MHz

Motorola RFIC-4

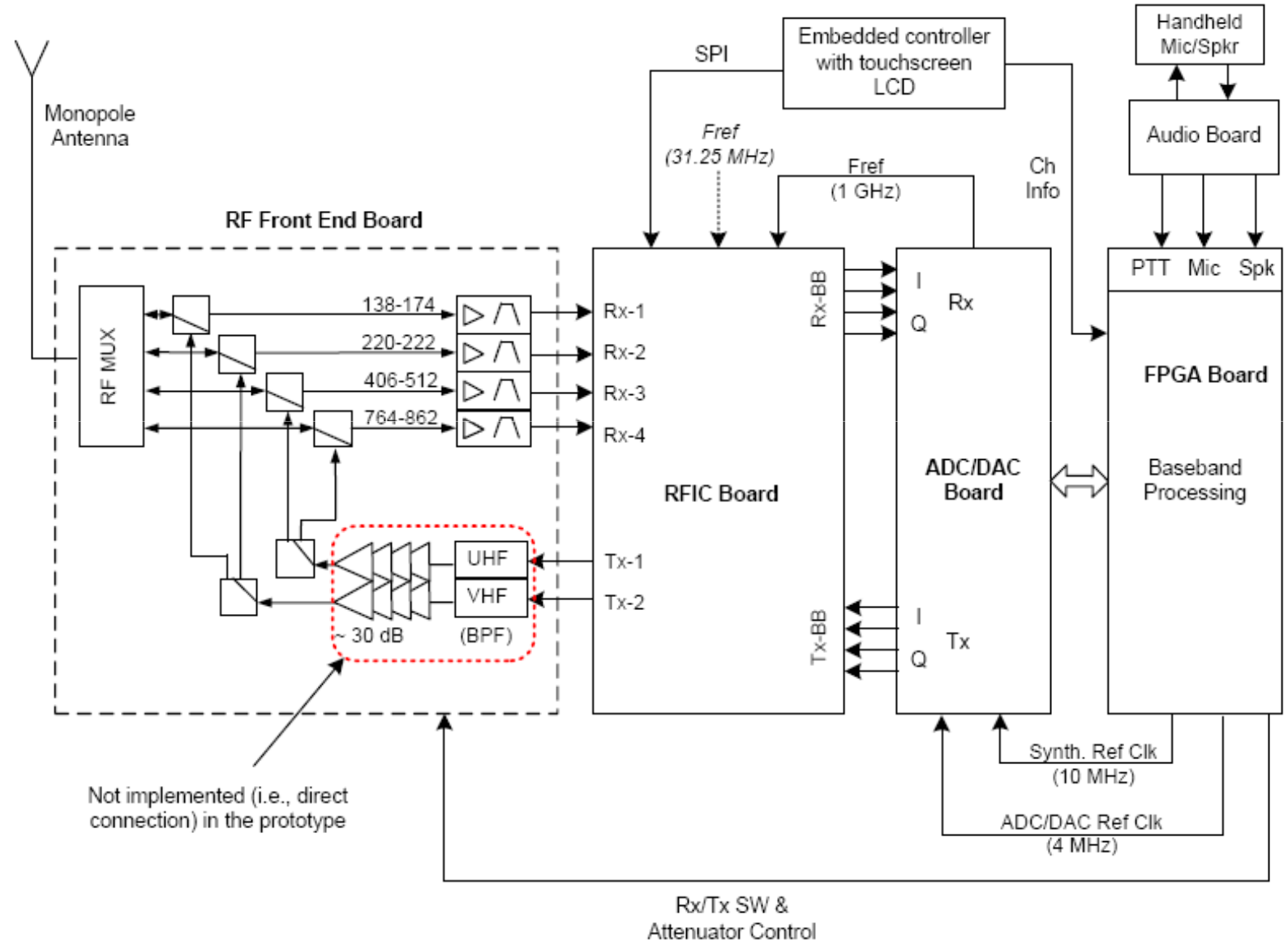
4 MSPS baseband ADC/DAC

No µP; Instead completely implemented in FPGA

Tested and Implemented in 2008

33 Technical Reports are available at:
http://www.ece.vt.edu/swe/chamrad/

System Diagram of the Prototype



VT Transceiver Board

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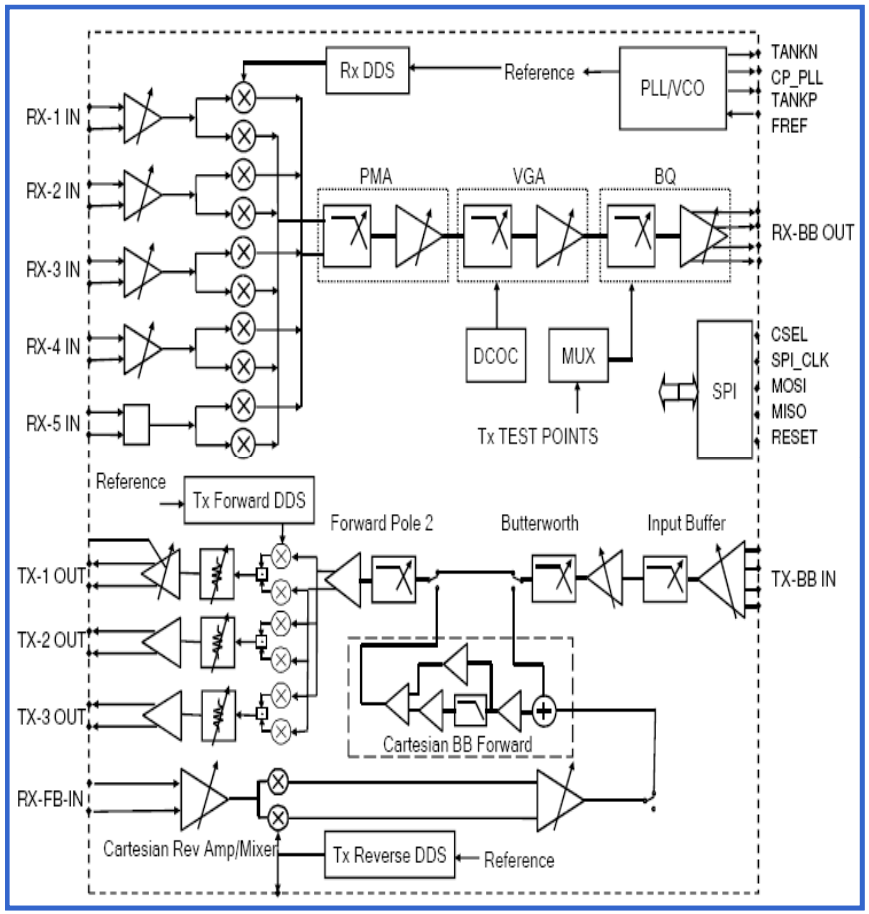
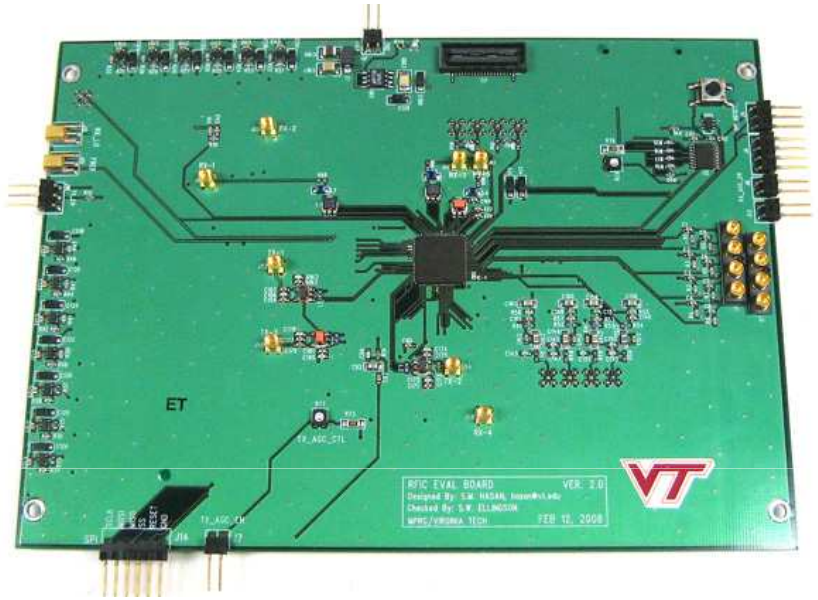
Motorola RFIC-4



- Broadband 100 MHz – 4 GHz operation
- Programmable 9 KHz to 20 MHz bandwidth

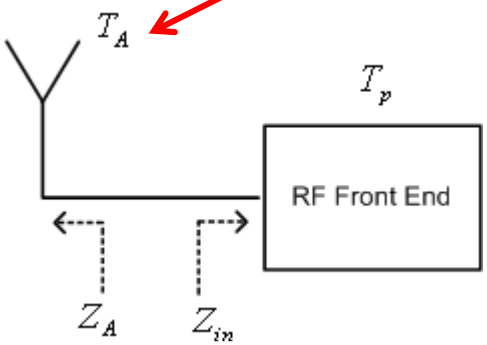


- 4-Band Transceiver Board
- Implemented on a 4-layer PCB
- About $100 in parts to implement, excluding PCB.

G. Cafaro *et al.*, "A 100 MHz – 2.5 GHz Direct Conversion CMOS Transceiver for SDR Applications," *2007 IEEE RFIC Symp.*, June 2007.

Sensitivity Constrained RF Front End (1/3)

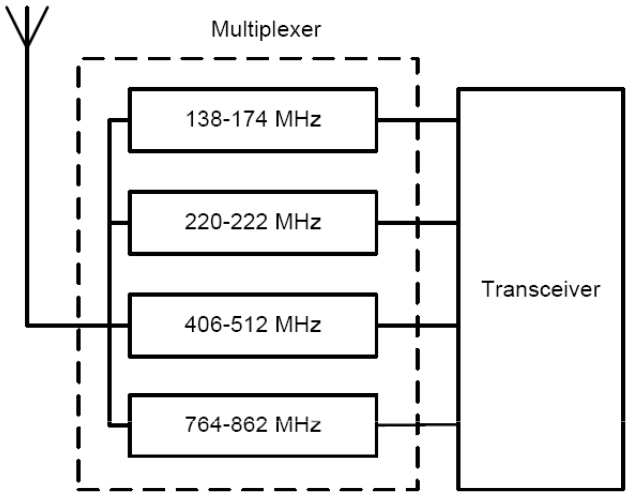
Irreducible



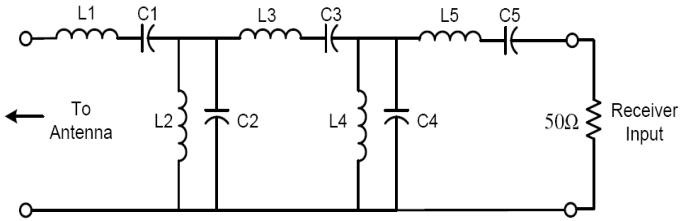
$$T_{opt} = \eta \frac{T_A}{\gamma}\left[1 - |\Gamma|^2\right]$$

γ is the ratio of external to internal noise

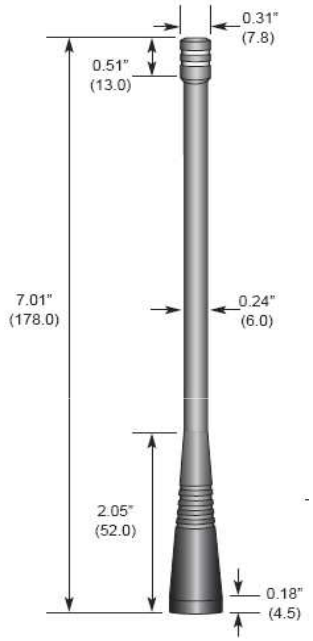
Front End for Public Safety Radio



5th order Chebyshev topology



ANT-418-CW-QW (Price $5/pc)



Specification from Manufacturer

- Center Freq: 418 MHz
- Bandwidth: 80 MHz
- Typical VSWR < 1.9 @ 418 MHz
- 50Ω impedance

Sensitivity Constrained RF Front End (2/3)

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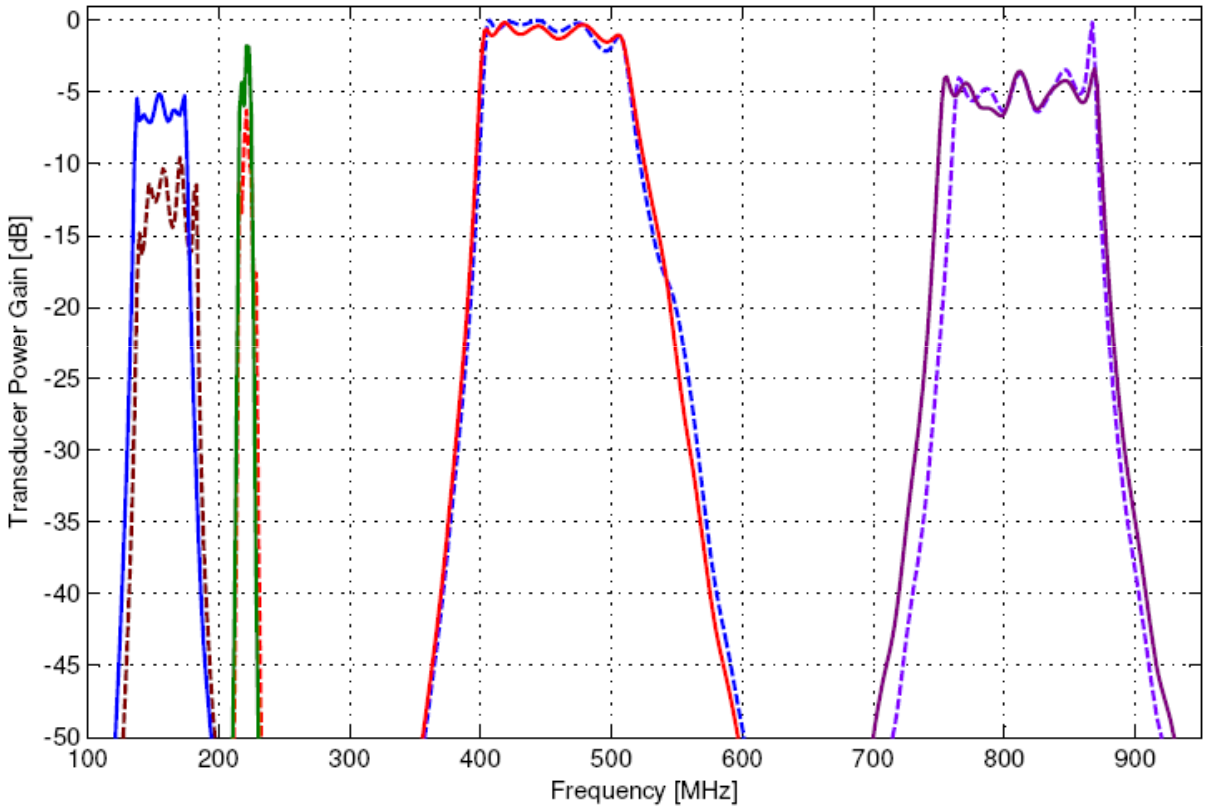
Performance (TPG) of Optimized Multiplexer



	Bode-Fano (Series RC)	Achieved
CH 1	-1.4 dB	-6.5 dB
CH 2	~0 dB	-2.0 dB
CH 3	~0 dB	-1.0 dB
CH 4	~0 dB	-5.5 dB

Degradation of TPG in Channel 4 degrades sensitivity only by 2 dB

- Solid Line: Results after optimization
- Dotted Line: Results before optimization

Sensitivity Constrained RF Front End (3/3)

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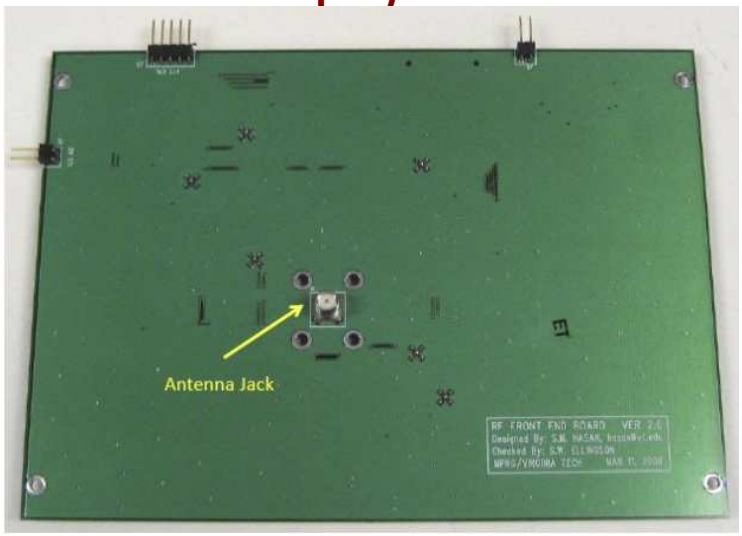
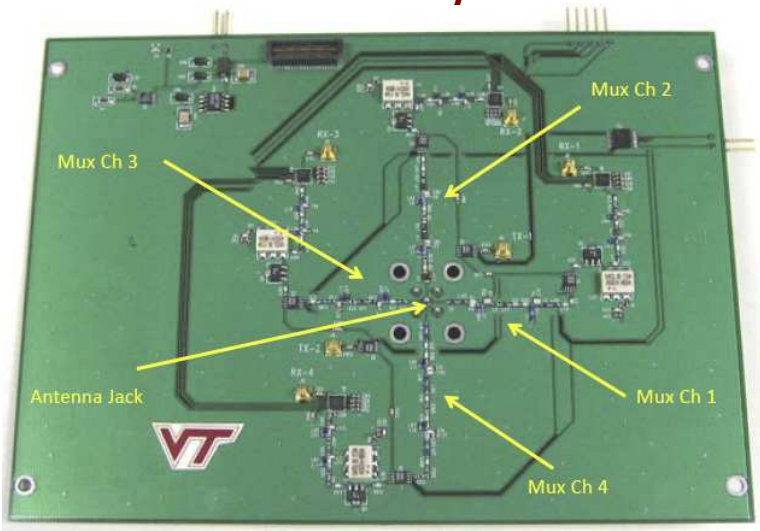
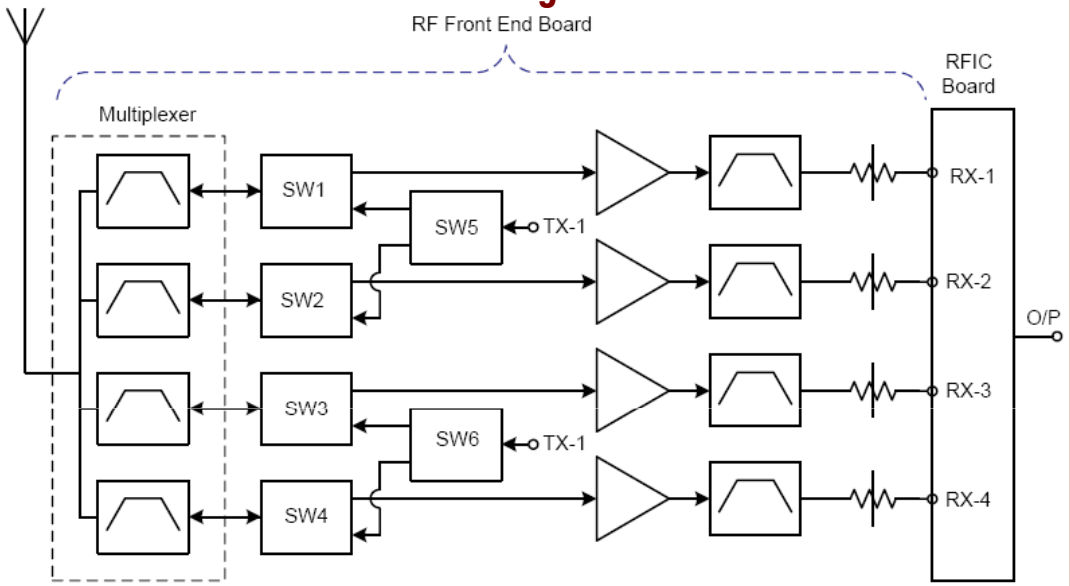
Top Layer



Bottom Layer



Block Diagram



- RF Multiplexer to interface with Antenna
- Low Noise Amplifier
- Additional Filters
- Variable Attenuators to control gain
- 4 Layer PCB
- About $200 in parts to implement

New Project: Antenna System Design

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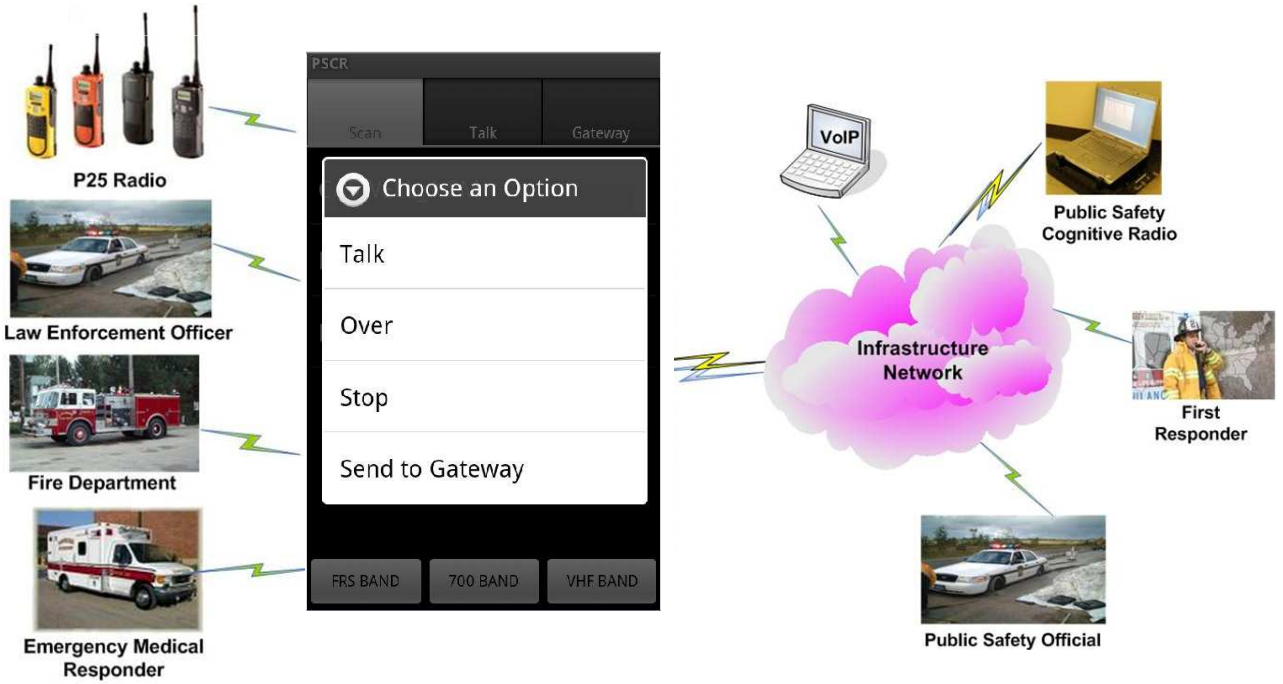
- Determine the **actual limits** of existing antenna technologies
  - What is the best that one can do with one traditional monopole?
  - The practical limits are not currently defined in a useful way
- Prior research suggests that **system-level** improvement is possible by carefully trading off band-specific requirements for **sensitivity and transmit efficiency.**
- We speculate that further significant improvements are possible using **reconfigurable matching and "non-Foster" technologies**
- Unique features of this project:
  - No dramatic changes to antennas (similar or identical form factor)
  - Auxiliary electronics that work with existing systems
  - Performance quantified with respect to relevant system-level metrics

Cognitive Radio Technology

Public Safety CR on a DSP Platform for Affordable Interoperability

To solve the interoperability problem by providing **intelligent and affordable** all-band all-mode radios that find and identify public safety networks and **configure themselves** to interoperate with them.



Operating Modes

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SCAN

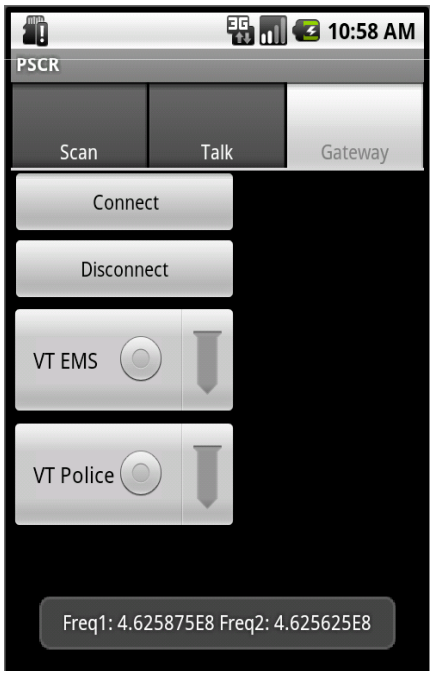
- Find and identify public safety waveforms
- Assign names to known channels

TALK

- PTT operation with any identified public safety network

GATEWAY

- Establish audio bridge between any two networks



Prototype as of March 2009

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VPSCR System View

VirginiaTech
Invent the Future

Software & Hardware Configuration

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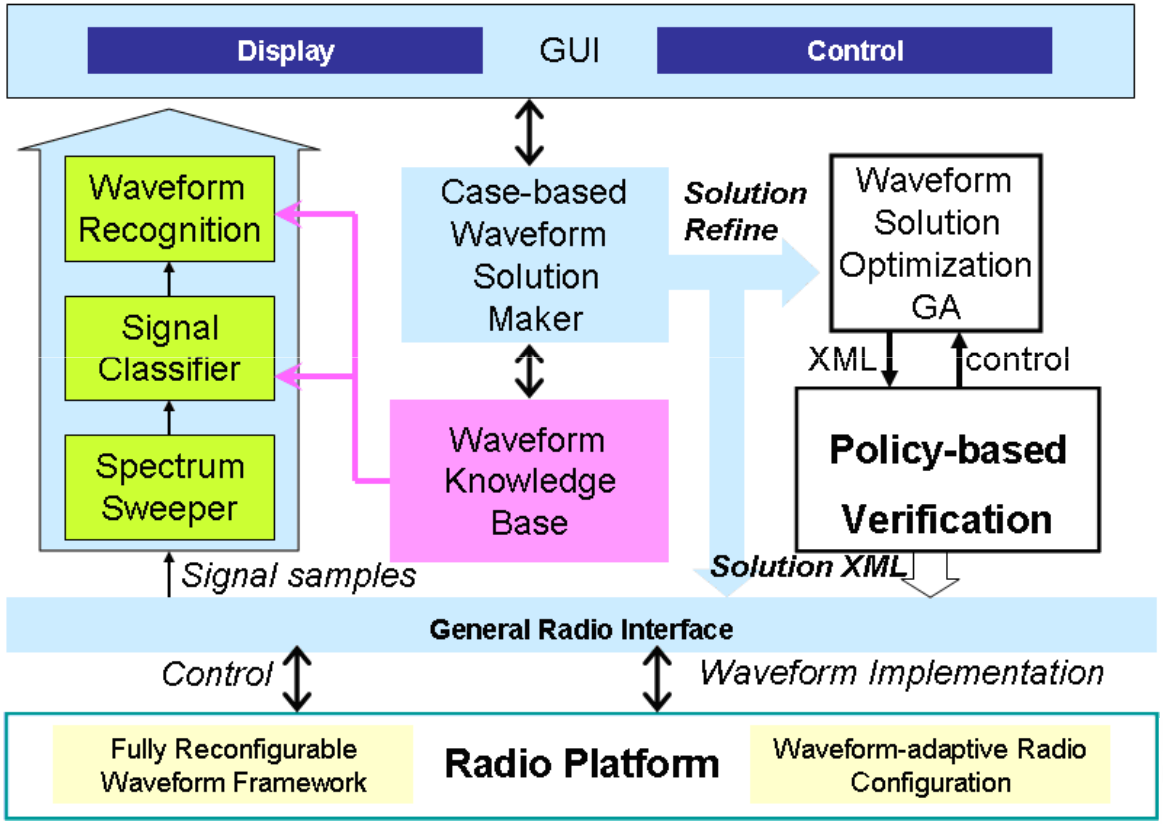
as of March 2009

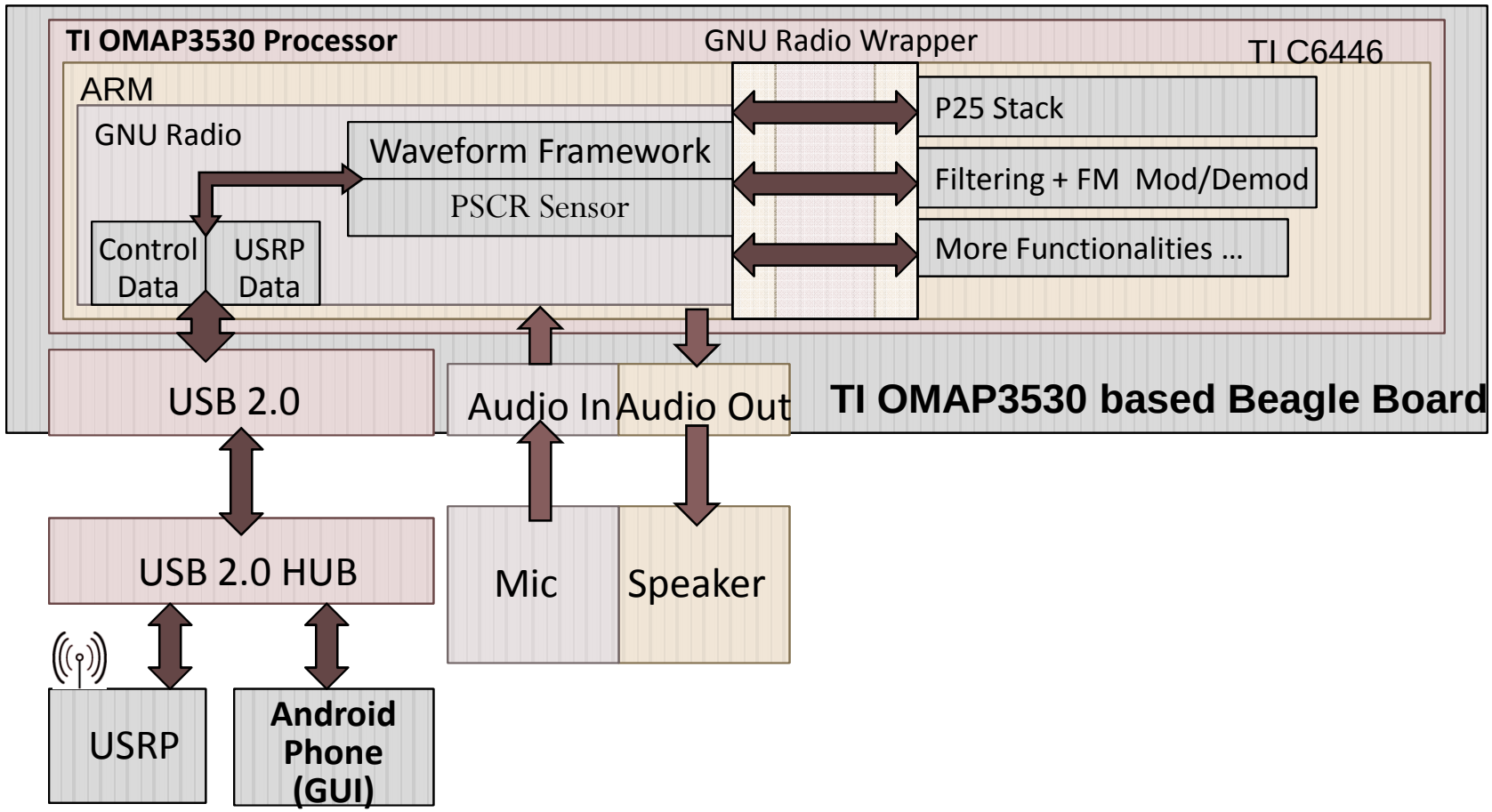


PDA

Laptop

USRP in a casing with RF amps and power supply

Prototype using Beagle Board & Android



- The platform and development environment lends its to adding and modifying the radio by LMRs.
- The environment depends entirely on free/open source software.

Adding P25 Capability

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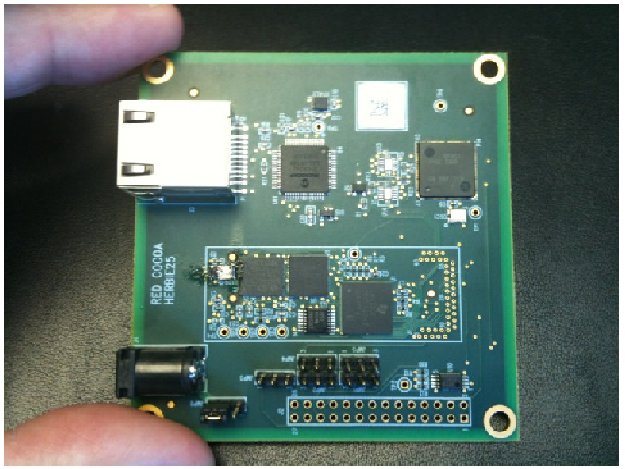
- Red Cocoa is developing a daughterboard to provide full P25 capabilities
- Tentative cost is $500 in single quantities
- Virginia Tech is collaborating with Red Cocoa to develop this board
- At present it has several technical problems (particularly SPI bus issues) but VT continue to work with them on it.



redcocoa

New Technology

Wireless Distributed Computing

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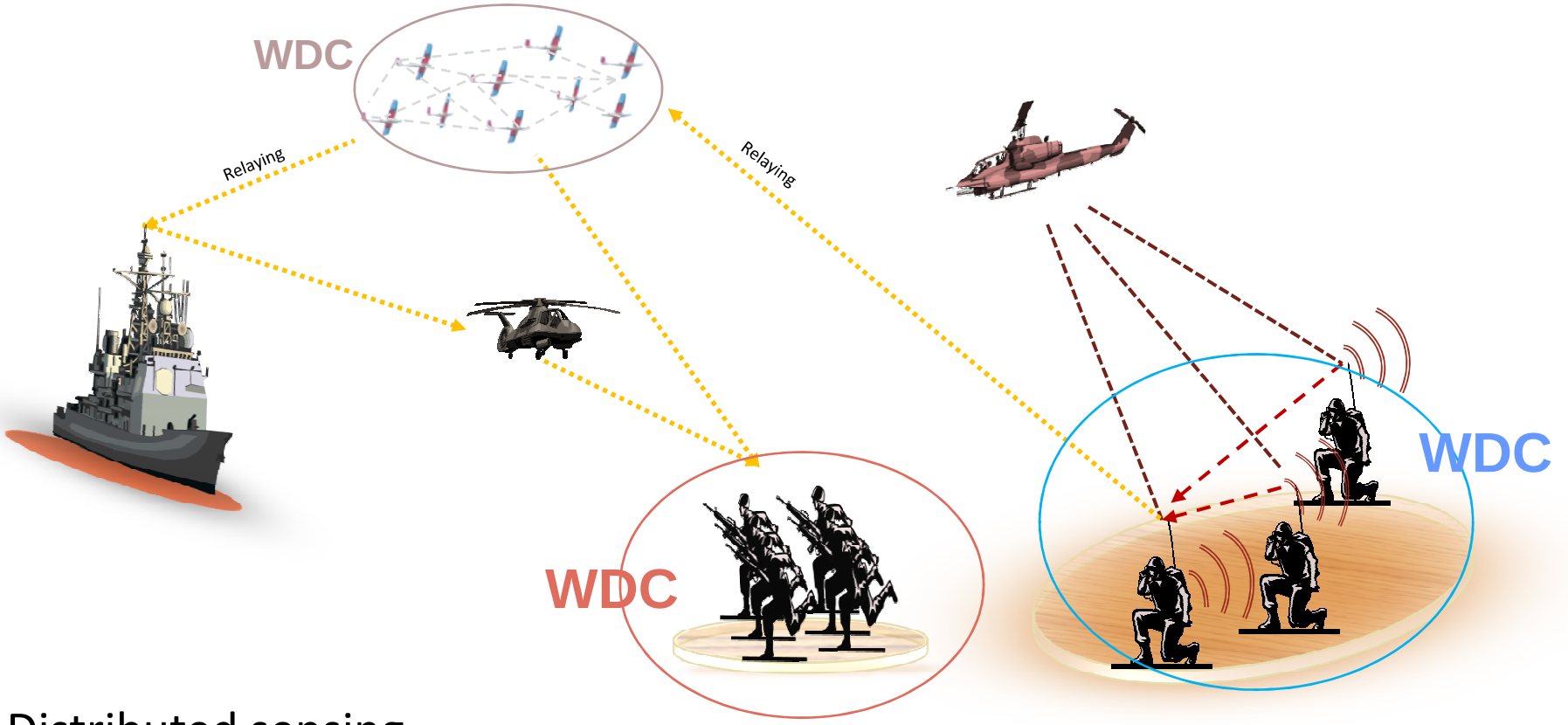
- **Complex computation can be distributed to meet high QoS constraints**
- **Wireless versus wired distributed computing design:**
  - Wireless systems consume higher power, energy, and latency
  - Radio environment influences workload balancing
  - Design tradeoffs involve interaction between application and comm layers
  - Wireless channels may induce delays
- **Cognitive SDR based networks can offer-**
  - A dynamically reconfigurable collaborative radio platform
  - Efficient realization of power constrained distributed computing algorithms

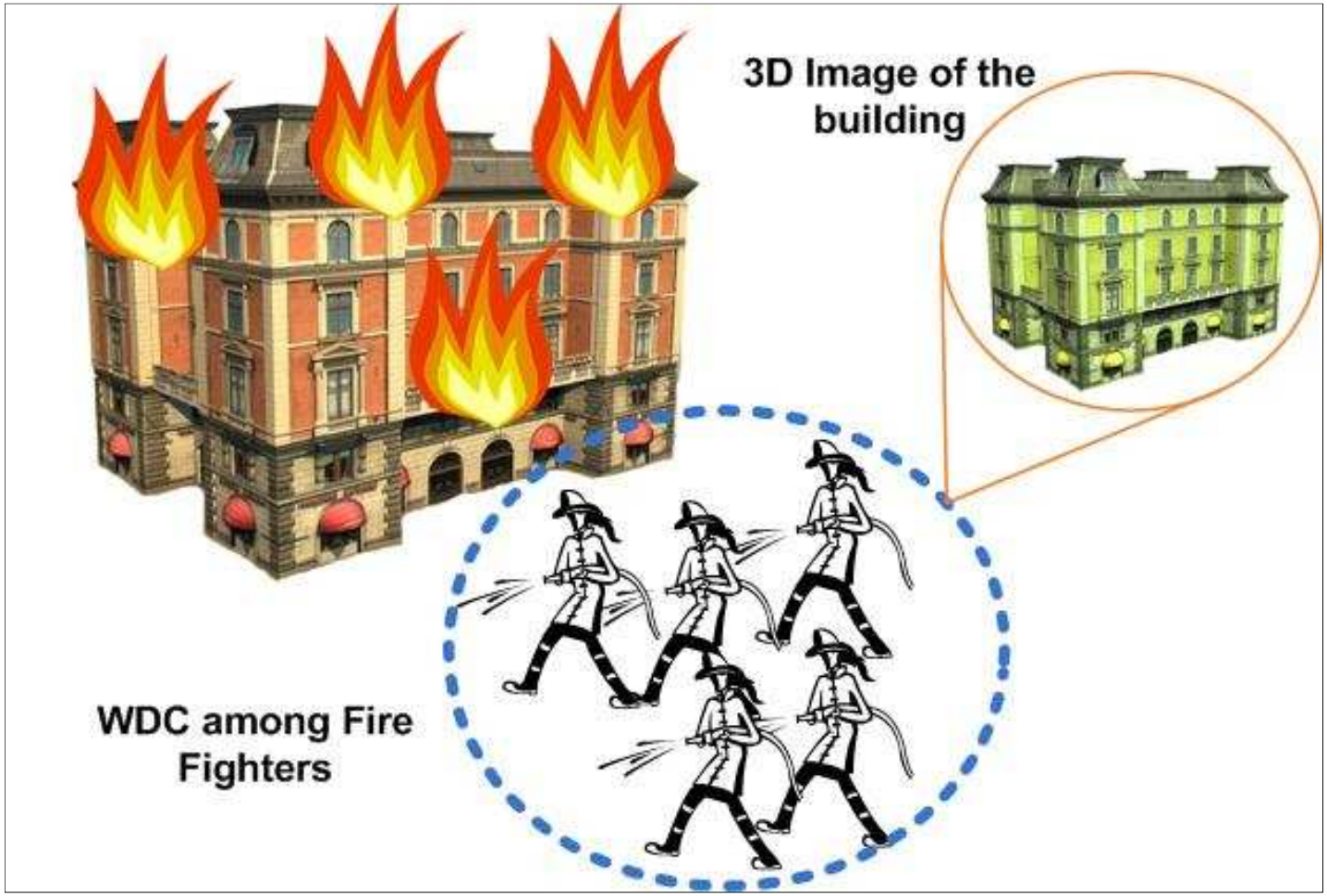
Potential Applications



- Distributed sensing
- Geo-location
- Coordinated jamming
- Image processing/ recognition
- Collaborative robotics

- Cooperative MIMO
- Direction finding
- Secure systems

Example Public Safety Applications



Example: A UAV Scenario

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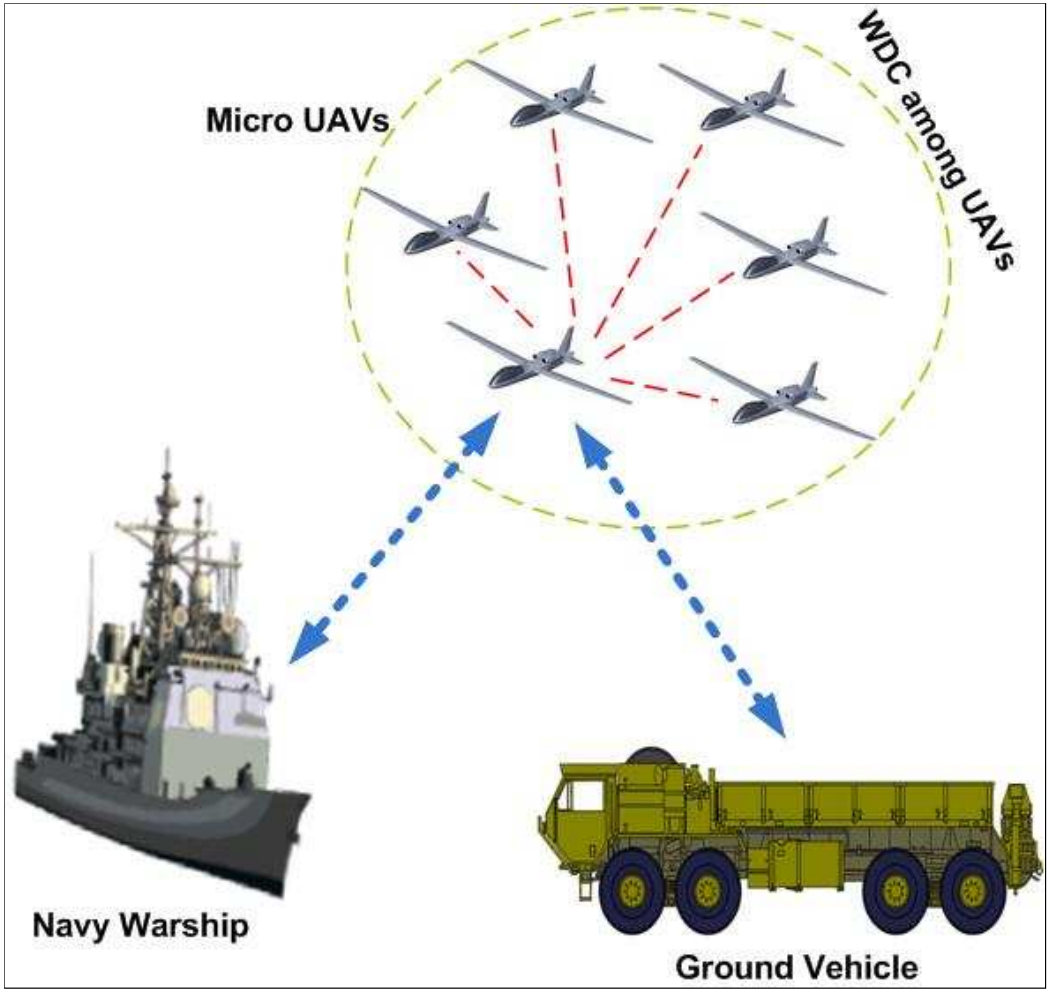
WDC can be especially useful for problems that otherwise would require a long distance communications link

Information can be processed and compressed to reduce the demand on communications

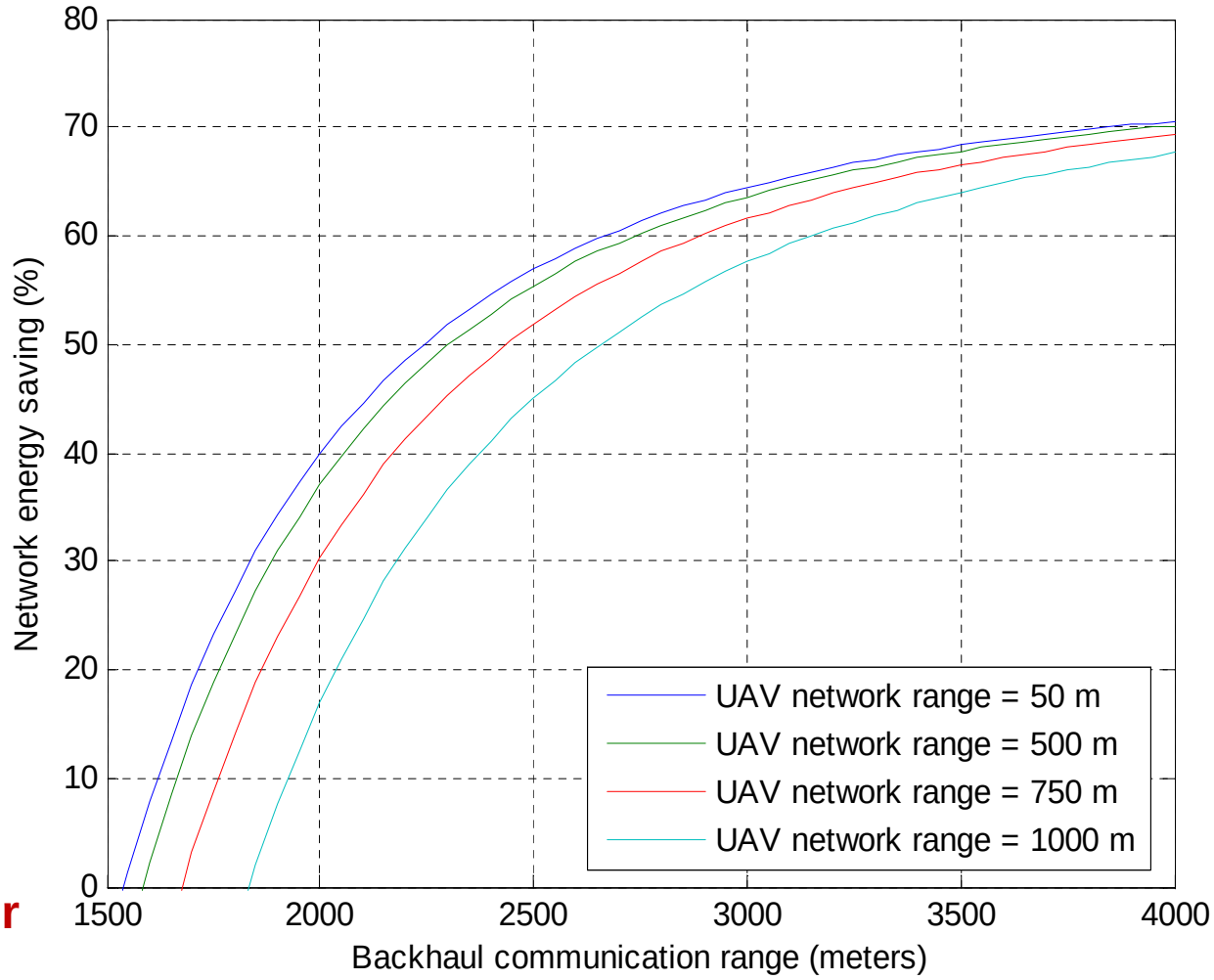
Example: FFT-based correlation for pattern recognition



A UAV Scenario:

Theoretical System Gain

The results show that for 16 UAVs, a back haul range of 4 km and a UAV network range of 1 kms, **68 % energy savings** can be achieved by WDC assuming the computational workload is evenly distributed among the WDC network nodes.



Energy savings come from trading communications for computing.

Development of a WDC Testbed

[Testbed Setup]

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Node = Laptop (with Gnuradio) + USRP
USRP: RFX 400 Daughterboards

Four nodes used in Demo

Basic Knobs :

- *Carrier Freq. (e.g., 463 MHz)*
- *Modulation (e.g., GMSK, 8PSK, DBPSK)*
- *Bandwidth*
- *Data Rate*
- *Participation threshold (carrier sense)*

Master (M)
IP : 192.168.1.1
Port for Slave 1: 9875
Port for Slave 2: 9500
Port for Slave 3: 9400

Connection : TCP/IP socket

Slave 1
IP : 192.168.1.2
Port: 9875

Slave 2
IP : 192.168.1.3
Port: 9500

Slave 3
IP : 192.168.1.4
Port: 9400

Processing steps at master node (M)

1. M sends encrypted file to Slave nodes
2. M in Rx mode waits for results
3. M displays results

Processing steps at a slave node

1. Slave node in Rx mode receives file
2. Image processing
3. Slave node sends result to M

Ongoing WDC Implementation

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USRP E100 Embedded Series

- 720 MHz OMAP 3
- FPGA is connected via the GPMC
- Spartan 3 FPGA
- Better software support from GNU radio community

DARPA WNaN Radio

- 4-Transceiver Node @ $500 in Lots of 100K
- Wide Frequency Coverage
- Dynamic Spectrum Access

Cognitive Radio Network Testbed (CORNET)

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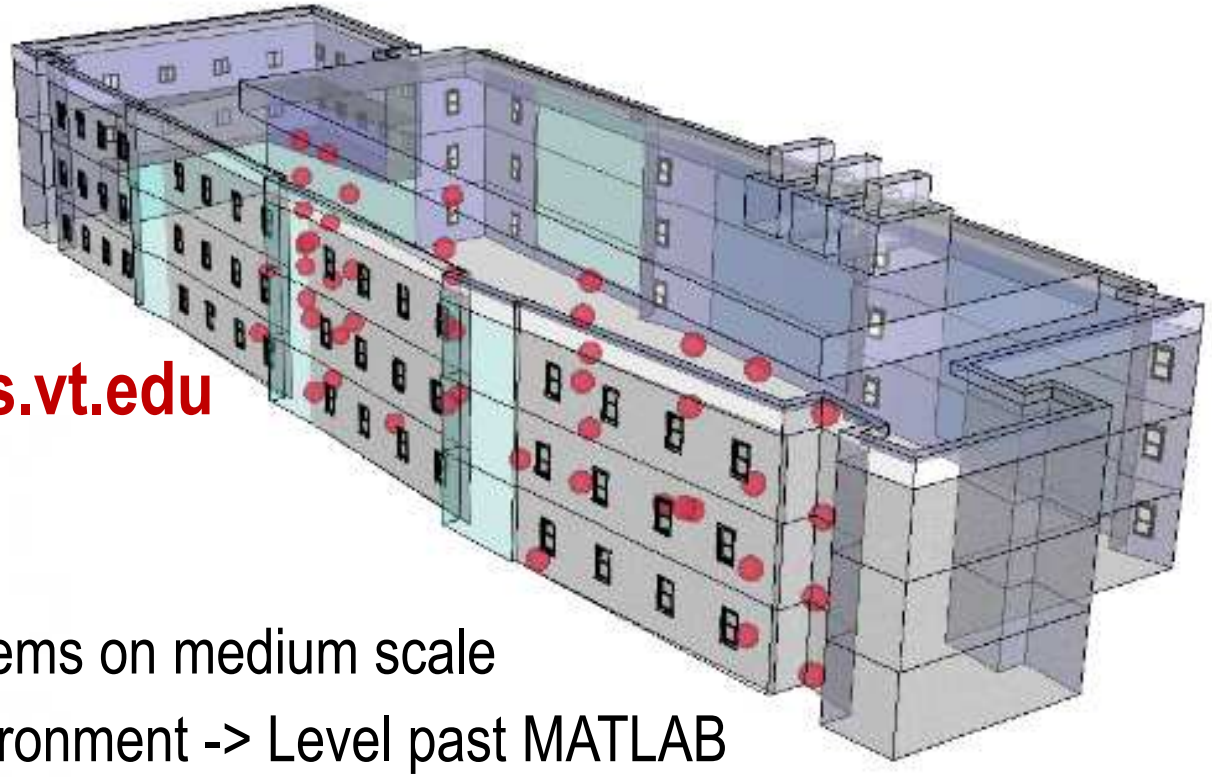
- Physical testbed deployed throughout a campus building
- Total size of testbed is 48 nodes (12 nodes per floor)



http://cornet.wireless.vt.edu

- Develop wireless systems on medium scale
- Practical wireless environment -> Level past MATLAB
- Emulate wireless systems and integrate new ones

Concluding Remarks

Wireless @ Virginia Tech

- Prototype multiband multimode radio for public safety applications has already been developed
- Antenna design & integration is a big challenge
- Antenna-RF front end co-design can solve the problem

SDR

- Implementing Cognitive Radio functionality in a DSP/Embedded environment is going on
- University-Industry collaboration is going on to implement P25 functionality in academic prototype PS radios

CR

- Wireless Distributed Computing can play an important role to solve various computationally intensive tasks during major disaster
- VT's CORNET can play an important role to test various cognitive radio functionalities, protocols, and algorithms

NEW

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Thanks !!

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