Rapidly Deployable Broadband Communications for Disaster Response

VirginiaTech

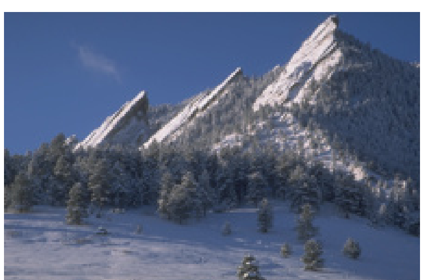
VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Charles W. Bostian, Scott F. Midkiff, Timothy M. Gallagher, Christian J. Rieser, and Thomas W. Rondeau

Center for Wireless Telecommunications

Virginia Tech

Blacksburg, VA 24061-0111



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6th ANNUAL

INTERNATIONAL SYMPOSIUM ON ADVANCED RADIO TECHNOLOGIES

Testbed for High-Speed 'End-to-End' Communications in Support of Comprehensive Emergency Management

A Project of

Virginia Tech's Center for Wireless Telecommunications (CWT)

Science Applications International Corporation

Sponsored by the National Science Foundation
(Digital Government Program Award 9983463)

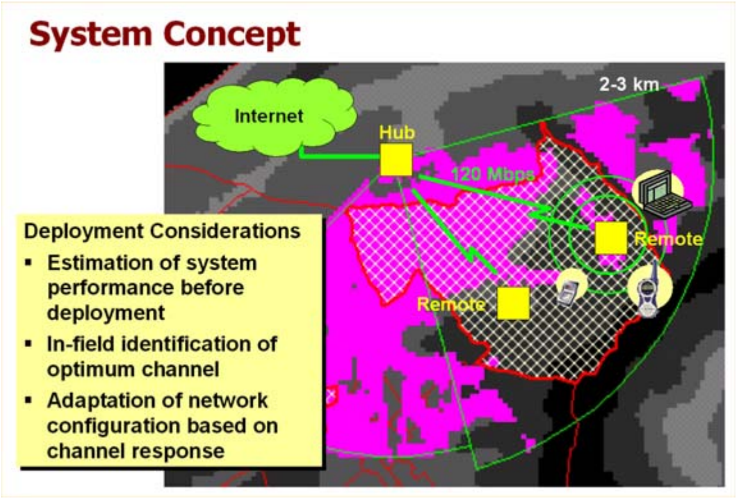
With additional support from the National Response Center (NRC)

C.W. Bostian, PI, S.F. Midkiff, and W. M. Kurgan Co-PIs

Disaster Communications Project Research Objectives

Overall Objective: Develop a rapidly deployable high capacity backbone radio system that seamlessly links on-site communications systems and networks to each other and to the outside world.

Technical Challenges: find short-lived radio paths of opportunity and compensate for the shortcomings of these paths at both the radio and the network levels to deliver optimum performance.



The Situation Our Project Addresses – A disaster area several miles on a side in which almost all communications have been wiped out.

Cell phones provide voice service but are quickly saturated.

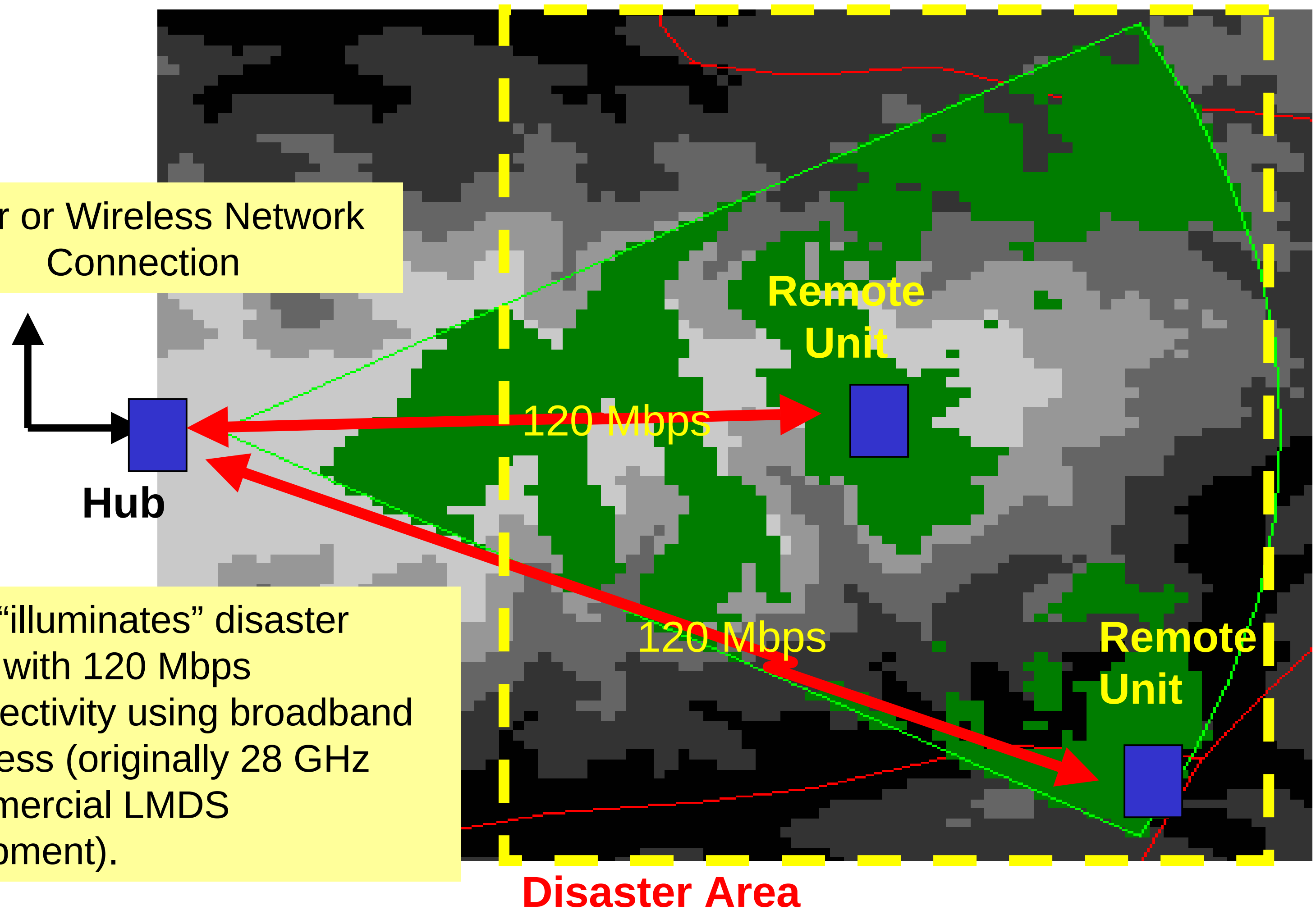
Landline connections exist at the perimeter of disaster area that could be accessed via high-speed wireless links.

Responders need rapidly deployable broadband communications.
On September 11, getting needed connectivity took about a week.

Our Project: System Concept

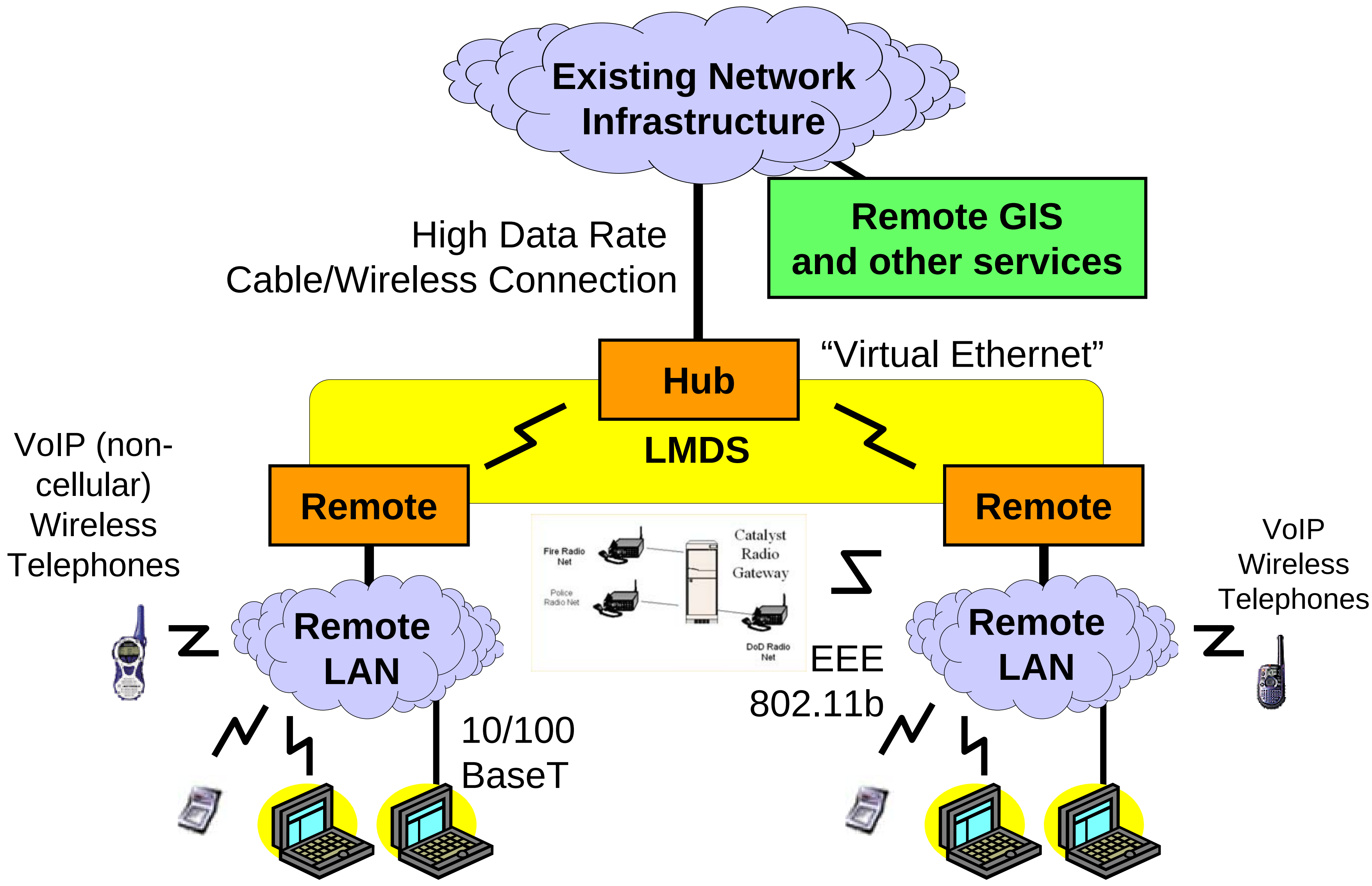
2-3 km range
(to be extended)

Fiber or Wireless Network Connection



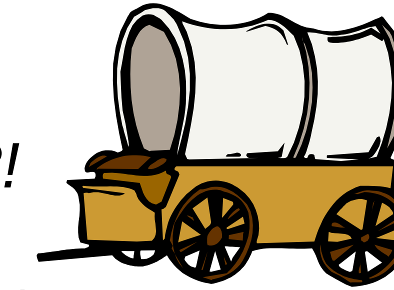
Hub “illuminates” disaster area with 120 Mbps connectivity using broadband wireless (originally 28 GHz commercial LMDS equipment).

System Overview



Why did we use the 28 GHz LMDS band?

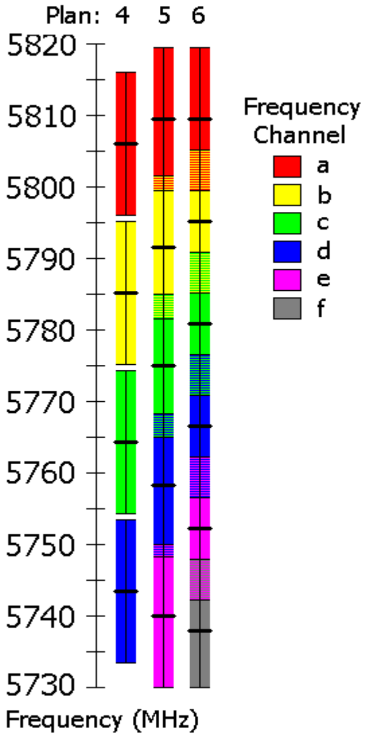
Remember wireless data technology in 1998!

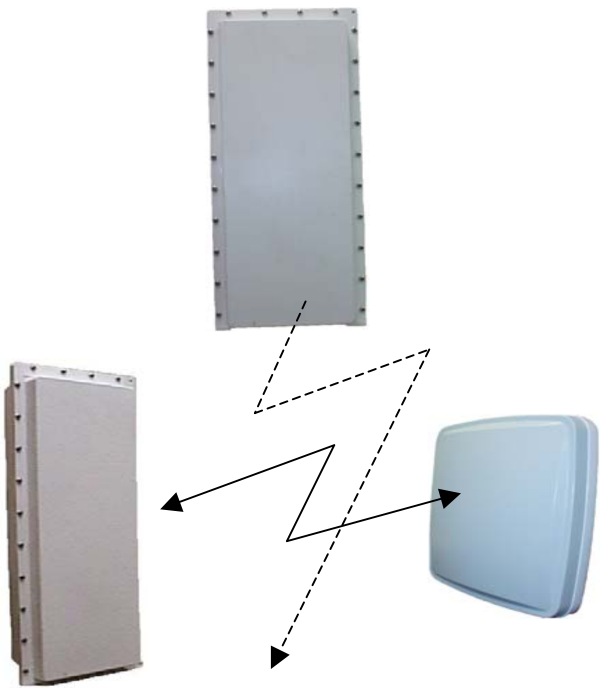


- IEEE 802.11b was an 11 Mbps indoor LAN for the office market.
- Only one or two companies offered radio modems that worked above 100 Mbps. These were intended for satellite links and priced accordingly.
- Successful 155 Mbps transmission over a wireless link was an expensive laboratory demonstration.
- The Dot.Com Bubble was on and equipment manufacturers were selling everything they could possibly manufacture. They were not very interested in the disaster relief market.

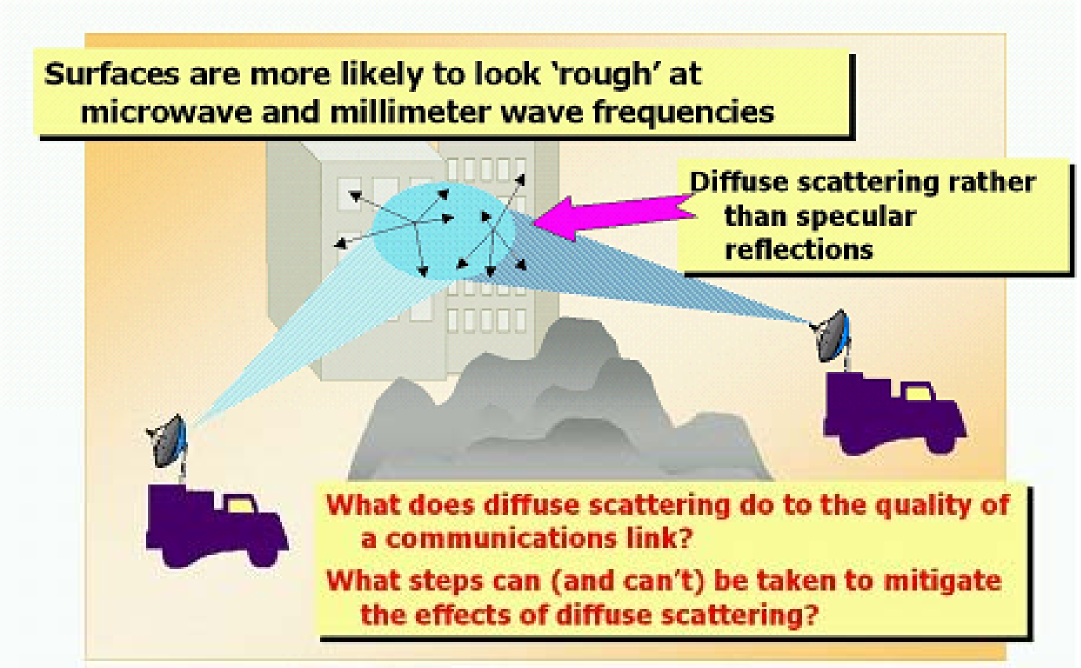
AP3000E
Access Point

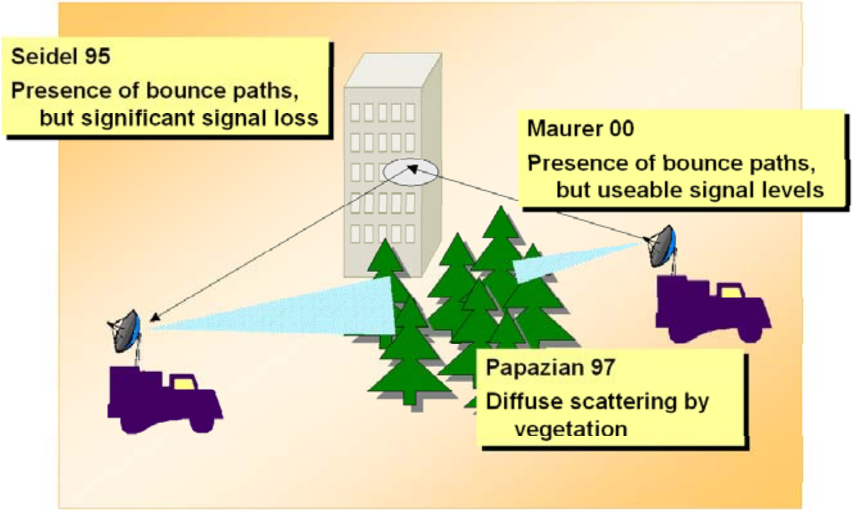
With the IEEE 802.11x and 802.16 technology now available, we are in the process of changing our operating frequency to the 5 GHz UNII band and using Proxim Tsunami Radios. But we learned a lot about 28 GHz.





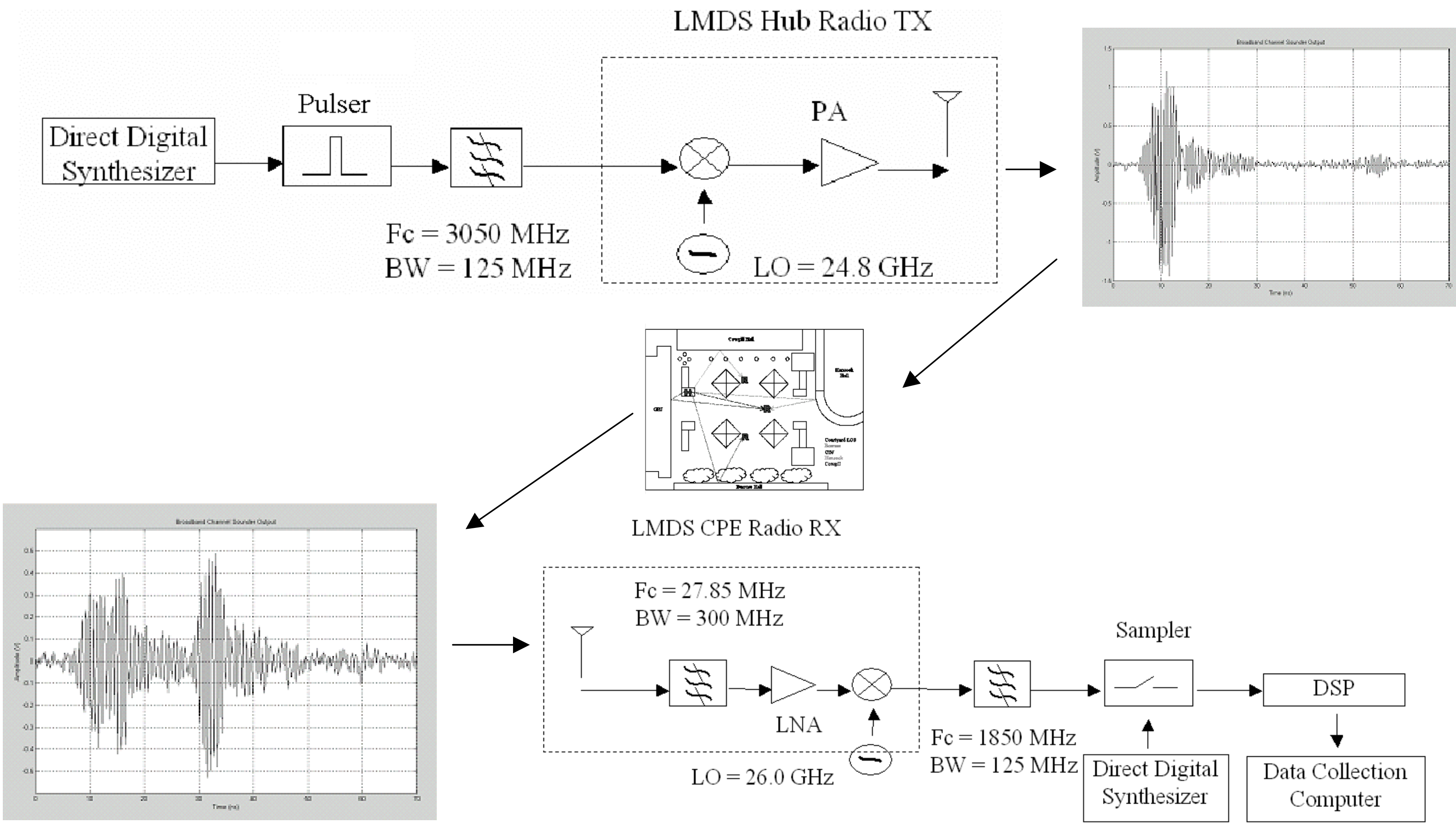
28 GHz works best with LOS but NLOS paths exist and will work. These “paths of opportunity”can come from any direction and differ significantly from each other in radio channel characteristics.



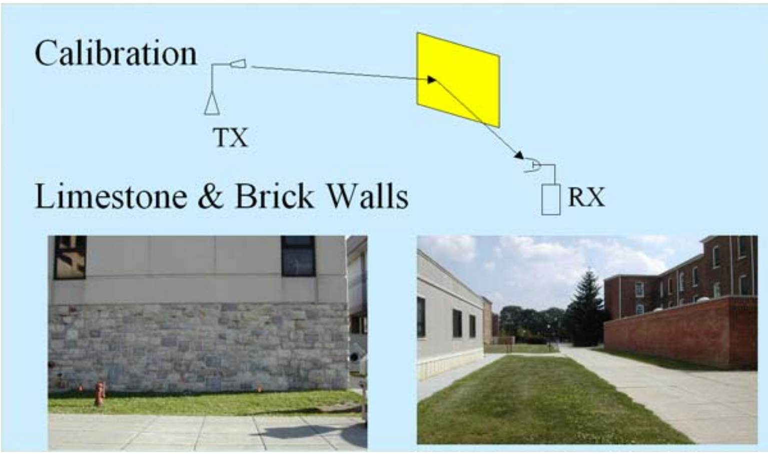


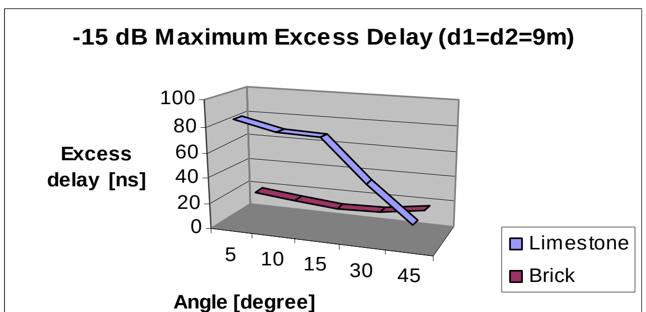
Researchers disagree about their characteristics

To study the broadband characteristics of 28 GHz bounce paths, we developed an impulse channel sounder using UWB technology.

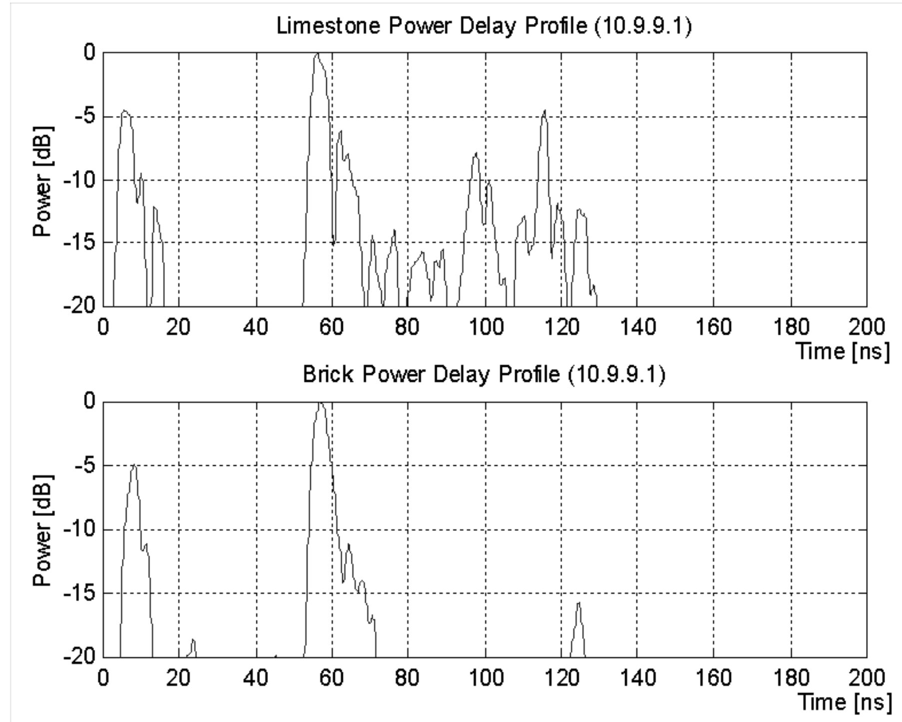


28 GHz paths of opportunity involve rough surface scattering and produce a continuous distribution of multipath components.



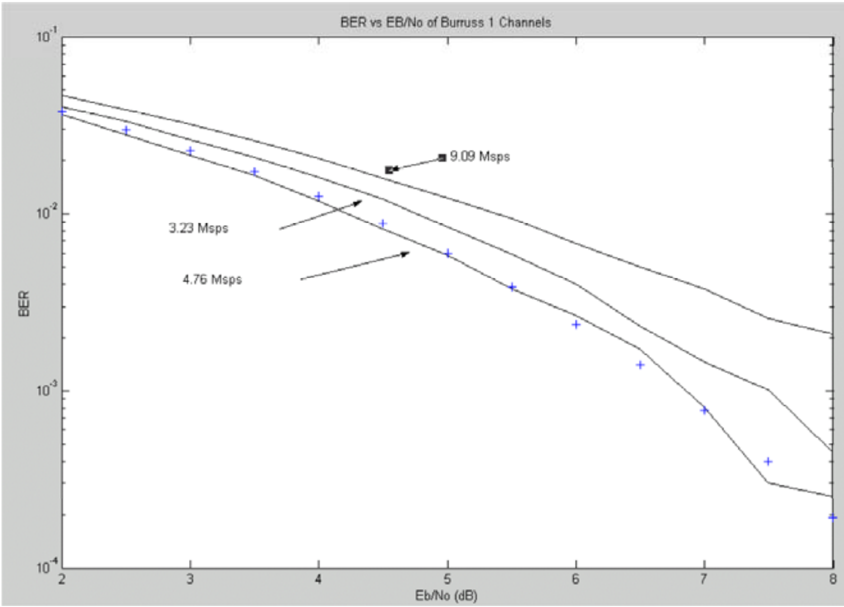


	5	10	15	30	45
Limestone	85	77.5	76	45	17
Brick	18	15	12	13	18

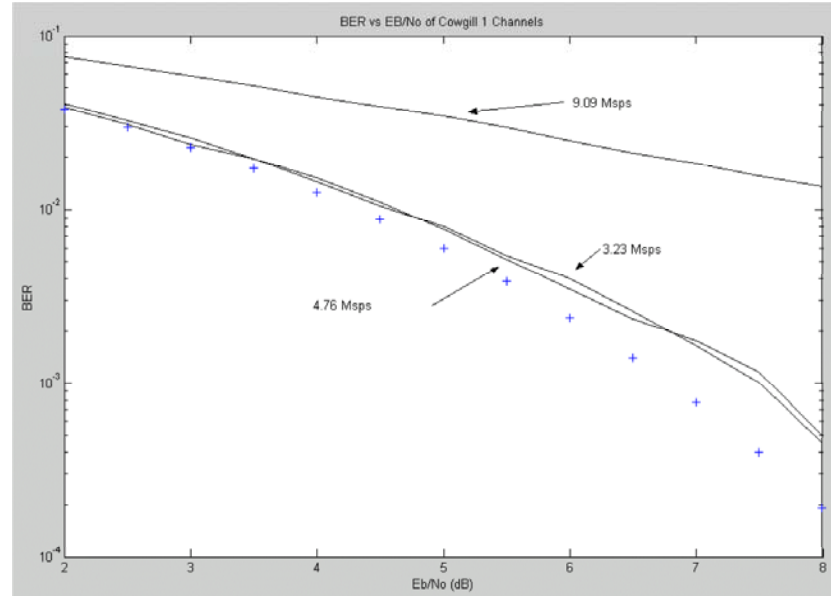


Power delay profiles for scattering by limestone and brick walls.The first waveform is the LOS signal and the second is the scattered signal. From C. L. Dillard, T. M. Gallagher, C. W. Bostian, D. G. Sweeney. “28 GHz scattering by brick and limestone walls,” *2003 IEEE Antennas and Propagation Society International Symposium*, Vol. 3, pp. 1024-1027

Because of rough surface scattering, paths of opportunity can have significantly different channel characteristics.

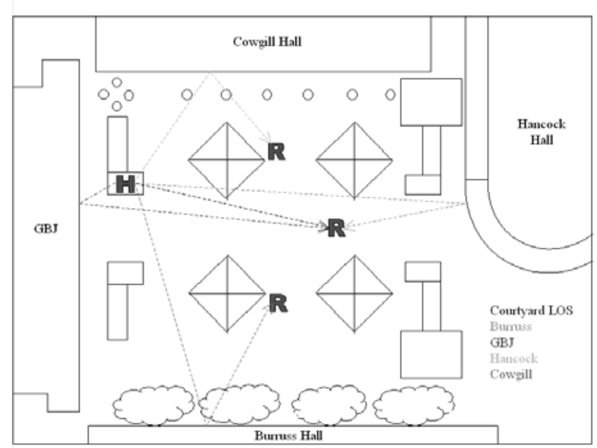


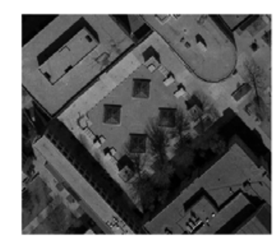
Calculated BER for Burruss path ↑



Calculated BER for Cowgill path ↑

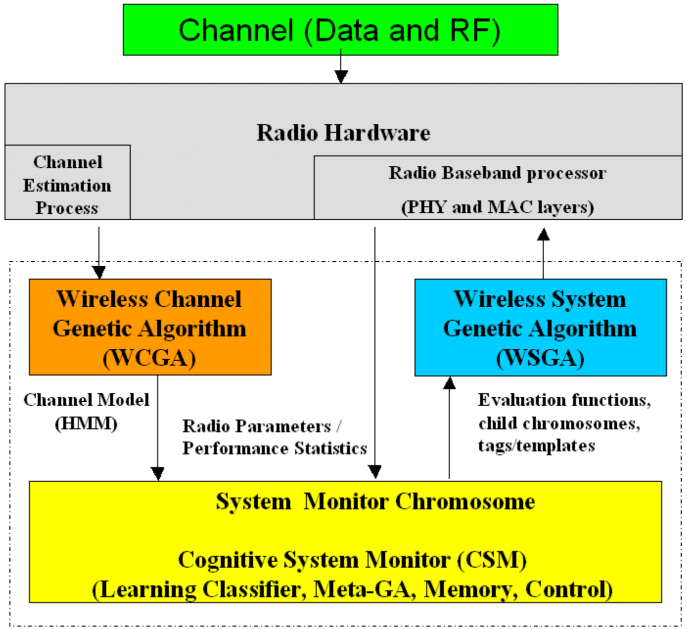
Measurement Layout →





Calculated plots of BER versus E_b/N_0 for paths whose power delay profiles we measured.

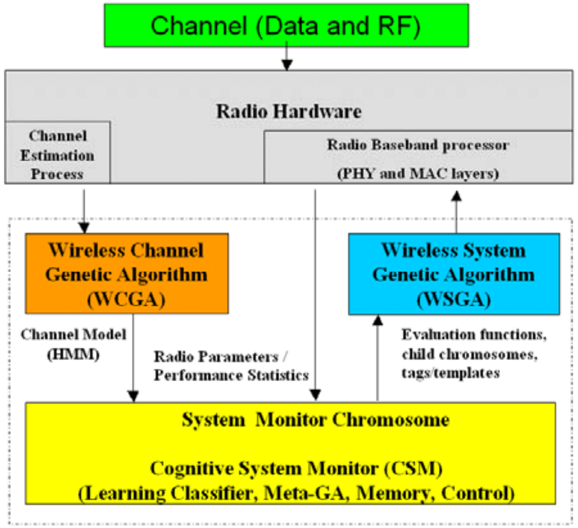
We need a radio that is capable of finding these paths of opportunity and configuring itself to make optimal use of them.



In addition, there is a human factors problem.

Fire fighters and other first responders emphatically do not want a radio that requires hands-on operation or frequent adjustment by an expert. They need a radio that is smart enough to find the best path of opportunity, configure itself for it, and close a link, all without human intervention.

In other words, they need a cognitive radio.

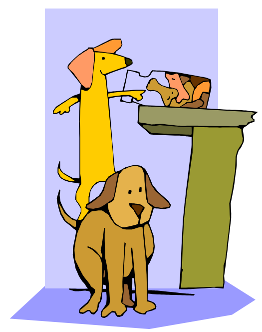


What is a Cognitive Radio?

Fixed radios
are set by their operators

Beyond adaptive radios, cognitive radios can handle unanticipated channels and environments

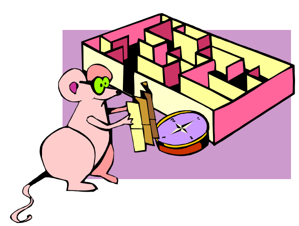
Adaptive radios
can adjust themselves to accommodate anticipated channels and environment



Cognitive radios require:

- Sensing
- Adaptation
- Learning

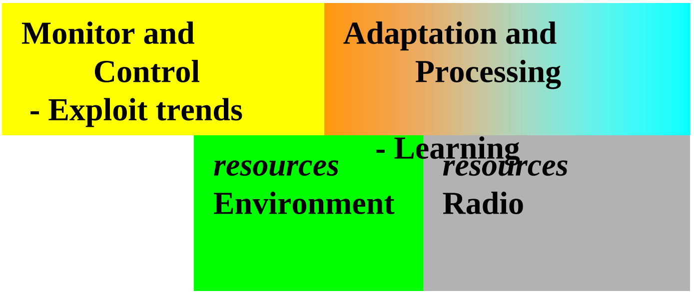
Cognitive radios
can sense their environment and learn how to adapt



Cognitive radios can maintain a quality of service (smart transmitter) and reduce interference to neighboring radios (smart receiver)

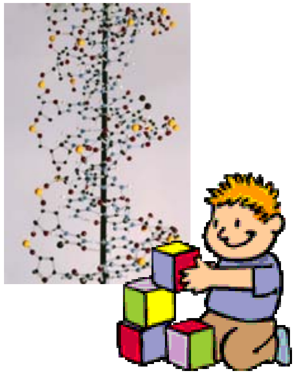
A cognitive radio is not necessarily a software radio!

How can we model a cognitive radio?



- Biological model of cognition
  - **Left brain processing –** “Logical”
  - **Right brain processing –** “Creative”

- Synthesize biological cognition model and genetic algorithms (GA)
  - **Fundamental principles evolve to optimize response through genetic** crossover
  - **Random discoveries and spontaneous inspiration occur through genetic** mutation



Our Approach to Realizing a Cognitive Radio

- Use biologically-inspired genetic algorithms to control and adapt the radios
- Like biological organisms, the radio will play and learn from current and past behavior

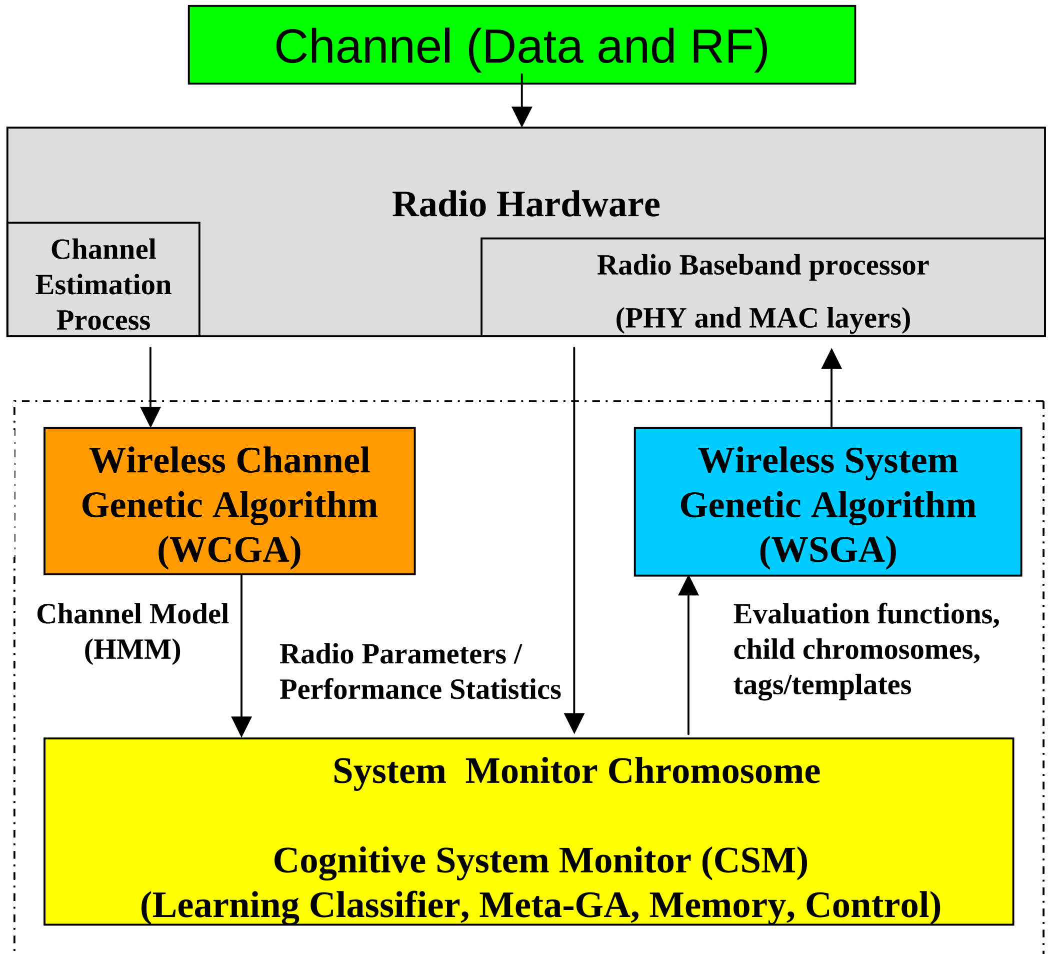
DNA Strand, Gilbert – Apple, 2003
Performing Feats of Bioinformagic
http://www.apple.com/pro/science/gilbert/

- System is designed in terms of chromosomes
  - Represents radio parameters
  - Channel model also encapsulated in a chromosome
- **“Controlled Chaos”**
  - **Allow evolution through unique solutions**
  - **Force compliance with regulations**

Cognitive Radio System Diagram

“Model channel”

“Take action to adapt radio”



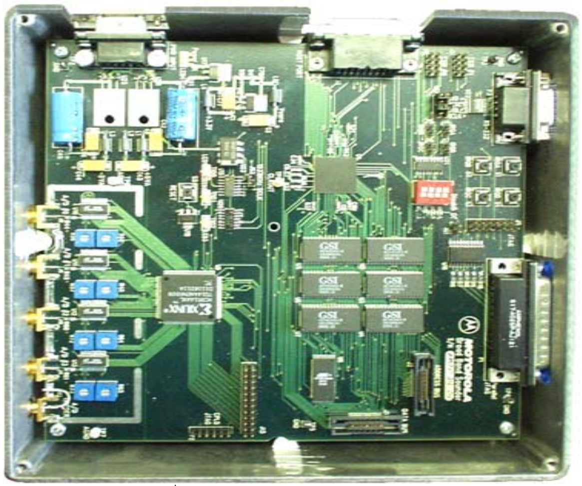
“How to play: Use channel models and radio parameters to enable radio evolution”

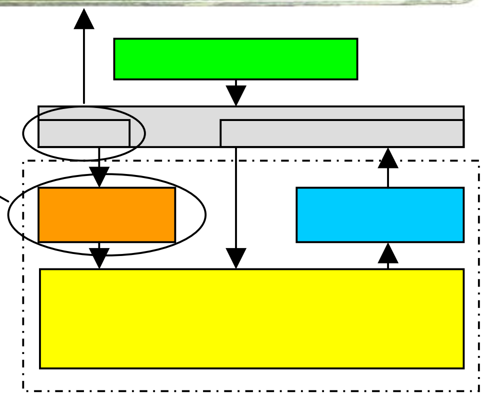
WCGA and HMMs for Wireless Channels

Wireless Channel Genetic Algorithm (WCGA)

The WCGA uses CWT's broadband sounder technology to observe the channel.

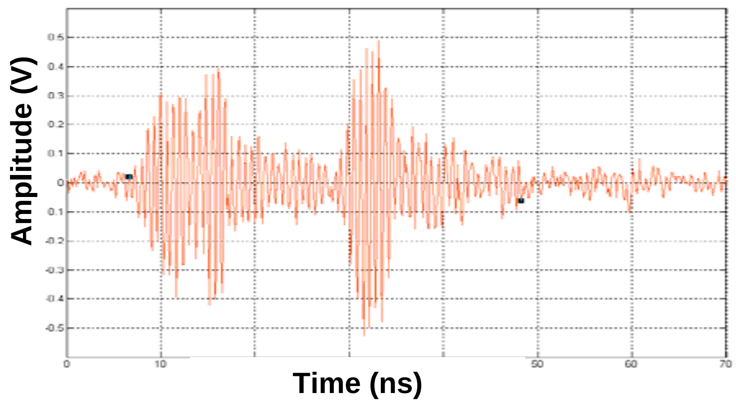
CWT's Broadband Channel Sounder





The channel is then modeled by a Hidden Markov Model (HMM) that is compact and computationally efficient.

WCGA and HMMs for Wireless Channels



Channel Impulse Response

A:

0.8495	0.0932	0.0397	0.0068	0.0086	0.0013	0.0002	0.0005
0.5356	0.3006	0.1415	0.0019	0.0144	0.0043	0.0004	0.0012
0.8531	0.0622	0.0279	0.0210	0.0228	0.0022	0.0064	0.0044
0.9126	0.0159	0.0569	0.0079	0.0027	0.0014	0.0024	0.0001
0.8079	0.1502	0.0153	0.0026	0.0233	0.0001	0.0000	0.0006
0.5376	0.1589	0.0614	0.1659	0.0677	0.0028	0.0017	0.0039
0.7347	0.1712	0.0628	0.0013	0.0001	0.0044	0.0067	0.0189
0.6530	0.3113	0.0149	0.0139	0.0013	0.0004	0.0042	0.0009

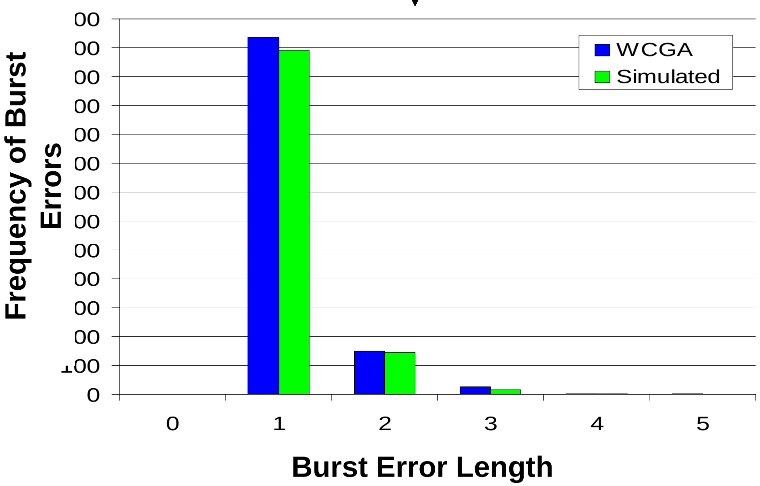
B:

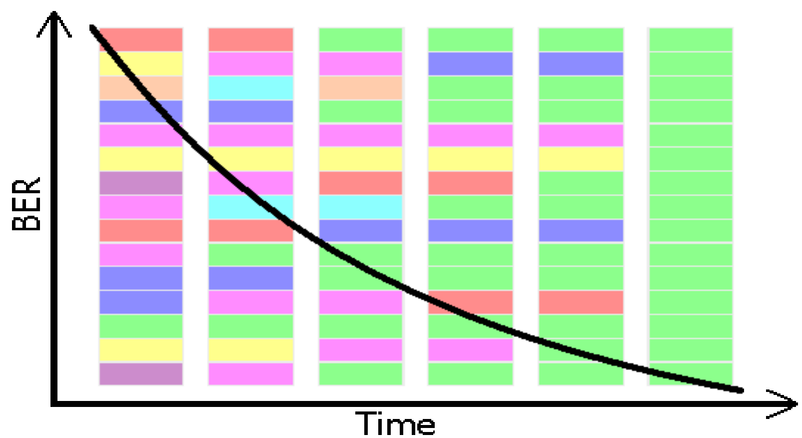
0.8871	0.1129
0.9762	0.0238
0.8137	0.1863
0.0441	0.9559
0.8285	0.1715
0.2553	0.7447
0.2976	0.7024
0.6245	0.3755

π:

0.2602	0.3616	0.3647	0.0120	0.0058	0.0005	0.0000	0.0006

Hidden Markov Model





Radio Adaptation – Improved performance over time

CWT

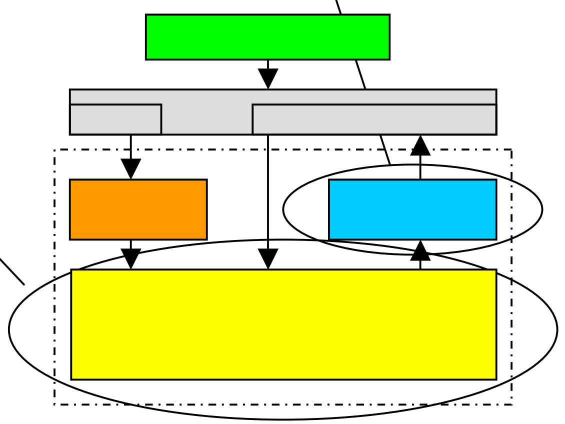
CSM and WSGA for Intelligent Radio Adaptation

The WSGA takes the channel model and information from the CSM to adapt the radio using a Genetic Algorithm.

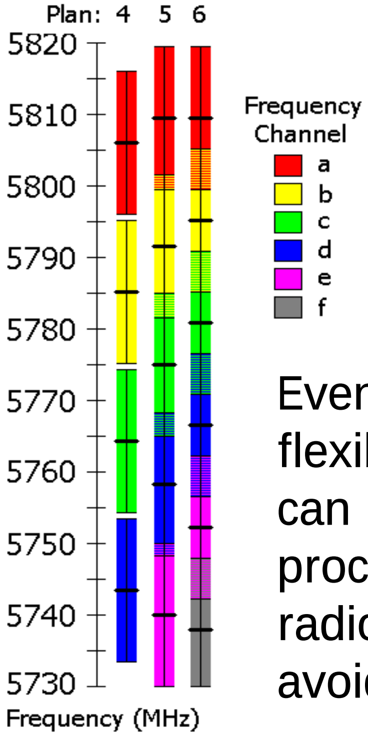
Wireless System Genetic Algorithm (WSGA)

Cognitive System Monitor (CSM) (Learning Classifier, Meta-GA, Memory, Control)

The CSM synthesizes channel model and adaptation process and better directs radio evolution from observed and learned behavior.



Current Work – Proxim Tsunami Radios

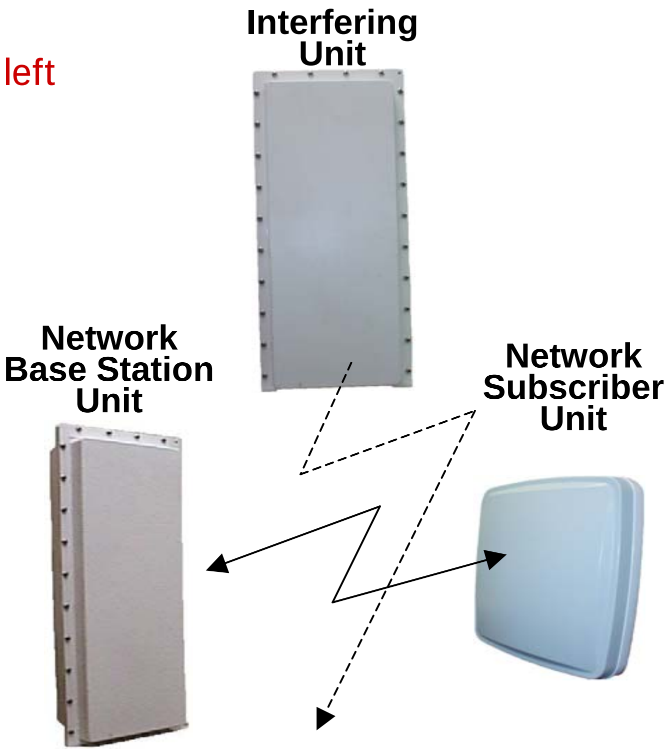


Frequency Channels available to Proxim Tsunamis

Adapting with limited range of adaptable parameters:

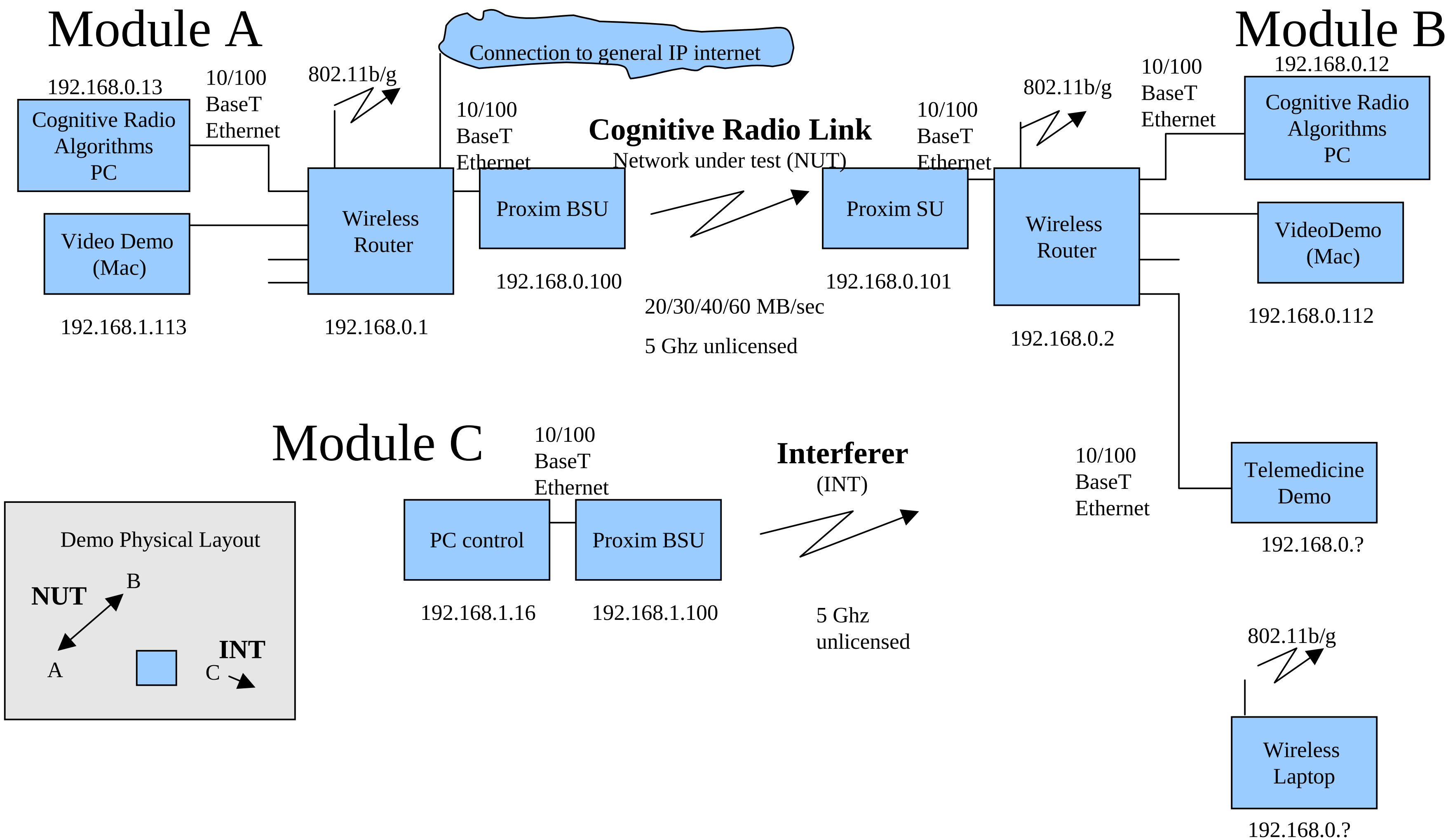
- Modulation: QPSK, QAM8, QAM16
- Power: 6 dBm – 17 dBm
- Frequency: See figure on left
- Uplink/Downlink ratio

Even with this limited-flexibility legacy radio, we can use our cognitive processes to adapt the radio, including the avoidance of an interferer.



Interference Test setup

Cognitive Radio Testbed Demo



Cognitive Radio Testbed Demo

Interferer Broadband Wireless Link

- Cognitive Radio Testbed Link

- Interferer Degrades Broadband Wireless Link

- WSGA evolves radio operation

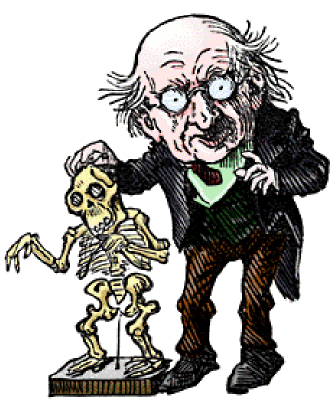
Interferer	Link	→ Link
Tx=11dBm	Tx=6dBm	Tx=16dBm
QAM 16	QAM 16	QPSK 4
Fibs 12	Fibs 22	Fibs 4
3/4 FEC	3/4 FEC	1/2 FEC
Freq=b-5	Freq=a-5	Freq=a-5

- Link quality of service (QOS) is restored even in presence of interferer

Future Work: Building A More Complete Cognitive Radio

Build an adaptive radio

- 88 MHz – 6 GHz
- **100 Mbps data link**
- Programmable power and diversity **techniques**
- **Arbitrary signal constellations for increased modulation capability**
- Programmable MAC layer **for timing, payload sizes, and connection maintenance**



Extend cognitive radio algorithms

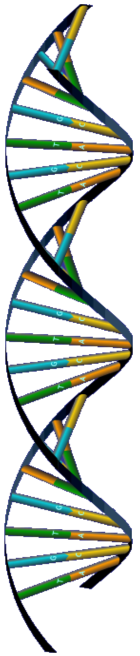
- Include **MAC layer** adaptation using **economic** market analysis models

Improve sensing, modeling, and learning

Future Work: Cognitive Radio Network

- Extend cognitive radio techniques to build network test bed
  - **Analyze cognitive radio network coordination via** economic theory
- Investigate adaptation mechanisms at MAC layer
  - **Apply** genetic algorithm **approach to MAC/Data Link Layer**
  - **Provide a requested** quality of service

Enable dynamic spectrum access



Gene Splicing Presentation
Biotechnology Online
http://www.biotechnology.gov.au/biotechnologyOnline/interactives/gene_splicing_interactive.htm

References

• C.W. Bostian, S. F. Midkiff, W. M. Kurgan, L. W. Carstensen, D. G. Sweeney, and T. Gallagher, “Broadband Communications for Disaster Response”, *Space Communications*, Vol. 18 No. 3-4 (double issue), pp. 167-177, 2002

• C.L. Dillard, T.M. Gallagher, C.W. Bostian, and D.G. Sweeney, “Rough Surface Scattering From Exterior Walls at 28 GHz,” *IEEE Trans. Antennas and Propagation*, in press.

• T.W. Rondeau, C.J. Rieser, T.M. Gallagher, and C.W. Bostian. “Online Modeling of Wireless Channels with Hidden Markov Models and Channel Impulse Responses for Cognitive Radios,” 2004 International Microwave Symposium

Contact Information

Charles W. Bostian bostian@vt.edu

Scott F. Midkiff midkiff@vt.edu

Timothy M. Gallagher tgallagh@vt.edu

Christian J. Rieser cjrieser@vt.edu

Thomas W. Rondeau trondeau@vt.edu

http://www.cwt.vt.edu

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