A Design Workflow for Software Defined Radios

Frederick Weidling
tedjw@ittc.ku.edu

Presented August 22, 2007 to:
Dr. Gary J. Minden
Dr. Joseph B. Evans
Dr. Alexander M. Wyglinski

Acknowledgements

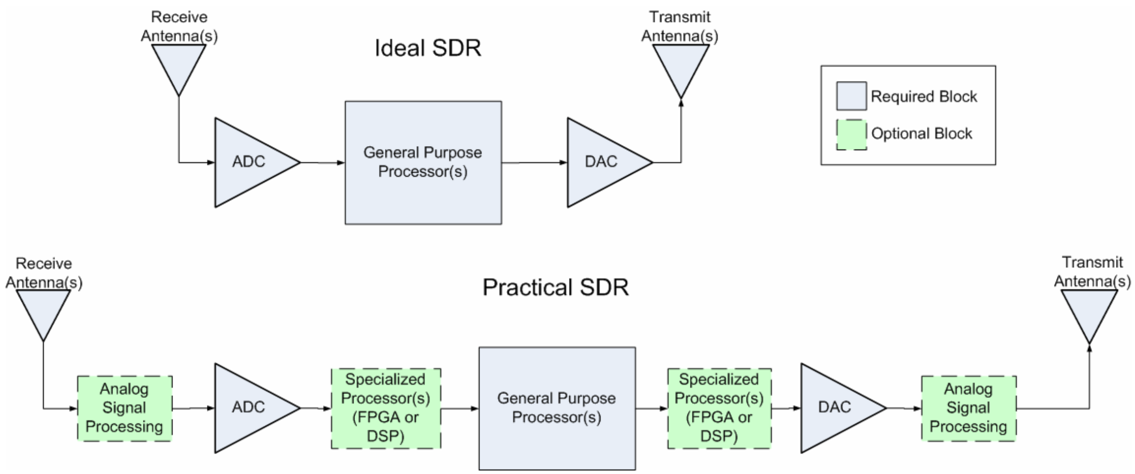
- Defense Committee
  - Dr. Gary J. Minden (Chair)
  - Dr. Joseph B. Evans
  - Dr. Alexander M. Wyglinski
- KU Agile Radio Group
  - Leon Searl and Dan DePardo
  - Jordan Guffey, Rory Petty, Tim Newman, Brian Cordill, Dinesh Datla, Rakesh Rajbanshi, Qi Chen, and Megan Peck

Outline

- Background
  - Software Defined Radios (SDR)
  - Dynamic Spectrum Access (DSA)
- Proposed Research
  - A workflow for SDRs
- Validation
  - Apply design workflow to KUAR
  - Generate systems
- Extension
  - Generic SDR API
  - Hardware Agnostic Cognitive Network
- Conclusion

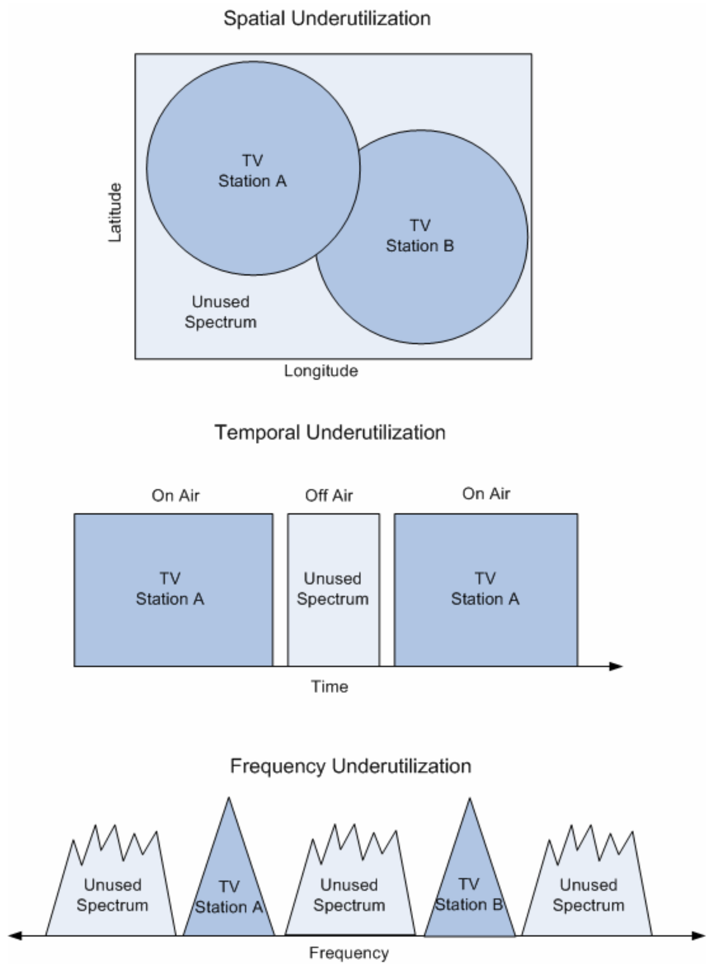
What is an SDR?

- Ideal SDR
  - Direct conversion between digital samples and analog waveform
  - Use only general purpose processors (GPP)
  - Unrealistic for high frequencies – cost, processor speed, algorithm complexity
- Practical SDR
  - Baseband processing, analog components translate to transmission band
  - Optimizations using digital signal processors (DSP) and field programmable gate arrays (FPGA)



Why do we need SDRs?

- FCC “Command-and-Control” Policy Limits
  - What can be transmitted
  - Who can transmit
  - Where they can transmit
- Results in apparent spectrum scarcity
  - Restricts research and novel services
  - New York 13.1% utilization 3.0 MHz – 3.0 GHz
  - TV utilization often less than 50%
- Solution: SDRs



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Dynamic Spectrum Access

- SDR detects unused frequencies (whitespace) and utilizes them
- Cognitive Radio (CR)
  - Radio which adapts to its environment
  - Cognitive algorithms implemented on SDR platforms
- Dynamic Spectrum Access (DSA)
  - Avoid licensed users
  - Utilize whitespace

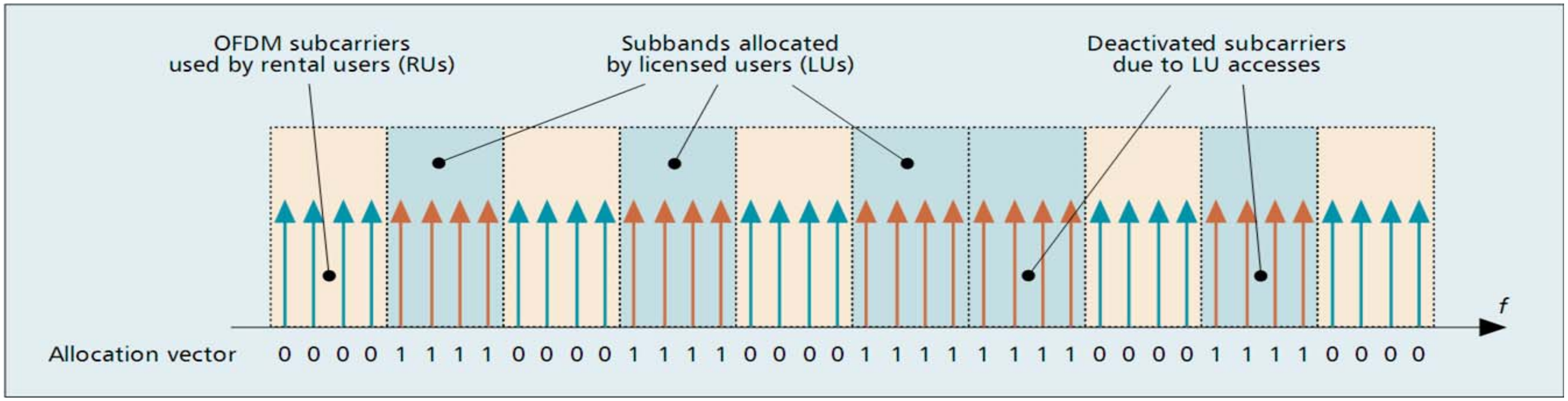


Image From "Spectrum Pooling an Innovative Strategy for the Enhancement of Spectrum Efficiency," by T. Weiss and F. Jondral

Current SDR Technologies

- Universal Serial Radio Peripheral (USRP)
  - Generic RF front-end
  - Modular transmit/receive bands
- GNU Radio
  - Open source SDR software
  - Only supports general purpose processors
  - Based around USRP
- Global Mobile (GloMo) API
  - Generic radio modem API
- Software Communications Architecture (SCA)
  - CORBA based communications model for SDR modules
- Joint Tactical Radio System (JTRS)
  - SDR platform commissioned by Defense Advanced Research Projects Agency (DARPA)
  - Built using SCA

The KU Agile Radio (KUAR)

- Digital Board
  - 1.4 GHz Pentium M
  - 1 GB RAM & 8 GB microdrive
  - PCI Express, USB, 1 Gb ethernet
  - 160 MSPS Digital-to-Analog Converter (DAC)
  - 105 MSPS Analog-to-Digital Converter (ADC)
  - Xilinx Virtex II Pro 30 FPGA
- RF Front-End
  - Modular
  - 5.25 GHz – 5.85 GHz UNII Research Band
  - Receiver sensitivity -100 dBm
  - Transmitter power +25 dBm
  - Quadrature modulation & demodulation
  - Baseband bandwidth of 30 MHz

SDR: A Federation of Components

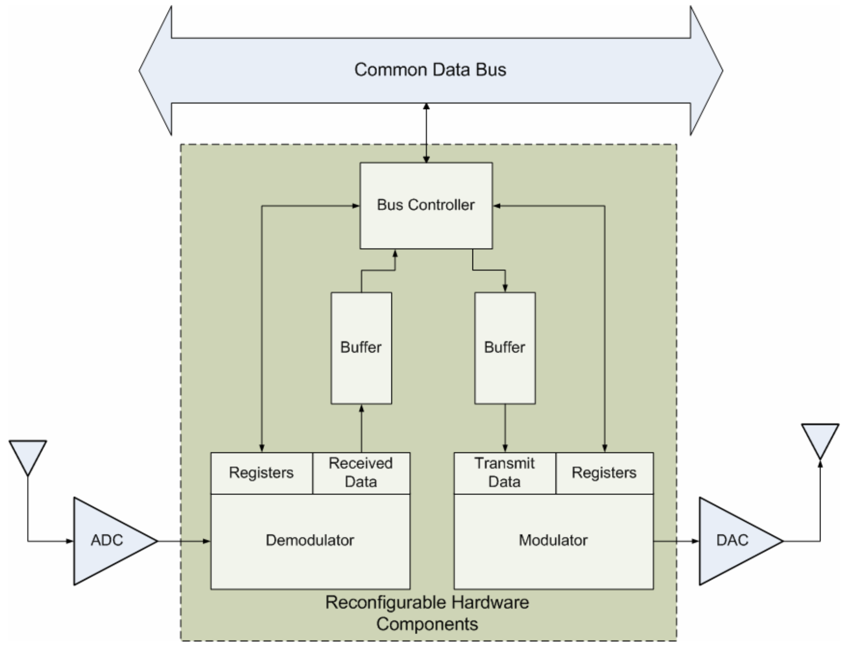
- Variety of components must work in unison to transmit/receive
  - General purpose processors
  - Special purpose processors (FPGA, Microcontrollers)
  - Frequency synthesizers
  - Modulators/Demodulators
  - Attenuators
- Different types of design problems on SDR
  - Cognitive network design
  - Real time data management
  - Communication systems

Development Domains

- Break the problem into domains
  - Reconfigurable hardware domain aimed at Communications Engineers
  - Embedded software domain aimed at System Engineers
  - Radio management domain aimed at Network Engineers and general radio maintenance
- Each domain has its own workflow requirements
  - Different set of development tools
  - Each domain's toolset must support designing, implementing, and verifying modules
  - Domains interact but implementations are independent

Reconfigurable Hardware Domain

- Implement physical layer communication systems
  - Direct access to ADC/DAC
  - Signal processing optimizations possible in FPGA
- Generic memory elements need to be provided
  - Bus controller
  - Buffers (FIFOs, RAMs)
  - Registers (Status, Control)



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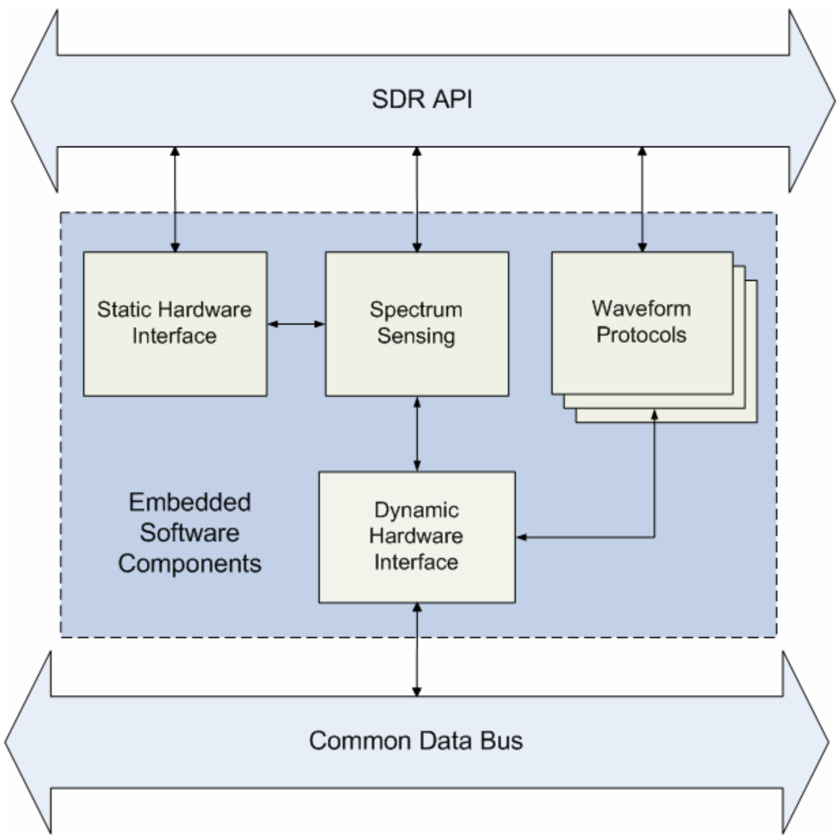
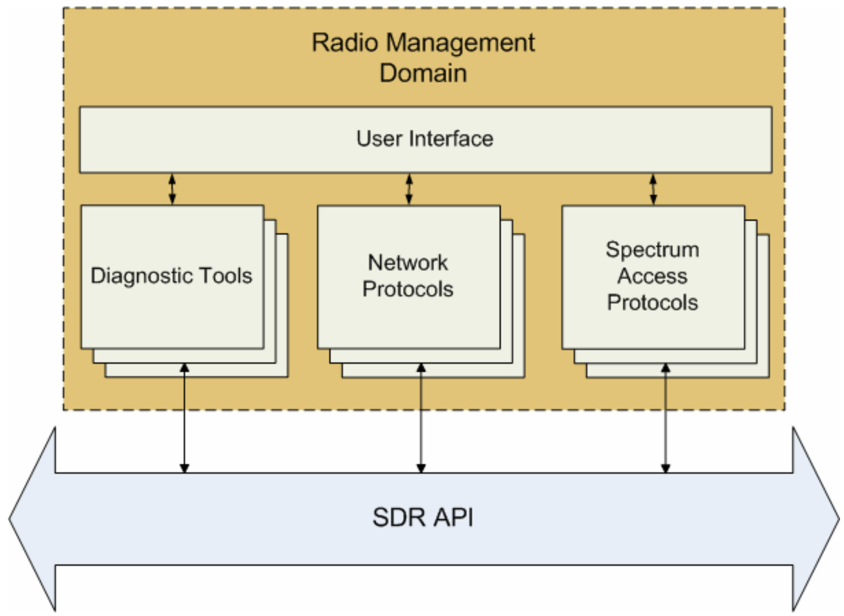
Embedded Software Domain



- Manage hardware interfaces and data streams
- Components
  - Dynamic Hardware Interface: configure/communicate with reconfigurable hardware
  - Static Hardware Interface: communicate with RF modules and sensors
  - Spectrum Sensing: perform spectral sweeps
  - Waveform Protocols: physical layer protocols

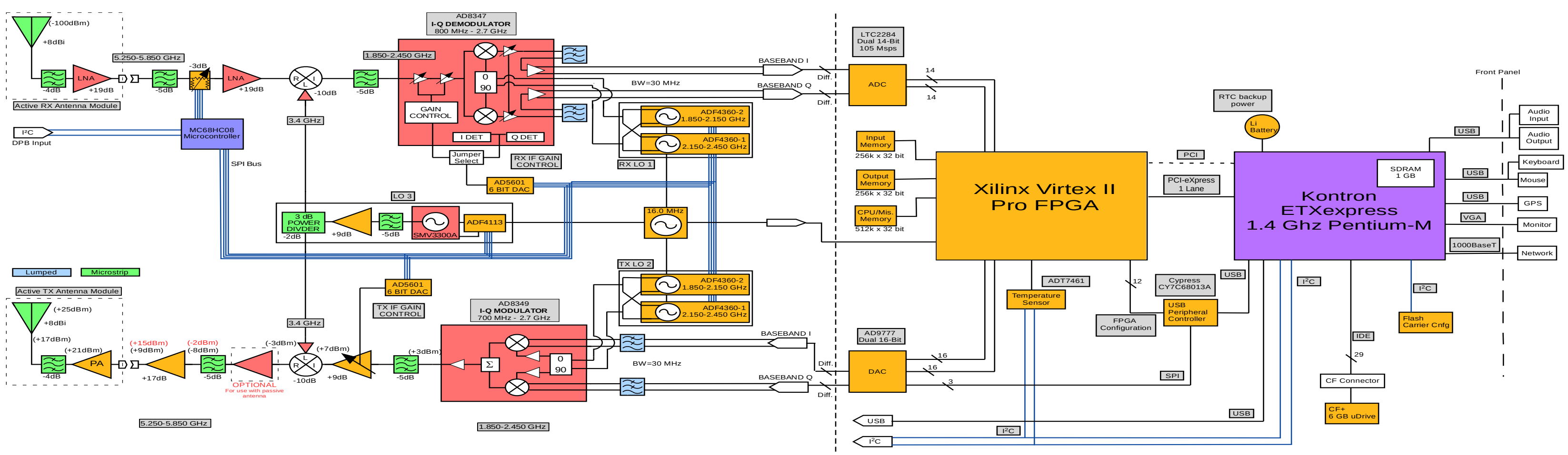
Radio Management Domain

- Radio Management
  - Diagnostic tools
  - Network protocols
  - Spectrum access protocols
- User interface enables network tests
  - Control multiple radio nodes
  - Define co-operative tests
  - Display results



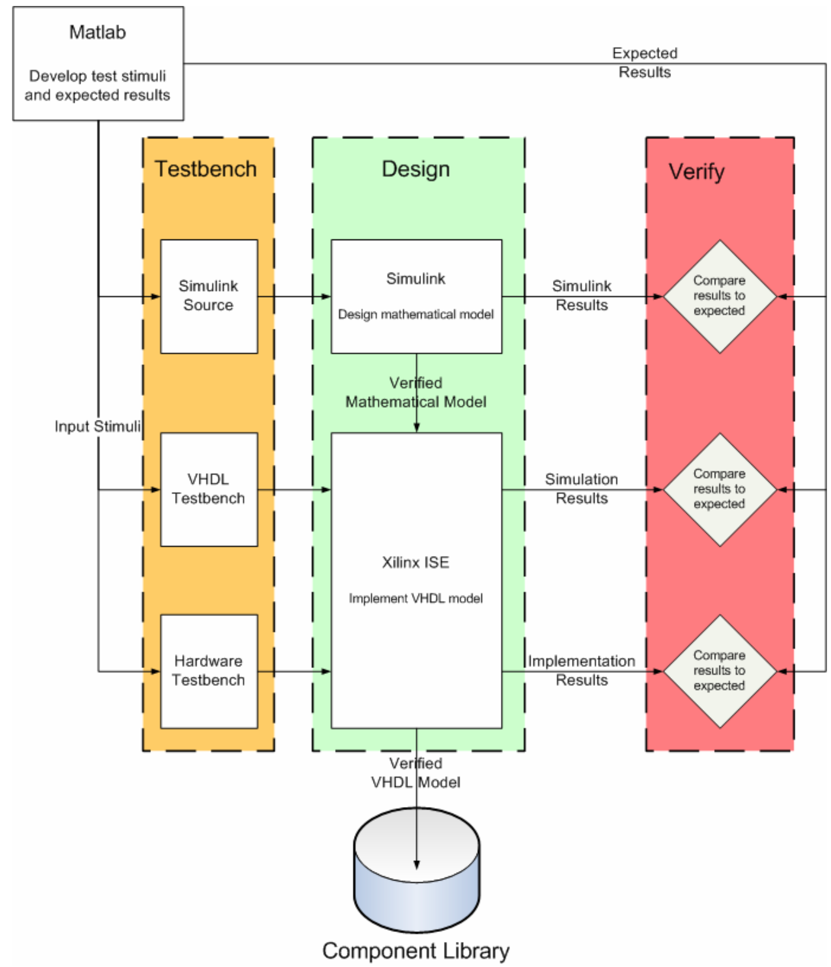
Implementation on the KUAR

- Reconfigurable Hardware Domain
  - Xilinx Virtex II FPGA
  - PCI, PCIe, or USB bus
- Embedded Software Domain
  - 1.4 GHz Pentium M with 1 GB RAM
- Radio Management Domain
  - Remote KUAR interface



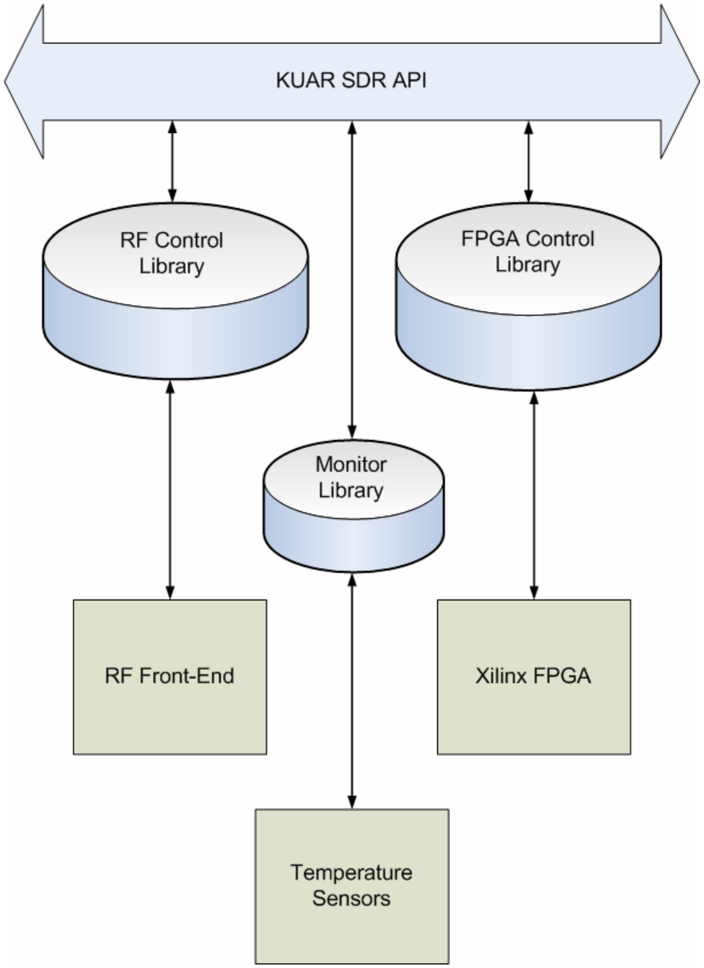
Communication Systems

- Development tools
  - Develop using Matlab/Simulink
  - Implement using Xilinx VHDL
  - Verify with Simulink, Modelsim, and hardware test bench
- Test cases translated down flow
- Verified components added to shared library
- Systems Built
  - BPSK, MQAM, OFDM, Spectrum Analyzer, …

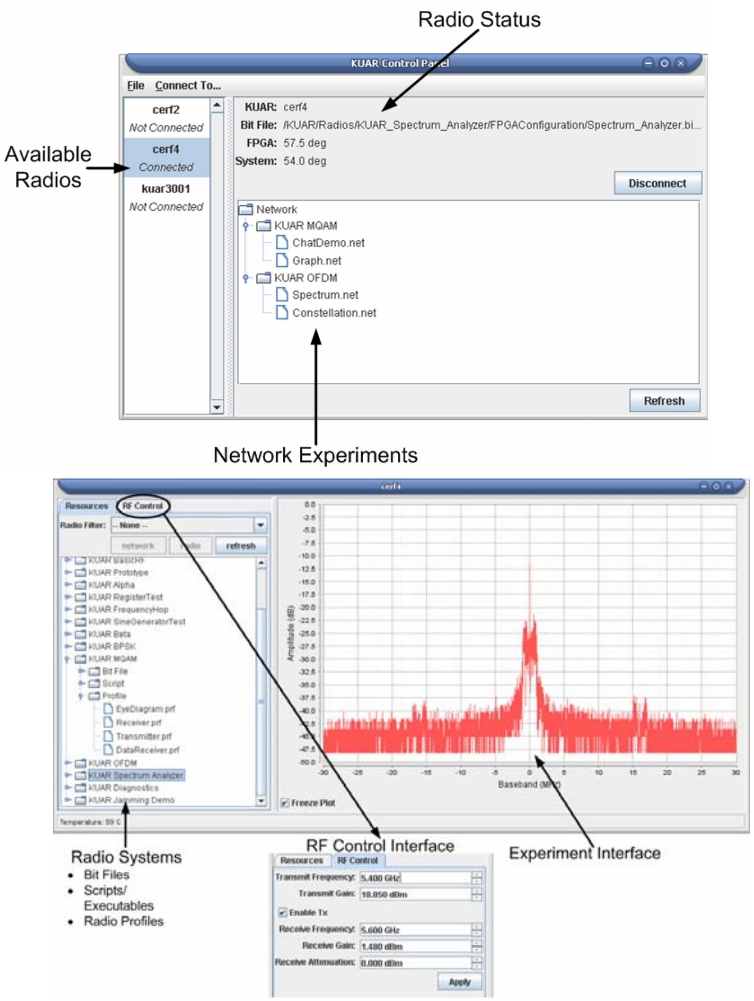


Support Libraries

- Development tools
  - Implement using GCC & GNU Makefile
  - User validation & cUnit
- FPGA Library
  - Configure bit file
  - Read from and write to hardware configurations
- RF Control Library
  - Manage the RF front-end
  - Set and get frequencies and gains
  - Query hardware capabilities
- Monitor Library
  - Monitor system temperatures



The KUAR Control Panel



- Control multiple radios from one interface
  - Radio status
  - Configure radio profile
  - Control RF front-end
- Define network and single radio tests
  - Test definitions XML based
- Extendable interface
  - Java based remote KUAR API
  - Programmable test window

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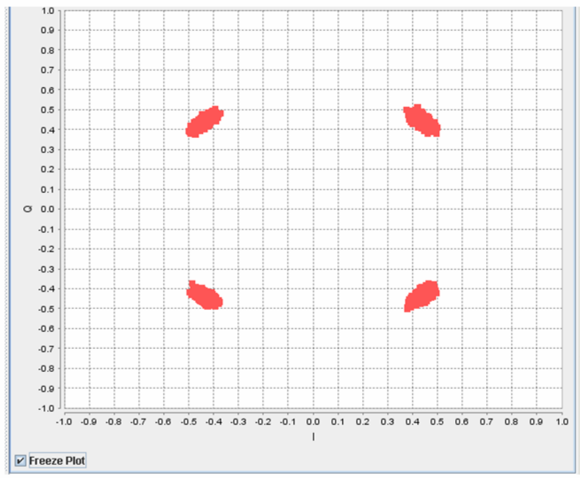
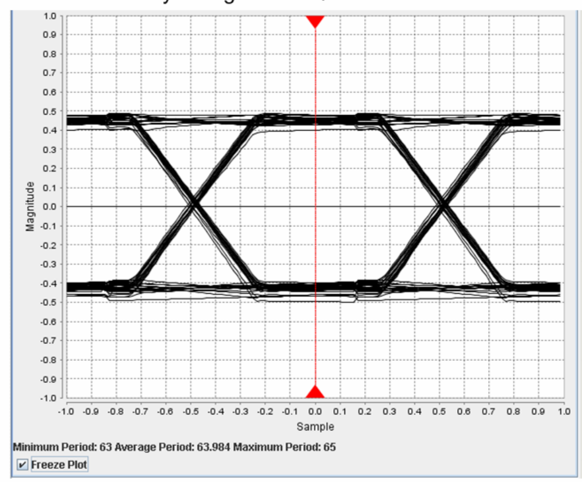
KUAR Control Panel: Visualizations

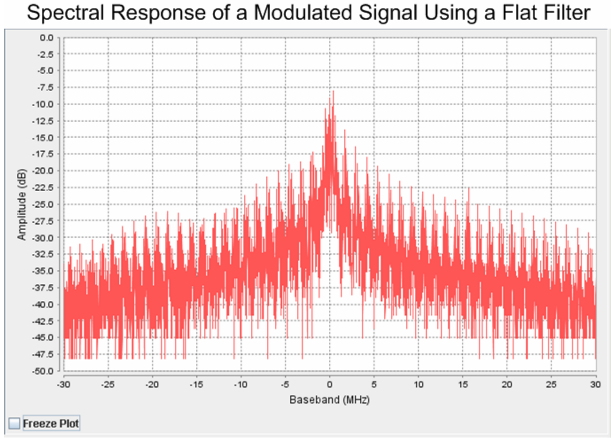
Constellation for QPSK Transmitter



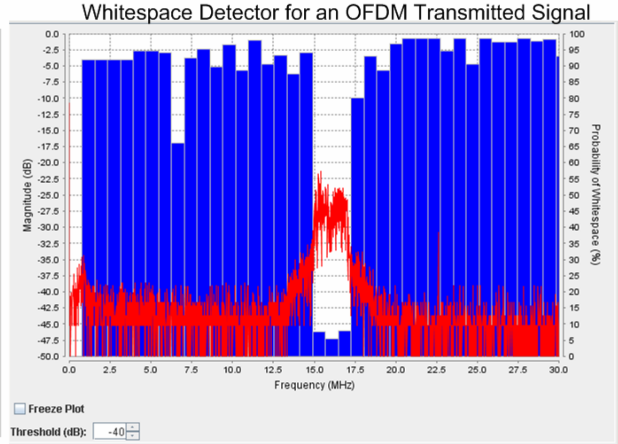
Eye-Diagram for QPSK Transmitter



Spectral Response of a Modulated Signal Using a Flat Filter



Whitespace Detector for an OFDM Transmitted Signal



Achievements

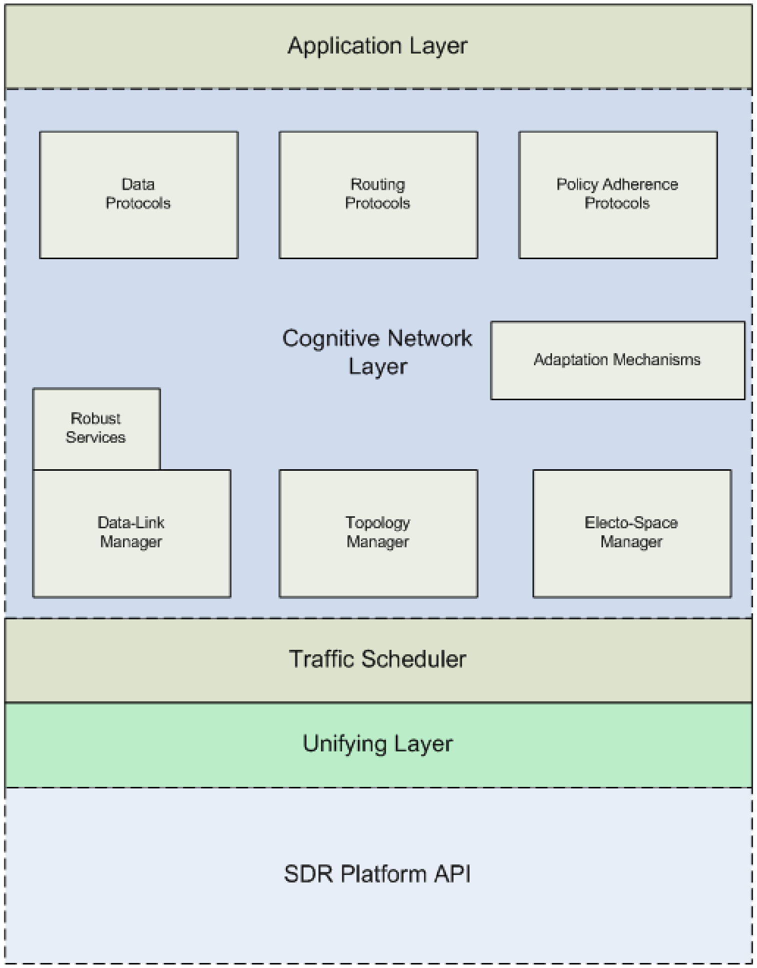
- Developed design workflows to handle
  - Reconfigurable hardware
  - Embedded software
  - Radio management
- Implemented on the KUAR
  - Communications systems
    - BPSK, QPSK, OFDM
  - KUAR API
    - RF Control, FPGA Control, Monitoring libraries
  - Analytical systems
    - Whitespace detector, spectrum analyzer

Enabling Generic SDR Development

- Physical layer implementations often tailored to system
  - Dependent on sampling rates
  - Optimized for parallel and signal processing
  - Hard real-time deadlines
- Cognitive algorithms are complex but more generic
  - Wide variety of issues: whitespace, battery life, channel characteristics, noise power, …
  - Complex solutions: frequency selective modulation, expert systems, genetic algorithms, ontology based systems, …
- Should be able to re-use cognitive algorithms

Hardware Agnostic Network Stack

- SDR Platform API handles the physical layer implementations
- Unifying Layer exposes generic SDR interface
- Traffic Scheduler manages access to shared RF front-end
- Cognitive Network Layer is independent of SDR implementation platform



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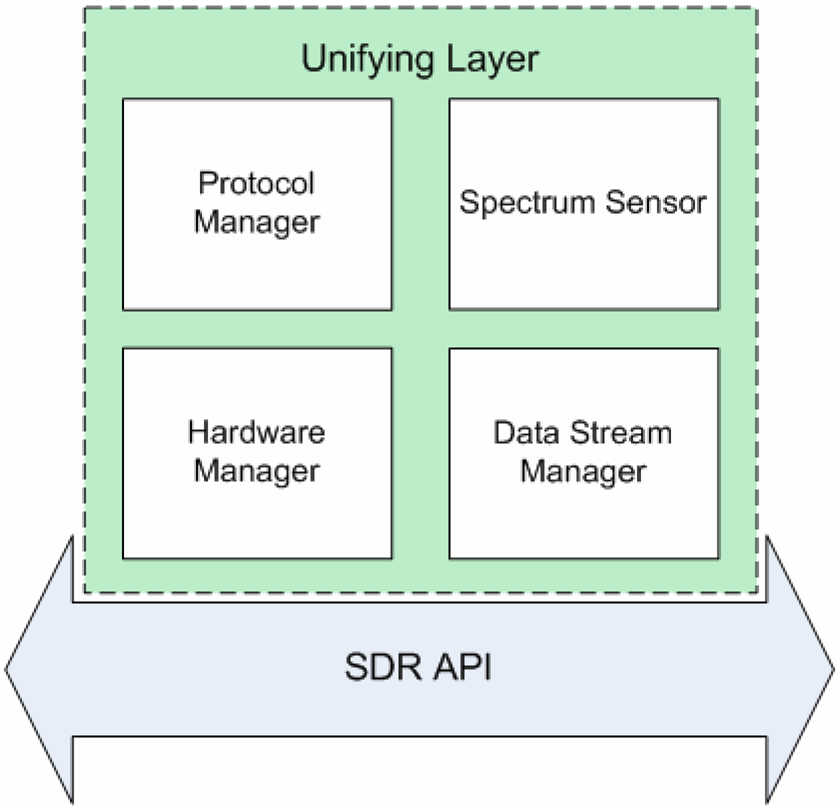
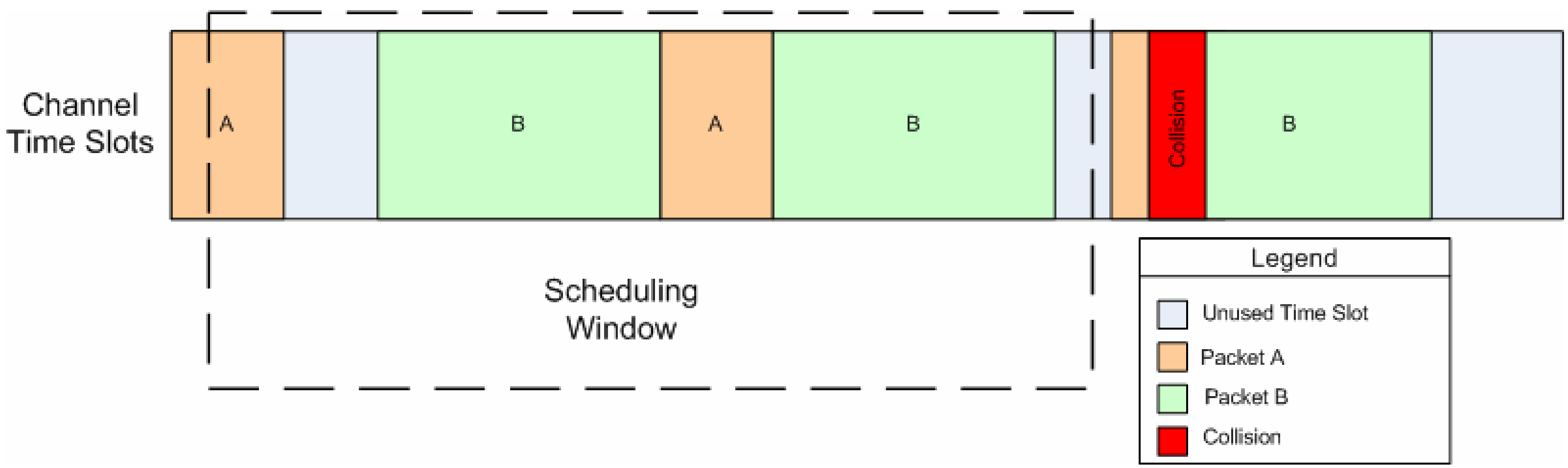
Unifying Layer



- Hardware Manager
  - List hardware capabilities
  - Control RF front-end
- Protocol Manager
  - List waveform protocols
  - Manage waveform protocols
- Spectrum Sensor
  - Handle spectral sweeps
- Data Stream Manager
  - Similar to GloMo API
  - Interact with configured waveform protocols

Traffic Scheduler

- Schedule packets to channels
  - Channel is a hardware digital/analog chain
  - Scheduled packet includes protocol, frequency, power, and time frame
  - Each channel has an allocation list
- Packets are scheduled in a sliding window
  - Packets may be scheduled periodic or single-shot
  - Call back interface for error states and packet completion



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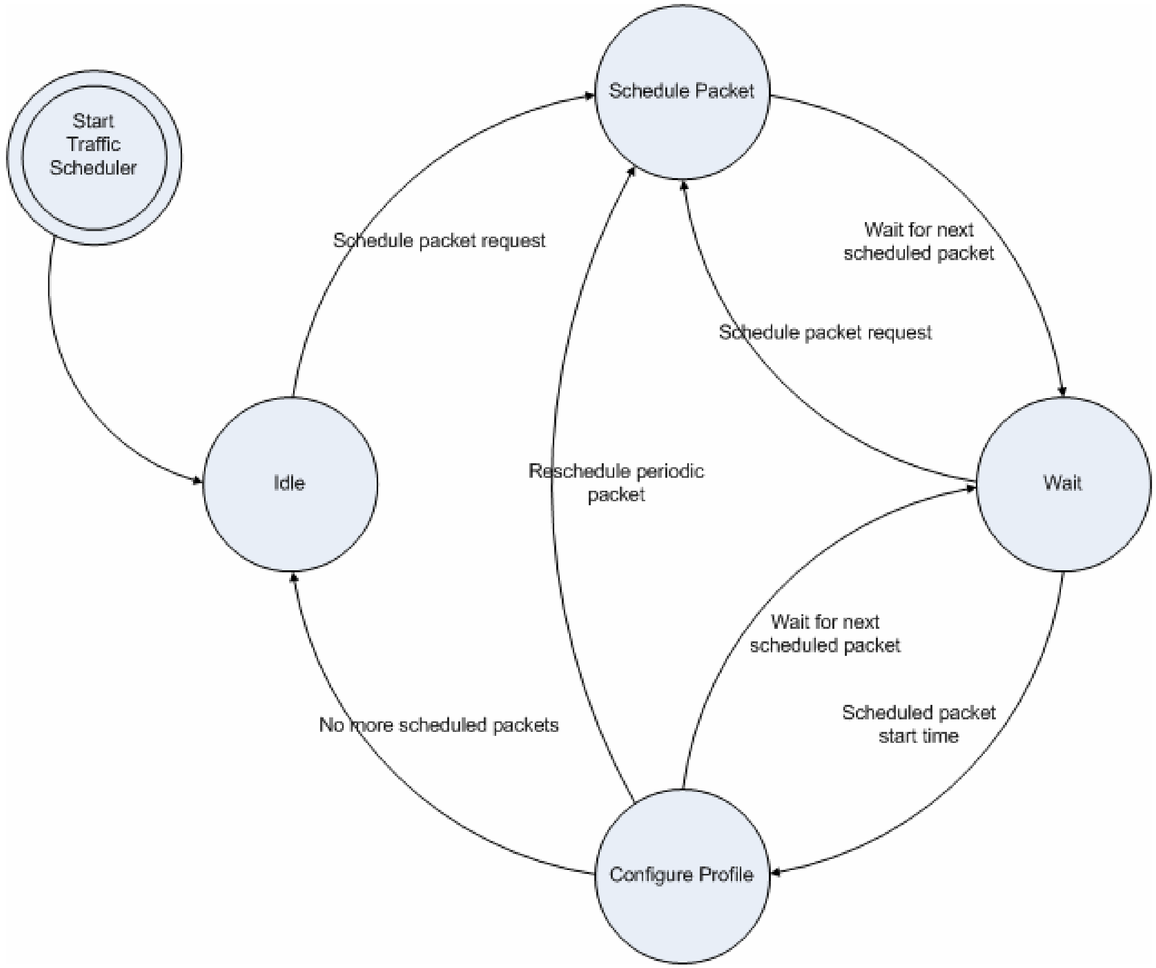
Traffic Scheduler: State Diagram



Conclusion

- Achievements
  - Developed a design workflow for SDRs
  - Workflow used to develop systems for KUAR
  - Proposed generic SDR API (Unifying Layer)
  - Described infrastructure to support hardware agnostic cognitive networks
- Future work
  - Implement hardware agnostic network stack
  - Develop more robust cognitive algorithms for KUAR
  - Apply workflow to another SDR platform

Resources

- SDR Resources
  - SDR Forum: http://www.sdrforum.org/
  - Wikipedia Article: http://en.wikipedia.org/wiki/Software-defined_radio
- Publications
  - G. J. Minden, J. B. Evans, L. Searl, D. DePardo, R. Rajbanshi, J. Guffey, Qi Chen, T. Newman, V. R. Petty, F. Weidling, M. Lehnherr, B. Cordill, D. Datla, B. Barker, A. M. Wyglinski, A. Agah, "An Agile Radio for Wireless Innovation" *IEEE Communications Magazine*, Vol. 45, Issue 5, pp 113-121, May, 2007.
  - V. R. Petty, R. Rajbanshi, D. Datla, F. Weidling, D. DePardo, P. J. Kolodzy, M. J. Marcus, A. M. Wyglinski, J. B. Evans, G. J. Minden, J. A. Roberts, "Feasibility of Dynamic Spectrum Access in Underutilized Television Bands" in *Proceedings of the 2nd IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySpan 2007)*, (Dublin, Ireland), April 2007.
  - G. J. Minden, J. B. Evans, L. Searl, D. DePardo, V. R. Petty, R. Rajbanshi, T. Newman, Q. Chen, F. Weidling, J. Guffey, D. Datla, B. Barker, M. Peck, B. Cordill, A. M. Wyglinski and A. Agah, "KUAR: A Flexible Software-Defined Radio Development Platform" in *Proceedings of the 2nd IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySpan 2007)*, (Dublin, Ireland), April 2007.
  - F. Weidling, D. Datla, V. Petty, P. Krishnan, and G. J. Minden, “A Framework for RF Spectrum Measurements and Analysis,” in *Proceedings of the 1st IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySpan 2005)*, (Baltimore, MD, USA), pp. 573– 576, Nov. 2005.
- Questions?