Network Layer with High Performance of Cognitive Radio networksPlatform

M.Y.Babu[1]Machha.Narender[2]M.Mohan Rao

GJCST Classification C.2.2,C.4

***Abstract*-Network Layer with Radio networks High Performance Platform" being developed under the NSF NeTS ProWIN (programmable wireless networks) grant CNS-0435370. The network-centric cognitive radio architecture under consideration in this project is aimed at providing a high-performance platform for experimentation with various adaptive wireless network protocols ranging from simple etiquettes to more complex ad-hoccollaboration. Particular emphasis has been placed on high performance in a networked environment where each nodemay be required to carry out high throughput packet forwarding functions between multiple physical layers. Keydesign objectives for the cognitive radio platform include 1.multi-band operation, fast frequency scanning and agility;**

2.software-defined modem including waveforms such as DSSS/QPSK and OFDM operating at speeds up to 50 Mbps;

3.packet processor capable of ad-hoc packet routing with aggregate throughput 100 Mbps; 4.Spectrum policyprocessor that implements etiquette protocols and algorithmsfor dynamic spectrum sharing

I. Cognitive Radio Architecture & Design

The cognitive radio prototype' s architecture is based on four major elements: (1) MEMS-based tri-band agile RF front-end, (2) FPGA-based software defined radio (SDR); (3) FPGA-based packet processing engine; and (4) embedded CPU core for control and management. Thesecomponents will be integrated into a single prototype board which leverages an SDR implementation from Lucent Bell Labs as the starting point. A proof-of-concept demonstration
board is planned for the end of year 2 (Sept 2006), and several prototype boards will full functionality are expected to be ready at the end of year 3 (Sept 2007).

The network-centric cognitive radio architectureunder consideration in this project is aimed atproviding a high-performance platform forexperimentation with various adaptive wirelessnetwork protocols ranging from simple etiquettesto more complex ad-hoc collaboration. Thebasic design provides for fast RF scanning capability, an agile RF transceiver working over a range of frequency bands, a software-defined radio modem capable of supporting a variety ofwaveforms including OFDM and DSSS/QPSK, a packet processing engine for protocol androuting functionality, and a general purposeprocessor for implementation of spectrumetiquette policies andalgorithms.The proposed architecture along with theassociated partitioning of design/prototyping responsibilities between Rutgers, GA Tech and Lucent is shown in Figure 1.1 below

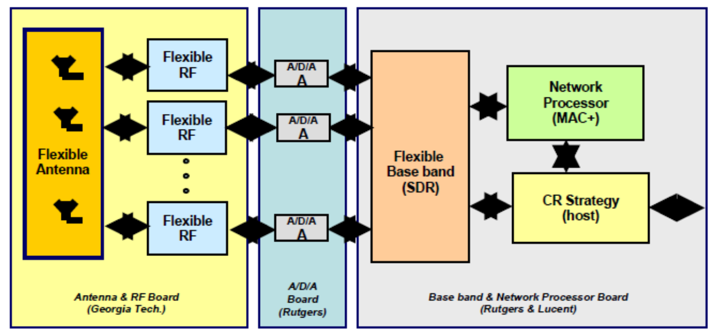


Figure 1.1 - Architecture of network-centriccognitive radio networks platform

In the original proposal, we identified the need for a base band and network processor board that would interface to the RF front-end and allow dynamically reconfigurable software and hardware implementations of multiple wirelesslinks supporting individual data rates up to50Mb/s and a maximum aggregate data rate of100 Mb/s. It was expected that this board wouldcontain some mix of DSP and FPGA blockstogether with their required memories. At thefirst coordination meeting in 4Q2004, we made adecision to avoid the use of DSP' s because of thedifficulty associated with programming thesedevices. Rather, we decided to use acombination of FPGA for hardwareimplementation and embedded RISC forsoftware implementation. Embedded RISC mcannot match the cost and power efficiency of aDSP, but it was felt that ease of programmingwas of more importance in an experimental platform – especially one that would be used bystudents. The group also decided to aim for triband(700 MHz, 2.4 GHz and 5.1 GHz)capabilities using a novel MEMS device fromGA Tech – this was viewed as an importantflexibility feature for an experimental platformof this type. The analog front-end would alsosupport two channels, one for measurement andone for data, with bandwidths selectable in 1MHz increments.

A. Hardware architecture

Even though the prototyping effort is focused on an FPGA-based design, we are also exploring the architectural benefits of custom integrated circuitry, primarily related to power consumption and the silicon area, which are important performance parameters for hardware designs used in

About-[1]Asst.Professor, Aurora Engg College
e-mail-mannavababu@gmail.com
About-[2]Asst.Professor, HITS College of Engg
(e-mail- machha.narender@gmail.com)
About-[3]Asst.Professor, Tirumala Engg College
(e-mail-mohanrao19@yahoo.com)

mobile/portable platforms. The approach we have chosen to take involves identifying the hardware architecture appropriate for low-power configurable design based on heterogeneous blocks (i.e. blocks that are highly optimized for aparticular function, yet flexible enough to support a variety of configuration parameters) as a compromise for the tradeoff between programmability and power consumption/area. In addition to fast prototyping, the additional benefits of using modern FPGAs (e.g. Xilinx Virtex 4) are the availability of highly optimized features implemented as non-standard configurable logic blocks (CLB) like phaselocked loops, low-voltage differential signal, clock data recovery, lots of internal routing resources, hardware multipliers for DSP functions, memory, programmable I/O, and microprocessor cores. These advantages simplify mapping from hierarchical blocks to FPGA resources.

The hardware design effort started with anevaluation of architectures presentlyavailable for base band SDR processingat rates of 50-100 mbps. All thesearchitectures use massive hardwareparallelism to sustain high data rate. Wealso looked at the base band processingrequirements of different wirelessstandards such as 802.11a/b, Bluetoothand WCDMA, and found that differentstages of base band processing have verydifferent hardware needs. Thus, using ageneric hardware design leads toinefficient usage of chip area and powerconsumption. As a result, we proposed a "heterogeneous block-based architecture" which would help implement SDR baseband processing in an efficient way. Anadditional feature is the ability toefficiently reconfigure blocks in a fewclock cycles to facilitate fastchangeover between multiple SDRphysical layers.

B. Heterogeneous block-based architecture

The heterogeneous-block based architecture (see Figure 1.2 below) combines a general microprocessor with special purpose hardware blocks. The microprocessor containing multiplier/accumulator units handles control intensive operations such as channel estimation, synchronization, and programming and interconnection of the heterogeneous blocks, while data intensive operations are handled by the heterogeneous blocks. The following heterogeneous-blocks have been identified:

1. Channel utilization Block: A configurable multi-stage filter used toselect a sub-band and/or decimate theinput signal for different standards
2.FFT/MWT Block: A configurablearchitecture which can handle FFToperations used in OFDM and alsohandle the modifier Walsh transformused in 802.11b.
3. Rake Block: A generic four fingerRake accelerator for channel estimation,de-spreading in DSSS and CDMA.
4. Inter leaver Block: Using a blockbasedmemory and multiplexer-basedaddress handler, a multi-modearchitecture can handle de-interleavingfor different standards.
5. Data and Channel Encoding/Decoding Block: A configurablearchitecture can handle both Viterbi (for802.11a) and Encoder/Turbo Decoder(for WCDMA). Both the Data andChannel Encoder have a similar connection pattern, but only the Data Encoder needs feedback. A commonblock is proposed which can beconfigured in one clock cycle to perform either of the twofunctionalities.
6. Detection and Estimation Block: Common interference detection block.

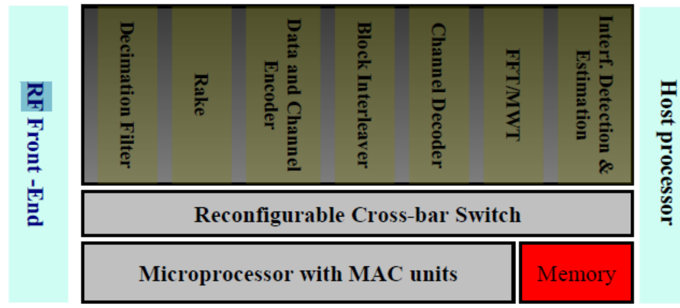


Figure 1.2 - Heterogeneous Blocks based Base band Processor Architecture

The hardware design effort started with an evaluation of architectures presently available for base band SDR processing at rates of 50-100 mbps. All these architectures use massive hardware parallelism to sustain high data rate. We also looked at the base band processing requirements of different wireless standards such as 802.11a/b, Bluetooth and WCDMA, and found that different stages of base band processing have very different hardware needs. Thus, using a generic hardware design leads to inefficient usage of chip area and power consumption. As a result, we proposed a "heterogeneous block-based architecture" which would help implement SDR base band processing in an efficient way. An additional feature is the ability to efficiently reconfigure blocks in a few clock cycles to facilitate fast changeover between multiple SDR physical layers.

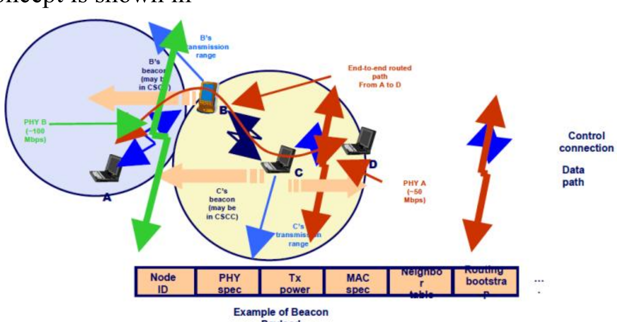
Ongoing work is aimed at creating animplementation of the above SDR design usingavailable FPGA boards and conductingevaluations on flexibility and performance. The packet processing engine's architecture will alsobe considered during the remainder of thisreporting year. The goal is to have both SDRand packet processor FPGA implementationstested and evaluated by the end of 2005.

II. Spectrum Scanning Algorithms

An important aspect of the cognitive radioplatform is its ability to opportunistically useportions of the spectrum that are not being used,which requires the ability to efficiently scanspectrum usage. Furthermore, it is veryimportant to detect and identify types ofinterference that the platform is facing. Thisbecomes increasingly difficult for arbitrary radiosystems. Thus we can focus on an OFDM radioplatform because it allows a simplecharacterization of interference in terms of theOFDM sub carriers. A project on spectrum detection algorithms was carried out in order to understand the computational complexity and response times for the scanning receiver. In order to solve this detection and estimation problem, we used an eigen value decomposition of the sample covariance matrix of the received signal. This analysis was performed using computer simulations for two common sources of interference: a microwave oven and a Bluetooth radio. Simulations carried out show that the influence of an interfering signal on the OFDM system depends on the power of the interfering signal and the data rate in the OFDM system (this system supports the following data rates: 6, 9, 12, 18, 24, 36, 48 and 54 Mbps). As expected, the BER of the system increases with the increasing power of the interfering signal and increasing data rate of the OFDM system. In the presence of the microwave oven signal, only one of the 64 eigen values of the covariance matrix is affected. In the presence of the Bluetooth radio interference, several eigen values will be affected. The number of affected eigen values in this case is proportional to the power of the interfering signal. In the future work, we will examine how multiple radios can collaborate in the detection of interferers, including the development of protocols for the exchange and aggregation of measurements.

III. Adaptive Network Protocols

In parallel to SDR and packet processor designwork described above, a project has been startedon adaptive network protocols and relatedalgorithms. In particular, we are studying theconcept of an adaptive wireless network bootstrapped from the CSCC etiquette protocolpreviously developed at WINLAB. The CSCCprotocol (which uses a broadcast beaconmechanism to inform neighboring radios ofsignal properties) is being extended to includeinformation necessary for self-organization intoa collaborative network of cognitive radios.Information on transmit power, PHY speeds,channel quality and aggregated routinginformation is added to the beacon to facilitateself-organization. This concept is shown in



below Figure 1.3

Figure 1.3 - Concept for CSCC-based selforganization
In a cognitive radio network

A preliminary evaluation of the protocol concepts is planned for year 2 of the project using a GNU radio extension to the ORBIT radio grid test bed. A GNU radio kit has been procured and an RF front end module is being developed for subsequent use as softwaredefined ORBIT radio node extension.

IV. Security

One of the factors which should be considered during design process of CRN emergency network is security of the network infrastructure and security of transmitted information. Without proper network security terrorists responsible for the disaster would be able to eavesdrop emergency information and utilize it for future attacks. Moreover the some of the possible methods of attacks on CRN and ways of prevention:

Licensed user emulation attack: Because cognitive radios cannot be completely sure whether a licensed spectrum is free and available for transmission they simply defer from licensed bands and utilize other non-licensed parts of the band if they are not sure if it is really free. Suppose that attacker knows in which specific area CRN works. Knowing which licensed bands CRN might use attacker can simply transmit signal in the licensed band emulating real transmission and thus limiting overall CRN capacity. Until now we don't know any method of prevention against this attack.

Common control channel jamming*:* Oneof the possible solutions for commoncontrol channeldeployment is the UWB. In this casepotential attacker can simply transmit periodical pulses whichhave the same spectrum as common control channel of CRN but with higherpower than legitimateusers. Throughout jamming of just onechannel attacker blocks the possibility ofcommunicationbetween all CR nodes. This is the reasonfor building sophisticated UWBtransmission methods forcontrol channels utilizing UWB. It has tobe underlined that a need for special careof control channel isthe same for any type of approach (dedicated channel, channel hopping etc.).

Attacks on spectrum managers:We cannot allow having one central spectrum manager responsible for assigning frequency bands for nodes (see paragraph 2.3) because it constitutes a single point of attack. Whenever the spectrum manager is not available for CR nodes the communication process becomes impossible. That is whyinformation about spectrum availabilityshould be as distributed andreplicated as possible. This constraint is inline with the requirement for moreaccurate measurements of spectrum availability (see paragraph2.3). One of the preventing ways for thisattack is to use specific pilot channel innetwork elements due to their poor securitycould become a target of attack itself. Becausecognitive radio constitute a new approach forbuilding wireless networks it simultaneouslyopens a door for new methods of attacks ontheir physical structure. Below we outline each license band. It would inform secondary users about the reservation of
the nodes.

Eavesdropping: Usually in the infrastructure-based corporate WLAN it was assumed that signal will not leave building due to his short distance and will be limited to eavesdropping and sniffing. However cognitive radios are allowed to work in the bands lower than UNII and ISM. This means that they can perform longer transmission distances with the same powers. It also allows foreasy physical data collection from locations far distancedfrom CRN location where attackers invisible to emergency services. This yields a need for strong dataencryption at the physical level. Frequent leaving and joining the emergency network must be preceded by authentication process. It is open for discussion which layer should be responsible for this step. Currently the most possible approach is that application layer willperform all the necessary authentication procedures. Moreover the entire WEP infrastructure should be the basis for authentication procedures in CRNs.

VIII. Conclusions

The rapidly changing radio environment, more radio channels to utilize, number of parameters to choose during decisions taken by MAC and routing protocols, etc. makes design of CRNs very challenging. In this deliverable we have outlined some specific parameters and constraints which have to be taken into consideration while designing protocols for layers above PHY. Many protocols have the same design requirements (like robustness, no clock synchronization or localizing capabilities) which simplify design by small fraction. Moreover we can state that UWB as a common control channel might become a good solution for realizing certain functions outlined in this document. We also outline that cooperation between physical and link layer is essential for accurate operation of CRN. We have to emphasize that new requirements might occur during design process so this document will be constantly updated.

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