IMPLEMENTATION OF A WLAN WAVEFORM UNDER COST EFFECTIVE NOVEL SOFTWARE AND HARDWARE ARCHITECTURE

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ABSTRACT

Research and development of software defined radio (SDR) systems has been on the rise in recent years. However, there are still many challenges to overcome. Among these, the issue of creating an affordable software architecture that supports different types of waveforms for possible commercial use is a critical one. In this paper, based on our novel low cost system software architecture design, we will describe the implementation of an IEEE 802.11a WLAN waveform by using GNU Radio. In order to realize low cost and real time application, middleware such as CORBA will not be used in our system. By using GNU Radio software and Universal Software Radio Peripheral (USRP) hardware, the overall development period will be greatly shortened. Algorithms are first simulated in Matlab and then tested in a real environment. Multi-band, multi-protocol communication systems and cognitive radio capabilities will also be discussed in this paper as a future extension of our prototype as well as using the proposed SDR as the data communications platform for the “Enhanced Image Capture and Transfer” (EICT) application.

1. INTRODUCTION

Software Defined Radio design is becoming more popular these days. Current systems such as Joint Tactical Radio System (JTRS) have the capability of providing multi-channel and multi-protocol high performance wireless communication. However, according to a 2006 DOD report, JTRS was initiated to address long-term military communications needs. The commercial applications have not been considered, and this limits its widespread use. In contrast to JTRS, our prototype is a low cost implementation using commercially-available hardware along with open-source software. The IEEE 802.11a physical layer standard is supported by our system. OFDM transmission performances such as synchronization and BER are first simulated in Matlab, and then transferred to our prototype under real indoor channel environment.

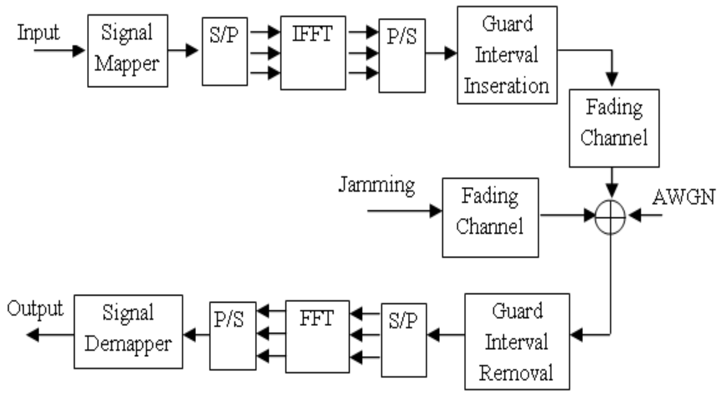

Figure 1 OFDM System Model

2. WLAN TECHNOLOGIES

Commercial wireless networks, such as IEEE 802.11, have established expectations for seamless connectivity with relatively static and slow changing locations. OFDM (Orthogonal Frequency Division Multiplexing) is used as the physical layer transmission standard in IEEE 802.11a. It uses orthogonal sub-carriers to reduce Inter-symbol Interference (ISI) and improve the throughput. Above is system diagram for OFDM transmission.

Assume the whole system as linear system:

$$y(n) = x(n) \otimes h(n) + w(n) \qquad (1)$$

Where $w(n)$ is the additive white Gaussian noise, whose real and imaginary parts obey Gaussian distribution and phase obeys uniform distribution. Because OFDM system is robust against frequency selective fading, the channel model is taken as flat Rayleigh fading channel. $h(n)$ is the impulse response for Rayleigh fading channel.

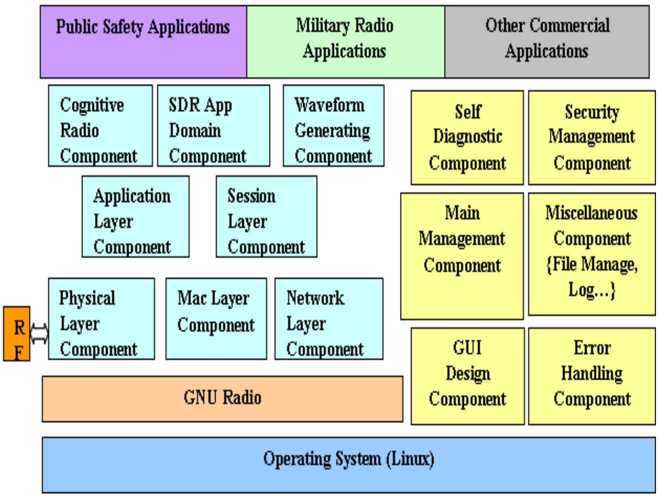

Figure 2. Software Components Architecture

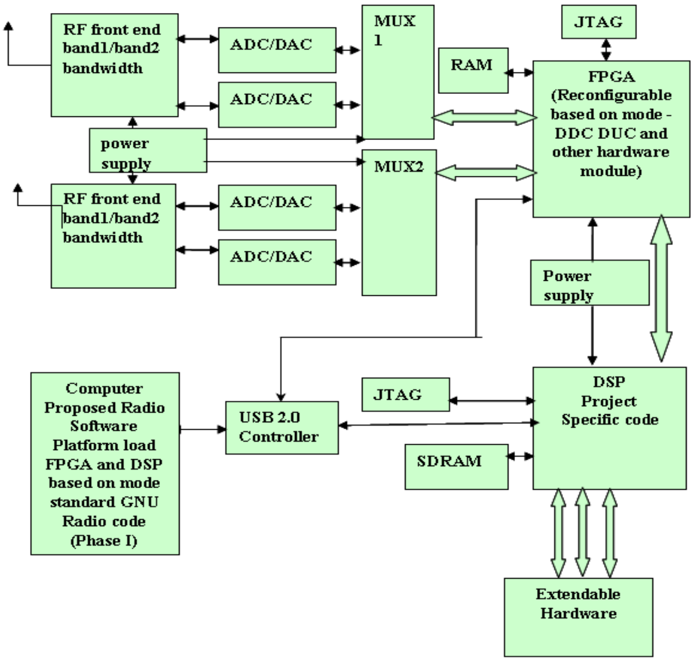

Figure 3. System Hardware Architecture

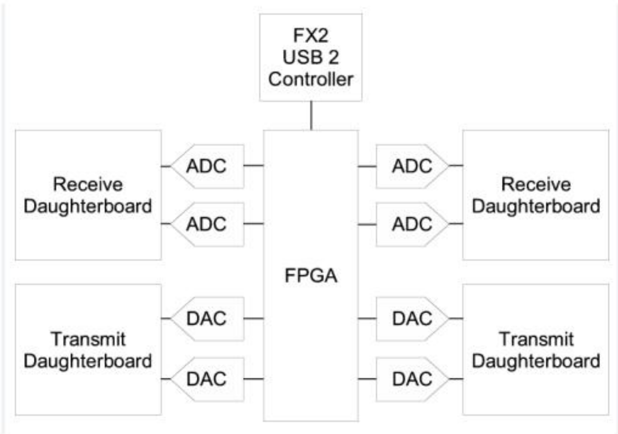

Figure 4. USRP Diagram

3. SOFTWARE COMPONENTS DESIGN

The implementation of the software modules is based on the GNU Radio platform. GNU Radio is a collection of software when combined with minimal hardware allows the construction of radios where the actual waveforms transmitted and received are defined by software. What this means is the digital modulation schemes used in today's high performance wireless devices are now software problems. It is free, open source and hardware independent. Rooted from the GNU Radio, the proposed software architecture will be developed.

For the existing SCA architecture which is used in the JTRS program, CORBA is the core element in SCA architecture. In CORBA, the IDL and proxy processes consume a lot memory and processor speed, and only give us limited benefits.

Instead, our goal is to achieve a simple software architecture design and COTS technology, using the Linux operating system as our platform. We use GNU radio as our base library to shorten developing time because GNU radio provides a library of signal processing blocks and the glue to tie them all together, which will lower our development efforts.

In our solution, software design is based on the function division principle in which different software components are defined by the function they perform in the system. The explanation of our proposed structure is given above in Figure 2. Our design is object oriented and hierarchical based. Based on the network 7-layer definition, we create the corresponding components. There are elegant design patterns within each component.

4. HARDWARE PLATFORM

Figure 3 is our system hardware architecture. Lowering the cost is the key point in this project. We choose the cost-effective hardware USRP to implement WLAN waveform.

USRP is an extremely flexible USB device that connects the CF-19 Toughbook to the RF world. The USRP consists of a small motherboard containing up to four 12-bit 64M samples/sec ADCs, four 14-bit, 128M sample/sec DACs, a million gate-field programmable gate array (FPGA)

Figure 5. USRP Workstation

and a programmable USB 2.0 controller[1]. Figure 4 and 5 shows the system diagram of USRP and its workstation.

5. COMPUTER SIMULATION

Physical layer transmission protocol is simulated by Matlab under Rayleigh fading channel. Bit Error Rate of OFDM is calculated. Here, we consider four different jamming scenarios in OFDM transmission. They are Broadband Noise Jamming, Partial Band Jamming, Multiple-tone Jamming and Pulse Jamming. In this paper, based on realistic Rayleigh fading channel, different jamming effects are compared and an optimal jamming method is proposed based on the theoretical analysis and simulation results. Furthermore, the influence of parameter ρ to PBJ effect is investigated. ρ is the ratio of jammed band compared to the whole band.

5.1. Broadband Noise Jamming

For BNJ, BER regarding QAM over Rayleigh fading channel is [2]

$$P_b = 2Q(\sqrt{\frac{E_b}{N_0}}) + Q(\sqrt{\frac{2E_b}{N_0}}) \qquad (2)$$

P_b is BER, E_b is the signal energy per bit and N_0 is the Rayleigh fading channel noise power:

$$N_0 = E[\alpha^2(\tau)] = 2\sigma^2 \qquad (3)$$

In equation (3), only path loss and shadowing is taken into consideration. The power spectral density of the jamming signal is assumed to be J_0. The bit error probability combined these three factors mentioned above is:

$$P_b = 2Q(\sqrt{\frac{E_b}{N_0 + J_0}}) + Q(\sqrt{\frac{2E_b}{N_0 + J_0}}) \qquad (4)$$

5.2. Partial Band Jamming

For PBJ, we assume jamming band is $W = \rho W_{ss}$, where W_{ss} is the whole band. In this case, a specific transmitted symbol will be received unjammed, with probability of (1-ρ); while it will be jammed with probability ρ and will be perturbed by jammer power with spectral density J_0 / ρ. Hence, the bit error probability is:

$$P_b = (1-\rho)[2Q(\sqrt{\frac{E_b}{N_0}}) + Q(\sqrt{\frac{2E_b}{N_0}})] + \rho[2Q(\sqrt{\frac{E_b}{N_0 + J_0/\rho}}) + Q(\sqrt{\frac{2E_b}{N_0 + J_0/\rho}})]$$

(5)

5.3. Multiple-tone Jamming

The difference between MTJ and PBJ is MTJ signals do not occupy continuous band. Instead, they occupy discrete signal band. In this paper, three discrete signal bands are used for MTJ. BER of MTJ is expressed as:

$$\begin{aligned} P_b &= (1-\rho_1-\rho_2-\rho_3)[2Q(\sqrt{\frac{E_b}{N_0}}) + Q(\sqrt{\frac{2E_b}{N_0}})] + \rho_1[2Q(\sqrt{\frac{E_b}{N_0 + J_0/\rho_1}}) + Q(\sqrt{\frac{2E_b}{N_0 + J_0/\rho_1}})] \\ &+ \rho_2[2Q(\sqrt{\frac{E_b}{N_0 + J_0/\rho_2}}) + Q(\sqrt{\frac{2E_b}{N_0 + J_0/\rho_2}})] + \rho_3[2Q(\sqrt{\frac{E_b}{N_0 + J_0/\rho_3}}) + Q(\sqrt{\frac{2E_b}{N_0 + J_0/\rho_3}})] \end{aligned}$$

(6)

5.4. Pulse Jamming

PSJ is treated as a special case of PBJ. The only difference is PSJ only occupies a small fraction of continuous band. In this paper, 1% of the continuous band is jammed as PSJ, while 50% of the continuous band is jammed as PBJ. BER of PSJ is:

$$P_b = (1-\rho)[2Q(\sqrt{\frac{E_b}{N_0}}) + Q(\sqrt{\frac{2E_b}{N_0}})] + \rho[2Q(\sqrt{\frac{E_b}{N_0 + J_0/\rho}}) + Q(\sqrt{\frac{2E_b}{N_0 + J_0/\rho}})]$$

(7)

A total of 256 orthogonal sub-carriers, QAM modulation/demodulation method and Rayleigh fading channel are used to simulate OFDM system.

For channel estimation, combo-type, LS, time-invariant, flat fading Rayleigh channel model is utilized.

Furthermore, for simulation, SIR is varied from 1 to 10 dB. For one specific SIR, the signal power and jamming power are fixed. Therefore, at one specific SIR, signal and jamming power are kept the same for different jamming types. Consequently, BER analysis for different jamming types is feasible and convincible. A total of 500 iterations

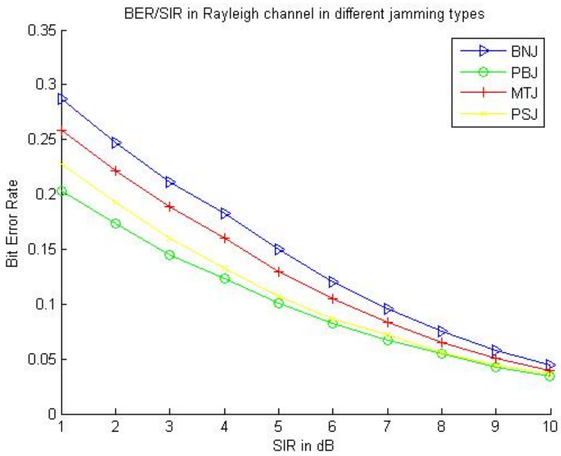

Figure 6. Simulation with different jamming types

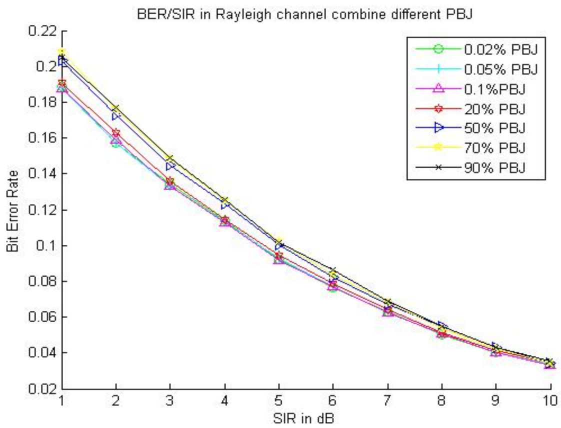

Figure 7. The effect of different ρ in Partial Band Jamming

Table 1. Simulation Parameters

Parameters	Specification
FFT size	1024
Number of Carriers (N)	256
Pilot Ratio	1/8
Guard Interval	64
Guard type	Cyclic Prefix
Signal Constellation	QAM
Channel Model	Rayleigh Fading
Channel length	16
Iteration Number	500
Sample Rate	44.1 KHz
Bandwidth	17.5 KHz

are employed to generate the original sending data, Rayleigh fading channel and jamming signals to avoid the arbitrary values. Table 1 is simulation parameter table. Figure 6 and 7 are simulation results.

6. REAL-TIME HARDWARE PROTOTYPING

After the modeling and simulation described above is completed, it is necessary to perform "hardware-in-the-loop (HITL)" testing using our hardware platform. This particular process of combining hardware and simulation has the advantage of allowing the hardware designer to implement the software defined radio hardware architecture on a module by module basis. In short, HITL makes possible to combine simulation and real world parameters into the SDR design process [3]. The HITL process is usually performed in an iteratively way that allows the SDR architecture design team to optimize the system around certain parameters of interest, such as power, bit rate, among others.

In order to successfully design and implement the hardware architecture, waveforms are generated from a system software simulation and applied as inputs to each one of the hardware modules. Correspondingly, the outputs of each module, after applying the software generated waveforms, are verified by comparing them to the expected outputs. Therefore, a compromise has to be reached between the size of the modules being evaluated and the number of input waveforms that need to be created. That is, as the size of the modules is increased, the efficiency of the design process and the number of simulated input waveforms decrease.

As it was previously mentioned, the hardware architecture in this paper is implemented through the described HITL process. Here, different input waveforms that simulate diverse diffraction scenarios is used to specific modules making possible the realization of an efficient design process for SDR architecture. In the end, the HITL methodology serves to provide the functional verification of the proposed system.

7. CONCLUSION AND FUTURE WORK

Multi-band and multi-protocol communication system is our future extension. By adding new RF front end, we plan to support several frequency bands. Cognitive radio component will be added in the software components architecture in order to achieve spectrum sensing, resource allocation and mutual trust among several hosts. Specifically, building a hardware and software platform based on our prototype is the next phase in order for it to be used by the EICT application.

7.1. Interface with Enhanced Image Capture and Transfer (EICT) Application

VIPMobile is in the process of releasing a commercial application that compresses images and allows users to transmit these images over very low-bandwidth channels.

Table 2. EICT Performance

	Original File Size	JPEG File Size (10:1)	EICT Compressed File Size (2000:1)	Upload Time @ 28.8 kBaud
Text Page	70 KB	7 KB	350 Bytes	.025 Sec
Grayscale Image	2.6 MB	260 KB	1.3 KB	.9 Sec
Color Image	12 MB	1.2 MB	6 KB	4.2 Sec

The initial version of the EICT application will use Satellite Phones as the physical data transmission device, which have a data rate of about 4 kbps. A future version of EICT will use ViaSat PC-Cards (VDC-600) to allow the user to send images over a combat soldier radio, such as an MBITR radio.

We plan to use the SDR proposed in this paper as yet another physical data transmission device in the future, which could be used by commercial end users or non-military public safety groups and teams.

7.2. Cognitive Radio Capabilities

Cognitive, or Intelligent Adaptive Radios, can be considered the "next generation" version of the Software Defined Radio. Current development in this area is producing innovative technologies, but it is expensive. A low-cost, scalable and extensible approach for Cognitive Radios will be investigated for eventual design and development in later GNU Radio development stages based on our prototype.

The technical approach is to provide an extensible, scalable, and preferably low-cost powerful software control processing engine using Open Source infrastructure, tools and libraries. This engine will implement artificial intelligence (AI) and processing algorithms that will give the SDR a truly adaptive capability. The technical approach would investigate into the following main technical issues of an SDR for possible future development:

1. Embedded Location sensors (GPS)
2. Environment Monitoring Intelligence
3. Location Tracking
4. Communications Etiquette
5. Communications Demand Sharing
6. Man-Machine Interface

8. REFERENCES

[1]http://www.gnu.org/software/gnuradio/doc/exploringgnuradio.html. A high level overview of GNU Radio and the USRP;

[2] Andrea Goldsmith, Wireless Communications, 2005.

[3] E. Azarnasab, P. Amini, B. Farhang-Bouroujeny, "Hardware in the Loop: A Development Strategy for Software Radios", 2007 Software Defined Radio Technical Conference, November 5-9, 2007, Denver/Colorado.