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Design and Implementation of a Software Radio based WiMAX Communication System

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Abstract:

This paper presents the design and implementation of a software defined radio for the physical layer implementation of WiMAX using MATLAB and Simulink. This work focuses on two important aspects of communications, WiMAX standard and the OFDM technique. **OFDM** is a spectrally efficient version of multicarrier modulation, where the subcarriers are selected such that they are all orthogonal to one another over the symbol duration, thereby avoiding the need to have nonoverlapping subcarrier channels to eliminate intercarrier interference. In order to completely eliminate ISI, guard intervals are used between OFDM symbols. By making the guard interval larger than the expected multipath delay spread, ISI can be completely eliminated. Adding a guard interval, however, implies power wastage and a decrease in bandwidth efficiency. The results show successful operation of the software, that uses part of the algorithm on a PC and part on the FPGA board

Introduction:

The advances in digital signal processors, Application Specific Integrated Circuits (ASICs) and more recently Field Programmable Gate Arrays (FPGAs) are shaping the future of Telecommunication industry. Many standards are being developed concurrently for high-end mobile market. Equipment based on standards, such as GSM, WCDMA, HSPDA, 802.11ab/g for wireless communication and mobile TV such as DVB-H are being deployed. In addition research for upcoming standards is in progress. The multitude of evolving standards, along with advances in technology from processing power point of view as well as system integration, are all major factors that are changing the system architect's approach towards development. However, the system However, the system designer is faced with the challenges of using the right approach to design such systems.

1.1 Software Defined Radio: Concept and Architecture:

SDR: Background

Software Defined Radio (SDR) technology is a promisingfeature for next-generation mobile communicationsystems. The commercialization of this technologycurrently centers on the core technologies, such as highspeed Analog to Digital Conversion / Digital to AnalogConversion (ADC/DAC) technologies of base stationsystems. Moreover, the Digital Signal Processing (DSP)processors associated with SDR are rapidly evolving. Forexample, ETRI(Electronics and TelecommunicationsResearch Institute) is developing a double-mode basestation termed a Reconfigurable Base Station (RBS),which is reconfigurable to an IEEE 802.16d WiMAXsystem based on Orthogonal Frequency DivisionMultiplexing (OFDM) technology and to a HSDPA (HighSpeed Downlink Packet Access) system based on CDMA(Code Division Multiple Access) technology. An RBSuses SDR technologies in which modems and otherfunctional blocks can be reconfigured easily, withsoftware downloaded onto identical hardware platforms.

The classical view of Software Defined radio has been proposed by Mitola, wherein the concept of a completely digital radio, except for analog to digital and digital to analog converters is given in such a manner that there is a very high degree of re configurability and concurrent transmission and reception of many channels is possible. Since then there have been implementations of the concept on different platforms, including PC, single and dual General purpose Processors(GPP), a cluster of workstations, a DSP and a reconfigurable FPGA. All these implementations are for the terminal side, similar work also has been done to make the network software radio based. A novel concept along these lines is the cognitive radio and is an active area of research. In this case the device will intelligently scan for available networks and connect to one without user intervention. Such a device is desirable for next generation networks that require seamless mobility in different wireless domains.

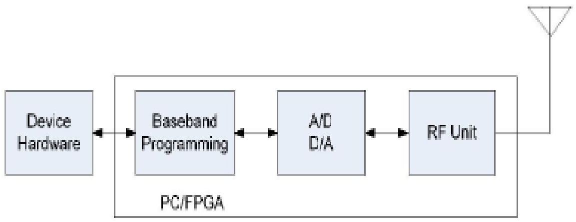

Figure 2.1: Schematic showing the Software Defined Radio

The general Software Defined Radio allows reconfigurabilty by identifying the algorithmic functions that different standards share and emulating those by using reconfigurable data paths.

2.2 IEEE 802.16-2004 standard:

The IEEE standards board established the IEEE**802.16** working group in 1999 to prepare formal specifications for global deployment of broadband wireless metropolitan area networks. The first standard in the 802.16 family , addresses the LOS communication in the 10-66 GHz frequency band. Revision 802.16a extended the operation to include the NLOS communication in the lower frequency band of 2-11 GHz and the support for the MAC layer for OFDMA was also included. The revision 802.16d also known as 802.16-2004 standard supports communication in the 2-66GHz range. As the LOS and NLOS propagation characteristics are different the physical and the Mac layers should support these differences, therefore the standard covers the specifications of both the layers. The salient features of the WiMAX are given as follows:

- The WiMAX physical layer is based on OFDM, a scheme that is robust to multipath delays and is suitable for NLOS operations.
- WiMAX can support very high peak data rates as high as 74Mbps using 20 MHz bandwidth
- WiMAX is scalable by varying the FFT size from 128 to 2048 on a channel bandwidth of 1.25 MHz, 5 MHz or 10 MHz.
- Adaptive Modulation is possible with FEC schemes per user and frame basis depending on the channel conditions.

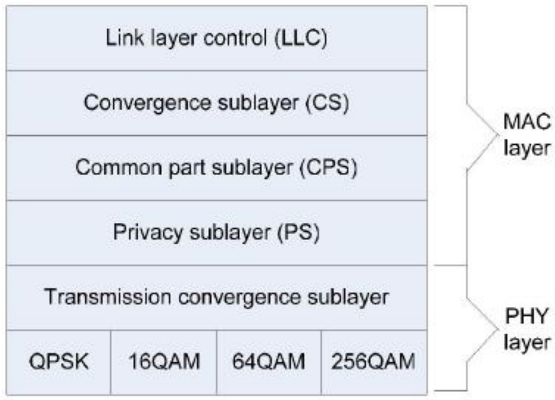

Figure 2.2: WiMAX protocol stack

The protocol stack of WiMAX MAC and PHY layers is shown in the figure 2.2. IEEE 802.16-2004 is designed to carry IP versions of 4,6 and packetized voice over IP(VOIP) , Ethernet and ATM and Virtual LAN(VLANs) services. This is accomplished by dividing the MAC layer into separate sublayers with different functions as follows:

- The physical layer is based on OFDM, and supports TDD and FDD. The uplink is based on TDMA and DAMA. The downlink includes a transmission convergence sublayer that inserts a header to help identify the beginning of a MAC PDU. Data bits from the transmission convergence sublayer are randomized, FEC encoded and mapped to modulation scheme, i.e., QPSK, 16QAM, 64QAM or 256 QAM.

2.Wi-MAX (Worldwide Interoperability for Microwave Access)

WiMAX is becoming one of the hottest topics in thedevelopment of wireless technology. Researchers anddevelopers are focusing on the development of WiMAX basestation technology which is expected to provide services in2008 around the world. In the 4th quantum of 2005, the IEEE802.16e specification was launched to the market detailing thefull specification of mobile WiMAX. In essence, theQuality of Service (QoS) for WiMAX is desperately required.

Up to present, the research of CAC and bandwidthallocation of IEEE802.16e is still a pilot work. Two different predictive CAC schemes were proposed toadapt the variant traffic of IEEE 802.16 network. Performanceof different QoS strategy combinations are also investigatedby researchers. The relationship of CAC and packet scheduling has been studiedand also the performance of power allocation and CAC has been focused upon.

To support a variety of applications, IEEE 802.16 has defined four types of service:

1) unsolicited grant service (UGS);
2) real-time polling service (rtPS);
3) non-real-time polling service (nrtPS); and
4) best effort (BE) service.

3.2.QOS Architecture

3.2.1. Base Station Architecture:

Figure 3.1 depicts our proposed QoS architecture at thebase station, that uses GPC mode for granting bandwidthto SSs. Our main goals in designing the architecture areto provide delay and bandwidth guarantees for variousapplications while still achieving high system Utilization.The architecture supports all types of services specified inIEEE 802.16 standard. Since

4.1 ORTHOGONAL FREQENCY DIVISION MULTIPLEXING (OFDM) :

As described in the earlier chapters, physical systems only take care of certain aspects of communication. The type of modulation and how the data is coded plays an important role in making communications more robust which will improve the range and reliability. In selecting a scheme, it is important to recall that support for future growth is desirable.
This leads to a modulation scheme that is flexible, being both robust and has ready support for multicarrier systems across a wide frequency band, thus being implementable to systems with low carrier frequencies.

4.3Simulation of OFDM

OFDM is used in standards such as IEEE 802.11a/g and DVB-T/H for transmissions at high data rates with good spectral efficiency. This section provides proof of concept of the principles established in previous sections. The error coding and decoding blocks will be omitted due to it being beyond the scope of this current section.

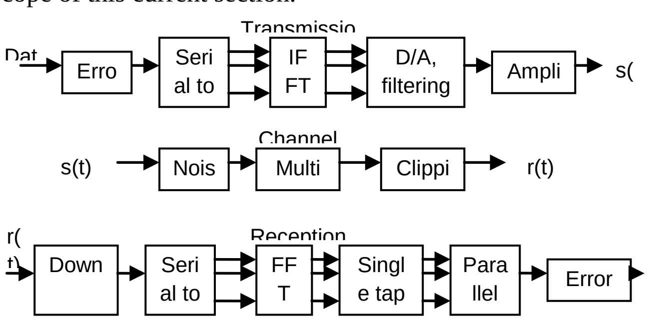

Figure 4.4: Overall OFDM system block diagram

As the figure shows, the initial step is to create 4-QAM symbols from transmission at stage 1, to be processed by the 4096-FFT. At stage 2, the complex baseband OFDM signal moves on into a transmit filter to convert them into a form to prepare for analogue processing. Stage 3 is a low pass filter to smooth out the waveform and we see an analogue waveform. Stage 4 passes the analogue waveform to be modulated. The signal to be modulated is

$$s(t) = sm_i(t)\cos(2\pi f_c t) + sm_q(t)\sin(2\pi f_c t),$$

where $sm_i(t)$ and $sm_q(t)$ are stage 4's in-phase and quadrature components respectively.
It is noted that since this is 4 QAM, the constellation is identical to QPSK. Accessing the matrix for storing the 1705 symbols at stage 1 will show this as only the phase varies.

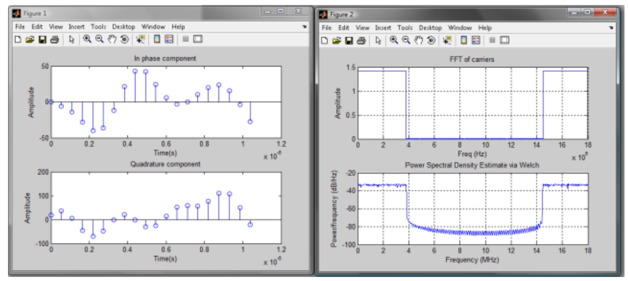

Figure 4.6: Stage 2 - Time and frequency response of carriers after 4096-IFFT

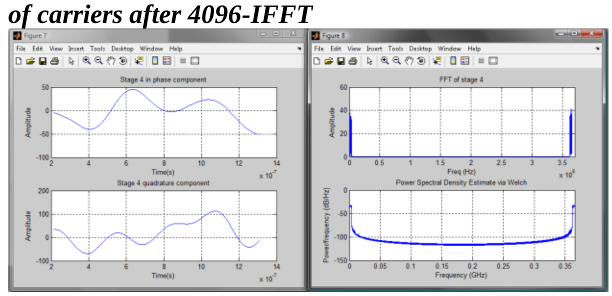

Figure 4.9: Stage 4 - Data after completed D/A conversion (time and frequency response)

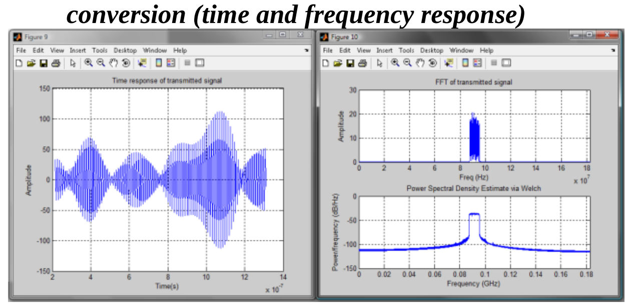

Figure 4.10: Signal to be transmitted, s(t)

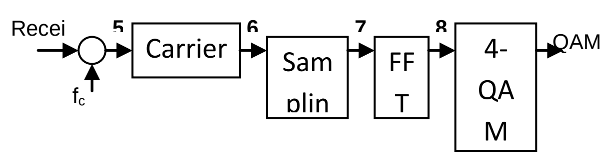

Figure 4.11: OFDM reception model using 4-QAM data

OFDM has its own vulnerabilities and frequency selectiveness is a key issue, together with timing offsets. Hence, for the simulation, a small delay is added to account for filters during the modulation, demodulation and reconstruction of the data. This is taken to be an arbitrary value of $t_d = 64/ R_s$. Though small, it is significant enough to produce slight delays when comparing the figures below with the figures from the portion on the transmission simulation. Refer to Appendix B; section B.2 for the code relating to the figures 5.12 to 5.15.

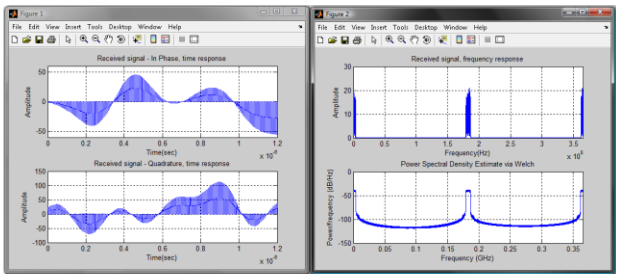

Figure 4.12: Stage 5 - Time (left) and frequency (right) response of signal

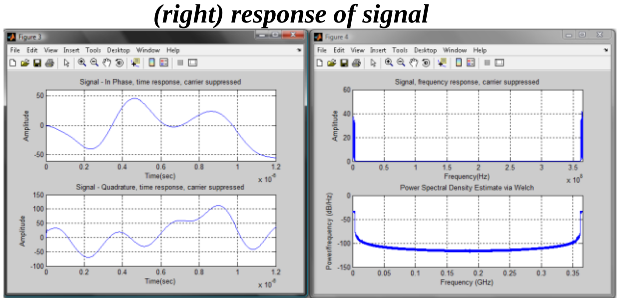

Figure 4.13: Stage6 - Time (left) and frequency (right) response after carrier suppression

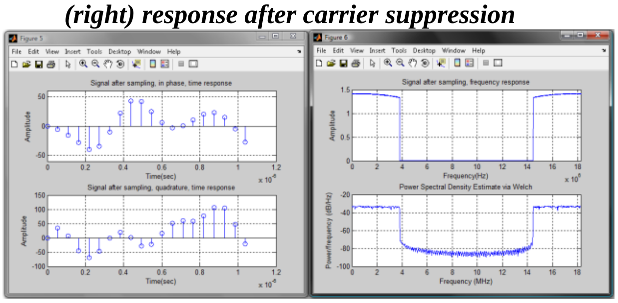

Figure 4.14: Stage 7 - Time (left) and frequency (right) response after sampling

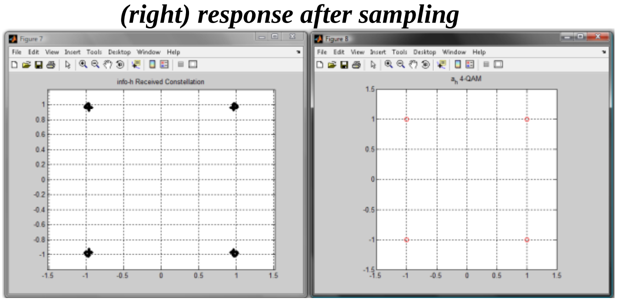

Figure 4.15: QAM at stage 8 (left) and after slicing (right)

With proof of concept established, other issues should be addressed. Primarily, ensuring orthogonality of subcarriers and overcoming the disadvantages inherent in OFDM.

inMatlab to view the waveforms with the minimum values for separation to maintain orthogonality, the following figures were obtained.

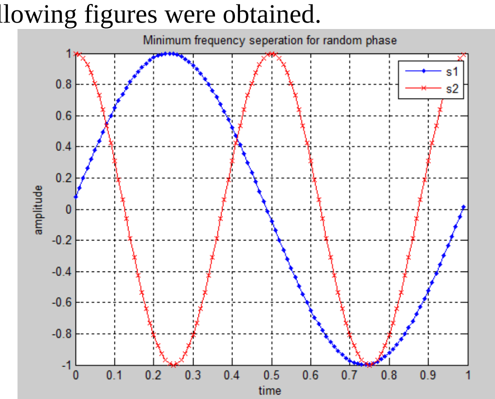

Figure 4.16: Two sinusoids with frequency difference = 1/T

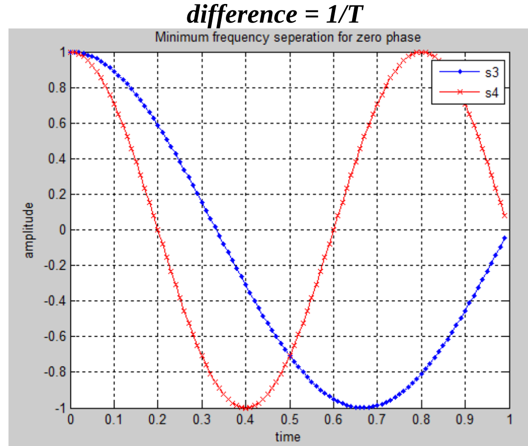

Figure 4.17: Two sinusoids with frequency difference = 1/2T

To conclude this section, when the phase difference between two sinusoids is unknown, the minimum frequency separation between them is 1/T for orthogonality. In addition, when the phase difference is zero between the two sinusoids, the minimum separation is 1/(2T). The next section begins discussion on the shortcomings of OFDM.

4.6.**Problem of high peak to average power ratio (PAPR)**

As mentioned, OFDM has poor PAPR, reducing the power efficiency of amplifier. To understand this, a short discussion on the concepts is necessary. PAPR of a signal x(t) is defined as,

$$PAPR = \frac{\max[x(t)x^*(t)]}{E[x(t)x^*t)]}, PAPR_{dB} = 10\log_{10} PAPR$$

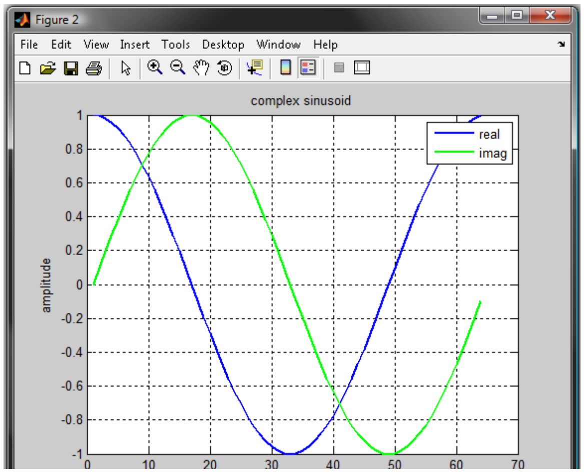

Figure 4.18: Waveform a single complex sinusoidal

Thus the peak to average power ratio for an OFDM system with K subcarriers where all subcarriers are given the same modulation is PAPR= K2/K = K. As per IEEE 802.11a specifications, using 52 subcarriers, the maximum expected PAPR is 52 (≈ 17dB). However, all subcarriers in an OFDM symbol being equally modulated is unlikely in practice. The key implication of the large PAPR is that it creates susceptibilities to system non-linearities, such as in the power amplifier; due to the large amplitude fluctuations as seen in figure 5.12, which results in clipping and non-linear distortion.

The second method show that implementation of multiple transmit and receive antennas to form a MIMO system that increases system capacity compared to a single input single output (SISO) system. Work done in the field uses mathematical derivation and simulations to conclude that for flat Rayleigh channels, an increase in the number of transmitting antennas lowers the PAPR for MIMO-OFDM compared to SISO-OFDM. This makes it ideal for the operation of swarms of AUVS working together.

1. Conclusion and Future Scope:

Given the versatility of OFDM across a wide spectrum for a variety of physical implementations and given the potential of RF communications underwater, a great deal more can be done if further funding could be secured. In order for the project to accomplish full functionality, suggestions for areas to work on are as follows:

- Utilise a microprocessor and integrate the communication module together with it to begin integrating various subsystems that would be developed in future.
- Conduct further simulations of OFDM to approximate the attenuation with RF and acoustics underwater, implementing it by using Matlab.
- Fabricate all circuit boards as PCBs instead of relying on prototyping boards after design has been finalised and expected range has been approximated by simulations.
- Obtain functionality in terms of remote control and remote transmission of information back to the operator.
- If the above are achieved, conversion of the communication module to support MIMO-OFDM for further expansion.

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