Modeling a Multicarrier Wireless Communication Transceiver

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Abstract

The objective of this work is to develop a model for the simulation of a multicarrier wireless communication transceiver and channel. Multicarrier wireless transmission techniques are widely deployed in today's Wireless Local Area Networks(WLANs), Asymmetric Digital Subscriber Line (ADSL), very high bit-rate Digital Subscriber Line (VDSL) modems, etc. The explosive growth of wireless communication has created a demand for high speed and reliable quality of service over the wireless communication medium. When it comes to cellular and mobile communication systems, single carrier techniques as opposed to multicarrier are the main candidates. In this project, I model and simulate an OFDM (Orthogonal Frequency Division Multiplexing) transceiver and the wireless channel in National Instrument's LabVIEW, which is a graphical programming tool based on the dataflow language G. The simulation would enable designers to explore wide deployment of a multicarrier transmission schemes for cellular or mobile communications. The project evaluates communication performance, transceiver complexity and implementation cost of cellular OFDM systems.

I. INTRODUCTION

Multicarrier modulation, in the most general sense, can refer to any modulation scheme that uses multiple carrier frequencies to transmit data. Multicarrier modulation finds its application in recently standardized high rate data transmission systems such as Digital Audio and Video Broadcasting, Wireless LAN, Asymmetric Digital Subscriber Lines (ADSL) and Very High Rate Digital Subscriber Lines (VDSL) [10]. The explosive growth of wireless communication has created a demand for high speed and reliable quality of service over the wireless communication medium.

Multicarrier techniques have been developed since as early as the sixties. Initially, the underlying operations were too computationally intensive for cost-effective implementation. For about a decade, increasing computational power of Digital Signal Processors (DSPs) has been enabling cost-effective real-time implementations. For real-time operations to ensure reliability and efficiency, these complex operations must be done fast and hence requiring more powerful DSPs.

Early commercial multicarrier modems used guard intervals in the time and frequency domains to reduce the effects of intersymbol interference (ISI) and interchannel interference (ICI). Each subcarrier was modulated using the same power and data rate. Towards the end of the sixties, a number of authors, notably Chang [1], used overlapping orthogonal spectra to increase the efficiency of multicarrier systems.

II. TRANSMISSION ALGORITHMS

The two primary candidates for a broadband mobile transmission technique are the Direct Sequence (DS) CDMA (Code Division Multiple Access) [3], [4], [5] and Frequency

Hopping (FH)-CDMA [6] with powerful channel coding for both deploying a single carrier transmission scheme.

The capacity of a DS-CDMA system is limited by multi-user interference. A channel estimation, equalization and power-control procedures are necessary in a DS-CDMA system, which makes the receiver more complex to design. On the other hand, in FH-CDMA systems, a narrowband receiver technique is used, but the carrier hops in a large bandwidth using frequency allocation techniques with orthogonal codes. In this case the receiver must be synchronized to the hopping carrier frequency using a precise synchronization technique. However, no channel estimation and equalization techniques have too be performed compared with DS-CDMA systems, but the impact of occurring multipath leads to fading effects in the received signals and hence powerful channel coding is essential [6].

The solution to the problems posed by the two CMDA proposals is to use a multicarrier transmission technique for broadband communications. No channel estimation or equalization as DS-CDMA is necessary nor a powerful synchronization as in FH-CDMA is required. The solution is basically is to use an OFDM (Orthogonal Frequency Division Multiplexing) transmission system [6].

III. THE OFDM TRANSMISSION SYSTEM

Orthogonal Frequency Division Multiplexing (OFDM) is a special form of multicarrier modulation, which was patented in 1970. It is well suited for transmission over a dispersive channel [7]. Basically, in an OFDM system, the total bandwidth B is divided into K subbands with orthogonal subcarriers; that is a block of M symbols is transmitted.

Each block has 1/M of the available bandwidth instead of just transmitting one symbol as in single-carrier data transmission [8]. OFDM transmission techniques are widely deployed for WLANs, ADSL, VDSL modems, etc., but a standard using this technique for cellular or mobile communications still does not exist. Hence the motivation for this project.

IV. MODELING AND SIMULATION

A basic OFDM modem transceiver is illustrated below.

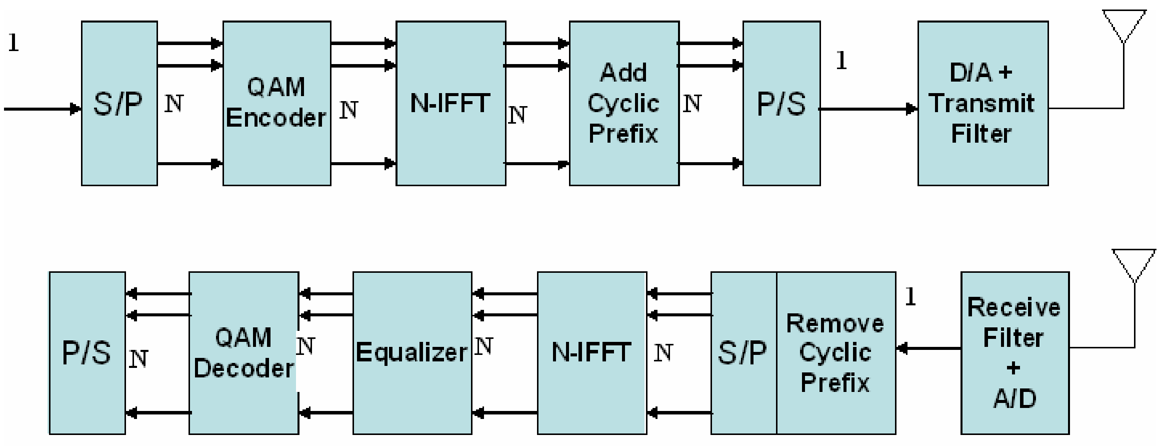

Fig. 1. An OFDM modem transceiver

Dataflow is a natural representation for signal processing algorithms. Applications are specified by a dataflow graph in which the nodes represent computations, and data tokens flow between them along the arcs of the graph.

A. OFDM Transmitter and Receiver

The transmitter and receiver of the OFDM modem described in the Fig. 1 contains the original data stream node, S/P (spreading node), IFFT/FFT, etc. All of these nodes consume and produce a constant number of tokens. For instance, the original data stream node produces one token for each firing. The spreading node consumes one token and produces N tokens for each firing (where N is the number of symbols to be transmitted). The IFFT node consumes and produces N tokens for each firing where N is the N point IFFT and is also the same as the length of the spreading code. Since the number of tokens produced and consumed by the nodes in the transmitter and receiver are fixed in one firing, they can be perfectly modeled in synchronous dataflow (SDF) which is a special case of the data flow family where execution order and memory requirements are known at compile time.

B. OFDM Channel Model

Since we are dealing with wireless communications, modulated signals are transmitted through impaired channels. These impairments are caused by things like additive white Gaussian noise (AWGN), multipath, fading and more. Noise in a communication system corrupts the signal in an additive fashion so the noise is modeled using an AWGN channel. The AWGN channel is very important in defining the noise added to the transmitted signal, but is inadequate in characterizing signal transmission over radio channels whose transmissions change over time.

Channels whose characteristics change with time are called multipath channels. Multipath conditions occur when a signal arrives at the receiver via different propagation paths with various delays and hence causing them to add destructively.

These are some of the main challenges that inhibit in providing high-quality transmission in the dynamic environment. The challenges basically include channel time-variation and the limited spectral bandwidth available for transmission. [9] is concerned with the role of time-variation in the transceiver design. Two cases are discussed: channel completely known at the transmitter and receiver; and channel unknown at transmitter and known at the receiver. Data transmission over frequency selective time-invariant channels has been researched in depth. [9] also develops a theoretic analysis of multicarrier transceiver design in wireless communications and also derives information rate for OFDM in fast time-varying channels.

C. Complexity

The data encoder/decoder and IFFT/FFT blocks for modulation/demodulation are the functions that utilize most of the processing power during data transmission. Since the encoding and decoding can be efficiently implemented by field-programmable gate arrays, we only consider the complexity of the IFFT/FFT blocks. For an N-point FFT/IFFT the computational complexity is $O(N \log N)$ where $O(x)$ means "on the order of x".

V. IMPLEMENTATION

LabVIEW is a graphical programming language that uses icons instead of lines of text to create applications. It is a powerful computational tool and is fast gaining popularity in science and engineering circles. Recently, runtime support for a hard real time environment has become available for LabVIEW, which makes it an option for embedded system prototyping. Due to its characteristics, the environment presents itself as an ideal tool for both the design and implementation of embedded software.

I use SDF to model the OFDM transceiver blocks and the channel. SDF is very suitable for modeling signal processing and communication systems in which a stream of data is processed by signal processing functional blocks. Inputs and outputs of the SDF blocks are the sub-symbols. The data consumption and production of each block in SDF are predetermined.

CHANNEL MODEL

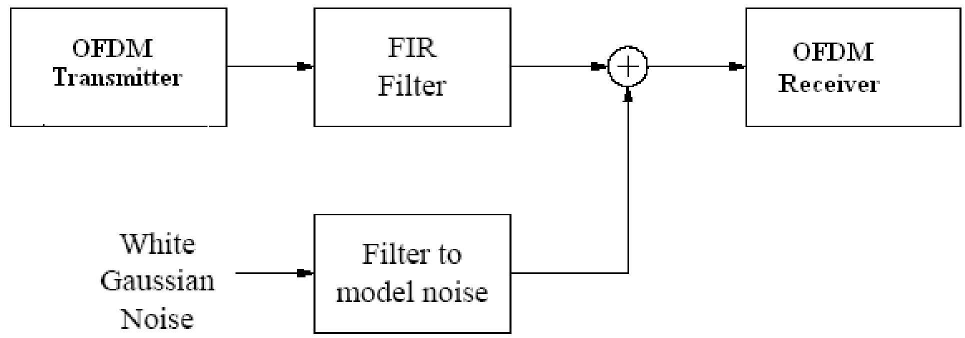

Figure 2: Block diagram of the channel model

The effect of transmission of the signal over the channel is modeled by a discrete time finite impulse response (FIR) filter determined by characteristics of the wireless channel. The channel model is shown in the figure above. The channel has time-varying parameters but it can still be modeled as SDF. I use a long FIR filter and let the end coefficients be zero when a shorter length is needed.

I implemented the OFDM transmission system using National Instrument's LabVIEW. LabVIEW enables hierarchial design of systems. I built most the top-level transmitter, receiver and channel SDF blocks using the LabVIEW's signal processing library components and using the MIMO (Multiple Input Multiple Output) toolkit which was developed under the guidance of Dr. Robert W. Heath Jr. by Shailesh Patil, Shrut Kirti and Roopsha Samanta. The toolkit contains a complete range of baseband simulation VIs right from modulation to decoders. Apart from this, it also contains some useful supplementary VIs for storing simulation results and combining different results to compare them.

VI. CONCLUSION

Multicarrier techniques such as OFDM are widely used and deployed in WLAN, ADSL and VDSL modems as mentioned earlier, but a standard for cellular or mobile communications that deploys multicarrier scheme still has to be proposed. In this project, I model and simulate an OFDM (Orthogonal Frequency Division Multiplexing) transceiver and the wireless channel in National Instrument's LabVIEW, which is a graphical programming tool based on the dataflow language G. The simulation would enable designers to explore wide deployment of a multicarrier transmission schemes for cellular or mobile communications. The project evaluates communication performance, transceiver complexity and implementation cost of cellular OFDM systems.

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