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Performance Evaluation of OFDMA Wireless Systems using WM-SIM Platform

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ABSTRACT
Orthogonal Frequency-Division Multiple Access (OFDMA) is becoming a very promising candidate for Long Term Evolution (LTE) and future Forth Generation (4G) technology specifications. This paper presents the work-in-progress development of an OFDMA wireless system model, which runs on top of the Wireless Mobile SIMulation platform (WM-SIM). The main physical (PHY) and Medium Access Control (MAC) functionalities at the radio interface have been implemented and evaluated. A multi-user downlink scheme, where a Base Station (BS) transmits variable-rate information to a set of mobile terminals, is assumed. Performance results show the accuracy of the simulations compared to theoretical estimations.

Categories and Subject Descriptors
I.6.7 [**Simulation and Modeling**]: Simulation Support Systems – *Environments.*

General Terms
Performance, Design, Algorithms.

Keywords
Wireless, Performance, OFDMA, Simulator, Platform

1. INTRODUCTION
Orthogonal Frequency-Division Multiple Access (OFDMA) is a promising technique to provide an efficient access over high-speed wireless networks. In fact, it is becoming the more likely option for Long Term Evolution (LTE) and future 4G technology specifications. Performance evaluation of OFDMA-based systems is currently a hot topic. In this context, development of reliable and fast simulation tools is providing the necessary support for these emerging technologies.

There already exist several simulation tools for modeling communication systems, such as Simulink [1] or Ptolemy II [2].

However, simulator efficiency is critical when complex algorithms are intended to be tested. For that purpose, a new simulation platform, oriented to the modeling and simulation of wireless systems, has been implemented. Wireless Mobile SIMulation (WM-SIM) is a data flow oriented platform, which is based on C++ in order to maximize simulation efficiency.

On top of the WM-SIM platform, an OFDMA wireless system has been modeled and analyzed, focusing on the main functionalities at the physical (PHY) and Medium Access Control (MAC) layers. This model's purpose is to carry out a performance evaluation of such a system. A multi-user downlink scheme, where a Base Station (BS) transmits variable-rate information to a set of mobile terminals, is assumed. Radio link is modeled by a configurable mobile channel.

This paper is structured as follows. Firstly, the new WM-SIM platform is introduced in section 2. Section 3 contains a description of the OFDMA wireless system model. Analysis of the simulations results, obtained from the previous model, is addressed in section 4. Finally, conclusions and future work are presented in section 5.

2. WM-SIM PLATFORM

2.1 Block and System concepts
WM-SIM platform allows an easy modular design, algorithms implementation and simulation of wireless communication systems. This platform is data flow oriented, and its modular architecture is based on the *Block* and *System* concepts.

The *Block* concept is defined as the basic modular element with independent execution. It is implemented as a C++ class, from which any other class is derived. An inter-block signaling mechanism is also defined in order to manage blocks execution sequence, as well as the exchange of data among blocks.

On the other hand, *System* class is defined as a group of *Block* instances, or even by other *System* instances (*Subsystem*). Thus, the design of complex system models with fine-grained or coarse-grained level is feasible, depending on programmers' preferences and particular needs.

One of the main advantages of this platform is its extensibility. A proper design and implementation of new blocks (following certain specifications) allow the future reuse of these blocks.

2.2 Signals, blockages and execution lists
System model execution is automatically managed by WM-SIM platform. In order to control block and system execution, a signal-based mechanism is defined

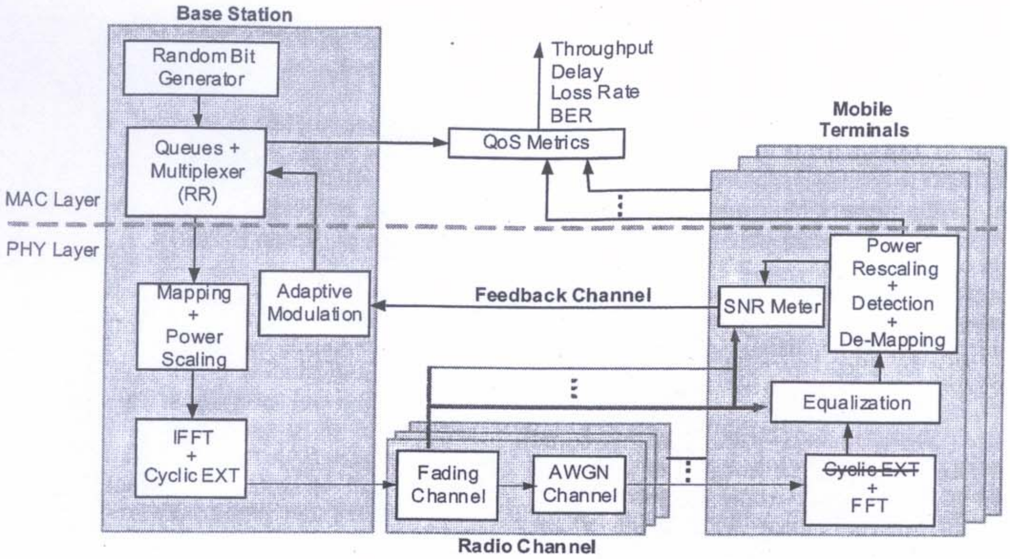

Figure 1. Downlink OFDMA Wireless System model.

2.2.1 *Execution Lists*

When a new system or subsystem is created, it is mandatory to define a basic execution list with all the blocks defined within system or subsystem. This list is used by the platform to execute the blocks in a certain order that may change whenever any block in the list is blocked. In fact, execution list only establishes the order in which blocks status is checked before execution.

2.2.2 *Signals*

The communication among blocks is carried out via a special auxiliary class called *Signal*. This class contains the exchanged data among blocks as well as the information required to control data availability and consumption.

2.2.3 *Blockages*

Block interfaces are defined by a set of {*N*-inputs, *M*-outputs} signal, where *N* and *M* are non-negative integers. As soon as a block is executed, its outputs are set to *'available'* for any other potential reader blocks. Therefore, a block is only executed if the following two conditions are true:

- All its inputs are available. That means that all the other blocks providing input data have been previously executed.
- All its outputs have been consumed. This is true only if all the others blocks that read its outputs have been executed and marked the data as *'read'*.

Whenever one of these conditions is not fulfilled, a blockage occurs. In that situation, the execution turn is given to the next item in the execution list.

3. OFDMA WIRELESS SYSTEM MODEL

The implemented model represents the downlink direction of an OFDMA Wireless System, in which a Base Station (BS) or Node B (in UMTS) is connected to one or several Mobile Terminals (MT) through a frequency-selective radio channel.

3.1 Model description

The model is made up by three subsystems (*BS*, *Radio Channel* and *MTs*) in addition to an independent block that collects QoS statistics, called *QoS Metrics* block, as illustrated in Figure 1.

3.1.1 *BS Subsystem*

BS subsystem aims to simulate the basic functionalities of a OFDMA base station and it is made up by five different blocks

- *Random Bits Generator*

This block generates a random sequence of bits for each MT. The mean amount of bits per OFDM symbol $\bar{r}_i$ is computed as

$$\bar{r}_i = \log_2\left(1+\frac{1.5}{-\ln(5BER_T)}\bar{\gamma}_i\right)\cdot\frac{N_c}{N_u}\cdot Load$$

where BER_T is the predefined target BER, N_c is the number of data carriers per OFDM symbol, N_u is the number of MTs, is the mean Signal-to-Noise Ratio (SNR) for the i-th user, and *Load* is a configurable parameter that allows changing the overall data load.

- *Queues & Multiplexer*

Bits sequences generated by the previous block are stored into N_u First-In First-Out (FIFO) queues, one for each user. The size of each queue is a configurable parameter. Multiplexer is responsible for allocating transmission turns to users following a certain algorithm. Current implementation includes a simple Round Robin (RR) technique, although more sophisticated algorithms (e.g. based on channel state and/or the queue occupancy) will be added. Once the transmission turn is allocated, a number of bits (according to the MT modulation level) are extracted from their corresponding queue.

- *Mapping & Power Scaling*

The sequence of bits coming from the multiplexer must be mapped onto their corresponding constellation[1]. Therefore, different

[1] Note that channel coding should be performed before mapping procedure. This feature is not included in current model.

constellations can be used in the same OFDM symbol since the information conveyed for each user may has a different modulation level. Afterwards, there is a power scaling procedure to assure that the mean transmitted power equals to one.

- *IFFT & Cyclic Extension.*

This block applies the Inverse Fast Fourier Transform (IFFT) to the received complex values to convert the OFDM symbol to the time-domain. Afterwards, the cyclic prefix is appended to the OFDM symbol.

- *Adaptive Modulation*

In this block, the modulation level for each user is selected at a frame-by-frame basis, according to their estimated instantaneous SNR and target BER values. Instantaneous SNR (γ) is received through an ideal feedback channel (no losses or delay) form each MT. Adaptive modulation is carried out by means of predefined SNR thresholds in order to select a proper modulation level m(γ) depending on the BER_T.

3.1.2 Channel Subsystem

As the signal received by a particular MT is different from the signal received by other MTs, *Radio Channel* subsystem must include several independent channels, one for each MT. Each channel is composed by a *Fading Channel* block and an *Additive White Gaussian Noise* (*AWGN*) *Channel* block.

The former block models a frequency-selective Rayleigh or Rice channel with fading effects due to multipath propagation [4], and the later adds white Gaussian noise to the signal in order to ensure a pre-configured average SNR.

3.1.3 MTs Subsystem

Every MT processes independently its received signal through the following blocks sequence (see Figure 1):

- *Cyclic Extension removal & FFT*

This block removes the cyclic extension introduced by the BS, and afterwards, applies the Fast Fourier Transform (FFT) to the received signal in order to recover the received OFDM symbol into frequency-domain.

- *Equalization*

To compensate the undesirable effects of the radio channel on the received OFDM symbol, ideal channel estimation is assumed, i.e. each MT receives its associated channel frequency response from the *Radio Channel* block to equalize its received OFDM symbol.

- *Power Rescaling, Detection & De-Mapper*

It carries out a power rescaling of the equalized signal as well as performs symbol detection and de-mapping procedures.

- *SNR Meter*

Each MT estimates the instantaneous SNR value of its received signal and sends it back to the BS through an ideal feedback channel.

3.1.4 QoS Metrics

All the statistical information about QoS for each user, like BER, delay, throughput or loss rate is gathered by this block. For that purpose, this block receives information about the queue occupancy, transmission rate and data flows for each user from the BS, as well as the received data flows from each MT.

4. SIMULATION RESULTS

The model presented in previous section is converted by WM-SIM platform into a stand-alone executable file, which has been compiled using Microsoft Visual Studio .NET 2003. Main parameters setting for the simulations are listed in Table 1.

Table 1. Parameters Settings

Parameter	Value
Number of Users (N_u)	10
Carrier Frequency (f_c)	1.8 GHz
Sampling Frequency (f_s)	2 MHz
Channel type	Flat Rayleigh
Mobile terminal speed (v)	≈11 m/s
Cyclic prefix length	16 samples
Number of data carriers	192
FFT size	256

4.1 Analysis of Results

After introducing WM-SIM framework and describing the model used as proof of concept, it is time to study the results of the different simulations carried out with this model.

4.1.1 Non-Adaptive Modulation

In Figure 2, BER values obtained from simulations are compared with analytic values for each constellation. This figure makes clear that the model used in the simulation is well designed and its results are very close to the analytic ones.

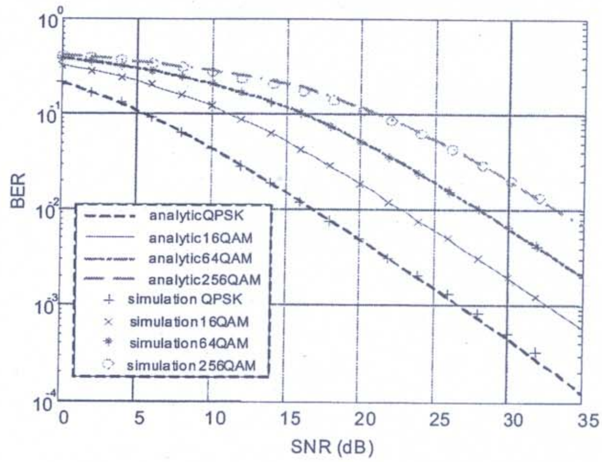

Figure 2. Comparison between analytic BER values and simulation values for different constellations.

4.1.2 Adaptive Modulation

Mean BER results are shown in Figure 3 as a function of the average SNR. As expected, adaptive modulation mechanism allows achieving a BER below the target, assuming ideal SNR estimation. On the other hand, BER results are kept below the target at the expense reducing the modulation level as the SNR is lower, leading to a reduction in the spectral efficiency (as shown in Figure 4). Results are similar to the theoretical ones, making clear that the model is working properly.

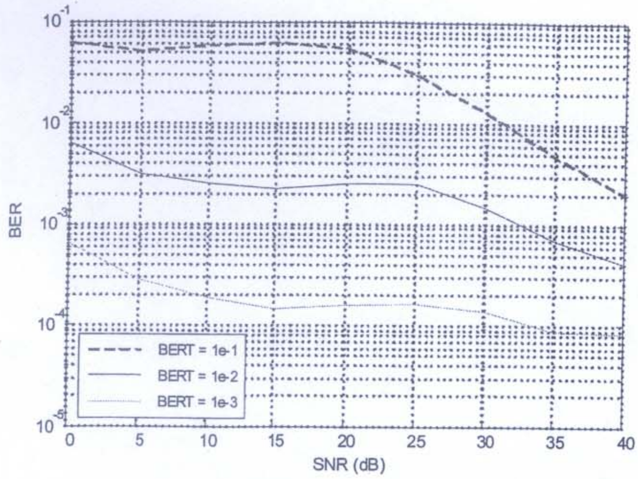

Figure 3. Mean BER for adaptive modulation.

Mean delay and bit loss rate results in MAC queues are shown in Figure 5, considering a set of 10 users with an average SNR of 20dB. Radio resource sharing among users is managed by a Round Robin algorithm.

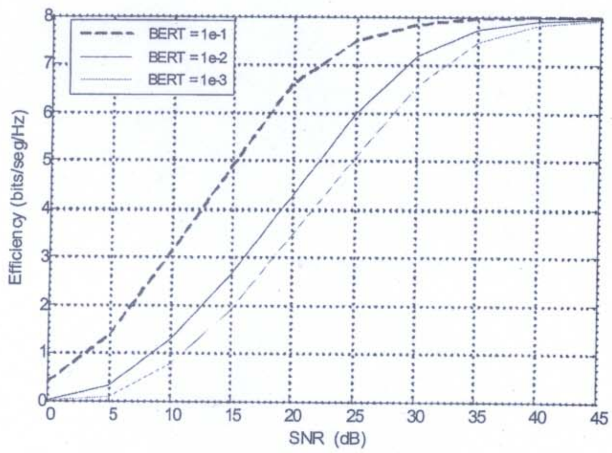

Figure 4. Spectral Efficiency in OFDMA.

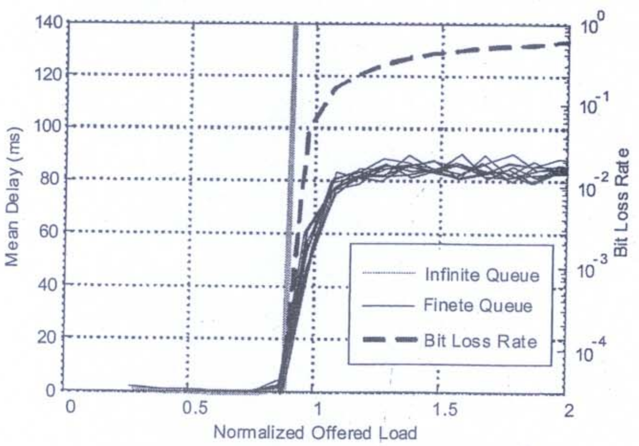

Figure 5. Mean delay and bit loss rate results.

Mean delay results represent delay per bit for each user, in two different situations: infinite queue length, and a 6KB queue length. Mean delay suddenly increases as soon as the radio capacity can not afford the incoming load (around *normalized offered load* = 1), and for finite queue sizes, such delay is limited at the expense of increasing the bit loss rate (in dashed line).

5. CONCLUSIONS AND FUTURE WORK

Along this paper, the performance analysis of an OFDMA wireless system using WM-SIM platform has been provided. Performance results show the accuracy of the model compared to theoretical estimations. WM-SIM platform has shown to be a very valuable tool for developing and testing communication systems.

Future works will be focused Long Term Evolution (LTE) technology [4] evolution in the 3rd Generation Partnership Project (3GPP) [6]. The target is to develop a model of a complete LTE-based communication system. Additionally, WM-SIM is expected to be a useful tool for testing digital signal processing algorithms (like channel estimation and signal synchronization) or Radio Resource Management (RRM) techniques.

6. ACKNOWLEDGMENTS

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