Chapter 19

Cross-Layer Optimization in OFDM Wireless Communication Network

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ABSTRACT

The wide use of OFDM systems in multiuser environments to overcome problem of communication over the wireless channel has gained prominence in recent years. Cross-layer Optimization technique is aimed to further improve the efficiency of this network. This chapter demonstrates that significant improvements in data traffic parameters can be achieved by applying cross-layer optimization techniques to packet switched wireless networks. This work compares the system capacity, delay time and data throughput of QoS traffic in a multiuser OFDM system using two algorithms. The first algorithm, Maximum Weighted Capacity, uses a cross-layer design to share resources and schedule traffic to users on the network, while the other algorithm (Maximum Capacity) simply allocates resources based only on the users channel quality. The results of the research shows that the delay time and data throughput of the Maximum Weighted Capacity algorithm in cross layer OFDM system is much better than that of the Maximum Capacity in simply based users channel quality system. The cost incurred for this gain is the increased complexity of the Maximum Weighted Capacity scheme.

INTRODUCTION

Describe the general perspective of the chapter. Toward the end, specifically state the objectives of the chapter.

The current visible trend in the current communication market is the increase in the wireless technology. Current phone manufacturer such as Samsung and Nokia are daily increasing in the sales of smart phones and even PDAs. A number of these hand held devices come with one or more wireless technologies such as Bluetooth, WI-Fi or even connections to cellular mobile networks. Due to the continuous growth of the internet and its various applications, a lot of emphasis is the past years have being placed on satisfying the needs of mobile users.

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In order to satisfy the ever growing wireless users, a new paradigm, called cross-layer optimization was proposed. Cross-layer optimization exploits layer dependencies and thus allows the propagation of ambient parameter changes quickly throughout the protocol stack. Hence, it is well-suited for mobile multimedia applications where the characteristics of the wireless medium and the application requirements vary over time.

Wireless Local Area Networks (WLAN) can successfully transmit at data rates of up to a hundred megabyte currently; but its low range which is typically a few tens of meters makes it unsuitably for large scale deployments. High speed wireless communication systems would require a Metropolitan Area Network (MAN) infrastructure to provide efficient and scalable services. Designing a wireless communication system supporting data and real-time traffic using a packet switched approach and having a high spectral efficiency is difficult.

Orthogonal Frequency Division Multiplexing (OFDM) increases the efficiency of limited spectral resources available when compared with other multiplexing schemes such as Frequency Division Multiplexing (FDM) and Time Division Multiplexing (TDM) (Nicopolitidis, 2003). OFDM has gained a lot of interest to combat wireless link impairments and simultaneously offering flexibility at the link layer (Herrman, 1999). OFDM promises higher user data rate and great resilience to severe signal fading effects of the wireless channel at a reasonable level of implementation complexity. It has been taken as the primary physical layer technology in high data rate Wireless LAN/MAN standards. Furthermore next generation wireless communication systems uses OFDM technology (Muhammad, 2004).

Current wireless networks are said to be all IP based and using the standard protocol stack for example TCP/IP stack to ensure interoperability (Jamalipour, 2001). The standard protocol stacks are architected and implemented in a layered manner and function inefficiently in mobile wireless environments (Xylomenos, 1999). This is due to the highly variable nature of wireless links and the resource-poor nature of mobile devices. Data communication over wireless connection can be improved by Cross-Layer Optimization or design (Shakkottai, 2003).

At the end of this work, we would have used cross-layer optimization techniques to:

- Improved Quality of Service (QoS) provisioning for multi-user wireless networks. Users of these networks want multimedia services with various QoS requirements. The cross-layer design used in this project is intended to balance delay, QoS and efficient resource utilization by exploiting the knowledge of channel and queuing states along with users' subjective performance metrics.
- Showed in this work that QoS delay for Real Time (RT), non-Real Time (nRT) and Best Effort (BE) traffic can be significantly reduced while ensuring a degree of fairness by using the Maximum Weighted Capacity (MWC) algorithm. This algorithm, using a joint physical and MAC layer optimization approach, addresses the requirements of the packet switched data sent from the base station to users. It uses information about the channel to allocate resource at the physical layer and schedule resources at the MAC layer to satisfy the data requirements.

A wholly physical layer system is compared to the MWC system in other to determine the amount of gains that has been achieved by it. The Maximum capacity (MC) algorithm is described by (Jurdak, 2007). This system uses an algorithm that allocates wireless resources to users that can maximize its use.

BACKGROUND

Traditionally, all data networks operate using the Open System Interconnect (OSI) protocol stack which is divided into seven layers for easier development and flexibility (i.e. Physical, Datalink, Network, Transport, Session, Presentation and Application layers) (Tanenbaum, 2003). Each layer is only able to communicate with adjacent layers as the message is transmitted from the source host to the destination host. Each is responsible for a subset of the system's operational functions. Messages are interchanged between entities of the same layer in both the transmitter and receiver side. Each layer is aware of its own messages and embeds its information into upper layer messages when they go down in the layer stack, while it's discarding the lower layers information when messages go up.

Cross-Layer Design takes into account the dependencies and the interactions among layers and allows optimization across their boundaries. A common misconception about CLD is that it consists of designing networks without layers. Layering is just a standard that allows for simplification of the network design and management tasks. Cross-Layer Design allows the joint optimization of the parameters of multiple layers. Therefore, Cross-Layer Design/Optimization should not be viewed as an alternative to the layering paradigm, but rather as a complement. Layering and cross-layer optimization are tools that can be used together to design highly adaptive wireless networks in the nearest future (Ravi1, n.d.).

This traditional approach was successful with wired networks but this network architecture does not utilize resources effectively in wireless networks (Srivastava, 2005). Wireless networks have to cope with various elements such as congestion, scheduling, fading channels, limited bandwidth, competition for limited air resources between multiple users and an overwhelming increase in demands for high speed multi-media services (Srivastava, 2005). The busty nature of data communication means that packet switched network have to deal with channel states that change from good to bad within a few milliseconds (Haykin, 1994). Circuit switched wireless networks cope well with this variations because users monopolize their respective time-slots regardless of usage.

Cross-layer Design was defined by (Aune, 2004) as a process in which, " to fully optimize wireless broadband networks, both the challenges from the physical medium and the QoS-demands from the applications have to be taken into account. Rate, power and coding at the physical layer can be adapted to meet the requirements of the applications given the current channel and network conditions. Knowledge has to be shared between all layers to obtain the highest possible adaptivity".

OVERVIEW OF OFDM

OFDM is a multicarrier scheme which transmits data using several subcarriers which are orthogonal in the frequency domain. It is a concept that was proposed and implemented about 50 years ago (Saltzberg, 2000). A resurgence of OFDM in wideband digital communication, whether wireless or over copper wires is being experienced as a result of the availability of low cost all-digital implementation of the Fast-Fourier Transform (FFT) (Van, 2002). This has significantly lowered the cost of the signal processing that is needed to implement OFDM systems.

OFDM systems transmit data on parallel subcarriers which overlap in the frequency domain, unlike frequency division multiplexing systems which do not overlap. Orthogonality between the subcarriers ensures that they are spaced such that the center frequency of one subcarrier coincides with the spectral zeros of all other subcarrier (Langton, 2004). This is done by ensuring that the subcarrier periods are integer multiples for each subcarrier and the difference between adjacent subcarrier periods must be exactly one. This way, interferences that may occur between the subcarriers are prevented. See Figure 1 for the OFDM transceiver block diagram.

At the OFDM transmitter modem, a high rate data sequence is split into a number of lower rate sequences which are then transmitted simultaneously over a number of subcarriers. These streams of data experience flat fading because the bandwidth of each subcarrier is smaller than the coherent bandwidth of the channel. Thus, a highly frequency selective channel is converted into a large set of individual flat fading narrowband channels.

Orthogonal waveform modulation is carried out by using an inverse FFT and a parallel-to-serial converter. The inverse FFT block converts the inputs from the subcarriers (in the frequency domain) to an output several taps which is then converted from parallel to serial to form a symbol (in the time domain).

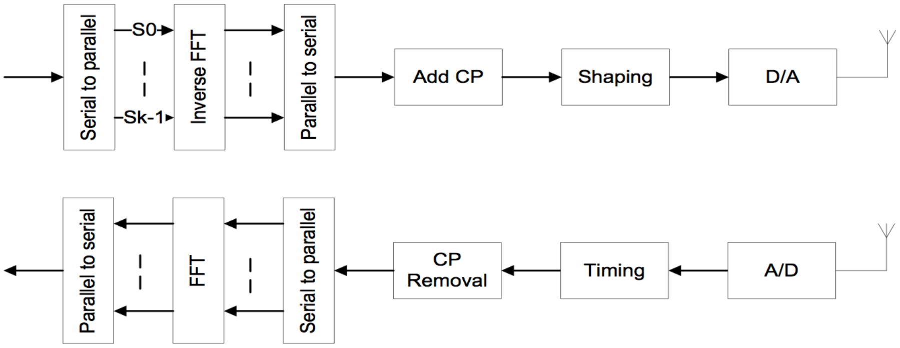
A Cyclic Prefix (CP) is appended to the symbol produced. A cyclic prefix, which is a repeat of the end of a symbol at the beginning of the symbol, is used to allow a multipath channel to settle before the start of the next symbol. The cyclic prefix allows OFDM to remain robust despite Inter-Block-Interference (Oppenheim, 1989). An OFDM symbol with CP is shown in Figure 2.

BENEFITS OF OFDM

There are various advantages of OFDM that aids its use in most wireless communication systems. They include:

- It is very useful in combating multipath fading of a signal.
- For high bit rate transmission over mobile wireless channels.
- It also alleviates the effect of impulse noise.
- It is good for power allocation.
- Higher transmission rates can be sent over the subcarrier so as to improve throughput and simultaneously to ensure an acceptable BER on each subcarrier.

Figure 1. OFDM transceiver block diagram



BENEFITS OF CROSS-LAYER OPTIMIZATION

Allocation and management of resources is crucial to the operation wireless networks, this is due to the scarce wireless spectral resources that are shared by multiple users. In the current layered network architecture, each layer is designed to operate independently in order to support transparency between the layers. Among these layers, the physical layer whose function is to transmit raw-bit, and the medium access control (MAC) layer as a function which involves controlling multiuser access to the shared wireless resources. However, wireless channels suffer from time-varying multipath fading; which is looked at in this project work. Also, the channel characteristics of different users are different. The sub-optimality and inflexibility of this architecture result in inefficient resource utilization in wireless networks. We need an integrated adaptive design across different layers. Therefore, cross layered design and optimization across the physical and MAC layers are desired for wireless resource allocation and packet scheduling (Shakkottai, 2003; Akyildiz, 2004).

For cross-layer optimization, channel-aware scheduling strategies are proposed to adaptively transmit data and dynamically assign wireless resources based on channel state information (CSI). The key idea of channel-aware scheduling is to choose a user with good channel conditions to transmit packets (Viterbi, 1995). Taking advantage of the independent channel variation across users, channel-aware scheduling can substantially improve the network performance through multiuser diversity, whose gain increases with the number of users (Viswanath, 2002; Knopp, 1995). To guarantee fairness for resource allocation and exploit multiuser diversity, utility-pricing structures in network economics are usually preferred for scheduling design (Liu, 2001).

- It overcomes limitations such as jitter, delay and fading experienced in wireless mediums.
- It allows coordination, interaction and joint optimization of protocols crossing different layers.
- It improves wireless system indices such as throughput, delay.

RESOURCE ALLOCATION

The current trend in wireless communication networks is the provisioning of multimedia services such as voice services, videophone services and animation services (Hendrik). There are different QoS requirements for each of these multimedia applications over the wireless channel (Jose). The high data rate needed by the applications make the use of one single channel for each user insufficient. The use of multicarrier systems is seen as the solution to the problem.

OFDM is the multicarrier system of choice because it divides an entire channel into many orthogonal narrowband subcarriers to deal with frequency-selective fading and to support an increased data rate. Furthermore, in an OFDM-based wireless network, different subcarriers can be allocated to different users to provide a flexible multiuser access scheme and exploit multiuser diversity. OFDM offers a high degree of flexibility of radio resources management which can significantly improve the performance of OFDM networks. Using data rate adaption, the transmitter can send higher transmission rate over the subcarriers with better conditions so as to improve throughput and simultaneously ensure an acceptable bit-error rate (BER) at each subcarrier (Nanda, 2000).

Dynamic resource allocation is used. This research work uses a rate adaptive multiuser optimization technique to maximize each user's error

SLOW FADING

In a slow fading channel, the channel impulse response changes at a rate much slower than the transmitted baseband signal. The channel seems static over one or several reciprocal bandwidth intervals. The Doppler spread of the channel is much less than the bandwidth of the baseband signals in the frequency domain. So the signal undergoes slow fading if

$$B_s >> B_d \text{ and } T_s << T_c \quad (6)$$

CROSS-LAYER OPTIMIZATION FOR OFDM WIRELESS NETWORK

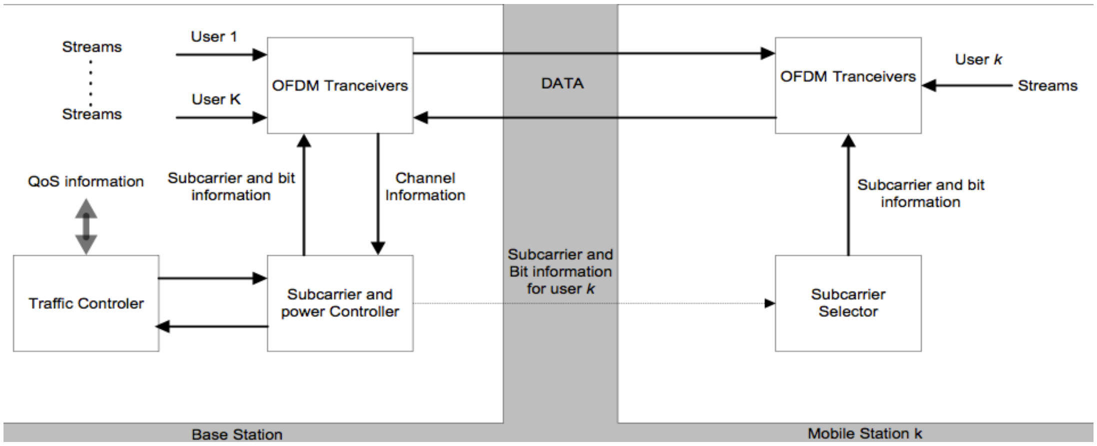
Downlink Model

We have been able to establish that there are significant challenges involved with data transmission over the wireless communication medium. The nature of the medium necessitates that instantaneous measurements of the medium is done and results of this is used to dynamically allocate the required channel resources to the user. OFDM is used to implement this process.

The Multiuser OFDM system model considered in this project is illustrated in Figure 5. This is a downlink model that is made up of two parts; the base station and the mobile user. Downstream data traffic destined for various users arrive at the base station. The base station module must ensure the data for each of the user is transmitted to it as efficiently as possible. The Subcarrier and Power Controller, at the Physical layer, perform subcarrier and power allocation while the Traffic Controller at the MAC layer performs data scheduling, respectively. The traffic controller transfers the QoS information of each user to the Subcarrier and Power Controller for the purpose of resource allocation, and the result of the resource allocation process is fed back to the traffic controller in the base station for the scheduling of the data to be sent out in each slot. The subcarrier and Power controller checks the wireless channel for the channel state information (CSI) of each user. It uses this information to efficiently allocate resources to users.

The OFDM transceiver at the transmitter delivers the OFDM symbols to the receiver. Figure 6 shows the transceivers at the base station and mobile station (Debbah, 2002).

Figure 5. Multiuser OFDM system model



FLAT FADING

This is the type of fading in which the multipath structure of the channel is such that the spectral characteristics of the transmitted signal is preserved at the receiver. The reciprocal bandwidth of the transmitted signal is much larger than the multi-path time delay spread of the channel. Flat fading channels are sometimes called narrowband channels because the bandwidth of the applied signal is narrow compared to the channel bandwidth. The characteristics of the flat fading channel are illustrated in Figure 3.

A signal under goes flat fading if

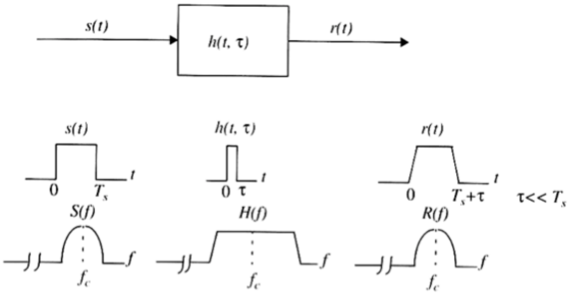
$$B_s << B_c \text{ and } T_s >> \sigma\tau \qquad (3)$$

where T_s is the symbol period and B_s is the bandwidth, respectively of the transmitted modulation; and $\sigma\tau$ and B_c are the rms delay spread and coherence bandwidth, respectively, of the channel.

FREQUENCY SELECTIVE FADING

If a channel possesses a constant gain and linear phase response over a bandwidth that is smaller than the bandwidth of the transmitted signal, then the channel creates frequency selective fading on the transmitted signal. The received signal contains multiple versions of the transmitted waveform which are attenuated and delayed in time. The received signal is distorted due to ISI induced by the channel. In essence, the gain of various frequency components vary with the receive signal spectrum.

Figure 3. Flat fading channel characteristics



Frequency selective fading channels are also known as wideband channels since the bandwidth of the signal $S(t)$ is wider than the bandwidth of the impulse response of the channel. The characteristics of the frequency selective fading channels are illustrated in Figure 4.

A signal under goes flat fading if

$$B_s > B_c \text{ and } T_s < \sigma\tau \qquad (4)$$

FAST FADING

The channel impulse response changes rapidly within the symbol duration. That is, the coherence time of the channel is smaller than the symbol period of the transmitted signal. In the frequency domain, signal distortion due to fast fading increases with increasing Doppler spread relative to the bandwidth of the transmitted signal. Hence

$$B_s < B_d \text{ and } T_s > T_c \qquad (5)$$

Figure 4. Frequency selective fading channel characteristics

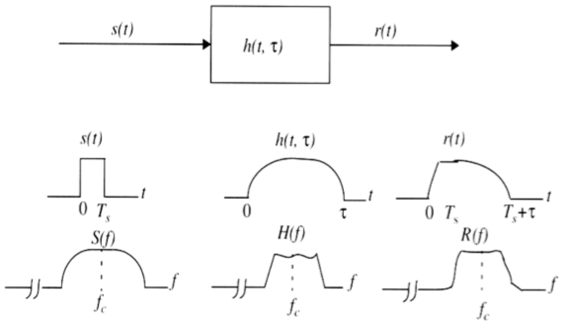
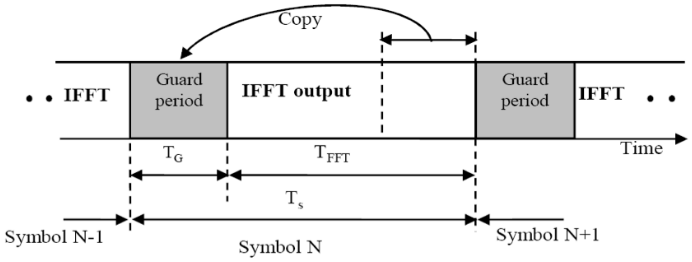


Figure 2. Cyclic prefix in an OFDM symbol (Emad, 2008)



FADING CHANNEL

The mechanism behind electromagnetic wave propagation can generally be attributed to reflection, diffraction and scattering (Rappaport, 2002). Propagation models traditionally focus on predicting the average received signal strength at a given distance from the transmitter, as well as its variability in close spatial proximity to a particular location. Large scale propagation models characterize signal strength over large distance separation (hundreds to thousands of meters) between the transmitter and the receiver. This is useful for estimating the radio coverage area of a transmitter.

However, propagation models that characterize the rapid fluctuation of the received signal strength over very short distance or for short time durations are described as small scale fading models. Fading is caused by interference between two or more versions of the transmitted signal which arrive at the receiver at slightly different times.

Fading occurs when there are several line-of-sight paths from the receiver to the base station, especially in well developed urban areas. The incoming radio waves arrive from multiple paths with different propagation delays due to reflection from the ground and surrounding structures. This lengthens the time required for the baseband signal portion of the signal to reach the receiver, causing signal smearing due to inter-symbol interference (Tse, 2005). Also relative motion of the mobile device, surrounding objects and the base station can induce Doppler shift in the multipath components.

The signal received at the mobile at any point in space may consist of a large number of plane waves having randomly distributed amplitudes, phase and angles of arrival. This causes time dispersion of received signal, rapid changes in signal strength over a small travel distance or time interval and random frequency modulation due to varying Doppler shift of different multipath signals.

Due to the different multipath waves with propagation delays that vary over different spatial locations of the receiver, the impulse response of the linear time invariant channel should also be a function of position of the receiver. The received signal $\mathrm{y}(\mathrm{d},\mathrm{t})$ at position d transmitted over a channel with impulse response $\mathrm{h}(\mathrm{d},\mathrm{t})$ is given as

$$\mathrm{y}(\mathrm{d},\mathrm{t}) = \mathrm{x}(\mathrm{t}) \otimes \mathrm{h}(\mathrm{d},\mathrm{t}) = \int_{-\infty}^{\infty} \mathrm{x}(\tau)\,\mathrm{h}(\mathrm{d},\ \mathrm{t}-\tau)\,\mathrm{d}\tau \tag{1}$$

where $\mathrm{x}(\mathrm{t})$ is the transmitted signal and A is the channel multipath delay for a fixed value of t. Assuming the receiver moves at constant velocity, the equation can be rewritten as

$$\mathrm{y}(\mathrm{t}) = \int_{-\infty}^{\infty} \mathrm{x}(\tau)\,\mathrm{h}(\mathrm{t},\tau)\,\mathrm{d}\tau = \mathrm{x}(\mathrm{t}) \otimes \mathrm{h}(\mathrm{t},\tau) \tag{2}$$

free capacity under given total power constraint. The resource allocation is done at the physical layer, while the MAC layer controller schedules data to be transmitted. The following algorithms are looked at:

1. Maximum Capacity Algorithm
2. Maximum Weighted Algorithm

MAXIMUM CAPACITY (MC) BASED RESOURCE ALLOCATION

The Maximum Capacity algorithm is the first resource allocation algorithm to be discussed. It is based on (Jang, 2003). A transmit power adaptation scheme was developed, which maximizes the total data rate of multiuser OFDM systems in downlink transmission. The transmit power adaptation method solves the maximization problem in two step; assigning subcarriers to users first, then allocating power to each of this subcarriers. Transmit power is distributed over the subcarriers using the water-filling policy.

SUBCARRIER ALLOCATION

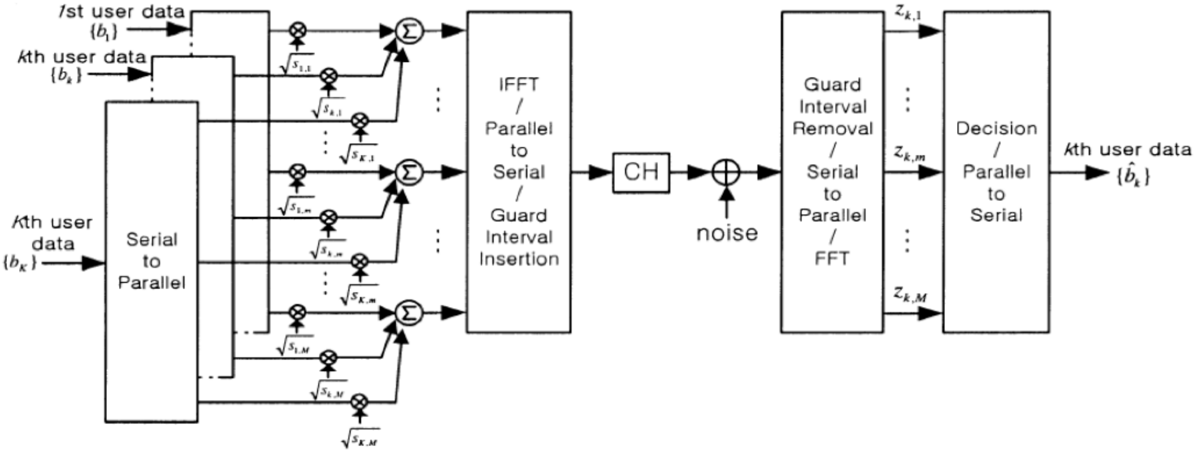
In order to maximize the total data rate of the system, Jang and Lee set the BER to a fixed value, thereby imposing an upper limit to the system. The modulation constellation is modified by changing the number of bits in each transmitted symbol depending on the channel gain for each subcarrier. Setting the BER imposes an upper bound on the system, such that by continually adapting the constellation size, this BER would be the maximum for any channel condition.

For an OFDM system with a bandwidth B, total transmit power $\bar{S}$ and N subcarriers, the problem is formulated as:

$$R = \frac{B}{N}\sum_{n=1}^{N}\log_2\left(1 + s_{k_n^*}\left|\alpha_{k_n^*}\right|^2 \frac{N}{N_0 B\Gamma}\right)$$

$$k_n^* = \arg_k \max\left\{\left|\alpha_{1,n}\right|^2, \left|\alpha_{2,n}\right|^2, \ldots, \left|\alpha_{K,n}\right|^2\right\} \text{for } n = 1, 2, \ldots, N. \qquad (7)$$

Figure 6. OFDM transceivers



Subject to

$$\sum_{n=1}^{N} s_{k_n^*} = \bar{S} \tag{8}$$

where $\alpha_{k_n^*}$ and $s_{k_n^*}$ are the channel gain and power assigned to user k with the best channel gain for subcarrier. Γ is a function of the required BER and is defined as $\Gamma = -\ln(5BER)/1.5$ (Song, 2005).

The algorithm selects the user with the best channel gain for a subcarrier and assigns the subcarrier to the user in order to maximize the total data rate in Equation (7). Since there is no constraint on the user data rate, a user may not be assigned any subcarrier if the user has no best subcarrier.

POWER ALLOCATION

The transmit power adaptation method used for the maximum capacity algorithm is water-filling over the subcarriers with the best channel gains among multiple users. The method takes the inverse of the channel gains of all users as a container in which when power is poured in, it is distributed over all users so that the power levels of all users are uniform. In essence, more power is allocated to a user with a high channel gain and less or no power is allotted to a user with lower channel gain. The aim of the process is to maximize the sum of data rate for each sub-channel. From Equation (7), we can see that capacity is a logarithmic function of power, hence, so there is a significant difference in the increase in capacity when a given power value is assigned to a subcarrier with high gain vis-à-vis one with low gain.

Thus, the water-filling algorithm adapts power allocation for subcarriers to the channel condition for a given total power in order to achieve maximum data rates. The optimum water level changes when the channel condition changes, so it has to be updated accordingly each time these changes occur.

To maximize the total data rate of the multiuser OFDM system, the transmit power should be allocated as

$$\begin{cases} s_{k_n^*} = \dfrac{N_0 B\Gamma}{N}\left[\dfrac{1}{\lambda_0} - \dfrac{1}{\left|\alpha_{k_n^*}\right|^2}\right]^+ , \text{for } n = 1,2,\ldots,N \\ s_{k_n^*} = 0, \qquad \text{for } k \neq k_n^* \end{cases} \tag{9}$$

$[.]^+$ represents the outcome of the water-filling algorithm. λ_0 is a threshold to be determine from the total transit power constraint in Equation (8) and is given as

$$\lambda_0 = (\bar{S} + \sum_{n=1}^{N} \frac{1}{\alpha_{k_n^*}}) / N \tag{10}$$

MAXIMUM WEIGHTED CAPACITY (MWC) BASED RESOURCE ALLOCATION

The maximum weighted capacity (MWC) algorithm as proposed by Zhou in (Zhou, 2008) is a resource allocation algorithm which can improve the QoS at the physical layer for multimedia data while maintaining high capacity in a multiuser OFDM network. This resource allocation algorithm is optimized with information about the channel state that is shared between the physical layer and the MAC layer. It uses a batch dependent scheduling scheme for the downlink system. Traffic data is classified broadly into 3 types based on their QoS requirements (i.e. Real Time, non Real Time and Best Effort). There are multiple queues per user; one for each traffic type.

A downlink OFDM multiuser system with a total of K users is considered for MWC. For simplicity, each subcarrier is occupied by only one user. At the base station, QoS information is transferred from the traffic controller to the subcarrier and power controller for resource allocation and the resource allocationresults are fed back to the traffic controller for scheduling as shown in Figure 6.

OPTIMAL SUBCARRIER ALLOCATION

A total bandwidth of B is shared by N subcarriers and the OFDM signalling is time slotted where the duration of each slot is T_{slot}. QoS information from the traffic controller is received at the physical layer in as weights, W. The weight for each user is denoted as W_k. Assuming perfect CSI, the achievable instantaneous data rate of user k on subcarrier n is expressed as:

$$R_{k,n} = \frac{B}{N}\log_2\left(1 + s_{k,n}\left|\alpha_{k,n}\right|^2 \frac{N}{N_0 B\Gamma}\right) \tag{11}$$

Thus, the total instantaneous data rate of user k is given by:

$$R_k = \sum\nolimits_{n\in\Omega_k} R_{k,n} \tag{12}$$

Ω_k is the set of all subcarriers allocated to user k.

So the MWC resource allocation strategy uses cross-layer optimization to maximize the sum of weighted capacities given as:

$$J = \sum\nolimits_{k=1}^{K} W_k R_k \tag{13}$$

Subject to $s_{k,n} \geq 0, \sum\nolimits_{k=1}^{K}\sum\nolimits_{n\in\Omega_k} s_{k,n} \leq \bar{S}$, $\Omega_i \cap \Omega_j = \varnothing (i \neq j)$, $\Omega_1 \cup \Omega_2 \cup \ldots \Omega_k \subseteq \{1, 2, \ldots, N\}$ and $R_k T_{slot} \leq Q_k$

Q_k denotes the total amount of data awaiting transmission for user k. The constraint $R_k T_{slot} \leq Q_k$ guarantees that no more resource is allocated to user k if the user has already obtained sufficient resources, to allow as much data as possible to be transmitted in the current slot.

OPTIMAL POWER ALLOCATION

Power allocation in for MWC uses the water filling strategy to assign power to users on the system. However, the water filling algorithm has to be modified to put the weights calculated at the MAC layer for each user into consideration. The proportion of power allocated to a user is a function of the total weight for the user relative to the sum total of the weight of all users. The optimal power allocation solution is given as

$$s_{k,n} = \left[\frac{W_k}{\sum_{m=1}^{K}\left(W_m \left|\Omega_m\right|\right)}\left(\bar{S} + \sum_{m=1}^{K}\sum_{q\in\copyright_i}\frac{1}{\alpha_{m,q}}\right) - \frac{1}{\alpha_{k,n}}\right]^+ \tag{14}$$

where $\left[x\right]^+ = \begin{cases} x, & x > 0 \\ 0, & x \leq 0 \end{cases}$, and $\left|\Omega_m\right|$ denotes the number of subcarriers in set Ω_m.

SIMULATIONS, RESULTS AND DISCUSSIONS

The simulation result for the MWC and MC schemes are presented in this section. The results are used to compare the performance of the MC scheme, which is a wholly physical layer scheme, and the MWC scheme. The MWC uses cross-layer optimization between the physical layer and the MAC layer to improve the performance system-centric quantities of QoS traffic. In order for the comparison to be fair, a modified version of the DS based scheduling algorithm used for MWC is applied to MC. The first part of the simulation is to reproduce the results for MC reported in (Jang, 2003) to show that the scheduling algorithm does not affect the physical layer properties of MC.

Since MC only maximises the R (Equation (8)) for the system, the weight $W_{k,i,l} = 1$ is assigned to all slots. MC scheme is ignorant of the QoS requirement of data traffic transmitted. The QoS coefficient is the same for all traffic types, i.e. $\beta_i = 1, \forall i$.

For MWC, the QoS coefficient, β_i for Real Time, non Real Time and Best Effort traffic are 1024, 512 and 1, respectively (see Tables 1 and 2). For subcarrier allocation, uniform power allocation is assumed across all subcarriers. So each subcarrier is allocated power $\bar{S} / N$.

The total bandwidth of the downlink OFDM system is $B=$ 1MHz, which is divided into $N =$ 256 subcarriers for $K=$ 16 users to share. The total power is $\bar{S} =$ 1W. The targeted bit error rate is $BER=$ $1x10^{-3}$. The channel has five independent Rayleigh fading paths with an exponential delay profile. The maximum delay tolerance for RT, nRT and BE traffic are set at 100msec, 400msec and 1sec, respectively (Zhou, 2008). Using voice traffic as a model for RT traffic, incoming data stream is fixed at 64Kbits. nRT traffic (using video traffic as a model), has an arrival rate that is Poisson distributed with a minimum data rate of 120Kbits and a maximum of 420Kbps. BE traffic has a Poisson distribution between 0 and 50 Kbit for each slot. It is assumed that perfect CSI of the downlink channel is available at the base station. SNR is defined as the average received signal power to noise power for each user. These values are standard values used in all simulation unless otherwise stated.

Figure 7 depicts the average system capacity versus the average SNR for each user. We can see here that MC has a maximum data rate that is higher than MWC with a constant difference of about 0.4 bit/sec/Hz. The AWGN curve shows the capacity of the AWGN channel and serves as a benchmark.

The MC scheme has a higher capacity because it assigns subcarriers to the user with the best channel gain for that subcarrier. However, the MWC scheme considers other parameters other than the channel gain to determine subcarrier allocation. Thus, there is more fairness in MWC, because a user stands a higher chance of having its data transmitted if it had poor channel gains.

Figure 8 shows the average delay of RT traffic. We can see that the delay experienced by traffic in this QoS class is significantly lower for MWC compared with MC. There is a difference of about 240msec to 200msec in the average packet delay at various SNR values. With the maximum delay tolerance expected for RT set at 100msec,

Table 1.

Quality of Service Coefficient		
Real Time Traffic	**Non-Real Time Traffic**	**Best Effort Traffic**
1024	512	1

Table 2.

Downlink OFDM System	
Bandwidth	1mhz
Number of subcarriers	256
Number of users	16
Total power	1w
Targeted BER	$1x10^{-3}$

Figure 7. System bandwidth efficiency versus average SNR

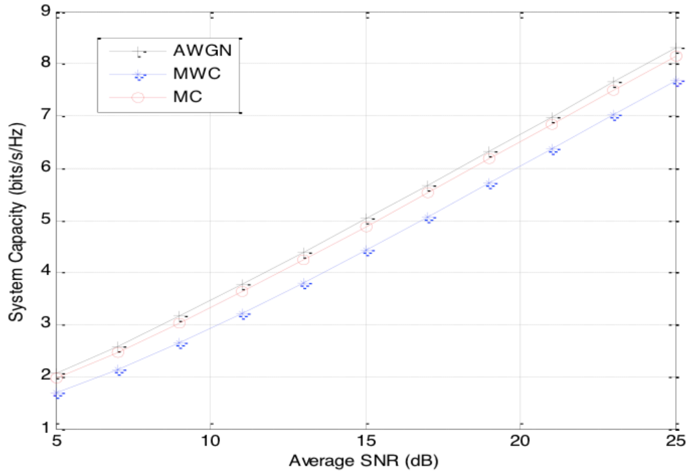
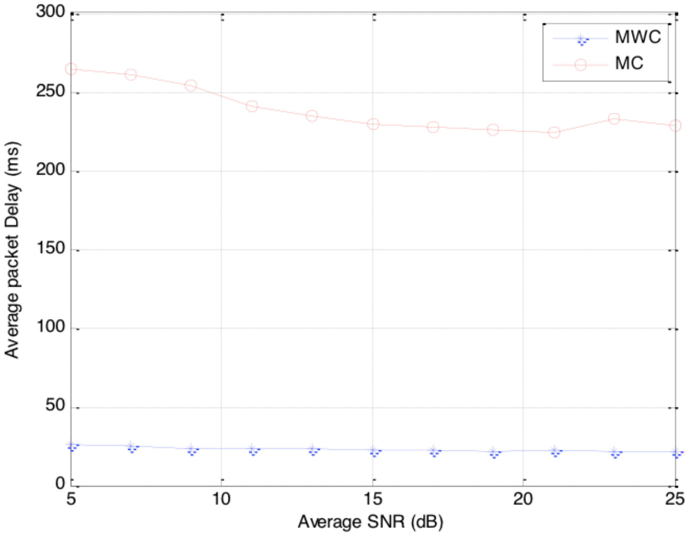


Figure 8. Average real time packet delay versus average SNR



we can see that RT traffic would perform badly with MC scheme.

Figure 9 shows that nRT traffic performs well under the MWC scheme in terms of delay. Traffic in this QoS class transmitted using this scheme is able to meet the delay time requirements at all SNR values. However, for MC traffic in this class had to endure an average delay time of over 400msec at SNR values below 13dB. The differences in the delays experienced nRT traffic for MWC and MC varies between about 1sec at 5dB and 300msec at 25dB.

The scenario that is played out with BE traffic is different. Figure 10 shows that, in this case, the

Figure 9. Average non real time packet delay versus average SNR

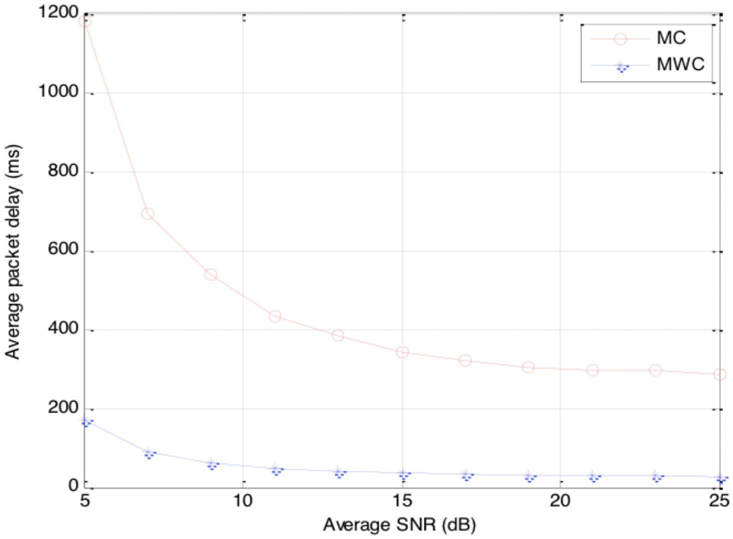
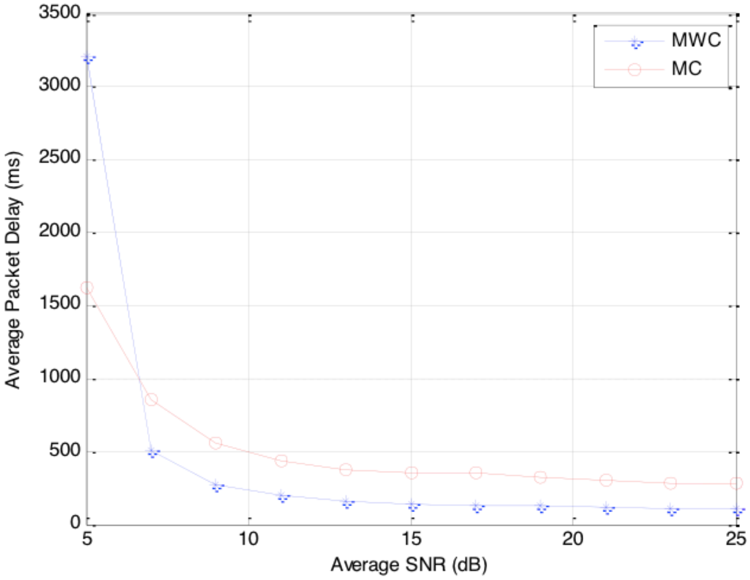


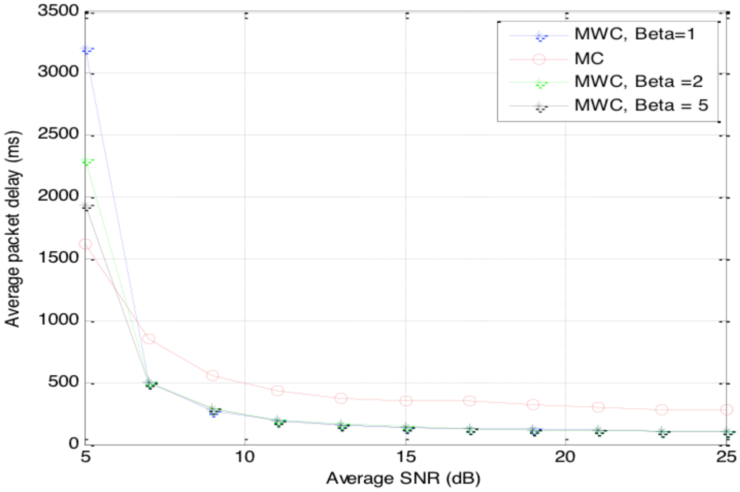
Figure 10. Average best effort packet delay versus average SNR



delay times experienced under MWC at low SNR value is quite large. This values falls rapidly so that at 7dB the delay time is 500msec, which is lower than the maximum tolerance of 1sec for BE traffic. The same is also true for MC. At higher SNR values, the delay experience by traffic in this class reduces slowly. At SNR values higher than 7dB, difference in the delay times for MWC and MC is about 200msec.

It is obvious that the delay time at SNR values below 7dB exceeds the maximum delay tolerance for MWC. Increasing the QoS coefficient β_i assigned to BE traffic would, however, reduce the the delay.

Figure 11. Best effort packet delay versus average SNR at $\beta_i = 1, 2, 5$ *for MWC*



So in Figure 11, the plot for MWC curves at $\beta_i = 1, 2, 5$ is done. The delay time for BE traffic reduces as β_i increases. Above 7dB, the delay curves for the three coefficient values are similar. The curve for MC does not change because it ignores the QoS traffic class for traffic it transmits. Hence, β_i is constant for it (MC). Thus, it is possible to vary the delay time by changing the QoS coefficients of the traffic class. However, it should be noted that changing β_i for one traffic class would result in changes in the delay times of other QoS traffic. This is a trade-off of the delay time for different traffic classes depending on the specifications of the multiuser system required.

In Figure 12, the actual throughput of data transmitted by the MWC and the MC scheme is shown. Throughput in this case refers to the total data that arrived at the base station and was successfully transmitted to all users by the base station in the simulation. The data structure for RT, nRT and BE traffic was described earlier in this section. It can be seen that the increase in throughput by MWC relative to MC varies from about 30% (at SNR of 5dB) to about 50% (at SNR values greater than 9dB). This is despite the fact that the maximum system capacity for MC, shown in Figure 7, is constantly higher than MWC at all SNR values.

Further comparison of the MWC and MC is shown in Figure 13. In this case, the SNR = 10dB and the number of subcarriers $N = 256$. This figure shows that the maximum data rate for MC and MWC increases significantly with the number of users on the system. The capacity of the system becomes higher than the capacity of the AWGN channel when the number of users K is equal to or larger than 22 users and 57users, for MC and MWC, respectively. The received average SNR for each subcarrier signal increases as the number of users increases and total data rate increases as a result. This increase in the data rate shows that multiuser diversity improves the system capacity of OFDM systems.

SOLUTIONS AND RECOMENDATIONS

There is no doubt that the current OSI model/standard as had an overwhelming impact in the wired communication network. This is not the same in the area of wireless communication system due to the various environmental factors

Figure 12. Total data throughput versus the average SNR

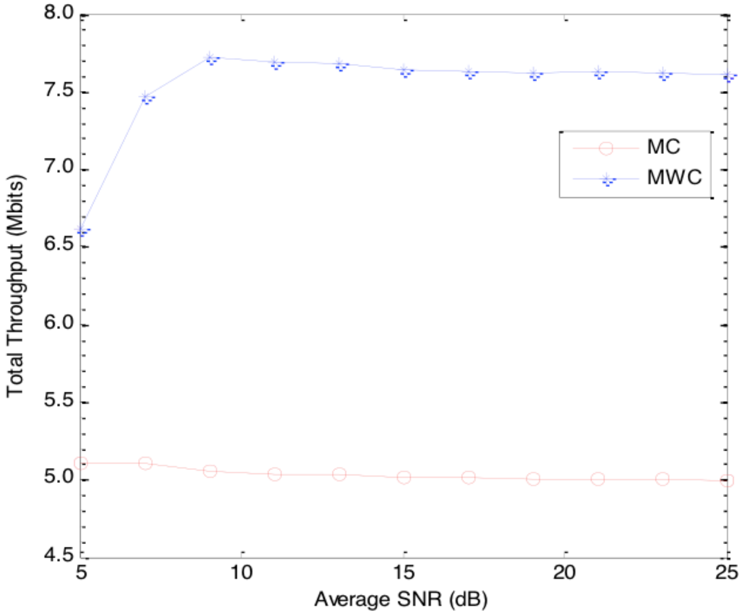
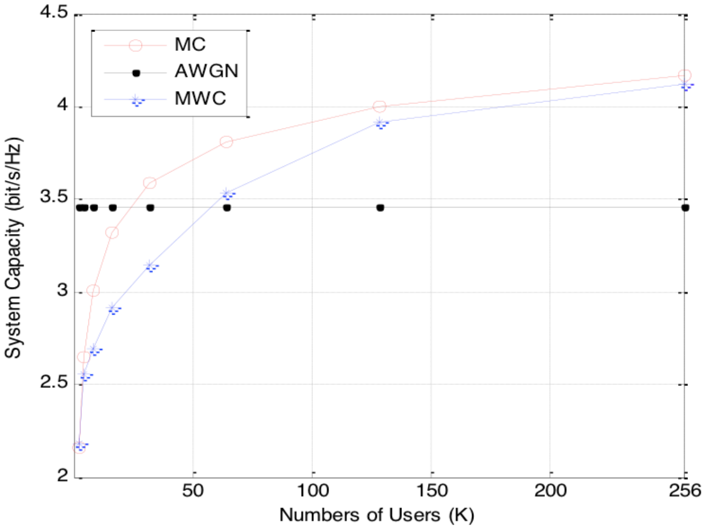


Figure 13. System capacity versus number of Users



that mitigate wireless communications networks. Such environmental factors include jitter, delay and fading.

We have been able to establish in this work that OFDM as a transmission channel helps in addressing some of these impairments experienced by wireless communication system.

There are quite a number of misconceptions about cross-layer optimization. Cross-layering does not mean there will be a new OSI model or standard, it only says there should be interaction between the various layers in the OSI model. Cross-layering as a new paradigm says there should be joint sharing and optimization between all layers of the OSI stack.

If the current layered approach been used is eliminated and all layers are integrated and jointly optimized, it will lead to the following issues

- A clearly impractical network design.
- It leads to spaghetti codes.
- It leads to disaster in terms of implementation, debugging, standardization and upgrading.

The solution required in implementing this new technique or paradigm is to have a holistic view of wireless networking. This involves maintaining the layered approach, while accounting for interactions between various protocols at different layers, more like a loose coupling design.

FUTURE RESEARCH DIRECTION

Further work on this project in future should investigate ways of reducing the complexity of MWC. Other cross-layer designs to improve other parameters of data traffic such as jitters and dropped packets should be explored. Ways of improving the efficiency of wireless communication system using interactions between other layers of the system apart from the MAC layer should also be explored.

CONCLUSION

This work is a comparative framework of two algorithms for resource allocation in a wireless system with multiple users vying for wireless network resources. The wireless channel is shared by using OFDMA. The main aim of the project is to improve system indices using cross-layer optimization techniques.

The first algorithm implemented is maximum capacity (MC) algorithm as described by Jang and Lee in (Jang, 2003). The algorithm allocates resources without using any information from layers apart from the physical layer. Subcarriers are allocated to uses with the maximum channel gain and power is allocated to these subcarriers by the water filling algorithm.

The second algorithm (MWC) is concerned about how the OFDM wireless network handles QoS traffic in a multiuser environment. It uses information about the QoS requirements of the data stream being transmitted to determine which slots gets priority over others for transmission to users. In other words, the algorithm combines knowledge of the state of the traffic packet at the MAC layer to apportion resources and schedule traffic to users.

The results show that while the MC has a higher system capacity, the MWC reliable transmits Real time and non Real Time traffic within the requirements for this traffic class. For Best Effort traffic, the performance of MWC at low SNR value is not within the specification. At higher SNR (above 7dB), its performance is satisfactory. On the hand, MC struggles to meet the delay requirements for all traffic classes, especially at lower SNR value. The overall data traffic throughput for MWC is also much better than that of MC despite MC having a better system capacity.

The resource allocation scheme and scheduling done using cross-layer optimization in MWC has reduced the delay time for real time, non real Time and partially for BE traffic. It has also improved the throughput for the system when compared with MC, which is a purely physical layer resource allocation scheme. The trade-off here is the complexity of the two algorithms. The complexity required to implement the scheduling in MWC increases the computational costs of the system, compared to MC.

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KEY TERMS AND DEFINITIONS

Bit Error Rate: In digital transmission, the number of bit errors is the number of received bits of a data stream over a communication channel that has been altered due to noise, interference, distortion or bit synchronization errors. The bit error rate or Bit Error Ratio (BER) is the number of bit errors divided by the total number of transferred bits during a studied time interval. BER is a unit less performance measure, often expressed as a percentage.

Multiplexing: In telecommunications and computer networks, multiplexing is a method by which multiple analog message signals or digital data streams are combined into one signal over a shared medium. The aim is to share an expensive resource.

Quality of Service (QoS): Quality of service is the ability to provide different priority to different applications, users, or data flows, or to guarantee a certain level of performance to a data flow. For example, a required bit rate, delay, jitter, packet dropping probability and/or bit error rate may be guaranteed. Quality of service guarantees are important if the network capacity is insufficient, especially for real-time streaming multimedia applications such as voice over IP, online games and IP-TV, since these often require fixed bit rate and are delay sensitive, and in networks where the capacity is a limited resource, for example in cellular data communication.

Signal to Noise Ratio: (Often abbreviated SNR or S/N) Is a measure used in science and engineering that compares the level of a desired signal to the level of background noise. It is defined as the ratio of signal power to the noise power. A ratio higher than 1:1 indicates more signal than noise.

Throughput: Throughput or network throughput is the average rate of successful message delivery over a communication channel. This data may be delivered over a physical or logical link, or pass through a certain network node. The throughput is usually measured in bits per second (bit/s or bps), and sometimes in data packets per second or data packets per time slot.

Transmission Control Protocol /Internet Protocol (TCP/IP): Transmission Control Protocol /Internet Protocol is the communication protocol for the internet. TCP/IP defines the rule computers must follow to communicate with each other over the internet. TCP/IP provides end-to-end connectivity specifying how data should be formatted, addressed, transmitted, routed, and received at the destination.