CHAPTER 1

INTRODUCTION

Rapid development of multimedia applications in the wireless environment has lead to the development of many broadband wireless technologies from 2G to 3G. This has increased the demand for newer, bandwidth hungry technologies such as Worldwide Interoperability for Microwave Access (WiMAX). The IEEE has proposed a new standard for this technology called the IEEE 802.16. This standard suggested modifications in the Medium Access Control (MAC) and Physical Layer (PHY) to accommodate the high bandwidth handling capabilities. The ever increasing demand of multimedia applications in WiMAX networks has made Quality of Service (QoS) optimization an important issue. As the IEEE 802.16 standards provide true QoS classes for different types of applications, each of the service class may be provisioned of the requested QoS separately and simultaneously (Haghani et al 2009). The WiMAX systems are based on the versions d and e of the IEEE 802.16 standard which defines the PHY and MAC layers for the broadband wireless access systems operating at frequencies below 11GHz.

1.1 IEEE 802.16 STANDARD

IEEE 802.16, a solution to Broadband Wireless Access (BWA), commonly known as WiMAX, is a recent wireless broadband standard that has promised high bandwidth over long-range transmission. The standard specifies the air interface, including the MAC and PHY layers of BWA. The
key development in the PHY layer includes Orthogonal Frequency Division Multiplexing (OFDM), in which multiple access is achieved by assigning a subset of sub-carriers to each individual user. This resembles Code Division Multiple Access (CDMA) spread spectrum that can provide different QoS for each user. Users achieve different data rates by assigning different code spreading factors or different numbers of spreading codes. In an OFDM system, the data is divided into multiple parallel sub-streams at a reduced data rate, and each one is modulated and transmitted on a separate orthogonal sub-carrier. This increases the symbol duration and improves the system robustness. OFDM is achieved by providing multiplexing on the user’s data streams on both uplink and downlink transmissions. The IEEE 802.16-2001 standard specified a frequency range of 10–66 GHz with a theoretical maximum bandwidth of 120 Mb/s and a maximum transmission range of 50 km. However, the initial standard supports only the Line-Of-Sight (LOS) transmission. Thus it does not seem to favor deployment in urban areas. A variant of the standard, IEEE 802.16a-2003 can support Non-LOS (NLOS) transmission and adopts OFDM at the PHY layer. It also adds support to the 2–11 GHz range. One of the main problems in the earlier draft of IEEE 802.16 is that it covers too many profiles and PHY layers, which can lead to potential interoperability problems. This has been largely recognized in the community and now focus is on several main profiles and defines interoperability testing for WiMAX equipment. From the initial variants, the IEEE 802.16 standard has undergone several amendments and evolved to the 802.16-2004 standard (also known as 802.16d). The standard provides technical specifications for the PHY and MAC layers for fixed wireless access and addresses the first or last-mile connection in Wireless Metropolitan Area Networks (WMANs). Lack of mobility support is considered to be one of the major hindrances to its deployment when compared to other standards such as IEEE 802.11 WLAN, since mobility support is regarded as one of the key features in wireless networks. As a consequence, the new IEEE 802.16e
has added mobility support. This is generally referred to as mobile WiMAX and it adds significant enhancements as given below,

- It improves the NLOS coverage by utilizing advanced antenna diversity schemes and Hybrid Automatic Repeat Request (HARQ).
- It adopts dense subchannelization, thus increasing the system gain and improving indoor penetration.
- It uses Adaptive Antenna System (AAS) and Multiple Input Multiple Output (MIMO) technologies to improve the coverage.
- It introduces a downlink subchannelization scheme, enabling better coverage and capacity trade-off. This brings potential benefits in terms of coverage, power consumption, self-installation, frequency reuse, and bandwidth efficiency.

One of the key complications is that the incompatibility in the Scalable OFDM (SOFDM) in IEEE 802.11e with the original OFDM scheme forces equipment manufacturers to come up with mechanisms to ease the transition. QoS provisioning is one of the most important issues, given the inherent QoS specification in the WiMAX MAC layer definition. It is anticipated that IEEE 802.16 is fully capable of supporting multimedia transmissions with differentiated QoS requirements through the use of scheduling mechanisms. With the rising popularity of multimedia applications in the Internet, IEEE 802.16 provides the capability to offer new wireless services such as multimedia streaming, real-time surveillance, Voice over IP (VoIP), and multimedia conferencing. Due to its long-range and high-bandwidth transmission, IEEE 802.16 has also been considered in areas where it can serve as the backbone network with long separation among the
infrastructure nodes. Another promising area is replacing the cellular technology using VoIP over WiMAX if QoS requirements can be satisfied. One of the main challenges in QoS provisioning is the effective mapping of the QoS requirements of potential applications across different wireless platforms (Bo Li 2007).

The 802.16 MAC is designed to support a point-to-multipoint architecture with a central Base Station (BS) communicating simultaneously with multiple Subscriber Stations (SS). The MAC includes the following sub-layers namely,

i) A Service-specific convergence sub-layer that classifies the service data units to the appropriate MAC connections, preserves or enables QoS and bandwidth allocation,

ii) The MAC common part sub-layer that provides a mechanism for requesting bandwidth, associating QoS and traffic parameters, transporting and routing data to the appropriate convergence sub-layer,

iii) A Privacy sub-layer that provides authentication of network access and connection establishment (Eklund et al 2002).

The IEEE 802.16e Standard specifies the Orthogonal Frequency Division Multiple Access (OFDMA) based PHY layer that has distinct features like flexible sub channelization, adaptive modulation and coding, space-time coding spatial multiplexing, dynamic packet switch based air interface and flexible network deployment such as fractional frequency re-use (Kennington et al 2011). Adaptive Modulation and Coding (AMC) employed in the PHY layer dynamically adapts the modulation and coding scheme to the channel conditions so as to achieve the highest spectral efficiency at all times (Ali-Yahiya et al 2008).
1.2 **WiMAX ARCHITECTURE**

IEEE Standard 802.16-2001, completed in October 2001 and published on 8 April 2002, defines the WirelessMAN™ air interface specification for wireless Metropolitan Area Networks (MANs). The completion of this standard signals the entry of broadband wireless access as a major new tool in the effort to link homes and businesses to core telecommunications networks worldwide. As currently defined through IEEE Standard 802.16, a wireless MAN provides network access to buildings through exterior antennas communicating with the central radio base stations. The wirelessMAN offers an alternative to cabled access networks, such as fiber optic links, coaxial systems using cable modems, and Digital Subscriber Line (DSL) links. As wireless systems have the capacity to address broad geographic areas without the costly infrastructure development required in deploying cable links to individual sites, the technology may prove less expensive and lead to more ubiquitous broadband access. Such systems have been in use for several years, but the development of the new standard marks the maturation of the industry and forms the basis of the success of new industries using second-generation equipment.

In this scenario, with WirelessMAN technology bringing the network to a building, users inside the building will connect to it with conventional in-building networks such as, for data, Ethernet (IEEE Standard 802.3) or wireless LANs (IEEE Standard 802.11). However, the fundamental design of the standard may eventually allow for the efficient extension of the WirelessMAN networking protocols directly to the individual user. For instance, a central BS may someday exchange MAC protocol data with an individual laptop computer in a home. The links from the BS to the home receiver and from the home receiver to the laptop would likely use different physical layers. However, design of the WirelessMAN MAC could
accommodate such a connection with the ensured QoS. With the technology expanding in this direction, it is likely that the standard will evolve to support nomadic and increasingly mobile users. For example, it could support the usage of the above standard in case of a stationary or slow moving vehicle. IEEE Standard 802.16 was designed to evolve as a set of air interfaces based on a common MAC protocol, but with the physical layer specifications dependent on the spectrum of use and the associated regulations. The standard, approved in 2001, addresses frequencies from 10 to 66 GHz, where extensive spectrum is currently available worldwide but at which the short wavelengths introduce significant deployment challenges. In 2002, an amendment to the existing document was carried out and it was denoted as IEEE 802.16a. This document has extended the air interface support to lower frequencies in the 2–11 GHz band, including both the licensed and license exempt spectra. Compared to the higher frequencies, such spectra offer the opportunity to reach many more customers at less cost, at lower data rates. This suggests that such services will be oriented towards individual homes or to small and medium-sized enterprises. (Eklund 2002).

1.2.1 IEEE 802.16 MAC Layer

Basic Functionality of MAC Layer in WiMAX

The reference model in IEEE 802.16 is presented in the Figure 1.1. The MAC layer of this reference model consists of three sub-layers namely,

- the service-specific Convergence Sublayer (CS)
- MAC Common Part Sublayer (MAC CPS)
- security sublayer

The main functionality of the CS is to transform or map external data from the upper layers into appropriate MAC Service Data Units (SDUs)
for the MAC CPS. This includes a classification of external data with the proper MAC Service Flow Identifier (SFID) and Connection Identifier (CID). SDU is the basic data unit exchanged between two adjacent protocol layers.

The MAC CPS provides the core functionality for system access, allocation of bandwidth, and connection establishment and maintenance. This sublayer also handles the QoS aspect of data transmission. The security sublayer provides functionalities such as authentication, secure key exchange, and encryption. For the PHY layer, the standard supports multiple PHY specifications, each handling a particular frequency range.

MAC CPS contains the essential functionalities for scheduling and QoS provisioning in the system. IEEE 802.16d MAC provides two modes of operation namely point-to-multipoint (PMP) and multipoint-to-multipoint (mesh).

![IEEE 802.16 reference model](image)

Figure 1.1 IEEE 802.16 reference model
Point-To-Multipoint

The PMP operational mode fits a typical fixed access scenario, where multiple service subscribers are served by a centralized service provider. In PMP mode, uplink transmissions from a subscriber station (SS) to a base station (BS) occur in separate timeframes. In the downlink subframe, the BS can transmit a burst of MAC Protocol Data Units (PDUs). Since the downlink transmission is broadcast, a SS listening to the data transmitted by the BS is required only to process PDUs addressed to it or explicitly intended for all SSs. Subscriber stations share the uplink to the BS on a demand basis. Depending on the class of service utilized, the SS may be issued continuing rights to transmit, or the right to transmit may be granted by the BS after the receipt of a request from the user. Downlink and uplink subframes are duplexed either using frequency-division duplex (FDD) or time-division duplex (TDD). SSs can be either full-duplex or half-duplex. PMP mode could support mobile WIMAX in IEEE 802.16e.

Multipoint-to-Multipoint

In mesh mode, nodes are organized in an ad hoc fashion. Unlike in the PMP mode, there are no explicitly separate downlink and uplink subframes here. Each station establishes a direct communication to a number of other stations in the system. However in a typical scenario, there can be certain nodes that provide the BS function of connecting the mesh network to the backhaul links. In fact, when using mesh centralized scheduling, the BS like nodes perform similar functions to the BS in the PMP mode. The key difference is that in mesh mode all SSs may have direct links with other SSs. The IEEE 802.16 defines two mechanisms to schedule data transmission in mesh mode namely, centralized and distributed scheduling. In centralized scheduling, the BS works like a cluster head and determines how SSs share the channel in different time slots. As all the control and data packets need to
go through the BS, the scheduling procedure is simple with a potentially long connection setup. In distributed scheduling, every node competes for channel access using a pseudo-random election algorithm based on the scheduling information of its two-hop neighbors. Data sub-frames are allocated based on a request-grant confirm three-way handshaking protocol. The mesh mode has coordinated and uncoordinated distributed scheduling. Both have adopted a three-way handshake mechanism. MSH_DSCH is the scheduling message in IEEE 802.16 standards, in which an availabilities request is made along with the MSH_DSCH. This indicates potential slots for replies and the actual schedule. A grant is sent in response, indicating a subset of the suggested availabilities that fit the request. The neighbors of this node who are not involved in this schedule shall assume that the transmission takes place as granted. The grant is sent by the original requester containing a copy of the grant from the other party, to confirm the schedule to the other party. The key difference between the coordinated and uncoordinated distributed scheduling is that in coordinated scheduling, the MSH-DSCH message are scheduled in the control sub-frame in a collision-free manner, whereas in the uncoordinated case, MSH-DSCH messages may collide. Nodes responding to a request should, in the uncoordinated case, wait a sufficient number of mini slots for the indicated availabilities before responding with a grant, so that the nodes listed earlier in the request have an opportunity to respond. The grant confirmation is sent immediately in the mini slots following the first successful reception of an associated grant packet. Similar to the PMP mode, the specific schedulers for mesh mode are not defined in the IEEE 802.16 standard. However, in the current IEEE 802.16e standard, mesh mode is not supported, since mesh mode is mainly for the stationary scenarios. There has been only a limited work on the performance analysis of the distributed schedulers in the mesh mode.
1.2.2 IEEE 802.16 PHY Layer

The IEEE 802.16 specification regarding PHY layer supports features such as AMC subchannels, hybrid automatic repeat request (H-ARQ), high efficiency uplink subchannel structures, multiple-input-multiple-output (MIMO) diversity and coverage enhancing safety channels, as well as other OFDMA default features such as the different sub-carrier allocations and diversity schemes (Hassan yaghoobi (2004)).

The WiMAX PHY layer is designed to work with different specifications for licensed and unlicensed frequency bands. For example, one is based on a single carrier (SC) to support the line of sight with high data rates. Others use OFDM and OFDMA to support both the line of sight and Non Line Of Sight (NLOS) (Manal Albzoor (2011)).

Orthogonal Frequency-Division Multiple Access

Orthogonal frequency-division multiple access (OFDMA) offers a very attractive solution to provide high performance and flexible deployment for broadband wireless access network. In particular, OFDMA provides more degrees of freedom for multi-user systems. The sub-carriers can be allocated dynamically at different instances to exploit the multi-user diversity and frequency diversity. Also, adaptive power allocation can be applied to further improve the power efficiency (Bo Bai et al (2010)).

Modulation and Coding

WiMAX has the capability of changing its burst profile values depending on the channel conditions per link and per connection. The two main parameters adjusted for the burst profile are the modulation and coding parameters shown in the Table 1.1 given below. The downlink burst profile
parameters such as Carrier to Interference plus Noise Ratio (CINR) threshold for entry and exit of a specific burst profile are also specified. In Uplink burst profile, a ranging data ratio can be seen. A Base station gets an estimate about the uplink channel conditions for each connection while it gets information about the downlink channel quality from the control information provided by the mobile stations.

<table>
<thead>
<tr>
<th>Modulation</th>
<th>Downlink</th>
<th>Uplink</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPSK, QPSK, 16 QAM, 64 QAM; BPSK optional for OFDMA-PHY</td>
<td>BPSK, QPSK, 16 QAM; 64 QAM optional</td>
<td></td>
</tr>
</tbody>
</table>

**Table 1.1 Modulation and Coding used with Uplink and Downlink**

1.3 **QoS ARCHITECTURE**

QoS refers to mechanisms that allow the network managers to control the mix of bandwidth, delay, latency, and packet loss in a network in order to deliver an acceptable level of user experience. QoS support is a fundamental design requirement in WiMAX and it is considerably more difficult due to the variable and unpredictable nature of wireless links. To
support QoS differentiation, the standard provides five classes of services namely,

(i) Unsolicited Grant Service (UGS): Specifically designed for constant bit rate services, such as T1/E1 emulation and VoIP without silence suppression.

(ii) Extended Real-Time Polling Service (ertPS): Built on the efficiency of both the UGS and rtPS. This is suitable for applications such as VoIP with silence suppression.

(iii) Real-Time Polling Service (rtPS): Designed for real-time services that generate variable size data packets on periodic basis, such as MPEG video.

(iv) Non-Real-Time Polling Service (nrtPS): Designed for delay tolerant services that generate variable size data packets on a regular basis.

(v) Best Effort (BE) Service: Designed for applications without any QoS requirements such as HTTP service.

According to the standard, there are three schedulers namely, BS uplink scheduler, BS downlink scheduler, and SS scheduler. The WiMAX framework provides the details of the types of service flows and schedulers that should be supported. However, it does not explicitly define the actual packet mechanisms at the schedulers. Hence, the service providers are free to choose the scheduling algorithms according to their needs. The WiMAX QoS architecture is shown in the Figure 1.2.
The WiMAX MAC is connection oriented and therefore the signaling messages need to be exchanged between BS and SS to establish a service flow, which is a MAC transport service that provides unidirectional transport of packets in either direction. All the service flows are identified by a 32-bit Service Flow ID (SFID). Once a flow is admitted and activated, it is also assigned a 16-bit Connection Identifier (CID). A service flow is characterized by QoS parameters, which include details of the requests by the SS for uplink bandwidth allocations and the method of working of BS uplink scheduler.

The standard uses Time division multiplexing (TDM), in which the MAC frame is divided into an uplink subframe and a downlink subframe. The subframes are further divided into time slots. The BS controls the number of time slots assigned to a SS. The slots assigned to a SS in the uplink subframe allow the SS to transmit data in the uplink direction. The information about
the allotment of the slots to SS in the uplink subframe is communicated by the BS through UL-MAP at the start of each frame. The UL-MAP is a MAC management message that defines the uplink access for all the SSs for the entire uplink subframe. For the SS-initiated flow, a SS first requests a connection. The Connection Admission Control (CAC) located in the BS determines whether the demanded QoS requirements may be fulfilled or not.

An SFID is assigned to a flow only if sufficient resources are available to provide the required QoS. In a BS initiated flow, in addition to above processes, the BS waits for the response from the SS indicating whether it can support the requested communication. The classification of frames into SS transmission queues is done according to the CIDs. The scheduler of a SS traverses the queues to select the most suitable packet for transmission, which is then transmitted in the time slots allotted to them by the BS uplink scheduler. The BS scheduler only grants bandwidth to SSs and not to individual CIDs. A SS itself makes the scheduling decision regarding the service flows associated with it. This simplifies the overall scheme and increases the effectiveness, as SSs have more updated views of their queues than the delayed estimates available at the BS (Zeeshan Ahmed et al (2012)).

**QoS Provisioning**

QoS provisioning is one of the essential features in IEEE 802.16. However, there are differences in the standard specifications, specifically, in IEEE 802.16-2004 and IEEE 802.16e. The two QoS issues that are of main concern are the service flow and bandwidth grant services. A service flow is defined as a one-way flow of MAC SDUs on a connection associated with specific QoS parameters such as latency, jitter, and throughput. These QoS parameters are used for transmission and scheduling. Service flows are typically identified by SSs and BSs based on their SFID. There are three basic types of service flows namely,
i) Provisioned service flows

ii) Admitted service flows

iii) Active service flows

A provisioned service flow is defined in the system with an SFID, but it might not have any traffic presence. It may be waiting to be activated for usage. An admitted service flow undergoes the process of activation. In response to an external request for a specific service flow, the BS/SS will check for available resources based on the QoS parameters to see if it can support the request. If there are sufficient resources, the service flow will be said to be admitted. The resources assigned to this service flow may still be used by the other services. A service flow will be active when all the checks are completed and the resources are allocated. Packets will flow through the connection allocated to the service flow. The use of service flow is the main mechanism used in QoS provisioning. Packets traversing the MAC sub-layer are associated with the service flows as identified by the CID when QoS is required. Bandwidth grant services define bandwidth allocation based on the QoS parameters associated with a connection. In downlink transmissions, a BS has sufficient information to perform scheduling, but in uplink transmissions a BS performs the scheduling of various service transmissions based on the information gathered from the SSs. In such cases, a SS will request an uplink bandwidth from the BS, and the BS will allocate the bandwidth on need basis. For proper allocation of the bandwidth, the four services mentioned earlier support different types of data flows. They are,

- **UGS** is designed to support real-time Constant Bit Rate (CBR) traffic such as VoIP. This provides fixed size transmission opportunities at a regular time intervals without the need for requests or polls.
rtPS is designed to support the Variable Bit Rate (VBR) traffic such as MPEG video. In this service, the BS offers the SS periodic request opportunities to indicate the required bandwidth.

nrtPS is for delay-tolerant data service with a minimum data rate, such as FTP. This service allows an SS to use contention request and unicast request opportunities for bandwidth request. Unicast request opportunities are offered regularly to ensure that the SS has a chance to request bandwidth even in a congested network environment.

BE service does not specify any service related requirements.

Similar to nrtPS, it provides contention request and unicast request opportunities, but it does not provide bandwidth reservation or regular unicast polls. While the concept of service flow is similar to a certain extent in both standards, IEEE 802.16e differs from IEEE 802.16-2004 in bandwidth grant services. In addition to the four data services listed above, IEEE 802.16e includes a new service known as extended rtPS. This service provides a scheduling algorithm that builds on the efficiency of both the UGS and rtPS. Similar to UGS, it is able to offer unsolicited unicast grants. However, the size of the bandwidth allocation is dynamic, unlike in UGS, in which the bandwidth allocation is fixed size. The purpose of this service is to support real-time service flows that generate variable size data packets on a periodic basis. A summary of the QoS categories is presented in the Table 1.2 given below (Bo Li 2007).
Table 1.2 Summary of QoS categories

<table>
<thead>
<tr>
<th>QoS category</th>
<th>Applications</th>
<th>QoS specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>UGS</td>
<td>VoIP</td>
<td>Maximum sustained rate</td>
</tr>
<tr>
<td>Unsolicited grant Service</td>
<td></td>
<td>Maximum latency tolerance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jitter tolerance</td>
</tr>
<tr>
<td>RtPS</td>
<td>Streaming audio or video</td>
<td>Minimum reserved rate</td>
</tr>
<tr>
<td>Real-time polling service</td>
<td></td>
<td>Maximum sustained rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximum latency tolerance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Traffic priority</td>
</tr>
<tr>
<td>ErtPS</td>
<td>Voice with activity detection (VoIP)</td>
<td>Minimum reserved rate</td>
</tr>
<tr>
<td>Extended real-time polling service</td>
<td></td>
<td>Maximum sustained rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximum latency tolerance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jitter tolerance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Traffic priority</td>
</tr>
<tr>
<td>NrtPS</td>
<td>File Transfer Protocol (FTP)</td>
<td>Minimum reserved rate</td>
</tr>
<tr>
<td>Non-real-time polling service</td>
<td></td>
<td>Maximum sustained rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximum latency tolerance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Traffic priority</td>
</tr>
<tr>
<td>BE</td>
<td>Data transfer, Web Browsing</td>
<td>Maximum sustained rate</td>
</tr>
<tr>
<td>Best effort service</td>
<td></td>
<td>Traffic priority</td>
</tr>
</tbody>
</table>

A significant number of proposals in the recent years have demonstrated that the Cross Layer Design (CLD) may be used to improve the performance of WiMAX networks. It allows communication to take place between the adjacent or nonadjacent layers through joint adaptation mechanisms introduced into the system’s architecture.
1.4 CROSS LAYER ARCHITECTURE

Many research proposals have been published, that deal with conceptual modification in individual layers. Recently an alternative approach has attracted many researchers which uses CLD. It is a new paradigm in network architecture design that considers the dependencies and interactions among layers, and supports optimization across layer boundaries. Most of the ongoing research in CLD focuses on joint optimization of the physical layer and data link (or MAC) layer (S. Khan et al 2006). Nowadays, the potential of cross-layer design for improving the critical performance aspects of modern wireless networks is widely recognized. However, a note of caution is given in that performance optimization using CLD can lead to short term gain, while the layered architecture is usually based on longer term considerations (Kawadia et al 2005)).

Standardization of layered protocol stacks has enabled fast development of interoperable systems. At the same time, it has also limited the performance of the overall architecture, due to the lack of coordination among the layers. This issue is particularly relevant for wireless networks, where the very physical nature of the transmission medium introduces several performance limitations. As a consequence, the performance of higher layer protocols (e.g., TCP/IP), historically designed for wired networks, is severely limited. To overcome such limitations, a modification of the layering paradigm has been proposed, namely, cross-layer design, or “cross-layering.” The core idea is to maintain the functionalities associated to the original layers but to allow coordination, interaction and joint optimization of protocols crossing different layers.

Several cross-layering approaches have been proposed in the literature so far (Toumpis & Goldsmith, 2003; Pollin, Bougard, & Lenoir, 2003; Chen, Low, & Doyle, 2005; Lin & Shroff, 2005). Based on the
available works on the topic, two approaches to cross-layering can be defined namely,

- **Weak cross-layering**: Enables interaction among entities at different layers of the protocol stack. It thus represents a generalization of the adjacency interaction concept of the layering paradigm to include “non-adjacent” interactions.

- **Strong cross-layering**: Enables joint design of the algorithms implemented within any entity at any level of the protocol stack. In this case, individual features related to the different layers can be lost due to the cross-layering optimization.

An alternative notation is the “evolutionary approach” for the “weak cross-layering” and “revolutionary approach” for the “strong cross-layering” (Aune, 2004).

CLD allows communication to take place even between non-adjacent layers through additional entities introduced into the system’s architecture. However, there is no reference model that specifies the functionality of each new entity (i.e., module) that must be realized in a CLD. This is addressed by a model proposed for determining the functionality that each new CLD entity might support. This model introduces four different planes that extend across the protocol layers of the OSI reference model in a visually vertical manner. Each of these coordination planes encapsulates the behavior of a CLD algorithm or protocol targeted at solving a specific problem. In wireless mobile devices these problems include security, mobility, quality of service (QoS), and adaptation of the wireless link, thus leading to four coordination planes that are discussed below. The four coordination planes are shown in the Figure 1.3.
The Security Plane

The security plane coordinates encryption protocols and security technologies across different layers. Several encryption methods are available at various protocol layers. SSH and SSL provide end-to-end encryption at the transport and the application layer, and IPSec provides an end-to-end encryption at the network layer. In the IEEE 802.11a/b/g wireless networks, Wired Equivalent Privacy (WEP) has been superseded by Wi-Fi Protected Access (WPA) for encryption. If each layer performs encryption independent of other layers, unnecessary duplication of encryption functionality occurs, thus consuming more power, wasting valuable processing resources, and degrading the network performance. Instead, the CLD technique may be used to determine the particular protocol layer that should perform encryption. If the use of encryption schemes offered by the different layers is coordinated by the security plane pertaining to the CLD, the selection of a single encryption scheme is possible.
The QoS Plane

So far, several QoS solutions involving various protocol layers, such as RTP and TCP receiving QoS information from the application layer have been proposed. The integrated services (IntServ) and differentiated services (DiffServ) architecture developed by the Internet Engineering Task Force (IETF) support IP QoS. They do not support cross-layer communications, and QoS requirements are not conveyed to layers further along the protocol stack. However, in the time-varying wireless environment, the need to communicate the protocol state information from the physical and link layers to the application layer, and to exploit it for improved QoS (e.g., in real-time data flows) is compelling. The provision of the QoS information between the non-adjacent protocol layers require a cross-layer design. Hence, the QoS coordination plane must facilitate the communication of QoS information and coordinate the provision of QoS across multiple layers.

The Mobility Plane

Mobility supports the movement of wireless terminals from one service area to another through handovers to appropriate radio access points (i.e., cellular base stations). There are two handover categories namely, horizontal handover, where the mobile device moves between the access points of the same technology, and vertical handover, dealing with the mobile device movements between the access points of different technologies. In both the cases, upper layers must be able to mitigate the effects of handover. Hence, mobility-related functionality must support the generation of notifications about handovers, that would facilitate a smooth and, ideally, seamless transition of the mobile device’s applications to the new wireless technology. To this end, the mobility coordination plane would take care of adapting the upper-layer services to the underlying wireless technologies.
The Wireless Link Adaptation Plane

This plane addresses effects that are specific to the wireless link, i.e., channel fading, Bit Error Rate (BER) variations, and transmission delays. These properties can affect the performance of the upper layers particularly that of TCP. The Automatic Repeat reQuest (ARQ) protocol at the data link layer tries retransmissions. Obviously, retransmission of lost packets from both the TCP and ARQ could half the congestion window and, thus, the utilization of the wireless link. To avoid such rate degradations, the coordination between the TCP and ARQ protocols is necessary. Another important CLD aspect is the management of cross-layer interactions in a way that can guarantee the system’s smooth operation. To this end, the aforementioned management model specifies an inter-layer coordination manager responsible for the central coordination of CLD processes. In general, CLD introduces management entities that operate either as an optimizer of performance or a scheduler of some kind, depending on the problem at hand. Such an entity may reside within the protocol stack of the affected system, in which case it is considered an internal entity, or in an external network node. In the former case, the internal entity may be either an inter-layer entity that coordinates the operation of all the protocol stack layers or a set of intra-layer entities, each of which is collocated with a protocol layer. In the case of external entities, these may be centralized and hosted by a specific network node or distributed over several network nodes. (Fotis Foukalas et al 2008).

1.5 OBJECTIVES

In the present thesis, a joint adaptation mechanism is proposed between two different set of layers for two different service classes with the objective of provisioning the QoS requested by each service class.
The First objective is that the system should dynamically choose the modulation and coding according to the priority of the traffic in the PHY layer. This requires that the physical layer should adaptively modulate and code, allocate the sub-channels dynamically, allocate the bandwidth requested and provide the QoS as per the request from each user.

The second objective is to prioritize traffic of different service classes by priority scheduling in the MAC layer. A joint mechanism combining the SNR from the PHY layer and the scheduling factor in the MAC layer may be used to estimate the priority value. The scheduling of the traffic belonging to multiple classes would be based on this priority value.

Finally, a joint adaptation mechanism is to be proposed in the application layer that would introduce error correction codes and enhance the throughput of the system. The BL value estimated in the PHY layer and given as feedback to the application layer is used for piggybacking. The redundant information that is required for recovering an erroneous frame is piggybacked on to the next frame in the queue which is ready for transmission.

1.6 ORGANIZATION OF THE PRESENT THESIS

The thesis is organized as follows:

- Chapter 2 reviews related work in the PHY layer algorithms, MAC layer algorithms and the cross layer design based algorithms.
- Chapter 3 discusses the proposed enhancement in the PHY layer in terms of the estimation of the Byte Loss in the
transmitted packets and the forwarding of it to the application layer using cross layer signaling.

- In Chapter 4, the design of a MAC scheduler that optimizes the traffic of various QoS classes is presented. A combination of scheduling parameters obtained from the higher layers and SNR of the Channel from the PHY layer is considered in the development of an expression for a priority value based on which the traffic is scheduled.

- Chapter 5 provides the design of the application layer. The H.263 codec is used to handle different classes of traffic. A decision algorithm is used to decide whether to perform piggybacking or request for retransmission.

- Chapter 6 provides a performance analysis of the system. The analysis is presented separately for the MAC layer output and the overall output.

- Chapter 7 concludes the thesis and offers suggestions for further research on the topic of the thesis.