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Multi-Standard Convergence in Mobile Terminals

Master Thesis

By

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in
Information and Communication Systems
(February 2005, Hamburg Germany)
Declaration

I hereby declare that I am the sole author of this thesis and the work in this thesis has been done by myself using only the specified sources as listed in bibliography.

Shakeel Ahmad
Hamburg, February 21, 2005
Acknowledgements

I am deeply obliged to M.Sc. Chunjiang Yin for supervising this master thesis. He took a keen interest in the project. He remained a source of guidance and constant inspiration throughout the period of the project. Thanks are also due to Prof. Dr. Hermann Rohling for hosting and reviewing this project.
Abstract

One vision for the future generation of mobile systems beyond 3G is that of convergence of wireless systems and standards, enabling seamless access to integrated broadband services. A concept of convergence manager is raised up and being investigated, as it may offer a number of benefits both to the users, service providers and network operators.

In this project we investigate the potential benefits and constraint of multi-standard convergence in a mobile terminal. For this purpose two standard HSDPA for UMTS and HIPERLAN2 is considered. A scenario is developed in Mission Level Designer (MLDesigner) simulation tool in which functionality of UMTS and HIPERLAN2 was realized. An instance of a Convergence Manager is designed and placed in the mobile terminal to optimize the system performance in the multi-standard scenario. The main functionality of the Convergence Manager is standard selection when a user request for a generic file download service arrives. With the help of simulation means we evaluated and compared the performance of various standard selection algorithm in single-user and multi-user environment.

The thesis is organized as follows:

Chapter 1 presents the introduction in detail. In chapter 2, the essential background and introduction of access network technologies HSDPA (for UMTS) and HL2 is presented. Chapter 3 describes the details about Convergence Manager. Chapter 4 describes the considerations about simulation scenario. In chapter 5 we describe the software part implemented in MLDesigner. Chapter 6 discusses the simulation results and finally chapter 7 presents conclusions and future work.
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<th>Description</th>
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<tbody>
<tr>
<td>2G</td>
<td>Second Generation</td>
</tr>
<tr>
<td>3G</td>
<td>Third Generation</td>
</tr>
<tr>
<td>ACH</td>
<td>Access feedback Channel</td>
</tr>
<tr>
<td>AMC</td>
<td>Adaptive Modulation and Coding</td>
</tr>
<tr>
<td>AP</td>
<td>Access Point</td>
</tr>
<tr>
<td>B3G</td>
<td>Beyond 3G</td>
</tr>
<tr>
<td>BPSK</td>
<td>Binary Phase Shift Keying</td>
</tr>
<tr>
<td>BRAN</td>
<td>Broadband Radio Access Networks</td>
</tr>
<tr>
<td>CDMA</td>
<td>Code Division Multiple Access</td>
</tr>
<tr>
<td>CL</td>
<td>Convergence Layer</td>
</tr>
<tr>
<td>CN</td>
<td>Core Network</td>
</tr>
<tr>
<td>DE</td>
<td>Discrete Event</td>
</tr>
<tr>
<td>DFS</td>
<td>Dynamic Frequency Selection</td>
</tr>
<tr>
<td>DiL</td>
<td>Direct Link</td>
</tr>
<tr>
<td>DLC</td>
<td>Data Link Control</td>
</tr>
<tr>
<td>DL</td>
<td>Down Link</td>
</tr>
<tr>
<td>EC</td>
<td>Error Control</td>
</tr>
<tr>
<td>EDGE</td>
<td>Enhanced Data GSM Environment</td>
</tr>
<tr>
<td>ETSI</td>
<td>European Telecommunication Standardization Institute</td>
</tr>
<tr>
<td>FCH</td>
<td>Frame Channel</td>
</tr>
<tr>
<td>FDD</td>
<td>Frequency Division Duplex</td>
</tr>
<tr>
<td>FTP</td>
<td>File Transfer Protocol</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>GSM</td>
<td>Global System for Mobile</td>
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<tr>
<td>HID</td>
<td>HL2 Id</td>
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<tr>
<td>HL2</td>
<td>HyperLAN/2</td>
</tr>
<tr>
<td>HOF</td>
<td>Higher Order Function</td>
</tr>
<tr>
<td>HSDPA</td>
<td>High Speed Downlink Packet Access</td>
</tr>
<tr>
<td>HS-DPCCH</td>
<td>High Speed-Dedicated Physical Control Channel</td>
</tr>
<tr>
<td>HS-DSCH</td>
<td>High Speed-Downlink Shared Channel</td>
</tr>
<tr>
<td>HS-SCCH</td>
<td>High Speed-Shared Control Channel</td>
</tr>
<tr>
<td>LAN</td>
<td>Local Area Network</td>
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<tr>
<td>MAC</td>
<td>Medium Access Control</td>
</tr>
<tr>
<td>MCS</td>
<td>Modulation-Coding-Schemes</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
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<tr>
<td>--------------</td>
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</tr>
<tr>
<td>MT</td>
<td>Mobile Terminal</td>
</tr>
<tr>
<td>NID</td>
<td>Node ID</td>
</tr>
<tr>
<td>OFDM</td>
<td>Orthogonal Frequency Division Multiplexing</td>
</tr>
<tr>
<td>PDN</td>
<td>Public Data Network</td>
</tr>
<tr>
<td>PDU</td>
<td>Protocol Data Unit</td>
</tr>
<tr>
<td>QAM</td>
<td>Quadrature Amplitude Modulation</td>
</tr>
<tr>
<td>QPSK</td>
<td>Quadrature Phase-Shift Keying</td>
</tr>
<tr>
<td>RCH</td>
<td>Random CHannel</td>
</tr>
<tr>
<td>RG</td>
<td>Resource Grant</td>
</tr>
<tr>
<td>RR</td>
<td>Resource Request</td>
</tr>
<tr>
<td>SIP</td>
<td>Session Initiation Protocol</td>
</tr>
<tr>
<td>SNR</td>
<td>Signal to Noise Ratio</td>
</tr>
<tr>
<td>TDD</td>
<td>Time Division Duplex</td>
</tr>
<tr>
<td>TDMA</td>
<td>Time Division Multiple Access</td>
</tr>
<tr>
<td>TTI</td>
<td>Transmission Time Interval</td>
</tr>
<tr>
<td>UE</td>
<td>User Equipment</td>
</tr>
<tr>
<td>UL</td>
<td>Up Link</td>
</tr>
<tr>
<td>UMTS</td>
<td>Universal Mobile Telecommunication System</td>
</tr>
<tr>
<td>UTRAN</td>
<td>UMTS Terrestrial Radio Access Network</td>
</tr>
<tr>
<td>WCDMA</td>
<td>Wideband CDMA</td>
</tr>
<tr>
<td>WLAN</td>
<td>Wireless Local Area Network</td>
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Chapter 1

Introduction

The emergence of different wireless technologies and the development of mobile terminal industry cater for the people’s basic need of communication and mobility. The second generation (2G) of mobile communication provided circuit switched voice and basic data transfer capability along with international roaming. The basic data rate was limited only to a few kbps (e.g., typical data rate with GSM is 9.6 Kbps). Whereas third generation (3G) of mobile communication provides circuit and packet switched data and multimedia communication services at data rates between a few hundreds of Kbps to a few Mbps with global coverage and roaming. The immense success of Internet with steadily increasing data rates gave birth to certain expectations in mobile communication world. Today’s mobile user expects a wired-service like Internet connection while on move, a challenge that cannot be met with only 3G-deployment.

Wireless Local Area Network (WLAN) is another rapidly growing wireless technology that enables a user’s equipment to connect with packet data network (PDN) on high data rates from 11 Mbps (IEEE 802.11 b) to 54 Mbps (IEEE 802.11 a/g or HIPERLAN2). Because of high data rates and free frequency licensing, WLAN can be a good candidate for future high-speed wireless networks however it suffers from low coverage area. A typical WLAN cell can be of 100 meters diameter or so. Therefore it is difficult to realize a nation-wide coverage based on purely WLAN-deployment.

Researchers proposed to utilize the large capacities offered by WLAN and possible interoperability of WLAN and 3G networks. Now WLAN and 3G networks can be seen as complementary technologies. The required integration of WLAN and 3G networks is the key elements for systems beyond 3G [1].
The inter-working of WLAN and 3G networks can bring many benefits to the end user, network operator and the service provider. User will be able to access different wireless standards through the same terminal. This is the key sense of ‘multi-standard convergence in mobile terminals’. Then next logical question that arises is how to use different wireless standards simultaneously in order to provide a certain service to the end user in an optimized way. This leads to an important concept of ‘Convergence Manager’ that will organize the simultaneous use of different wireless standards available to the mobile terminal [2]. The idea of convergence of multiple wireless standards is described in [3] under FLOWS [4] project and Figure 1.1 describes the concept of convergence of wireless standards. Location of the Convergence Manager is a critical issue. Researchers proposed different locations for Convergence Manager each with its own cons and pros which will be discussed later in the following chapters.

![Figure 1.1: Concept of convergence of wireless standards [3]](image)

### 1.1 Brief Outline of Thesis work

In this thesis we have tried to investigate the potential benefits and constraints in a situation where Convergence Manager is located only in the mobile terminal. For this purpose two access networks HSDPA for UMTS and HIPELAN2 (HL2) is considered. A scenario is developed in Mission Level Designer (ML.Designer) simulation tool in which functionality of UMTS and HIPERLAN2 was realized. With the help of simulation means we evaluated the request discarding rate and delay performance for different number of users under different standard-selection algorithms.
The thesis is organized as follows:

In chapter 2, the essential background and introduction of access network technologies HSDPA (for UMTS) and HL2 is presented. Chapter 3 describes the details about Convergence Manager. Chapter 4 describes the considerations about simulation scenario. In chapter 5 we describe the software part implemented in MLDesigner. Chapter 6 discusses the simulation results and finally chapter 7 presents conclusions and future work.
Chapter 2

Radio Access Networks

In this thesis the convergence of two wireless standards namely HSDPA (for UMTS) and HL2 is considered. Therefore it is necessary to give basic introduction about these wireless standards.

2.1 Overview of HL2

HL2 is a new high-performance 5GHz radio networking technology, specifically suited for operating in LAN environments. HL2 is being developed by the European Telecommunications Standardization Institute (ETSI) Broadband Radio Access Networks (BRAN) project [5].

HL2 allows interconnection into almost any type of fixed network technology. This makes it suitable, for example, to connect mobiles, portables and laptops to a fixed access point.

HL2 supports different Quality of Service (QoS) for different connections which allows the transmission of a mix of different types of information (e.g. voice, video or other data). HL2 also provides uni-cast, multicast and broadcast transmissions [6].

The radio uses Orthogonal Frequency division Multiplexing (OFDM), which is a radio technology ideal for broadband applications in a highly dispersive radio environments, where multiple reflections could cause delay spread and severe degradation of radio performance. Above the physical layer, the Medium Access Control (MAC) protocol is all-new which implements a form of dynamic time-division duplex to allow for most efficient utilization of radio resources. The MAC layer is developed and optimized for radio communication and realizes new
features such as Quality of Service (QoS) for real time multimedia applications and very efficient power save control [7].

### 2.1.1 General Features of HL2

The prominent features of HL2 can be described as follow.

**High Speed Transmission:** HL2 has a very high transmission rate up to 54 Mbps. This is achieved by making use of OFDM which is particularly efficient in time-dispersive environments, i.e. where the radio signals are reflected from many points, e.g. in offices.

**Connection Oriented:** HL2 connections are time-division multiplexed and connection-oriented, either bi-directional point-to-point or unidirectional point-to-multipoint connections. There is also a dedicated broadcast channel through which the traffic from an AP reaches all terminals.

**Quality of Service (QoS) Support:** Unlike other radio-based systems, the traffic on a LAN is inherently random and bursty. This may cause serious problems with respect to throughput, because the performance is one of the most important factors of wireless LANs. In HL2, each connection can be assigned either a simple relative priority level or a specific QoS in terms of bandwidth, delay, jitter, bit error rate, etc.

**Automatic Frequency Allocation:** The HL2 Access Points have a built-in support for automatic transmission frequency allocation within the AP's coverage area. This is performed by the Dynamic Frequency Selection (DFS) function. Thus, there is no need for manual frequency planning as in cellular networks like GSM.

**Security Support:** The HL2 network supports authentication and encryption. Both the AP and the MT can authenticate each other to ensure authorized access to the network or to a valid network operator. The encryption can be used on established connections to protect against eavesdropping and man-in-the-middle attacks. In HL2, each communicating node is given a HL2 ID (HID) and a Node ID (NID). The combination of these two IDs uniquely identifies any station, and restricts the way it can connect to other HL2 nodes. All nodes with the same HID can communicate with each other using a dynamic routing mechanism denoted as ‘Intra-HL2 Forwarding’.

**Mobility Support:** The support for handover enables mobility of MTs. The handover scheme is MT initiated, i.e. the MT uses the AP with the best signal as measured for instance by signal to noise ration (SNR), and as the user moves
around, all established connections move to the AP with the best radio transmission performance, while the MT stays associated to the HL2 network.

**Network and Application Independent:** The HL2 architecture is easily adapted and integrated with a variety of fixed networks. All applications running over a fixed infrastructure can also run over a HL2 network.

**Power Save:** The power save mechanism in HL2 is based on MT-initiated negotiation of sleep periods. The MT requests the AP for a low power state and a specific sleep period. At the expiration of the sleep period, the MT searches for a wake up indication from the AP, and in the absence of that sleeps for the next period, and so forth. The MT receives any pending data as the sleep period expires. Different sleep periods are supported depending on the requirements.

### 2.1.2 Protocol Stack

The protocol stack for HL2 on the Access Point side as described in [8], is shown Figure 2.1. It consists of the PHY layer on the bottom, the DLC layer in the middle and one or more convergence layers (CL) on top. The scope of the HL2 standard ends at the upper end of the CL on top of which higher layers are located.

### 2.1.3 Error Control (EC)

The basic function of Error Control unit is detection and recovery from transmission errors on the radio link. Moreover it ensures in-sequence delivery of data packets. For each DLC user a dedicated instance of EC is allocated.
2.1.4 Medium Access Control (MAC)

The Medium Access Control (MAC) protocol is based on a dynamic TDMA/TDD scheme with centralized control. The MAC frame appears with a period of 2 ms. The allocation of resources is controlled by an AP. It is assumed that one MAC entity with one instance is provided per AP or per MT. The MAC IDs are also used to administer broadcast and multicast services. The relation between MAC entities is created by a MAC ID which is unique in a radio cell. In order to control the allocation of resources, the AP needs to know the state of its own buffers and of the buffers in the MT. Therefore, the MTs report their buffer states in Resource Request (RR) messages to the AP. Using this mechanism, the MTs request for resources in terms of transmission capacity. Moreover, an optional feature is to negotiate a fixed capacity allocation over multiple frames. The AP allocates the resources according to the buffer states on a fair basis and, if required, taking quality of service parameters into account. The allocation of resources is conveyed by Resource Grant (RG) messages. The resource requests (RRs) and resource grants (RGs) are defined on a per-connection basis. Data and
control information are mapped onto transport channels. The transport channels are the basic elements to construct PDU trains that are delivered to and received from the physical layer. Six types of PDU trains are allowed: Broadcast, FCH and-ACH, Downlink, Uplink with short preamble, Uplink with long preamble, and Direct link PDU train.

2.1.5 Radio Link Control (RLC) sub layer

The Radio Link Control (RLC) sub-layer provided a transport service to the DLC User-Connection-Control, the Radio Resources Control and the Association Control Function.

2.1.6 Physical Layer (PHY)

Physical layer of HL2 is based on the modulation scheme Orthogonal Frequency Division Multiplexing (OFDM). The data is transmitted through data OFDM symbols. All data OFDM symbols contain data in data carriers and reference information in pilot carriers. For data there are $N_{SD} = 48$ carriers and for pilots $N_{SP} = 4$ carriers in each symbol. Thus each symbol is constituted by a set of $N_{ST}=52$ carriers and transmitted with a duration $T_s$. There are two parts which make the symbol duration $T_s$: a useful symbol-part with duration $T_u$ and a cyclic prefix with duration $T_{CP}$. The cyclic prefix consists of a cyclic continuation of the useful part, $T_u$ and it is inserted before it as shown in Figure 2.2. The length of the useful symbol part is equal to 64 samples and its duration is $T_u = 3.2 \mu s$. For the cyclic prefix length $T_{CP}$ there are two possible values in the HL2 system: mandatory 800 ns and optional 400 ns.

![Figure 2.2: Illustration of an OFDM symbol with cyclic prefix](image)

In order to improve the radio link capability due to different interference situations and distances of MTs to the AP, a multi-rate PHY layer is applied, where the appropriate mode can be selected by a link adaptation scheme. The data rate, which ranges from 6 Mbps to 54 Mbps, can be varied by using different signal alphabets for modulating the OFDM sub-carriers and by applying different puncturing patterns to a mother convolutional code. BPSK, QPSK, 16QAM are used as mandatory modulation formats, whereas 64QAM is applied as an optional one. The mode dependent parameters are listed in Table 2.1 according
to the ETSI standards. The relationship between nominal bit rate \( r \) and PHY mode is given in Equation 2.1

\[
r = \frac{\text{Coded bits per OFDM symbol}}{\text{OFDM symbol duration}} \times \text{coding rate}
\]  

(2.1)

<table>
<thead>
<tr>
<th>PHY-Mode</th>
<th>Mode number</th>
<th>Nominal bit rate (Mbps)</th>
<th>Coded bits per sub carrier</th>
<th>Coded bits per OFDM Symbol</th>
<th>Data bits per OFDM symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPSK (½)</td>
<td>1</td>
<td>6</td>
<td>1</td>
<td>48</td>
<td>24</td>
</tr>
<tr>
<td>BPSK (¾)</td>
<td>2</td>
<td>9</td>
<td>1</td>
<td>48</td>
<td>36</td>
</tr>
<tr>
<td>QPSK (½)</td>
<td>3</td>
<td>12</td>
<td>2</td>
<td>96</td>
<td>48</td>
</tr>
<tr>
<td>QPSK (¾)</td>
<td>4</td>
<td>18</td>
<td>2</td>
<td>96</td>
<td>72</td>
</tr>
<tr>
<td>16QAM (9/16)</td>
<td>5</td>
<td>27</td>
<td>4</td>
<td>192</td>
<td>108</td>
</tr>
<tr>
<td>16-QAM (¾)</td>
<td>6</td>
<td>36</td>
<td>4</td>
<td>192</td>
<td>144</td>
</tr>
<tr>
<td>64-QAM (¾)</td>
<td>7</td>
<td>54</td>
<td>6</td>
<td>288</td>
<td>216</td>
</tr>
</tbody>
</table>

Table 2.1: HL2 PHY Modes

2.1.7 Format and Overview of MAC Frame

The basic MAC frame structure for single sector system is shown in Figure 2.3. Each MAC frame shall consist of the transport channels BCH (Broadcast CHannel), FCH (Frame CHannel), ACH (Access feedback CHannel) and at least one RCH (Random CHannel). If user data is to be transmitted, a DL (Downlink phase) phase and/or an UL (uplink phase) phase shall be provided. If direct mode is used and data has to be transmitted, it shall also contain a DiL (Direct Link) phase between the DL and UL phase. The duration of the BCH is fixed. The duration of the FCH, DL phase, DiL phase, UL phase and the number of RCHs are dynamically adapted by the AP/CC depending on the current traffic situation. The order of the subcomponents shall be: BCH - FCH - ACH - DL phase - UL phase - RCHs for centralized mode, or BCH - FCH - ACH - DL phase - DiL phase - UL phase - RCHs for direct mode from the point of view of an MT. The specified order is from an MT’s point of view. This means that an AP may e.g. have several DL & UL phases and mix the phases randomly, as long as the order is kept for each individual MT.

If direct mode is used and data is to be transmitted, the frame also contains a DiL phase. The DiL phase is located between the DL and UL phase. The duration of the FCH, DL phase, DiL phase, UL phase and the number of RCHs are dynamically adapted by the AP depending on the current traffic situation.
2.2 Overview of UMTS

Universal Mobile Telecommunications System (UMTS) is envisioned as the successor to the Global System for Mobile Communication (GSM). UMTS signals the move into third generation (3G) of mobile networks. UMTS also addresses the growing demand of mobile and Internet applications for new capacity in the over-crowded mobile communication sky. The new network increases transmission speed to 2 Mbps per mobile user and establishes a global roaming standard.

A UMTS network consists of three interacting domains; Core Network (CN), UMTS Terrestrial Radio Access Network (UTRAN) and User Equipment (UE). The main function of the core network is to provide switching, routing and transit for user traffic. The UTRAN provides the air interface access method for User Equipment.

Wide band CDMA technology was selected for UTRAN air interface. UMTS WCDMA is a Direct-Sequence CDMA system where user data is multiplied with quasi-random bits derived from WCDMA Spreading-Codes. In UMTS, in addition to channelisation, codes are used for synchronisation and scrambling. WCDMA has two basic modes of operation: Frequency Division Duplex (FDD) and Time Division Duplex (TDD). In the following a brief overview of CDMA will be presented.

2.2.1 Overview of CDMA

For radio systems there are two resources, frequency and time. If we divide the frequency such that for each pair of sender and receiver there is a reserved spectrum of frequency for all times then this is called Frequency Division Multiple Access (FDMA). If we divided time in the same way instead of
frequency such that for each pair of sender and receiver there is a reserved time slot over the entire spectrum then this is called Time Division Multiple Access (TDMA). However, in Code Division Multiple Access (CDMA), every communicator will be allocated the entire spectrum all of the time. CDMA uses codes to identify connections. The concept is shown in Figure 2.4.

![Figure 2.4: Multiple access schemes](image)

CDMA uses unique spreading codes to spread the baseband data before transmission. The signal is transmitted in a channel, which is below noise level. The receiver then uses a correlator to despread the wanted signal, which is passed through a narrow bandpass filter. The unwanted signals will not be despread and will not pass through the filter. Codes take the form of a carefully designed one/zero sequence produced at a much higher rate than that of the baseband data [14]. The rate of a spreading code is referred to as chip rate rather than bit rate. The ratio between the bandwidth of the baseband signal after spreading to the bandwidth before spreading is known as Spreading Factor. Mathematically it can be given as in Equation 2.2.

\[
\text{spreading \_ Factor} = \frac{\text{chip \_ rate}}{\text{data \_ rate}} \tag{2.2}
\]

### 2.2.2 High Speed Downlink Packet Access (HSDPA) Concept

In UMTS release 5 a new feature ‘High Speed Downlink Packet Access’ (HSDPA) for WCDMA is added. For our work, from UMTS part, HSDPA is considered for packet switched data transmission. Therefore it is necessary to present the basics of HSDPA. In following a brief concept of HSDPA will be
presented. This description is per according to [9]. Interested user may consult the reference [9] for details.

The key idea of HSDPA is to increase packet data throughput by means of methods already known from GSM/EDGE standards including link adaptation and fast physical layer retransmission combining. The transport channel carrying the user data with HSDPA operation is denoted as High-speed Downlink-shared Channel (HS-DSCH). With HSDPA, two of the most fundamental features of WCDMA, variable spreading factor and fast power control are disabled and are replaced by means of adaptive modulation and coding (AMC), extensive multi-code operation and a fast and spectrally efficient retransmission strategy [9]. Different Modulation-Coding-Schemes (MCS) are given in Table 2.2. The physical layer transmission rate \( r \) can be calculated as shown in Equation set 2.3.

\[
\begin{align*}
    r &= \text{bits\_per\_symbol} \times \text{code\_rate} \times \text{code\_number} \times \text{symbol\_rate} \\
    \text{symbol\_rate} &= \frac{\text{chiprate}(3.84 \times 10^6)}{\text{spreading\_factor}(16)} = 240 \times 10^3 \text{symbols\_per\_sec}
\end{align*}
\]

Where \( \text{bits\_per\_symbol} = 2 \) for QPSK and \( 4 \) for 16-QAM

<table>
<thead>
<tr>
<th>MCS</th>
<th>Modulation</th>
<th>Code Rate</th>
<th>Code number</th>
<th>PHY layer transmission rate (Kbps)</th>
<th>Required SNR (db)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>QPSK</td>
<td>½</td>
<td>1</td>
<td>240</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>QPSK</td>
<td>½</td>
<td>2</td>
<td>480</td>
<td>13</td>
</tr>
<tr>
<td>3</td>
<td>QPSK</td>
<td>½</td>
<td>3</td>
<td>720</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>QPSK</td>
<td>¾</td>
<td>4</td>
<td>1440</td>
<td>18</td>
</tr>
<tr>
<td>5</td>
<td>16-QAM</td>
<td>½</td>
<td>5</td>
<td>2400</td>
<td>21</td>
</tr>
<tr>
<td>6</td>
<td>16-QAM</td>
<td>¾</td>
<td>5</td>
<td>3600</td>
<td>26</td>
</tr>
<tr>
<td>7</td>
<td>16-QAM</td>
<td>¾</td>
<td>10</td>
<td>7200</td>
<td>28</td>
</tr>
<tr>
<td>8</td>
<td>16-QAM</td>
<td>¾</td>
<td>15</td>
<td>10800</td>
<td>31</td>
</tr>
</tbody>
</table>

Table 2.2: MCSs in HSDPA for UMTS [2]
Figure 2.5 illustrates the general functionality of HSDPA. Node B estimates the channel quality of each active HSDPA user on the basis e.g., power control, ACK/NACK ratio, Quality of Service (QoS) and HSDPA-specific user feedback. Scheduling and link adaptation are then conducted at a fast pace depending on the active scheduling algorithm and the user prioritization scheme.

To implement the HSDPA features, three new channels are introduced in the physical layer specification [9]. HS-DSCH which carries the user data in the downlink direction, HS-SCCH which carries the necessary physical layer control information and HS-DPCCH which carries the necessary control information in the uplink. The transmission time interval (TTI) for HS-DSCH is fixed to be 2ms (3 slots). Interested reader may find a detailed description about these channels in reference [9].
Chapter 3

Convergence Manager

The Convergence Manager is the most important character to realize the convergence of wireless-standards. Today we have different wireless standards e.g., GSM, UMTS and different flavors of WLAN but at the moment each of them is being used independently. The existing wireless standards are certainly not sufficient to fulfill the increased demand for wire-like high speed Internet while on move. In order to realize the services as mentioned in B3G or 4G networks, researchers proposed to use the existing wireless standards in a combined fashion and they talk about the convergence of existing wireless standards. For this purpose we need an entity that manages the convergence of different wireless standards. This entity is named as Convergence Manager.

3.1 General functionality of Convergence Manager

The functionality of the Convergence Manager to some extent is also location dependent i.e., where the Convergence Manager is located in whole scenario. Different possible locations will be discussed later in this chapter. The general functionality of Convergence Manager can be described as below:

- Enabling convergence of different wireless standards.

- Mapping different applications or user requests to different wireless standards. In other words selections of wireless standard from a list of available wireless standards for a given service or user request. There might be different criterion for network/standard selection in order to optimize some performance figure e.g., overall delay performance.
• Hiding the complexity of spreading traffic over different access networks from the application or the user.

• Splitting/reassembling the traffic to/from different underlying technologies unburdening the remaining communication environment from being aware of it.

3.2 Benefits of Convergence Manager

The Convergence Manager promises certain benefits to the end user, network operator and the service provider. An end user will get better QoS e.g., higher data rate, lower download time etc. Not only the end user but the network operator and service provider will also get benefit as they can utilize the resources more efficiently and thus can generate more revenue. Overall system performance in terms of system throughput and system average delay can be improved significantly.

3.3 Location of Convergence Manager

From architecture point of view, location of Convergence Manage is a crucial issue. Researchers proposed different locations for Convergence Manager. On one side it affects the user’s experience of service rendering and on other side it also affects the service provider's ability to combine services into combined services. The network operator may also get advantages from Convergence Manager by utilizing the deployed network in more optimized way. Therefore the way in which Convergence Manager is implemented affects many players in the chain e.g., network operator, terminal manufacturer, terminal-software vendors and network equipment manufacturers [10]. Some possible locations of Convergence Manager are shown in Figure 3.1. The proposed locations or combinations of location for Convergence Manager are as follows:

• Convergence Manager located only in mobile terminal.

• Convergence Manager located in mobile terminal and radio access network.

• Convergence Manager located in mobile terminal and the core/backbone network.
Convergence Manager located in the mobile terminal and the corresponding server.

Figure 3.1: Some possible locations for Convergence Manager

In this thesis, Convergence Manager is supposed to be located only in mobile terminals and therefore only this approach would be discussed onward. Other possible locations of Convergence Manager have been discussed in literature and interested reader may consult reference [10] to get further details.

3.3.1 Convergence Manager only in Mobile Terminal

This is the simplest approach and it is sufficient to place an instance of Convergence Manager only in the mobile terminal in order to satisfy user-oriented policies (see Figure 3.2). The biggest advantage of this approach is backward compatibility i.e., it can be realized easily with the existing standards. All the existing wireless standards and infrastructure for access networks and backbone networks can be used without any change. We need to do essential changes only in the mobile terminal. The billing/charging system could also be modified because user would like to have one bill for all services.

Intelligent network selection for a given media stream would play an important role to increase QoS and the overall system performance. If we direct each of the media stream to the best network the overall QoS would be increased. Here ‘best network’ means a network that suits to support the characteristics of the media stream.
Different network selection algorithms can be formulated to reflect user-oriented policies. One example of such user-oriented policy might be to have minimum download delay always. It means that for background services like FTP or email download, a user would always select a network offering minimum download time. An access network will be selected on the basis of the estimated download time. Another example of user-oriented policy might be to prefer WLAN, for video channel of an outgoing videoconference, over UMTS whenever WLAN is available. The reason is obvious that WLAN offers higher bandwidth and better video codec can be used.

### 3.4 Operation of Convergence Manager

There are different possible ways out how the Convergence Manager would work if it were located only in the mobile terminal. In [10], two alternatives have been discussed.

- **Generic way**, by using Session Initiated Protocol (SIP) which can be used to direct media streams through different access networks. In reference [10] there is a detailed description about this mechanism.

- **Service specific way** i.e., enabling Convergence Manager functionality for a dedicated class of traffic, e.g., file transfer traffic. This approach is further investigated in this thesis and will be discussed in detail.
3.4.1 Service Specific way

In this sub-section we would investigate the functionality of Convergence Manager as “Application Level Standard Selection & Switching” for a generic file download FTP service. The FTP protocol provides some very useful commands e.g., RESTART, ABORT which makes it possible to switch the standard while mid way download and to start downloading a file at an arbitrary position. In this regard the functionality of Convergence Manager (located only in mobile terminal) can be summarized as follows:

- Background scanning for available access networks. In this way Convergence Manager keeps a list of all possible access networks e.g., UMTS and WLAN at all times along with their status of availability.

- When a service request arrives, Convergence Manager decides which access network this request should be directed to. This is standard selection. Download starts from this initially selected standard. But this selected network may not always be the best one during even one service completion time. Therefore Convergence Manager might need to switch to other standard while mid way of the service. This is standard switching. The factors involved in the process of standard-selection & switching procedure might include:
  
  - User context i.e., characteristics of user mobility.
  - Access network coverage information.
  - Current availability status of access network
  - Cost of connection.
  - Required Quality of Service (QoS) e.g., minimum overall download time.
  - Load balancing.

Among the above factors only Load Balancing is a factor which is hard to realize when Convergence Manager is only located in mobile terminal. Convergence Manager selects standard according to different network
selection algorithms. These network selection algorithm will be discussed in chapter 4 in detail.

It is important to note that FTP standard-switching algorithms will work [10]:

- Without any change in the network.
- Without any changes in the FTP server.
- Without any changes in the existing radio standards.
- Without any cooperation of the Telecommunication service providers.
- And without even modification of available physical Layer implementation in the mobile terminal.
Chapter 4

Simulation Scenario and Considerations

This chapter would describe the details about the simulation scenario that was considered in this work. The relevant features and parameters of the access network technologies i.e., HSDPA and HL2 would also be described and finally Convergence Manager and network selection algorithms would be presented.

4.1 Simulation Scenario

We have considered a simple scenario for the evaluation of potential benefits by deploying Convergence Manager only into the mobile terminal. The scenario consists of a busy main road in a city. It is supposed that UMTS coverage is available throughout the road and HL2 with limited coverage area (100 m radius) is available at some points as shown in Figure 4.1. The mobile users are moving on the main road and while on move users make request to download a file. Some other roads cross the main road thus creating cross points. These cross points can be considered as hot spots because mobile users are likely to stop here with a certain probability because of red signal. It is supposed that HL2 access points are installed on the cross points.

![Figure 4.1: Simulation scenario](image)
4.2 User Model

There are two perspectives of user model, one is the mobility and the other is source-traffic/request model.

- **Mobility Model:** We chose a simple mobility model in which every user is assigned an initial position (in terms of x and y coordinates) on the road. The y coordinate is fixed whereas x is assigned a value from 0 to 1500 uniformly distributed. The direction of motion is assigned as either 0 or 180 degree with 50 percent probability each. It is supposed that users are moving with a constant speed of 10 m/s. On arriving at crossing point an individual user can be scheduled with a stop event of fixed 15 seconds with a certain probability. When the user reaches at one end of road, it enters again to the road from opposite end and moving in the same direction. Thus users see an infinite road with successive UMTS only and UMTS/HL2 coverage periods.

- **Source-Traffic/Request Model:** While on move users generate requests to download files according to a Poisson process with a mean rate $\frac{1}{10}$ request per second. The file size distribution can be constant or uniformly distributed and will be given as related simulation parameters. If a request is under service and a second request arrives before the completion of previous request then the second request is simply discarded.

4.3 UMTS Consideration

High Speed Downlink Packet Access Channel (HSDPA) is considered for UMTS which is available throughout the scenario uniformly. Mobile users send request to download file to UMTS Scheduler which keeps track of all active users. In order to keep scheduling simple it is supposed that each user is assigned one chip code on each request which is equivalent to a data rate of 240 kbps. The figure 240 kbps comes as follows.

\[
\text{Total chip rate} = 3.84 \times 10^6 \text{ chips per second}
\]
\[
\text{Spreading Factor in HSDPA (S.F) = 16 (fixed)}
\]
\[
\text{Data Rate} = \frac{\text{chip Rate}}{\text{S.F}} = \frac{3.84 \times 10^6}{16} = 240 \text{ Kbps}
\]

If the number of active users are greater than 16 but less than 32 then one chip code is used for two users in time multiplexed fashion so as the effective data rate
becomes 120 kbps. Similarly if the number of users is between 32 and 64 then the effective data rate is 60 kbps and so on as shown in Table 4.1.

<table>
<thead>
<tr>
<th>Number of Active Users equal or less than</th>
<th>Data Rate Per User Kbps</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>240</td>
</tr>
<tr>
<td>32</td>
<td>120</td>
</tr>
<tr>
<td>64</td>
<td>60</td>
</tr>
<tr>
<td>128</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 4.1: Data rates in HSDPA for UMTS

4.4 HL2 Considerations

The coverage area of each HL2 AP is restricted to a circle of 100 m radius. Two important issues are PHY mode selection and scheduling. The PHY mode is a combination of a modulation scheme and Forward Error Correction (FEC) Code Rate. The choice of PHY mode depends upon the Signal to Noise ratio (SNR) measured by Physical Layer and the acceptable QoS requirement e.g., in terms of packet loss rate.

In the simulation we used a free space propagation model to describe the SNR. The received signal strength decays exponentially with path loss exponent of 3. We supposed that SNR depends directly on the distance between transmitter and receiver i.e., on the distance between mobile user and HL2 access point. Figure 4.2 shows the graph for minimum required SNR Vs PER for different PHY modes [12].

Figure 4.2: Peak Error Rates Vs SNR for HL2 PHY Modes [12]
If we take $\text{PER}=0.01$ and map the minimum required SNR (2.8 db taken from the graph) for lowest data rate supporting PHY mode (BPSK-1/2) at the boundary of coverage area (100m in our case) then we can calculate the maximum distances for all possible PHY modes. Equation 4.1 gives the relationship between distances and SNR and it can be derived as follows:

$$\text{SNR} = 20 \log \left( \frac{\text{receivedSignal}}{\text{Noise}} \right)$$

$$\text{receivedSignal} = P_t = P_i \frac{k}{D^3}$$

$$\Rightarrow \text{SNR} = 20 \log \left( P_i \frac{k}{D^3 \text{Noise}} \right)$$

where $\frac{k \cdot P_i}{\text{Noise}} = k'$

$$\Rightarrow \text{SNR} = 20 \log \left( \frac{k'}{D^3} \right)$$

$$\text{SNR} = 2.8, D = 100\text{m} \Rightarrow 2.8 = 20 \log \left( \frac{k'}{100^3} \right)$$

Combining the above two equations, relation between distance $D$ and SNR can be obtained as:

$$D = \text{Anti}\log \left( 2.046 - \frac{\text{SNR}}{60} \right) \quad (4.1)$$

Table 4.2 shows that mapping between SNR and physical distances.

<table>
<thead>
<tr>
<th>PHY-Mode</th>
<th>Nominal bit rate (Mbps)</th>
<th>Minimum Required SNR (db)</th>
<th>Maximum Distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPSK $\frac{1}{2}$</td>
<td>6</td>
<td>2.8</td>
<td>100</td>
</tr>
<tr>
<td>BPSK $\frac{3}{4}$</td>
<td>9</td>
<td>Not Used</td>
<td>Not Used</td>
</tr>
<tr>
<td>QPSK $\frac{1}{2}$</td>
<td>12</td>
<td>5.7</td>
<td>89.5</td>
</tr>
<tr>
<td>QPSK $\frac{3}{4}$</td>
<td>18</td>
<td>11.8</td>
<td>80</td>
</tr>
<tr>
<td>16-QAM $\frac{9}{16}$</td>
<td>27</td>
<td>13</td>
<td>67.5</td>
</tr>
<tr>
<td>16-QAM $\frac{3}{4}$</td>
<td>36</td>
<td>17.7</td>
<td>56.5</td>
</tr>
<tr>
<td>64-QAM $\frac{3}{4}$</td>
<td>54</td>
<td>23.6</td>
<td>45</td>
</tr>
</tbody>
</table>

Table 4.2: Mapping between SNR and distances for PHY mode selection
When a user requests a file download and if HL2 is selected then a request is sent to the HL2 Scheduler. HL2 also knows the current distance of the mobile user from HL2 access point at all times which is used to determine the PHY mode. In this way HL2 knows the number of active users at all times. The scheduling policy used is based on FAIR TIME. It is assumed that all the frame time is used for data and no signaling overhead is considered. This assumption would affect absolute measurements but the relative measurements for different standard-selection algorithms will not be effected. In every MAC frame, time per user per frame and data for each user is calculated as given in Equation 4.2 and Equation 4.3.

\[
\frac{2\text{ms}}{\text{numberOfActiveUsers}} = \text{timePerUserPerFrame} \quad (4.2)
\]

\[
data\text{PerUserPerFrame} = \text{timePerUserPerFrame} \times \text{bitRateForSelectedPHYMode} \quad (4.3)
\]

If a user leaves the HL2 coverage area without completing the request then the connection is dropped and allocated time slot are becomes available to other active users. Please note that the distance of mobile user to the access point is observed at all times in a same way as SNR is measured continuously in real life and thus scheduling and PHY mode selection is dynamic and can be changed even during a file download.

### 4.5 Convergence Manager and Standard-Selection

Upon arrival of a user request the Convergence Manager selects the standard according to network selection algorithm and directs the request to the selected standard. Convergence Manager is continuously doing background scanning and thus it knows the status of availability of UMTS and HL2. It is supposed that Convergence Manager knows the current location, direction of motion and speed of the user. In addition to that it also knows coverage distribution of HL2 so that it can estimate when user will enter next HL2 coverage or when user will leave the current HL2 coverage. Three algorithms have been considered for network selection already reported in literature [11]. The operation of the three algorithms has been shown in Figure 4.3 and they will be explained below. In this discussion the words ‘access network’, ‘wireless standard’ and ‘standard’ will be used interchangeably.
Figure 4.3: Standard selection algorithms

4.5.1 Switched Algorithm

The operation of switched algorithm has been shown in Figure 4.4. When the request arrives, the access network providing the highest data rate is selected from a list of currently available access networks. Thus download starts immediately after the request arrives. This algorithm supposes that the terminal is capable of switching between access networks while mid file download. At the end of each coverage period mobile terminal switches between standards to keep continuous connectivity and also to make sure that download takes place always from the highest data rate bearer however parallel transmission on multiple standards is excluded. There are some complexities associated with Switching between different wireless access networks while mid file download e.g., it requires close coordination of all involved standards, significant interoperability and accurate synchronization for the transfer [11].
4.5.2 Location Algorithm

In Location algorithm it is assumed that the mobile terminal knows the mobility context of the user and the geographical coverage areas of wireless standards. The mobility context includes current location, moving direction and speed etc. The mobility context can be provided to the Convergence Manager by means of GPS. The user’s mobility context and the knowledge of standards coverage area is used to make more intelligent and informative standard selection decision. If a request arrives in UMTS only coverage period then the algorithm estimates that whether the download can be completed before the start of next HL2 area or not, if yes then select UMTS otherwise wait for HL2 coverage and download via HL2. Similarly if a request arrives in HL2/UMTS coverage area then it is estimated that whether the download can be completed before the end of current coverage of HL2 or not, if yes then select HL2 otherwise select UMTS. The flow diagram showing the operation of Location algorithm has been shown in Figure 4.5.
4.5.3 Current Algorithm

The operation of Current algorithm is similar to that of Switched algorithm in the sense that the standard providing the highest data rate is selected. However in contrast to Switched algorithm, download takes place via only one standard. The selection of standard is done at the time request arrives and download starts immediately thus the initial delay i.e., the delay before download starts is zero. The flow diagram showing the operation of Location algorithm has been shown in Figure 4.6.

Figure 4.5: Flow diagram for Location algorithm
Figure 4.6: Flow diagram for Current algorithm
Chapter 5

Implementation

The simulation scenario as described in chapter 4 has been implemented in Mission Level Designer (MLDesigner) in order get simulated results. The purpose of this chapter is to provide related information and details that would help to reuse and extend the work done in this thesis from software point of view. This chapter, after a brief introduction to MLDesigner, would describe the implementation details about the primitives, modules, different helping classes developed under the work of this thesis along with their parameter and usage.

5.1 Introduction to MLDesigner

MLDesigner is a unique system-level simulation-modeling platform that integrates both major system level modeling areas (architecture and function), and most simulation modeling domains, in a single tool. Among the available simulation domains, Discrete Event (DE) domain is of particular interest for us because it can be used to simulate asynchronous, non-periodic data transmission that makes it ideal for simulating mobile/fixed communication networks.

MLDesigner models are defined graphically as hierarchical block diagrams. Blocks have defined inputs and outputs that are connected via visible links or via shared memories. Control and information is passed between blocks via particles (tokens) that consist of either a simple trigger particle or a hierarchical data structure. Bottom level blocks contain primitives written in a form of C++ code. Higher-level blocks contain block diagrams. All blocks can be parameterized for easy “what if” analysis and to maximize block reusability [13].
5.2 Primitive LocationUpdate2

This primitive as the name shows implements mobility model described earlier in chapter 4. All the mobile users are initially assigned a location (X and Y values in 2D Cartesian system), direction of motion and speed. Location and direction are assigned randomly according to uniform distribution, however speed is constant and same for all users. Location is bounded by a boundary specified by max/min x and y values. The scenario as described in chapter 4 is a city road so there are only two possible values for direction 0 or 180 degree.

LocationUpdate2 uses a class MobilityManager2.h to manage mobility which in turns uses the instances of class UserMobility2 to control individual user. A simple UML diagram in Figure 5.1 shows the relation. LocationUpdate2 triggers MobilityManager2 after a period specified by location updateInterval to update the location of all users.

![Figure 5.1: UML diagram showing the composition](image)

Another function of LocationUpdate2 is to show the animation of users. Actually it transmits the x-y coordinates of each user to the TkXYPlot after every locationUpdateInterval and in this way TKXYPlot primitive updates the position of each user. A snapshot from MLDesigner in which the Tck/TK script is showing the animation of mobile users has been shown in Figure 5.2. When a user reaches at cross point, it might be scheduled with a stop event with the probability indicated by resSignalOnProb.
Later on any new mobility model can be implemented by providing the new implementation of the interface MobilityManage2.h.

![Animation of mobile users](image)

**Figure 5.2: Animation of mobile users**

### 5.2.1 Parameters of Primitive LocationUpdate2

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Default Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>appendLog</td>
<td>int</td>
<td>1</td>
<td>If set to one then results from successive runs would be appended otherwise they would be overwritten</td>
</tr>
<tr>
<td>isLocationBased</td>
<td>int</td>
<td>0</td>
<td>Normally it is set to zero. Set to 1 if we want to get results Vs location. in which case users would be symmetrically distributed and they would make request only at specific locations</td>
</tr>
<tr>
<td>maxXValue</td>
<td>float</td>
<td>200.00</td>
<td>Maximum x Value for the mobility of user</td>
</tr>
<tr>
<td>maxYValue</td>
<td>float</td>
<td>200.00</td>
<td>Maximum y Value for the mobility of user</td>
</tr>
<tr>
<td>minXValue</td>
<td>float</td>
<td>0.0</td>
<td>Minimum x Value for the mobility of user</td>
</tr>
<tr>
<td>minYValue</td>
<td>float</td>
<td>0.0</td>
<td>Minimum y Value for the mobility of user</td>
</tr>
<tr>
<td>NumUsers</td>
<td>int</td>
<td>1</td>
<td>Total Number of users</td>
</tr>
<tr>
<td>randomLocationSeed</td>
<td>float</td>
<td>-1</td>
<td>This value is used as seed to generate initial locations randomly. If set to -1, global seed is used as local seed if set to 0, local time is used as local seed, each run will diff</td>
</tr>
</tbody>
</table>
values if set to positive then this values is used as local seed, All instances using same value will generate same sequence of values

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Default Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>rsOnTime</td>
<td>float</td>
<td>15</td>
<td>The time in seconds for which red signal stays red at the crossings.</td>
</tr>
<tr>
<td>starId</td>
<td>string</td>
<td>LocationUpd</td>
<td>used as prefix in the log messages</td>
</tr>
<tr>
<td>UserSpeed</td>
<td>float</td>
<td>10</td>
<td>user speed in meter/second</td>
</tr>
<tr>
<td>verbose</td>
<td>Int</td>
<td>2</td>
<td>used to output messages, 1 to 2 for basic results and 3 for detailed debugging mode messages</td>
</tr>
<tr>
<td>redSignalOnProb</td>
<td>float</td>
<td>0</td>
<td>When a user reached at crossing the prob. that the red signal is on</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Default Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>interval</td>
<td>float</td>
<td>2e-3</td>
<td>The time period for the transmission of MAC frames in HL2</td>
</tr>
<tr>
<td>MACId</td>
<td>int</td>
<td>1</td>
<td>MAC ID is used to distinguish between signals from two different HL2</td>
</tr>
</tbody>
</table>

Table 5.1: Parameters of primitive LocationUpdate2

5.3 Primitive HL2_Server

This primitive as the name shows acts as HL2 AP. It receives request from users to download file and transmits instances of class MACFrame every 2ms. HL2_Server determines the location of each user by reading the memory HLMemory every locationUpdateInterval and it determines the PHY mode according to the distance of user from HL2 base station as described in section 4.4. It uses an instance of class HL2_Server_Schedular to implement scheduling which determines the amount of data for each active user as described in section 4.4.

5.3.1 Parameters of Primitive HL2_Server
5.4 Primitive UMTS_Server

This primitive acts as UMTS base station and transmits instance of class HSDPAFrame every 2ms. This primitive receives requests from users to download file and transmits data for each active user in HSDPAFrame. This primitive uses an instance of class UMTS_Server_Schedular to implement the functionality of scheduler as described in section 4.3. The scheduler determines the amount of data for individual active user in each HSDPFrame.

5.4.1 Parameters of Primitive UMTS_Server

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Default Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>interval</td>
<td>float</td>
<td>2e-3</td>
<td>The time period for the transmission of HSDPA frames in UMTS</td>
</tr>
<tr>
<td>numUsers</td>
<td>int</td>
<td>1</td>
<td>Total number of users</td>
</tr>
<tr>
<td>starId</td>
<td>string</td>
<td>_HL2Server-$Name-$NodeId</td>
<td>Used as prefix in the log messages</td>
</tr>
<tr>
<td>verbose</td>
<td>int</td>
<td>2</td>
<td>Used to output messages, 1 to 2 for basic results and 3 for detailed debugging mode messages</td>
</tr>
</tbody>
</table>

| x_location | float    | 0.0           | X value for the location of this access point                               |
| y_location | float    | 0.0           | Y value for the location of this access point                               |

Table 5.3: Parameters of primitive UMTS_Server
5.5 Primitive ConvergenceManager

This primitive is a part of mobile terminal and its task is to implement the standard selection and switching algorithms as described in section 4.5. It also tracks the user location and moving direction for which it reads the LocationMemory every locationUpdateInterval time. It also performs the background scanning by receiving the network status information from the lower layer primitives HL2_DLL and UMTS_DLL.

5.5.1 Parameters of Primitive ConvergenceManager

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Default Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NodeId</td>
<td>int</td>
<td>1</td>
<td>A unique ID to distinguish the users, starting from 1 and not 0.</td>
</tr>
<tr>
<td>userPolicy</td>
<td>int</td>
<td>1</td>
<td>0=UMTSOnly, 1=HL2Only, 2=UMTS/HL2Switched, 3=UMTS/HL2(Location), 4=UMTS/HL2(Current)</td>
</tr>
<tr>
<td>starId</td>
<td>string</td>
<td>_CM-$Name-$NodeId</td>
<td>Used as prefix in the log messages.</td>
</tr>
<tr>
<td>verbose</td>
<td>int</td>
<td>2</td>
<td>Used to output messages, 1 to 2 for basic results and 3 for detailed debugging mode messages</td>
</tr>
</tbody>
</table>

Table 5.4: Parameters of primitive ConvergenceManager

5.6 Primitive HL2_DLL

The functionality of primitive HL2_DLL is to receive the MACFrame from downlink transmitted by HL2 AP and extract the data intended for this mobile terminal (indicated by NodeId) and pass it to the upper layer primitive i.e., the ConvergenceManager. It also informs the primitive ConvergenceManager about the availability status of HL2 continuously. When a user makes a request and if the ConvergenceManager decides to direct this request toward HL2 then ConvergenceManager triggers the primitive HL2_DLL which in turns transmits an instance of class UserRequest on uplink to HL2 AP to indicate this request.
5.6.1 Parameters of Primitive HL2_DLL

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Default Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>userId</td>
<td>int</td>
<td>1</td>
<td>A unique ID to distinguish the users, starting from 1 and not 0</td>
</tr>
<tr>
<td>starId</td>
<td>string</td>
<td>_HL2DLL-$Name-$NodeId</td>
<td>Used as prefix in the log messages</td>
</tr>
<tr>
<td>verbose</td>
<td>int</td>
<td>2</td>
<td>Used to output messages, 1 to 2 for basic results and 3 for detailed debugging mode messages</td>
</tr>
</tbody>
</table>

Table 5.5: Parameters of primitive HL2_DLL

5.7 Primitive UMTS_DLL

This primitive is the counterpart of HL2_DLL for UMTS. The functionality of primitive UMTS_DLL is to receive the HSDPAFrame from downlink transmitted by UMTS base station and extract the data intended for this mobile terminal (indicated by NodeId) and pass it to the upper layer primitive i.e., ConvergenceManager. It also informs the primitive ConvergenceManager about the availability-status of UMTS. When a user makes a request and if the ConvergenceManager decides to direct this request toward UMTS then ConvergenceManager triggers the primitive UMTS_DLL which in turns transmits an instance of class UserRequest on uplink to the UMTS base station to indicate this request.

5.7.1 Parameters of Primitive UMTS_DLL

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Default Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>userId</td>
<td>int</td>
<td>1</td>
<td>A unique ID to distinguish the users, starting from 1 and not 0</td>
</tr>
<tr>
<td>starId</td>
<td>string</td>
<td>_UMTS_DLL-$Name-$NodeId</td>
<td>Used as prefix in the log messages</td>
</tr>
<tr>
<td>verbose</td>
<td>int</td>
<td>2</td>
<td>Same as in HL2_DLL</td>
</tr>
</tbody>
</table>

Table 5.6: Parameters of primitive UMTS_DLL
5.8 Primitive UserApplication

This primitive represents the user/application. Its task is to generate request to download file and send those requests to primitive ConvergenceManager, which selects appropriate standard to download files. The requests are generated according to the distribution indicated by reqArrivalDistr with the file size as indicated by fileSizeDist parameter.

5.8.1 Parameters of Primitive UserApplication

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Default Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>fileSizeDistr</td>
<td>string</td>
<td>constant</td>
<td>This parameter shows the file size distribution. It may be one of the followings: constant, uniform, Poisson.</td>
</tr>
<tr>
<td>maxFileSize</td>
<td>float</td>
<td>1000</td>
<td>Used for uniform distribution KB</td>
</tr>
<tr>
<td>maxReqArrivalRate</td>
<td>float</td>
<td>10</td>
<td>Used for uniform request arrival Rate</td>
</tr>
<tr>
<td>meanFileSize</td>
<td>float</td>
<td>125</td>
<td>Mean FileSize in KB used when distribution is Poisson or constant</td>
</tr>
<tr>
<td>meanReqArrivalRate</td>
<td>float</td>
<td>1/10</td>
<td>Mean Request arrival Rate, used when distribution is Poisson or constant.</td>
</tr>
<tr>
<td>minFileSize</td>
<td>float</td>
<td>12.5</td>
<td>Used for uniform distribution of file size</td>
</tr>
<tr>
<td>minReqArrivalRate</td>
<td>float</td>
<td>1/100</td>
<td>Used for uniform request arrival rate distribution</td>
</tr>
<tr>
<td>reqArrivalDistr</td>
<td>string</td>
<td>Poisson</td>
<td>This parameter shows distribution of the inter request arrival time</td>
</tr>
<tr>
<td>Seed</td>
<td>int</td>
<td>-1</td>
<td>This value is used as seed to generate initial locations, randomly If set to -1, global seed is used as local seed if set to 0, local time is used as local seed, each run will diff values if set to positive then this values is used as local</td>
</tr>
</tbody>
</table>
seed, All instances using same value will generate same sequence of values

<table>
<thead>
<tr>
<th>starId</th>
<th>string</th>
<th>_userApp-$Name-$NodeId</th>
<th>Used as prefix in the log messages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verbose</td>
<td>int</td>
<td>2</td>
<td>Used to output messages, 1 to 2 for basic results and 3 for detailed debugging mode</td>
</tr>
</tbody>
</table>

Table 5.7: Parameters of primitive UserApplication

5.9 Implementation of Scenario in MLDesigner

Figure 5.3 shows a snapshot of the simulation scenario as implemented in MLDesigner. It has four main modules, MobilityManager2, MobileUsersPool, UMTS_BS and HL2AccessPoint.

Figure 5.3: Implementation of simulation scenario in MLDesigner
5.9.1 Parameters of Scenario

All the parameters that are necessary to be initialized in order to run simulation properly are in fact exported from different primitives and they have been discussed under relevant primitives previously.

5.9.2 Module MobilityManager

Its Main function is to control the motion of mobile terminals and to show animation. In order to show animation it transmits the new position (x,y value pair) of each user to TKXYPlot which displays this information on a graph. A snapshot of this module has been shown in Figure 5.4. All the parameters of this module have already been discussed under primitive LocationUpdate2.

5.9.3 Module HL2AccessPoint

This module acts as HyperLAN2 base station. It receives request from users and transmits MACFrame every 2ms. It uses the primitives EtherSend and EtherRecMes to transmit and receive messages to and from the mobile terminals. The primitive EtherSend and EtherRecMes uses memory element to transmit particles therefore there is no need of physical links and thus they are ideal to show wireless links. A snapshot of module HL2AccessPoint has been shown in Figure 5.4.
5.9.4 Module MobileUsersPool

This module contains a higher order function (HOF) and the module MobileTerminal as block element. The higher order function creates instances of MobileTerminal equal to the total number of mobile users as indicated by parameter numUsers. In this way HOF makes it quite easy to simulate large number of users. A snapshot of module MobileUsersPool has been shown in Figure 5.6

5.9.5 Module MobileTerminal

This module represents the functionality of mobile terminal as shown in Figure 5.7. Every MobileTerminal has a unique id NodeId starting from 1 that is used to distinguish between different mobile terminals. It contains UserApplication to represent user behavior to generate requests. These requests are forwarded to ConvergenceManager which diverts this request to appropriate standards. The primitives HL2_DLL and UMTS_DLL on receiving trigger from ConvergenceManager create an instance of UserRequest and transmit it to UMT_Server/HL2_Server via EtherSend. The primitives HL2_DLL and UMTS_DLL receive MACFrame and HSDPAFrame respectively, extract data
intended for this mobile terminal and handover it to upper layer i.e., ConvergenceManager.

Figure 5.6: Implementation of MobileUsersPool in MLDesigner

Figure 5.7: Implementation of MobileTerminal in MLDesigner
5.9.6 Module UMTSBaseStation

A snapshot of this module has been shown in Figure 5.8. It receives user requests i.e., instances of class UserRequest from EtherRecMes and sends data to each active user in HSDPAFrame every 2ms via EtherSend. It is supposed the UMTS coverage is available everywhere.

![Figure 5.8: UMTS BaseStation in MLDesigner](image)

5.10 How to Get Results

Each time simulation is run a log file ‘msamt-$simulationNumber.log’ is generated provided that verbose is set to 1 or 2. (3 is reserved for debugging mode). Then run a perl script called ‘processLog3.pl’ in the directory containing the log files. This would generate some txt files like stasts.log, meanTDT.log (mean Total Download Time), meanDBDCArray.log (mean delay before download commence), meanPerDisArray.log (mean percentage discarding rate), meanPerSerArray.log (mean percentage serving rate). Finally by running matlab script getPlots.m graphs can be obtained.
Chapter 6

Simulation Results

As described earlier, the work in this thesis is based on the assumption that the Convergence Manager is located only in mobile terminal. With this assumption the main functionality of the Convergence Manager is then selection-and-switching of wireless standards. We considered HL2 and HSDPA from UMTS as wireless standards. The focus of this chapter is to present the performance analyses of various standard selection and switching algorithms on the basis of the results obtained by simulation means. The performance analysis is based on mean file download delay and user request discarding rate. These results are obtained for a given scenario and generic file download service. The details about wireless standards, simulation scenario and file download service have already been described in chapter 4, ‘Simulation Scenario and Considerations’, whereas the details about implementation in MLDesigner have been discussed in Chapter 5, ‘Implementation’.

6.1 Multi-Standard Single-User Study

The simulation scenario has been shown in Figure 6.1. Scheduling in HL2 and HSDPA is as per described under sections 4.3 and 4.4. We supposed users to be moving with a speed of 10 m/s continuously. The stopping probability at the crossing is zero for this consideration. The users’s file-download-request process is Poisson with a mean value of 1/10 requests per second. Simulation was run ten times with different Preferred-Seed each of 1000 second duration and then mean values were computed. The Preferred-Seed is used to generate the initial location of user, direction of motion and the Poisson user-request process.
Three kinds of user equipment were supposed. The first one is conventional and has single standard download capability (as used in ‘HL2-Only’ and ‘UMTS-Only’ methods). The second one has dual-standard-download capability but one file can be downloaded through only one standard (as used in Current and Location methods). The third one is also dual-standard enabled but in addition to that it can switch between standards while mid of file download (as used in Switched method).

There are two kinds of delays associated with a file download process. One is the delay before the download started, we may call it initial delay, and the other is the actual download time. The sum of the two gives the total download time. Figure 6.2 shows the mean initial delay Vs different file sizes whereas Figure 6.3 shows the mean total download time Vs file size.

With reference to Figure 6.2 it is clear that:

- In case of ‘UMTS-Only’ method, the initial delay is zero. It is because UMTS coverage is available throughout.

- The mean initial delay is significantly high in case of ‘HL2 Only’ method. It is because HL2 coverage is available only in a limited area and most of the user requests occur in an area where HL2 is not available and the user has to wait until it reaches in HL2 coverage area.

- In case of Switched and Current algorithm the initial delay is always zero. It is because that in both methods the currently available standard offering the highest data rate is selected and download starts immediately.

- In case of Location algorithm, there is a non-zero initial delay when HL2 is selected for a file requested during UMTS only coverage area i.e., an area where HL2 is not available. A large portion of small file sizes requested during UMTS only coverage area can be completed via UMTS before
entering to the next HL2 coverage area. Therefore UMTS is selected which results in zero initial delay. However for larger file sizes there is higher probability that file download cannot be completed in UMTS only coverage area and hence HL2 is selected (for which user has to wait) that introduces non-zero initial delay. The mean initial delay increases with file size.

![Figure 6.2: Mean initial delay Vs file-size](image)

With reference to Figure 6.3, a couple of observations can be made:

- Both ‘UMTS Only’ and ‘HL2 Only’ methods are not able to provide a realistic download time for full range of file sizes. It can also be observed that small file downloads can be completed much faster through ‘UMTS Only’ method which is because of full coverage of UMTS resulting in zero initial delay whereas file download via ‘HL2 Only’ operation is often penalized with large initial delay. As the file size grows the limitations arising from the inherent low data rate of UMTS become visible and it takes longer time to complete large file downloads. On the other hand overall download time via ‘HL2 Only’ method is largely independent of file size (at least for the file size range we considered). It is because of high data rate offered by HL2.
- The Switched algorithm exhibits the lowest overall delay because it always downloads via the higher data rate offering standard. It also serves as the theoretical lower bound of performance for comparison purpose.

- The Current algorithm offers better delay performance than ‘UMTS Only’ method for the entire range of file sizes. It is due to the regional availability of HL2 during which higher data rates reduces the file download. However in comparison to ‘HL2-Only’ method, Current algorithm performs better only for low file sizes and for large file sizes it performs inferior than ‘HL2-Only’ method. It is because large file downloads requested shortly before entering the HL2 coverage are downloaded via low data rate UMTS when it would be often faster to wait for HL2 coverage and start downloading via higher data rate offering HL2.

Figure 6.3: Mean total download time Vs file-size

- Location algorithm is of great interest because it helps to prevent the above said problem in Current algorithm by using the knowledge of user-mobility and coverage-range-information of UMTS and HL2. It exhibits the delay performance quite close to the Switched algorithm over all
range of file sizes and also it avoids the complexities associated with switching mid way of file download as is the case with Switched algorithm.

Figure 6.4 shows the mean discarding rate Vs file size for various algorithms. It is important to understand what we mean by discarding rate here. If a user makes request before the previous request have been completed then the later request would be discarded. Thus discarding rate is another mean to compare the relative performance of various algorithms. The mean discarding rate is a function of mean total download time, higher the mean total download time is, higher would be the number of requests that might arrive during file download process and would be discarded. Only those file downloads contribute in calculating the mean total download time that were served and the rejected requests do not effect the mean total download time. Therefore it is important to consider the mean discarding rate as well to evaluate the relative performance of various algorithms. Please note that absolute value of discarding rate also depends directly on the user request arriving rate. Therefore the mean discarding rate here is useful only to compare various algorithms.

It is pretty clear that Switched algorithm has lowest discarding rate because it is the theoretical lower bound as discussed before. The Location algorithm exhibits mean discarding rate very close to Switched algorithm over entire range of file sizes and it outperforms all other algorithms.
6.2 HotSpot Effect

HL2 access points are supposed to be located at crossings on the road. When a mobile user reaches at crossing there is some probability that the mobile user finds red signal on so that it has to stop and stay there for some time. This stopping event of mobile users at the crossing results in higher user density at the crossing thus creating a HotSpot. Due to this HotSpot effect a mobile user is like to spend some more time in HL2 coverage area. Hence it can get more benefits from large capacities offered by HL2.

We supposed that when a user arrives at crossing there is a probability of 0.1 that it might be stopped by a red signal in which case he has to stay there for 15 seconds. Figure 6.5 shows the results for zero stopping probability (graphs with asterisks *) and 0.1 stopping probability (graphs with square □). It is clear that there is significant improvement in the mean total file download delay when users are likely to stop at the crossing. The results also supports that crossing points on roads are good place to deploy HL2 access points.
6.3 Multi-Standard Multi-Users Study

As explained and proved in section 6.1 that Location algorithm is the best choice but those results were based on single user evaluation. In this section it will be investigated that whether the same holds in case of multiple users.

The simulation scenario and relevant parameters are same as in section 6.1 with the only difference that here simulation was run for different number of users instead of single user. Figure 6.6 shows the mean values for the total file download time for different number of users and Figure 6.7 shows the mean discarding rate. These results have been shown for file size 125 KB. For each curve in graphs all users are using same algorithm.
Figure 6.6: Mean total download time Vs number of users
6.3.1 Problem in Multi-Users environment

An important observation is that for a fixed file size as the number of users is increased the performance of Location algorithm is decreased both in terms of mean total download time and mean discarding rate.

6.3.2 Reasons and Explanation

It was investigated that the root cause for the above mentioned performance degradation lies in the false decision making process of standard selection. When user makes a request in ‘UMTS Only’ coverage area, the location method estimates that whether the download can be completed before the start of next HL2 coverage area. Similarly if the request arrives in HL2/UMTS coverage area then Location algorithm estimates that whether the download can be completed before the end of the current HL2 coverage area. Location algorithm uses the users’s mobility information, UMTS/HL2 coverage information and the data rate.
offered by both standards in order to do estimation. It is clear that to make estimation Convergence Manager must know the correct data rate from respective standard. In case of single user all available capacity is given to the single user when he makes request to download a file. It means that user will be assigned one chip code (240 kbps) from HSDPA and full time slot from HL2. It implies that data rate achieved throughout the download process is already known to the user hence he can calculate the time taken to download the file completely to make estimation at the time request arrives. This is true only in single user case. As the number of active users (users with outstanding requests) increase the available capacities from HL2 and UMTS is divided among them according to the scheduling policy chosen (Section 4.3 and 4.4 describes the scheduling policy implemented in the simulation). As an example when number of active users increases beyond 16 then one chip code is shared between two user in alternate frame decreasing the effective data rate from 240 kbps to 120 kbps. Similarly in HL2, MAC frame time is also shared between users. Although a User knows that how much data he will get in the next MAC frame but he cannot predict that how long will it take to download the file Via UMTS or HL2 completely at the time when request arrives. User still thinks that it will get the same data rate as it could get when there is only one user that results in wrong standard selection. Consider a simple example. Suppose that user makes a request for a file size of 250 KB in ‘UMTS Only’ coverage area at a point when user is just 10 seconds away from the start of HL2 coverage. Location algorithm assumes that it will get 240 kbps (as if there is only one user) throughout the download process from UMTS and hence file download can be completed before start of HL2 coverage. So it selects UMTS but actually it gets a mean data rate say just 60 kbps mean data rate because multiple are users sharing the capacity. This results in 4 times longer delay than the estimated one. If Location algorithm knew this already then definitely it would not have selected UMTS and it would wait for HL2.

6.3.3 Proposed Solution: History Based Location Algorithm

Both HSDPA and HL2 offer variable data rate for a file download service i.e, they do not give guarantee of a fixed data rate. So in this situation the mean data rate that would be achieved during the current download process can be inferred from the history i.e., mean data rate achieved during the last file download process. We modify the location algorithm and call it as ‘History Based Location Algorithm’. In this modified algorithm, history is used to predict the mean data rate to be offered in the respective standard. The mean data rate that was achieved in the last file download process is used as the predicted mean data rate which would be achieved for the current file download process from the
respective standard. A performance improvement in the Location algorithm can be seen in the results shown in Figure 6.8 and Figure 6.9 with modified new ‘History Based Location Algorithm’.

![Mean Total Download Times Vs num Users](image)

**Figure 6.8: Mean total download time Vs number of users (with new history based location algorithm)**

### 6.3.4 Limitations of the Proposed Solution

For Location algorithm and the History Based Location algorithm we made one assumption that the Convergence Manager knows the precise knowledge about user mobility and geographical coverage of wireless standards, which might not be true in real life. There might always be some error in the knowledge of users mobility and geographical coverage of standards which will degrade the performance.

Even with the above said assumption, the performance of ‘History Based Location Algorithm’ depends purely on how accurate we can guess the mean data rate which would be achieved for current file download. Obviously if there is a rapidly changing situations (because of time fading channels or load fluctuations) and the previous download situation is too old to be used as a means to infer
mean data rate to be obtained for current download then standard selection process is likely to be wrong and the performance will be degraded.

Figure 6.9: Mean discarding rate Vs number of Users (with new history based location algorithm)
Chapter 7

Conclusion and Future Work

In this master thesis we investigated the possibility and potential benefits of having an instance of Convergence Manager only in mobile terminal in which case the main functionality of Convergence Manager is standard-selection-and-switching. For a given scenario and generic file download service the performance of various standard-selection algorithms were compared. The performance was based on mean total download time and mean request discarding rate.

7.1 Benefits of Convergence Manager

Deploying an instance of Convergence Manager only in the mobile terminal is advantageous because it enables the mobile terminals to make combined use of multi-standards. The multi-standard enabled mobile terminals experience better QoS as compared to traditional single-standard approach. Overall system performance improves. Network operators are in a better position to offer better services to their mobile clients. From architecture point of view, it is easy to realize because it involves low complexities and no extras standardization efforts are required.

7.2 Comparison of Standard-Selection Algorithms

It was observed that Switched algorithm performs the best both in terms of overall delay and request discarding rate over the entire file size range. However it involves complexities associated with standard switching during the file download that might prohibit its usage.
Location algorithm seems to be most interesting one as it does not require switching during the file download and its performance is almost the same as that of Switched algorithm.

However in case of multiple users, it was revealed that Location algorithm suffers from a drawback and its performance degrades severely with increasing number of users. The reason stems from the wrong estimation process involved in Location algorithm as explained before in section 4.5.2.

To overcome the above said drawback, we proposed a new modified Location algorithm called, ‘History Based Location Algorithm’. In new algorithm the mean data rate that was achieved in the last file download process is used as the predicted mean data rate that would be achieved for the current file download process from the respective standard. Results show that by deploying new proposed ‘History Based Location Algorithm’ a significant performance improvement has been achieved over the old Location algorithm.

7.3 Modular and Extendable Simulation Setup

The framework for the simulation setup is a first time addition to MLDesigner library. The whole software is object oriented and modular based which makes it a useful off shelf component. The modular nature makes future extensibility very easy. E.g., other standards like BlueTooth, GSM or XYZ may also be incorporated. New standard-selection-and-switching algorithms and scheduling policies can be implemented and tested easily in future.

7.4 Limitations and Future Work

The performance of Location algorithms is limited because:

- It requires precise knowledge about location and motion of user
- It requires the geographical coverage information of wireless standards.
- It needs to predict the mean download time from respective standards accurately.

These strong dependencies indicate that there is always room for wrong standard-selection. This issue needs to be investigated more and is left as future work. The investigation about new standard selection algorithms, for different scenarios and services, is also a good direction for future work.
Bibliography


