Design and Implementation of WiMAX MAC Layer

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Abstract
In the last few years, the telecommunication industries' development has focused on an intensive use of broadband systems, which are characterized by high quality features. For this issue, new technologies with high transmission abilities have been designed. The broadband wireless access has become the best way to meet escalating business demand for rapid internet connection and integrated "triple play" services. In addition to not only topographic but also technological limitations, wireless solution alternatives have been found. That is the very base of the WiMAX concept: a wireless transmission infrastructure that allows a fast deployment as well as low maintenance costs.A technology developed to fulfill these characteristics, standardized by IEEE, is 802.16, also referred to as WiMAX. This architecture aims to apply high data rates, quality of services, long range and low deployment costs to a wireless access technology on a metropolitan scale. The technology and architecture of WiMAX is the focus of the thesis paper, and more specifically its mobility capabilities. The thesis investigates the handover and internetworking capabilities of WiMAX and then implements selected MAC-layer functionality in the GloMoSim network simulator. Through simulation attempts are made to identify MAC-parameters affecting performance during handovers.Results indicate that the study needs to be extended to cover upper layer protocols and procedures. At the MAC-layer the most deciding factors are predicted to be procedures executed in preparation for handover, rather than the specific handover process.
Key words: LPM, MMS, RRM, CSN, and ASN

1. Indroduction

Before we begin a real theory of WiMax, let's spend few minutes to understand background concepts on which WiMax has evolved. *Wireless* means transmitting signals using radio waves as the medium instead of wires. Wireless technologies are used for tasks as simple as switching off the television or as complex as supplying the sales force with information from an automated enterprise application while in the field. Now cordless keyboards and mice, PDAs, pagers and digital and cellular phones have become part of our daily life.
Some of the inherent characteristics of wireless communications systems which make it attractive for users, are given below:

- **Mobility:** A wireless communications system allows users to access information beyond their desk and conduct business from anywhere without having a wire connectivity.
- **Reachability:** Wireless communications systems enable people to be better connected and reachable without any limitation of any location.
- **Simplicity:** Wireless communication system are easy and fast to deploy in comparision of cabled network. Initial setup cost could be a bit high but other advantages overcome that high cost.
- **Maintainability:** Being a wireless system, you do no need to spend too much to maintain a wireless network setup.
- **Roaming Services:** Using a wireless network system you can provide service any where any time including train, busses, airoplans etc.
- **New Services:** Wireless communications systems provide new smart services like SMS and MMS.

2. Related Work

Research in mobility is a hyped area right now and a lot of work is done by many different persons and companies. Associations like IEEE refine and evolve existing standards or produce new ones. Companies put together working groups with each other to assure interoperability among equipment and a lot of students make thesis works with studies of and suggestions to existing/coming standards.
This section brings forth some of the interesting projects that have been found during the course of this thesis.
The 802.16d (now called 802.16-2004) only covers fixed networks which have lead to IEEE conducting work in a mobility version, 802.16e. Another approach to solve the lack of mobility in 802.16-2004 have been made in *"Mobility Support for IEEE 802.16d Wireless Networks"*. Their approach has the goal to enable mobility in 802.16-2004 without modifying the standard. To accomplish this mobility, tools such as hierarchical MIP, selected parts of the 802.12-2004 initialization process and a in the standard predefined message have been utilized.
Even though IEEE just completed the work on the 802.16e standard there have already been suggested a mechanism for enabling seamless handover in networks based on the standard. It is described in *"A Seamless Handover Mechanism for IEEE 802.16e Broadband Wireless Access"*.

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The mechanism is called Last Packet Marking (LPM) and integrates MAC-layer handover with the Network layer handover to decrease the handover effects on TCP service performance.

The 802.16e and 802.20 standards have many similarities and both are aiming to fill the gap between high mobility cellular networks and high data rate WLANs but there are some slight differences. 802.20 operate in frequencies below 3.5 GHz and the standard specifies the PHY and MAC-layers of the air interface. It is constructed to provide peak data rates higher than 1 Mbps/user in cells with up to 15 km coverage. This will be done in speeds up to 250 km/h, that means slightly higher speeds than the 802.16e will be able to handle. This high speed makes it possible to e.g. deploy 802.20 in high speed trains. An additional thing that pleads for 802.16 is the fact that the WiMAX Forum working group prolongs the standard with its WiMAX End-to-End Network Systems Architecture and fights for enabling interoperability between network equipment from different vendors. The vendor products can be certified and this can help 802.16 on its road to success.

802.20 is a new standard developed by IEEE especially for use in mobile networks. Due to this the standard can have some advantages over 802.16e (where the mobility is added upon a standard for fixed wireless networks) since problems can arise when making extensions to an existing standard. 802.16-2004 is build for fixed wireless networks and 802.16e has focus on mobility. Flaws from the original standard can tag along and some design choices might not optimal for the new target area. But on the other hand it can sometimes be faster to rework something already present then to start from scratch. This can lead to 802.16e products reaching the market before

802.20 do not have such a pronounced organization that brings the standard in to the bigger picture but it might be on its way. Telcordia have invited companies to a working group that will process the 802.20 standard. In a broad outline they will study coexistence between 802.20 and other systems in licensed bands below 3.5 GHz. The working group will produce conformance and interoperability specifications as a basis for certification testing. They will try to find procedures and services to enable cross vendor interoperability and interoperability to other systems. This group could be 802.20's WiMAX Forum.

3. Network Architecure

With the IEEE Std. 802.16 limiting itself to PHY and MAC-layer, the WiMAX Forum is developing a end-to-end network architecture, specifying the access/core systems and its functionalities. It contains procedures and protocols for how the network will support e.g mobility, security, internetworking and authentication to a WiMAX subscriber station. A depiction of the network architecture is presented in the network reference model in figure 1. It contains entities such as (Mobile) Subscriber Stations ((M)SS), Access Service Network (ASN) and Connectivity Service Network (CSN).

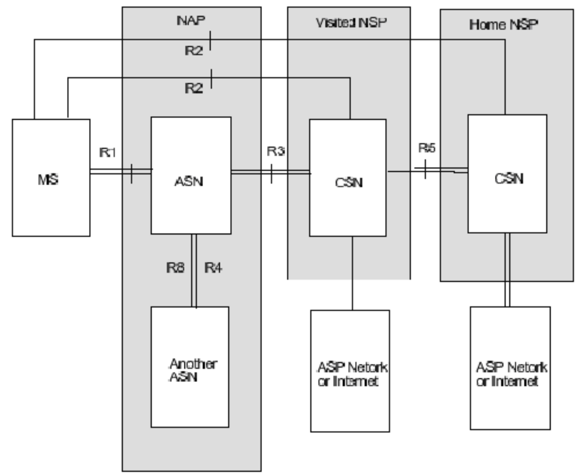

Fig. 1 The WiMAX Network Reference Model .

This reference model also contains interfaces between the different entities. These interfaces define procedures and protocols and serve as logical, rather than physical, links across the entities.

2.1 Access Service Network

The ASN consist of one or several ASN Gateways and base stations, supplying WiMAXradio coverage to a geographical area. A ASN manages MAC access functionality such as paging, locating, Radio Resource Management (RRM) and mobility between base stations. The ASN thus serves as management of the WiMAX radio links only, leaving much of the high level management to the CSN. The ASN can also be used as a proxy, as in the case of proxy Mobile IP (MIP). The ASN is deployed by a business entity called Network Access Provider (NAP) which provides a SS/MSS with L2 connectivity to a WiMAX radio network and connect users to Network Service Providers (NSP) managing a CSN. The ASN Gateway serves as the interconnection between ASN and CSN. This logical partition of the access network from the service network enables individual access networks to be deployed, e.g in the case of where several NAP can form cooperation or contractual roaming agreements with each other or one or several NSP.

2.2 Connectivity Service Network

A CSN is a set of network functions that provide IP connectivity to WiMAX subscriber stations. The CSN contains gateways for Internet access, routers, servers or proxies for AAA, IP-allocation, user databases, and internetworking devices. It also handles admission and policy control, mobility between ASN and specific WiMAX services such as Location Based Services or Law Enforcement Services. The CSN is deployed by a business entity called the NSP. WiMAX subscribers enter contractual agreements on e.g services, QoS, bandwidth etc with the NSP and access these services through the ASN it is currently situated in. The user can then use the service providers network or roam to networks deployed by other companies as long as the home network has a roaming agreement with the visitor network. The foreign ASN uses either its own management functions of the foreign CSN, and proxies them to the home network, or communicates directly with the home network CSN.

2.3 Topology Support

The WiMAX technology supports both 2-way PMP networks and a form of decentralized network topology called mesh. Mesh mode differs from PMP as in PMP mode the SSs only talk to the BS and all traffic goes through the BS while in mesh mode all nodes can communicate with each other either directly or by multi-hop routing through other SSs. A system with access to a backhaul connection is called Mesh BS, while the remaining systems are called Mesh SS. Even though the mesh has a system entitled the Mesh BS, this systems also has to coordinate broadcasts with other nodes. A mesh can utilize two types of broadcast scheduling. With distributed scheduling, systems within 2-hop radius of each other share schedules and cooperate to ensure collision avoidance and resource grants. A centralized scheduling mesh relies on the Mesh BS to gather resource requests from Mesh SSs within a certain range and allocate these with individual capacity. This capacity is shared with other Mesh SSs who’s data is relayed through the Mesh SSs corresponding with the Mesh BS. In mesh mode, QoS classification is done on a packet-by-packet basis rather than associated with links as in the case of PMP mode. There exists thus only one link between two communicating mesh nodes.

5. Result and Discussion

The three scenarios implemented are initial network entry, hard handover and Fast Base Station Switching (FBSS). A more detailed description of FBSS and soft handover1 can be found in.The scenarios were developed for two purposes. The first was to facilitate measurements of WiMAX processes like network entry and handover. The second was to facilitate the evaluation of GloMoSim as environment for future development as a WiMAX simulator The measurements done in these scenarios are in no way intended for use as performance evaluation of WiMAX and its air interface, but rather as a general MAC-layer performance comparison and analysis of the procedures used within WiMAX and their differences.

5.1 Network Entry

This scenario serves as a pilot study of coding a MAC-layer in GloMoSim and is also required by a node entering a WiMAX network. During this phase the MS performs ranging and negotiates capabilities with a BS. The end result is a setup of management and transport connections between the BS and MS. The scenario starts with the MS operating on the same frequency as BS1. At a random time2 after the simulation start the MS initiates the network entry sequence until it has one transport channel to BS1. As network entry is complete, the MAC-layer in the MS will relay data packets from the application layer to BS1. Data packets sent before network entry is complete will be lost.
The scenario makes the following assumptions.
Initial Ranging is always successful. To avoid cross layering the 802.11 PHY into the 802.16 MAC, there is no actual measurement of signal quality.
No computational overhead delays the response messages. This is the largest contributor to the idealization of measured data. The BS will need to interact with other base stations, gateways or upper layer protocols in practice, but such a architecture is not available for this simulation.
MS does not need to perform authentication, key exchange, DHCP negotiation or time synchronization. Such protocols are currently unavailable Initial analysis hinted that the selected frame rate would be the deciding factory for how fast network entry can be completed, but this is not the case. Since the MS needs to obtain the UCD3 message in order to send on the uplink, the interval in which this message is sent is crucial for the network entry time4.
The 802.16-2004 specification draft has this interval set at a maximum of 10 seconds, but does not recommend a minimum or default value. Worst case scenario would then mean that network entry can take slightly longer than 10s, as the MS needs to wait the full interval and then continue with the process.
The back of performed during initial, contention based, ranging also affects the network entry time but this impact is, in order of millisecond, a lot smaller compared to the length of the UCD interval which is in order of seconds.
For this scenario the time for network entry is measured with varying frame rates.
Frame duration is varied according to table 7.3. These frame durations are from the OFDM PHY specification of the 802.16-2004 standard.

Table 1:Tested Frame Rates

Frame Duration(ms)	*Frames per second*
2.5	400
4	250
5	200
8	125
10	100
12.5	80
20	50

Figure 2 on the facing page show how the network entry time varies with the frame rate for a UCD interval of 2s. Even though network entry delays could be neglected in certain scenarios when first entering a WiMAX network, it can seriously impact the time it takes to perform handover. This can be seen in the next scenario.

5.2 Hard Handover

The WiMAX mandatory handover case requires communication with both BSs and thus a frequency change for the MS5. Before and after the handover is completed the data tra_c shall continue uninterrupted, with the flow of data now moved from one BS to another after a completed handover. This type of handover is basically performed by releasing the MS from the associated BS and then performing network entry at another BS. Figure A.2 on page 74 shows

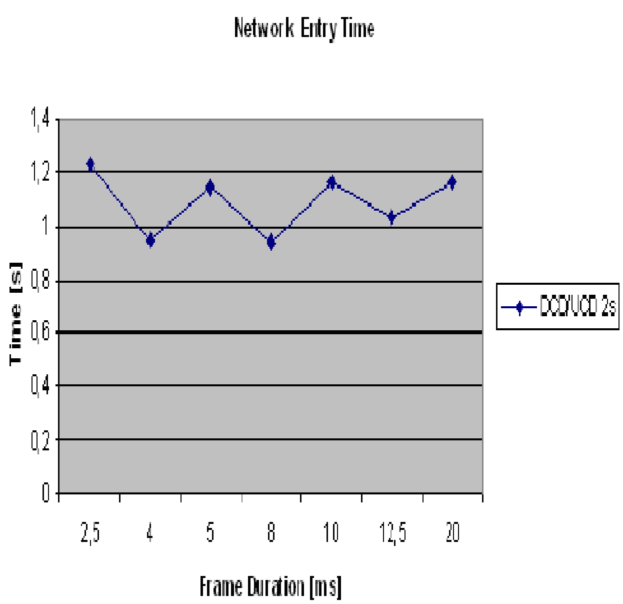

Fig. 2 Measured Network Entry Time.

the transition stages of a handover according to the 802.16e standard. The handover used in this case is MS initiated at a random interval between two broadcasted UCD messages6. Since the network entry procedure from the first scenario is used for hard handover, the same assumptions still hold. It is also assumed that the target BS always has resources available for accommodating the MS connections. Measured in this scenario is the time it takes to perform a handover, from the decision to make the handover to the time when application data is received at the second base station. It is also of interest to pin-point the parameters that govern how fast a handover can be completed. This scenario will vary frame rates and measure the different network entry times for a fixed UCD interval. Another measurement will for a selected frame rate vary the UCD interval This case will also look at how throughput of application data is affected by the handover and its associated overhead.

As this case is similar to network entry, with addition to exchange of handover request, response and indication messages, the resulting time measured will be affected by the same parameters, i.e. the interval of periodic messages needed for the process to complete. Figure 3 on the following page depicts how the handover time is affected by varying frame rates for an UCD interval of 2 seconds.

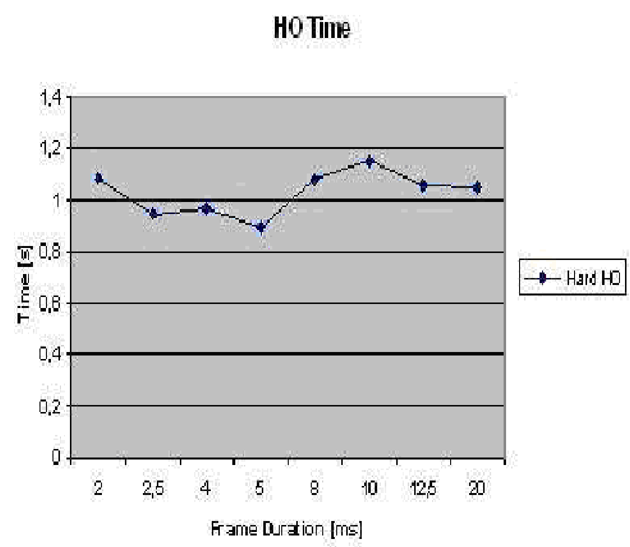

Fig. 3 Measured Handover Times (Varing Frame Rate).

An increase in frame rate does not speed up the handover procedure through more frequent request/response opportunities, as this procedure is dependent on broadcast messages that use a fixed time interval independently of the frame rate. If the information needed for uplink synchronization is sent via management messages or through periodic neighbor scanning, the handover could be completed faster. The MOB NBR-ADV management message has the purpose of distributing this information and is broadcasted at regular intervals by a BS, sharing channel information of neighbor base stations without the need for a MS to gather this information from each individual adjacent BSs. This does however introduce more management overhead. The impact on handover time by the UCD interval is shown in figure 4 on the next page. Frame rate is constant at 5 ms. If the decision to make a handover has a uniform distribution over the time interval, the results are as expected with the average handover time being almost half the UCD interval. Figure 7.5 on page 56 shows the throughput at BS1 and BS2 during the simulation. Throughput is reduced when the traffic of management messages reduced the portion of uplink available for application data. As the MS de-registers with BS1, the throughput for BS1 drops to zero. Maximum throughput at BS2 is reached after network entry is complete.

5.3 Fast Base Station Switching

FBSS is used for diversity combining of signals from several base stations. When measured signal characteristics fall beneath a threshold value, the MS initiates an anchor change of BS. The MS can immediately switch between base stations on a rame by frame

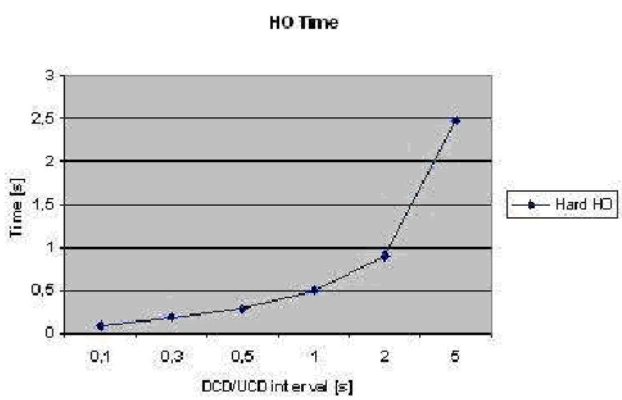

Fig 4. Measured Handover Times (varying UCD).

basis to quickly adapt to deteriorating channel environments. This is made possible by distributing the information needed for such a switch beforehand. A message sequence diagram of the FBSS phase can be seen in figure A.3 on page 74 according to the 802.16e standard.

Figure 7.6 on the following page shows the throughput at BS1 and BS2 during the simulation. Throughput is reduced when the traffic of management messages reduced the portion of uplink available for application data. These management messages consummate the anchor update and when this is procedure is completed the MS can send on the next frame of BS2. The throughput is never reduced to zero and the MS does not need to stop transmitting application layer data.

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