Performance Analysis of a Reliable Handoff Procedure for IEEE 802.16e based networks

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Abstract

IEEE 802.16 is a protocol for fixed broadband wireless access that is currently trying to add mobility among mobile users in the standard. However, mobility adds some technical barriers that should be solved first, this is the case of HO "handoff" (change of connection between two base stations "BS" by a mobile user). In this paper, the problem of HO in IEEE 802.16 is approached trying to maintain the quality of service (QoS) of mobile users. A mechanism for changing connection during HO is presented. A simulation model based on OPNET MODELER v11 was developed to evaluate the performance of the proposed HO mechanism. Finally, this paper demonstrates that it is possible to implement a seamless HO mechanism over IEEE 802.16 even for users with demanding applications such as voice over IP.

Introduction

A great demand for fast Internet access, voice and video applications, combined with the global tendency to use wireless devices, has given sprouting for broadband wireless access (BWA) networks. Unlike other broadband technologies, such as xDSL (Digital Subscriber Line), FITL (Fiber In The Loop), WITL (Wireless In The Loop) among others, BWA networks are easier to implement and to expand, they require a low initial investment and a low maintenance cost. In addition, BWA networks are easy to update and they promise to have a good future due to the evident growth of the market for broadband access.

Nevertheless, it was not until last decade that some international institutions began to make efforts to standardize this type of technologies. The first attempt of a BWA system was the Wireless ATM protocol [1], but the lack of industry support led this system to be an unviable broadband solution for residential users.

However, a promising solution for broadband wireless access is with the IEEE 802.16 [2] protocol that was developed at the beginning of this decade by hundreds of engineers from the world's leading operators and vendors as well as by many academic researchers. The first version of this protocol was standardized on April 2002 and supports data rates up to 134 Mbps in a 28MHz channel, with a 30-mile range. At the beginning of its development, this protocol was oriented for fixed wireless users with line of sight (LOS), using the 11-66 GHz spectrum range. But then on 2004, the aim of this protocol was changed to support residential access and NLOS. The second version is called the IEEE 802.16-20004 Standard [3] and supports two ways of Media Access Control: 1) point to multipoint (PMP), where traffic only occurs between Base Station (BS) and Subscriber Stations (SS), and 2) Mesh topology where traffic can be routed through other SSs and can occur directly between SSs. In addition, the second version also includes OFDM modulation and supports 256 carries, which reduces considerably multipath fading effects.

Recently, the IEEE 802.16 Task Force, released a new version that will provide mobility to SSs, this is the IEEE 802-16e [4] standard. Although this standard provides a HO mechanism, it have not been tested for the support of timing critical interactive applications, such as Voice over IP. Thus, in this paper we present a HO mechanism that guarantees QoS for realtime applications.

The rest of the paper is structured as follows. In section 2, we present an overview of the IEEE 802.16 MAC protocol and provide detailed information of the Initialization and Registration processes that each subscriber station performs with the BS after power-up. In Section 3 and 4 we describe the proposed HO mechanism and the simulation model, respectively. Then in Section 4, we present a performance analysis of the proposed HO mechanism for different traffic scenarios. Finally in Section 5, we present a conclusion and future work.

IEEE 802.16 Standard Overview

The IEEE 802.16e standard uses the same Medium Access Control (MAC) protocol defined in IEEE 802.16 [2], with several different physical layer specifications dependent on the spectrum of use and the associated regulations. In general, the MAC protocol defines both frequency division duplex (FDD) and time division duplex (TDD). Transmissions from a Base Station (BS) to Subscriber Stations (SSs) are conducted by a Downlink (DL) channel, with PMP wireless access using a frequency channel for FDD or a time signaling frame for TDD. Multiple SSs share one slotted uplink (UL) channel via TDD on a demand basis for voice, data, and multimedia traffic. Upon

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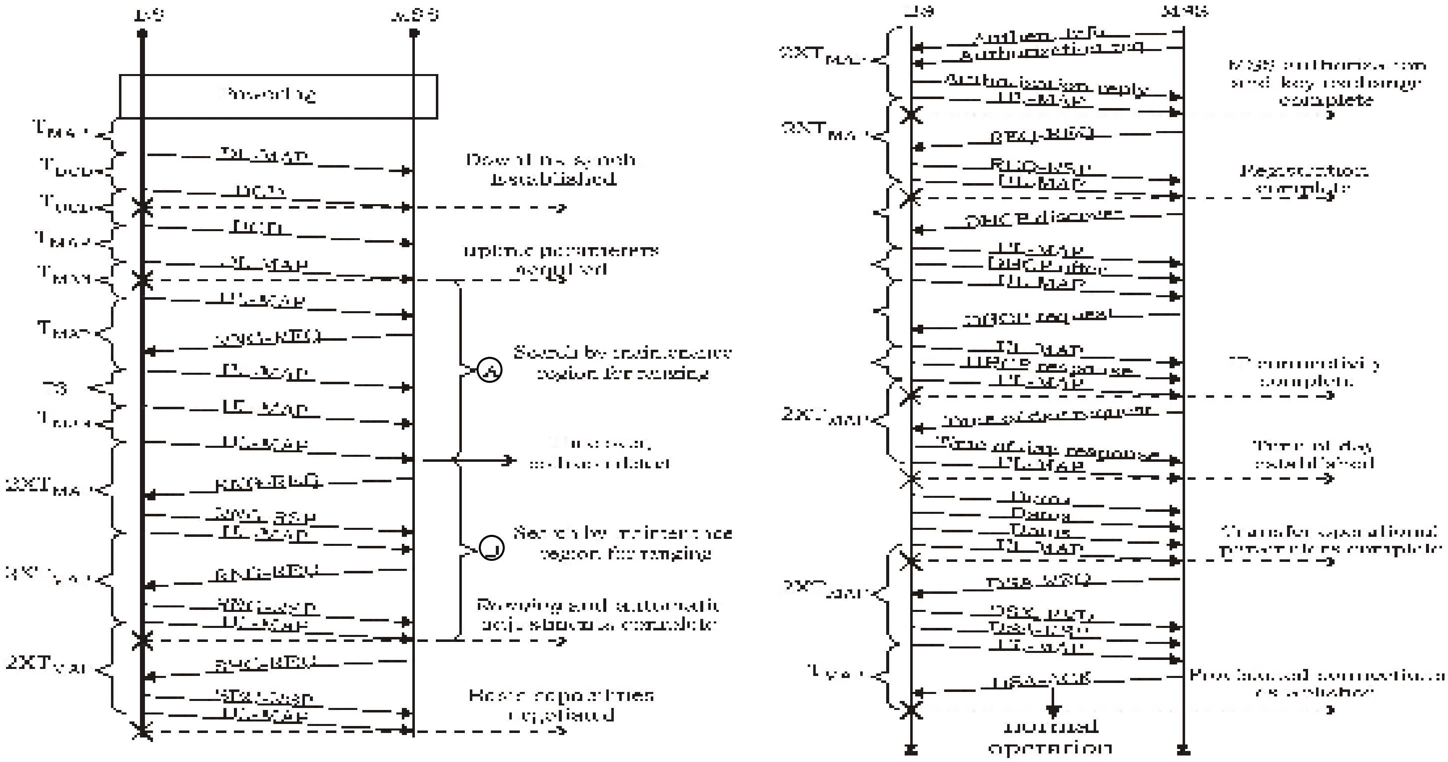

Figure 1. Initialization and Registration Procedure.

receiving the demand for bandwidth, the BS handles bandwidth allocation by assigning uplink grants based on requests from SSs. A typical signaling frame for TDD includes a DL subframe and a UL subframe. The DL subframe includes one downlink-physical-protocol data unit (DL-PHYPDU), which includes a preamble, Frame Control Header (FCH), and a number of data bursts. A UL-PHY-PDU includes preamble, multiple MAC PDUs, and a PAD. A MAC PDU includes MAC header, payload, and CRC.

Upon entering the BWA network, each Subscriber Station (SS) has to go through the Initialization and Registration setup illustrated in Figure 1.

On power-up, subscriber stations need to synchronize with a downlink channel (DL-Ch) and an uplink channel (UL-ch). When a SS has tuned to a DL-ch, it gets the frame structure of the UL-ch, called a UL-MAP frame as illustrated in Figure 2. Then the ranging procedure is performed, where the round-trip delay and power calibration are determined for each SS, so that SS transmissions are aligned to the correct mini-slot boundary. The next step is to establish IP connectivity, the Base Station (BS) uses the DHCP mechanisms in order to obtain an IP address for the SS and any other parameters needed to establish IP connectivity. Then, the SS establishes the time of the day, which is required for time-stamping logged events and key management. In the next step, the SS establishes a security association and transfers control parameters via TFTP, these parameters determine the BS and SS capabilities, such as QoS parameters, fragmentation, packing, among others. Finally, the registration process is performed; the SS must be authorized to forward traffic into the network once it is initialized, authenticated and configured.

The ranging and automatic adjustment procedure (points A and B in Figure 1) are considered as the most time consuming stages, since the first attempt to synchronize with the BS (in a UL channel) must be done using the initial maintenance region. This region normally describes two or four contentions opportunities, every 500 or 1000 ms, (depending on the network configuration), as show in Figure 2.

Thus the risk of collision is very high when there are more than two SSs trying to synchronize with the BS at the same time. In order to guarantee low delays for applications demanding QoS (e.g.: VoIP), we need to make sure this delay is under 50 ms for VoIP-quality calls, as described in [5].

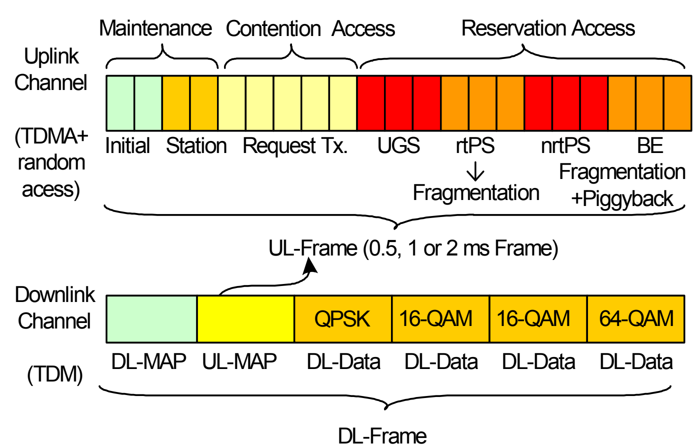

Figure 2. UL-MAP and DL-MAP channel structure.

Figure 3 presents the access delay when a SS carries up the Initialization and Registration process with the BS, for different UL-MAP structures, represented by the variable "*Tmap*" in Figure 3, (e.g. 0.5, 1.0, 1.5, 2.0, and 2.5 ms). In this figure we appreciate that access delays depend on the total number of collisions registered in the initial maintenance region. This delay could be up to 9 seconds, due to the exponential backoff algorithm and continuous collisions. Thus, in order to support QoS for mobile users, it is necessary to incorporate a Hand Off mechanism that could reduce significantly the delay for the Initialization and Registration process. In other words, mobile users do not need to go throughout the complete Initialization process when they want to change the BS, because the serving BS contains most of the information that the target BS needs to accept the incoming mobile user. Thus, in this paper we present a HO mechanist that guarantees very low delay for the support of realtime applications, multimedia services and high speed Internet access.

Once the Initialization and Registration setup is complete, a SS can create one or more connections over which their data are transmitted to and from the BS. Subscriber stations request for transmission opportunities on the UL channel. The BS gathers these requests and determines the number of time slots (grant size) that each SS will be allowed to transmit in the UL-Frame.

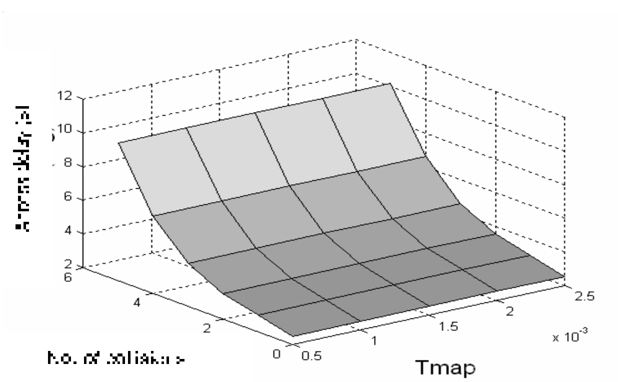

Figure 3. Initialization and Registration Delays.

This information is broadcasted in the DL channel by the BS using the UL-MAP message at the beginning of each DL-Frame, (see Figure 2). The UL-MAP frame contains Information Elements (IE) which describe the transmission opportunities in the UL channel, such as initial maintenance, station maintenance, contention and reservation access. After receiving a UL-MAP, a SS will transmit data in the predefined transmission indicated in the IE, these transmission opportunities are assigned by the BS using the following QoS service agreements described in [2] and [6]. These classes of services are described below.

*a) **Unsolicited Grant Service*** (*UGS)*: This service is oriented for the support of real-time service flows that generate fixed- size data packets on a periodic basis (CBR-like services), such as T1/E1, VoIP or videoconference.

b) ***Real-Time Polling Service*** (*rtPS*): This service is oriented for the support of real-time service flows that generate variable size data packets on a periodic basis (VBR-like services), such as MPEG video streams. The *rtPS* service offers periodic unicast transmission opportunities (*utxop)*, which meet the flow's real-time needs and allow the SS to specify the size of the desired channel reservation.

c) ***Non Real-Time Polling Service*** (*nrtPS*): This type of service is like the *rtPS*, however polling will typically occur at a much lower rate and may not necessarily be periodic. This applies to applications that have no requirement for a real time service but may need an assured high level of bandwidth. An example of this may be a bulk data transfer (via FTP) or an Internet gaming application.

d) ***Best Effort (BE)***: This kind of service is for standard Internet traffic, where no throughput or delay guarantees are provided.

Enhanced HO Mechanism for IEEE 802.16e

Currently, there are various handoff schemes that has been proposed for IEEE 802.16e[4]. In this section we present an enhanced HO mechanism that will enable a Mobile Subscriber Station (MSS) to change BS without interrupting or degrading its QoS.

In order to provide a rapid (or transparent) handoff process, it is necessarily that MSS demanding a real-time service (such as: UGS for voice o rtPS for video) makes an association with neighboring BS before a handoff decision is taken. For other QoS levels, such as Best Effort (for Internet traffic) or non real-time services (such as FTP traffic) this association could be optional. In general, the association process can be performed once the MSS is in normal operation with the serving BS, (this is after the registration and IP connectivity process). This association will enable the MSS to speed up the Initialization and Registration process described in Figure 1.

The association process is carried out as follows:

1) All BS must broadcast "*beacons*" to inform MSS about their presence and network topology using a Neighbor Advertisement Message (NBR-ADV), as show in Figure 4. These *beacons* help the MSS to identify neighboring BS and to obtain the DL-MAP and UL_MAP which include the DCD and UCD settings, respectively that the MSS needs for a rapid synchronization and initial ranging.

2) After receiving a NBR-ADV message, a MSS may issue a Scan Request message (SCN-REQ) to the serving BS in order to

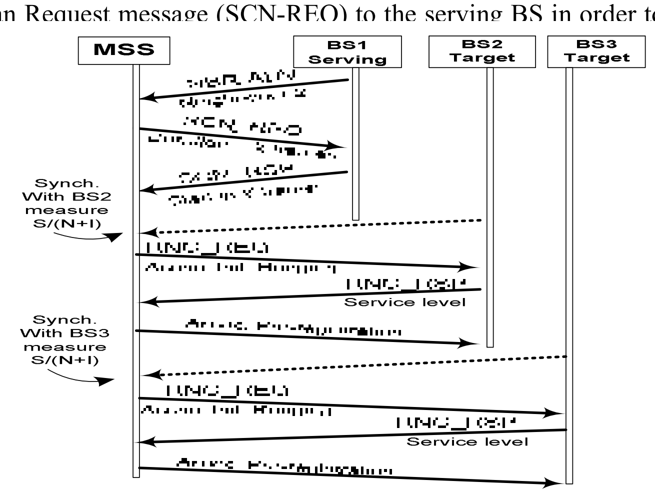

Figure 4. Association process.

registration

5) Association-initial ranging: This stage is performed by transmitting a ranging request message (RNG-REQ) with the following parameters: Basic CID, DL Ch. ID, MSS MAC Address, MSS Association Ch. ID and the Serving BS ID. This association will allow the neighboring BS to identify the MSS and its Serving BS when the HO process is initiated. This request may also be used to adjust transmission parameters, such as power, frequency and timing offset, as suggested by the neighboring BS. Thus, multiple RNG-REQ/RSP may be exchanged using the same scanning interval.

6) The neighboring BS, upon receiving a RNG-REQ with association, answers with a ranging respond message (RNG-RSP) indicating the type of service level that it could support for this MSS.

7) Association-pre-registration: After receiving a RNG-RSP which includes some service level, the MSS may pre-register with the neighboring BS to negotiate MSS capabilities. This state is called the association pre-registration and some of the parameters exchanged are: new CID, service flows, backoff windows for ranging (HO_ranging_start HO_ranging_end), service level prediction, modulation types (QPSK, QAM), FEC Types, MAC CRC support, etc.

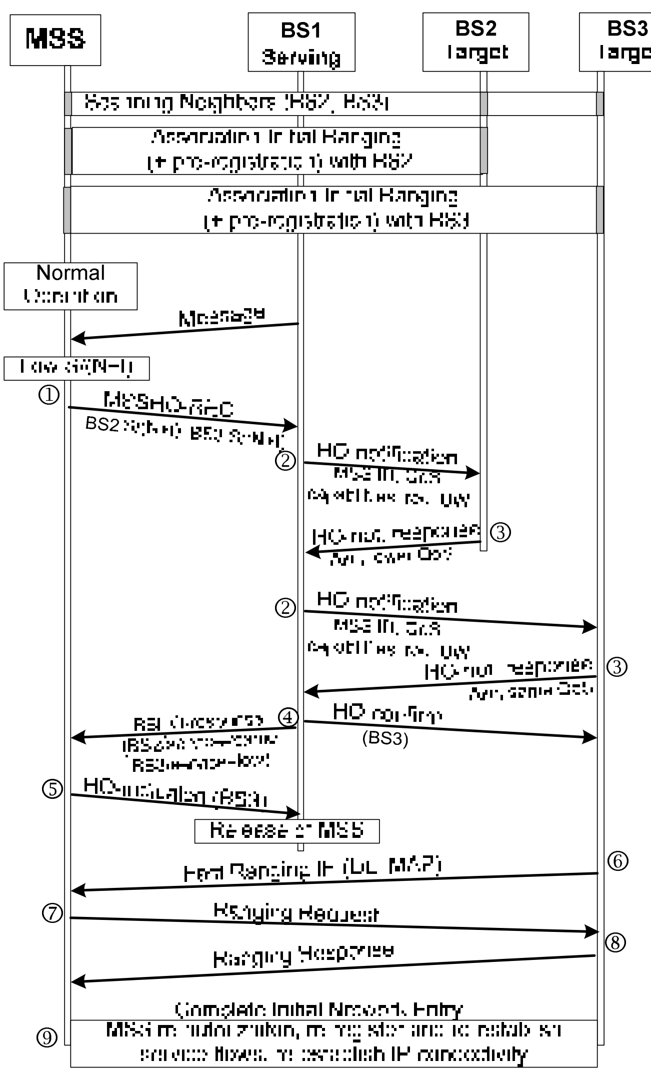

Figure 5. Enhanced HO Process.

Once association is performed, the HO process is carried out as follows (see Figure 5):

The messages between BS must be transmitted using a dedicated line with high transmission priority, thus reducing at minimum transmission delay between BS.

1) We assume the worst case, when a user is active and has a traffic session with its serving BS. Whenever the MSS o BS detect on the PHY channel a signal with a low quality (e.g S/N+I < 11.2 dB with QPSK), the HO process is initialized by sending a HO request message. In Figure 5 (point 1) we show the case when the MSS initializes the HO process by issuing a HO request message (MSSHO-REQ) to the serving BS. This message contains IDs of the neighboring BS, with its respective S/N+I and service level prediction acquired from the scanning interval.

In case the serving BS detects a low S/N+I from a registered MSS, it should send a handoff-BS request notification to the MSS indicating the recommended neighboring BS and service level prediction that they could provide to the MSS.

2) Upon receiving a MSSHO-REQ, the serving BS sends a HO-notification message to each neighboring BS added in the MSSHO-REQ. This notification includes the MSS ID, connection parameters, capabilities, required QoS and bandwidth that a MSS needs to continue normal operation.

3) Then, if the neighboring Base Stations (receiving a HO-notification) can accept the MSS with its minimum requirements, they should respond to the serving BS with the message HO-notification response (ACK) indicating the estimated QoS and BW that could provide to the MSS.

4) Upon receiving the HO-notification response from the neighboring BS, the serving BS creates two messages: the first message is a handoff response to the MSS, (BSHO-response) that includes the objective BS. This is the best neighboring BS that could accept the MSS, based on the service level prediction and S/N+I level (e.g. BS3). The second message is a confirmation (HO-confirm) to the neighboring BS that has been selected as the objective BS.

5) Once the BSHO-response is received, the MSS sends back to the serving BS a HO indication to close all connections. Then it should wait for a fast-ranging transmission opportunity from BS3 in order to re-adjust transmission parameters, such as power, frequency and timing offset.

6) The objective BS (Target BS3), upon receiving the HO-confirm message, should provide to the MSS with a fast ranging transmission opportunity in the following MAPs. The Ranging IE opportunity is set using the MAC address of the MSS.

7) Since a MSS has already associated with BS3, the MSS will send again RNG-REQ to BS3 (to re-adjust transmission parameters in case it is necessary), using the Ranging IE opportunity provided by BS3, (the MSS uses its MAC address to identify the ranging opportunity).

8) The MSS should complete initial network entry with target BS3. For this it is necessary to perform re-authorization, re-register, re-establish connections, and re-establish IP connectivity. In the re-authorization state, since the security information in not expected to change, this information is transferred from the old BS1 to the target BS3 via backbone. The re-register process is skipped if all MSS capabilities and management parameters were exchanged in the pre-registration process and a service level prediction was provided to the MSS. In the re-establish connection (service flows) process, the MSS needs to send a dynamic service addition request (DSA-REQ) to target BS3, in order to active the service flow. As a response, target BS3 activate the connection, and maps this service flow with the MSS CID (provided in the pre-registration process) and sends back to the MSS a DSA-RSP message, indicating the service flow activated.

Other stages, such as transfer-operational-parameters and time-of-day establishment (carried out on MSS power on) are skipped since none of the operational parameters nor time-of-day is expected to change.

The last process is to re-establish IP connectivity. This process should be carried out using Mobile IP as suggested in [7]. This is because when an MSS which has obtained an IP address by DHCP performs the inter-BS handoff, an ongoing session is disconnected due to the inherent lack of mobility of DHCP address allocation. The time taken to obtain the IP address is out of the scope in this paper. In the following sections we describe the simulation model and present a performance analysis on the enhanced HO mechanism, for different traffic scenarios.

OPNET Model Description

This section shows the key functional breakdown of the OPNET model implementation. The model used for the simulations consist of three cells, as shown in Figure 6. Each cell can be partitioned into two major parts: 1) Mobile Subscriber Stations and 2) a Base Station, as shown in Figure 6.

Mobile Subscriber Station

The *Mobile* Subscriber Station access node consists of a traffic generator, a Media Access Control unit and two RF modules for transmission and reception as pointed out in Figure 7.

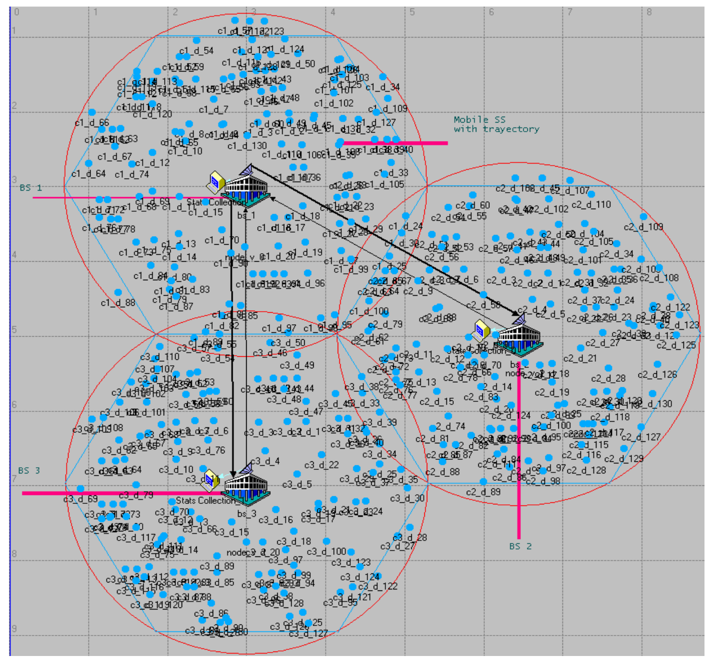

Figure 6. Network Model.

The traffic generator module produces three different traffic types according to the QoS agreed with the BS. These traffic types are described in the following section.

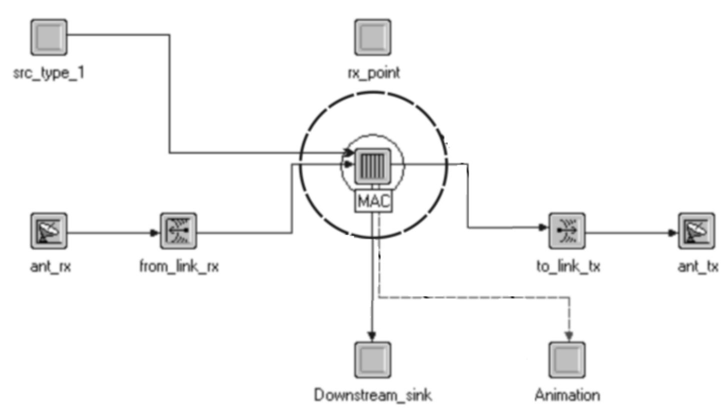

Figure 7. SS access node model.

The RF modules (ant_rx, from_link_rx, to_link_tx, and ant_tx) are responsible for accepting packets from or transmitting packes to the radio access network according to the propagation model described in [8].

The MAC module is responsible for processing packets of higher layers and transmitting packets to the radio access network according to its QoS level. The MAC module uses a primary Finite State Machine (FSM) and a secondary FSM. The primary FSM (Figure 8) is responsible of the Initialization and Registration procedure as well as the reception and processing of synchronization packets, UCD, UL-MAP and DL-MAP frames from the BS. All packets received from higher layers, are processed at the application traffic process and sent to the secondary FSM for transmission on the UL channel, as shown in Figure 9.

Upon receiving a traffic packet from the Primary FSM, the secondary FSM processes this packet according to its QoS level. If the packet is for a Best effort service (e.i. Internet packet), the transmit opportunity state (Tx_Opp_Proc) looks for a contention opportunity (either in the current or in the following UL-MAP frame) and transmits a reservation request to the BS. In case this request results in collision with other contention transmissions, the collision resolution (Collision_Res) state takes care to resolve it according to the exponential backoff algorithm. If the packet demands a UGS or rtPS service (i.e. for voice or video packets, respectively) the transmit opportunity state sends a Dynamic Service Addition (DSA) request to the based station, indicating its type of service needed for this connection. If this request is accepted, the No_Request_Outstanding process takes care of receiving the corresponding grants and to indicate to the Tx_Opp_Proc when to transmit these voice or video packets.

For nrtPS packets (e.g. for FTP traffic), the same procedure is carried out as in the previous case, with the exception that the Request_Outstanding state is now responsible for receiving the grants from the BS. But if no-grants are allocated for this service, these packet can still be transmitted in the radio access network using a Best Effort service.

Base Station

The BS is in charge of MSS´s identification and to provide a QoS level. The BS also serves as the main gate for incoming and outgoing packets. Figure 10 shows the BS node model, which is composed mainly of a MAC unit and one transmission and reception module for each neighboring cell associated.

The MAC module is responsible of providing to MSS´s with the right QoS level, and guarantees the correct transmission opportunities. In order to provide these transmission opportunities, the MAC module uses also two FSMs.

Basically the primary FSM, illustrated in Figure 11, performs the following three functions: 1) takes care of the Initialization and Registration procedure, which is done by the ranging, rng_rcvd and rng_complete states. 2) Based on MSS´s request,

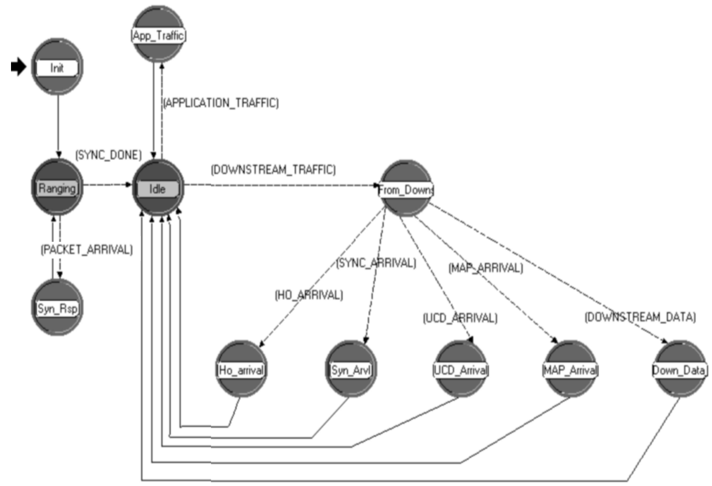

Figure 8. Primary SS´s FSM.

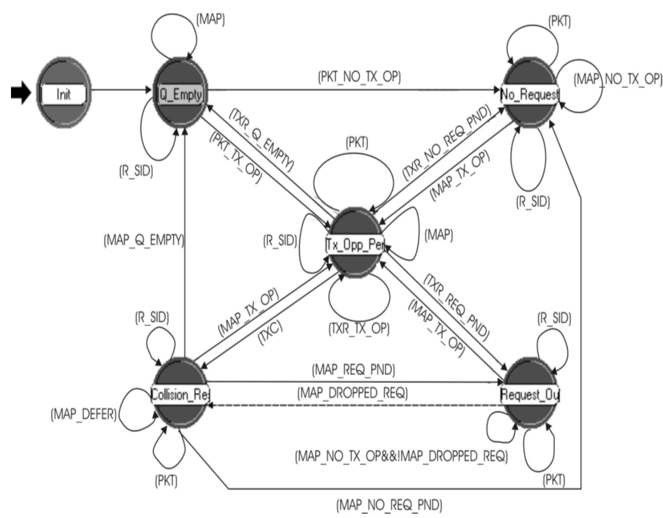

Figure 9. Secondary SS´s FSM.

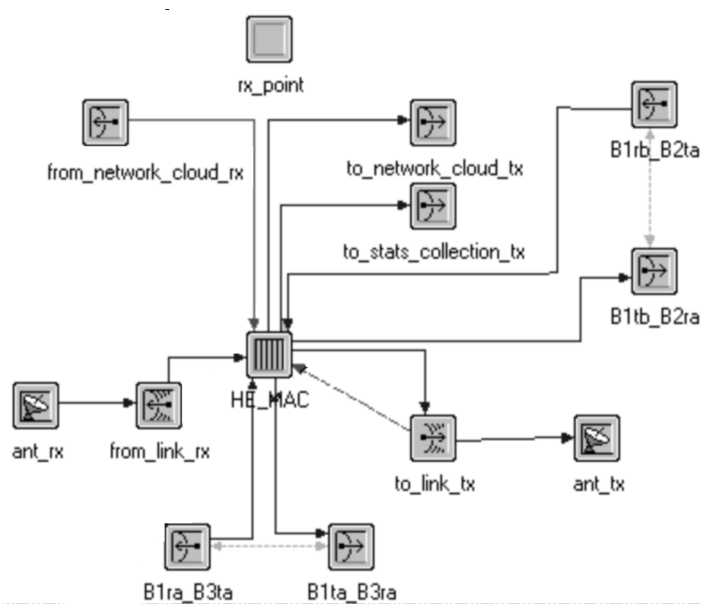

Figure 10. BS node model.

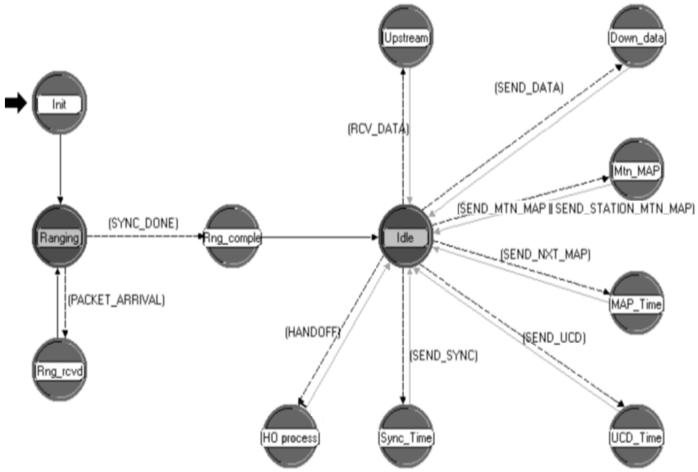

Figure 11. Primary BS´s FSM.

the Primary FSM creates the signaling MAPs, which describe the maintenance region (using the Mtn_MAP state), as well as contention and reservation access (using the MAP-Time state). 3) Provides with synchronizations and UCD information to MSSs.

All frames produced in the primary FSM, are passed to the secondary FSM, which takes care of transmitting theses frames in the correct DL channels as shown in Figure 12.

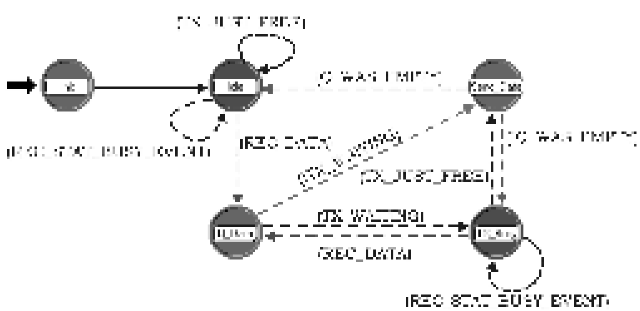

Figure 12. Secondary BS´s FSM.

Simulations Analysis

In all simulations, one UL channel with a capacity of 2.8 Mbps and one DL channel with a capacity of 22.4 Mbps were used. For the analysis, we have considered the simulation parameters given in Table I. Two traffic scenarios were considered for the results. These scenarios are based on the following traffic sources.

1) ***Internet Traffic-IP***: The Internet traffic distribution utilized is the one introduced by the IEEE 802.14 working group [9]. The message size distribution is as follows: 64-byte Pk. 60%, 128-byte Pk. 6%, 256-byte Pk. 4%, 512-byte Pk. 2%, 1024-byte Pk. 25% and 1518-byte Pk. 3%. The inter-arrival times are set in such a way that the Internet offered load per active station is 38.4 kbps at the PHY layer.

2) ***VoIP- G.723-UGS***. This traffic type emulates a speech codec "G.723.1", which according to the ITU, IETF and the VoIP Forum is the preferred speech codec for Internet telephony applications. This codec generates a data rate of 5.3 kbps or 6.3 kbps depending on the mode, where 20-byte data packets are generated and encoded every 30 ms. By adding all headers as illustrated in Table II, one obtains a VoIP stream of 38.4 kbps at the PHY layer.

Table I. Simulation Parameters

Parameter	Value
UL data rate (QPSK.)	2.816 Mbps
DL data rate (16-QAM)	22.4 Mbps
Minimum contention slots per UL-Frame	8 slots
UL minislot size	16 bytes
UL-Frame Duration	2 ms =44minislots
Simulation time for each run	60s
Distance from nearest/farthest SS to the BS	0.1 – 2.35 km
Reed Solomon (short grants/long grants)	6 bytes/ 10 bytes
Limit between short and long grants	245 bytes
Maximum number of users in the network	200

Table II. VoIP Codec (G.723.1.

Frame/layer	G.723.- 5.3 kbps
Frame size [ms]	30
Voice frame [bytes]	20
RTP [bytes]	12
UDP [bytes]	8
IP [bytes]	20
LLC [bytes]	3
SNAP [Bytes]	5
Ethernet MAC [bytes]	18
IEEE 802.16 MAC	6
PHY: (Prea+GB+FEC)	10+FEC
Total PacketSize	86 bytes or G=9 slots
Net rate at MAC / PHY	22.9 / 38.4 kbps

Prea = Preable, GB = Guarband, and FEC = 6* No_CodeWords

For the performance analysis of the proposed HO mechanism, we need to make sure the end-to-end delay during the handoff procedure does not exceed 50 ms for timing critical interactive services. Internet traffic or other delay-tolerant applications can support larger delays (up to 1second), thus in the remaining of this sections we will prove that our HO mechanism satisfy the requirements for the support of different QoS agreements.

Figure 13 and 14 show the results when Internet traffic is being transmitted. We considered a network size of 40 MSS which produce 70% of the UL channel capacity. In Figure 13, we see the access delays of a MSS that started the HO procedure (from BS1 to BS2) at the simulation time of 54.6 seconds. When the mobile station switched to BS2, the time consumed during the HO procedure was 12 ms approximately (6 UL- MAPs). This delay could be larger depending on the DHCP protocol, which was not included in the simulations. Once the MSS completed the Initialization and Registration procedures with BS2, the first packet transmitted in this cell had a total access delay of 15.5 ms, which is a low delay for Internet traffic. However, larger delays (up to 100 ms) were obtained during the simulation, but these delays are due to collisions in the contention region and the exponential backoff algorithm which reduces the contention transmissions opportunities for backlogged MSS.

In terms of throughput, Figure 14 shows that the effect of changing to another BS is transparent to the MSS, since neither throughput nor access delays suffered degradation. The average throughput reported by this simulation was of 32 kbps, which indicates that all packets were transmitted on time.

Results for VoIP traffic are presented in figures 15 and 16. In Figure 15 we appreciate a constant access delay of approximately 34 ms when the MSS moves from BS1 to BS2. This is because the MSS can not transmit the current VoIP frame during HO, and this voice frame is kept in the MSS buffer and transmitted when BS2 allocates a new periodic reservation opportunity. Thus, at the time of transmitting this voice frame, the MSS has already received another VoIP frame, which will be scheduled after its periodic grant interval agreed with BS2 (configured at 30 ms).

However in Figure 16, we see a small reduction in throughput during the HO procedure due to the buffered packet. But this reduction gradually disappears as the MSS transmits more voice frames in BS2.

In general, although the proposed HO mechanism can support delays under 50 ms for timing critical applications, these access delays could be significantly reduced if we consider the following considerations: 1) delete packets during HO for realtime applications as long as it does not become > 3%, 2) schedule more reservations opportunities after the HO procedure, and 3) use the periods of silence for the transmission of buffered packet. We are currently studying these functionalities and results will we presented in future publications.

In addition, we did not include a discussion about the impact of channel errors in the previous analysis. Channel errors can degrade the QoS observed by MSS in various ways depending of the particular service class being considered. We are also investigating ways to overcome this problem within the proposed HO mechanism.

Conclusion

In this paper we have presented the performance analysis of a HO mechanism for IEEE 802.16e based networks. The proposed algorithm is practical, compatible with IEEE QoS requirements, and easy to implement. This mechanism provides a fast Initialization and Registration procedure that guaranteed low delays for timing critical applications, such as Voice over IP, video and data. The performance of this HO mechanism with mixed traffic sources, and different QoS requirement (such as *UGS*, *rtPS*, *nrtPS* and *BE*) will be further investigated through simulations and theoretical analysis. The results of such performance will be provided in future publications.

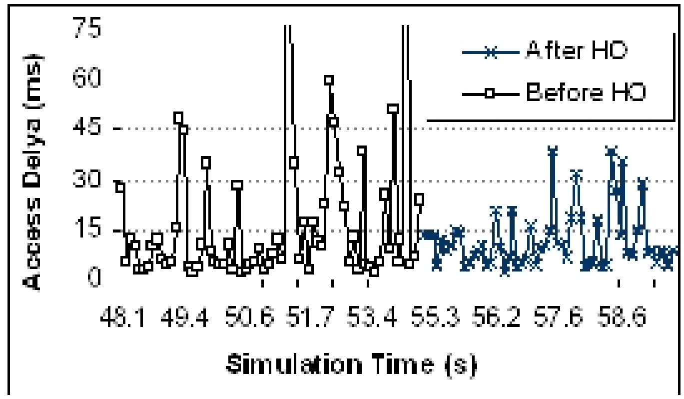

Figure 13 Access Delay for BE traffic.

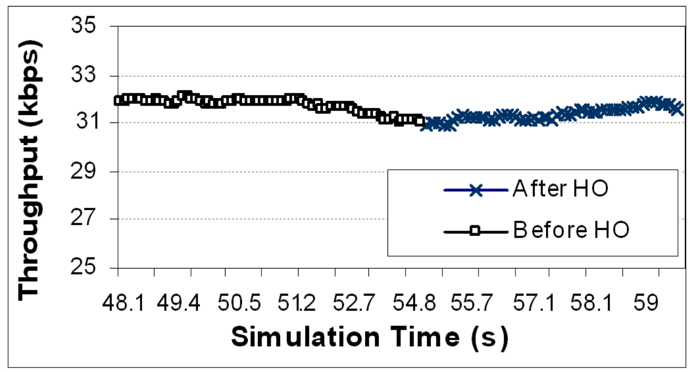

Figure 14. Throughput for Internet traffic.

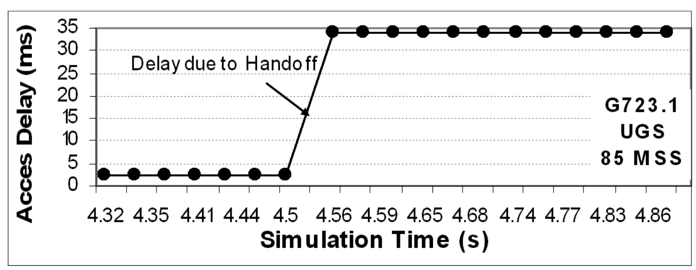

Figure 15 Access Delay for VoIP traffic.

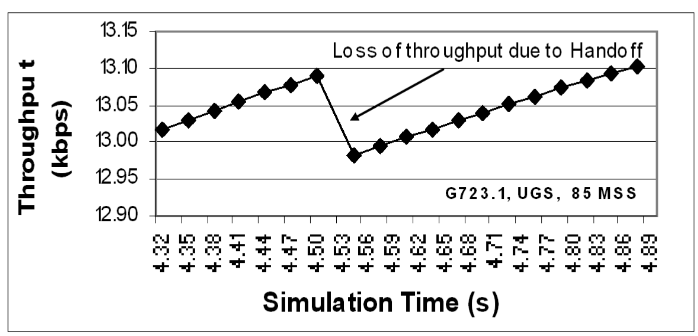

Figure 16. Throughput for VoIP traffic.

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