# A Fast MAC-Layer Handover for an IEEE 802.16e-Based WMAN

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**Abstract.** We propose a modification of the IEEE 802.16e hard handover (HHO) procedure, which significantly reduces the handover latency constraint of the original HHO procedure in IEEE 802.16e networks. It allows a better handling of the delay-sensitive traffic by avoiding unnecessary time-consuming scanning and synchronization activity as well as simplifies the network re-entry procedure. With the help of the backhaul network, it reduces the number of control messages in the original handover policy, making the handover latency acceptable also for real-time streaming traffic. Preliminary performance evaluation studies show that the modified handover procedure is able to reduce the total handover latency by about 50%.

**Keywords:** IEEE 802.16e, hard handover, ranging, backhaul network.

## 1 Introduction

The IEEE 802.16 (WiMAX) technology, both in its IEEE 802.16d [1] and IEEE 802.16e [2] versions, is regarded as a very promising candidate for next-generation WMANs, as it successfully addresses the requirements of higher data rate and efficient spectral efficiency for provisioning full-fledged mobile broadband access [3]. Mobility related research in IEEE 802.16e is mostly focused on the two main areas of concern: location management and handover. This paper deals with the latter and aims at minimizing the overall handover latency experienced by 802.16e supported Mobile Stations (MSs) when they are crossing cell boundaries. The IEEE 802.16e standard supports three types of handover. While Hard Handover (HHO) is the default and the most common scheme, Fast Base Station Switching (FBSS) and Macro-Diversity Handover (MDHO) are two other optional procedures. This paper will concentrate on performance issues related to the HHO procedure only. The entire HHO process in the IEEE 802.16e can be divided into the Network Topology Acquisition Phase (NTAP) and the Actual Handover Phase (AHOP), which consist of such sub-phases as scanning and synchronization, ranging and association, handover decision and initialization, authorization and registration.

C. Wang (Ed.): AccessNets, LNICST 6, pp. 102–117, 2009.

During the NTAP, the MS performs scanning and downlink synchronization activities with the neighbouring Base Stations (BSs), to select one of them as the Target BS (TBS) for the handover activity. During AHOP, the MS releases its connection with the current Serving BS (SBS) and performs synchronization and registration procedures with the selected TBS for completing the handover process. However, both NTAP and AHOP in their standard versions suffer from many ambiguities. During NTAP, unwanted handover delays and resource wastages may be introduced due to excessive (though not blind) scanning, synchronization and ranging activities. The AHOP suffers from drawbacks related to long inter-handover gap, owing to prolonged ranging and network re-entry activities. While Connection Disruption Time (CDT) in the range of 200 ms is generally acceptable for real-time streaming media traffic [4], the CDT of the IEEE 802.16e HHO handover exceeds this limit [5].

This paper reports results of research aimed at reduction of the overall handover latency along with the CDT. A fast handover procedure is obtained by merging and redesigning some steps of the original procedure. This modified BS-initialised, backhaul-assisted, fast and smooth HHO scheme not only simplifies the overall IEEE 802.16e handover procedure but also minimises wastage of network resources. The current SBS predicts the potential TBS based on the MS's direction of motion, the current load of Neighbouring BSs (NBSs), their locations with respect to the SBS and the estimated time needed by the MS for travelling from one cell to another [6]. The MS then performs fast ranging activities directly with the TBS, i.e. with the potential next SBS. The results of the ranging process are buffered until the AHOP, in which the stored results facilitate the resumption of fast downlink (DL) and uplink (UL) transmissions, avoiding execution of further synchronisation and ranging handshaking activities. Prolonged network authentication and authorisation phases are also avoided with the help of prior message passing over the backhaul network, which links BSs with routers. The scheme has been evaluated in simulation studies, which clearly show that it outperforms the standard IEEE 802.16e handover procedure, both in terms of overall handover latency and utilization of channel resources.

The rest of this paper is organised as follows. The IEEE 802.16e HHO procedure and the related research are discussed in Section 2. Section 3 details our new scheme and Section 4 describes our simulation studies and the obtained numerical results. This is followed by Conclusions in Section 5.

## 2 IEEE 802.16e HHO Scenario

A handover occurs when an MS moves through a cellular boundary to a cell served by another BS. In the IEEE 802.16e, the handover process is triggered when the strength of signal between the MS and its SBS drops below a certain threshold level. The handover is executed in the following two phases.

### 2.1 Network Topology Acquisition Phase

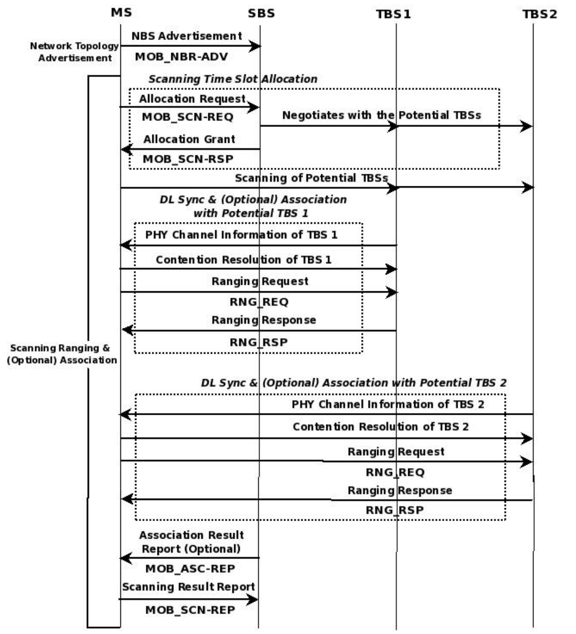
During the NTAP, the MS and SBS, with the help of the backhaul network, jointly gather information about the underlying network topology before the actual handover decision is made; see Figure 1(a)[6]. Using MOB_NBR-ADV (Mobile_Neighbour-Advertisement) message, the SBS periodically broadcasts information about the state of the neighbouring BSs, making preparation for potential handover activity. The MS scans the advertised BSs within specific time frames to select suitable candidate BSs for the handover. The scanning is followed by contention/non-contention ranging and optional association activities through which the MS gathers further information about the PHY channels related with the selected BSs.

### 2.2 Actual Handover Phase

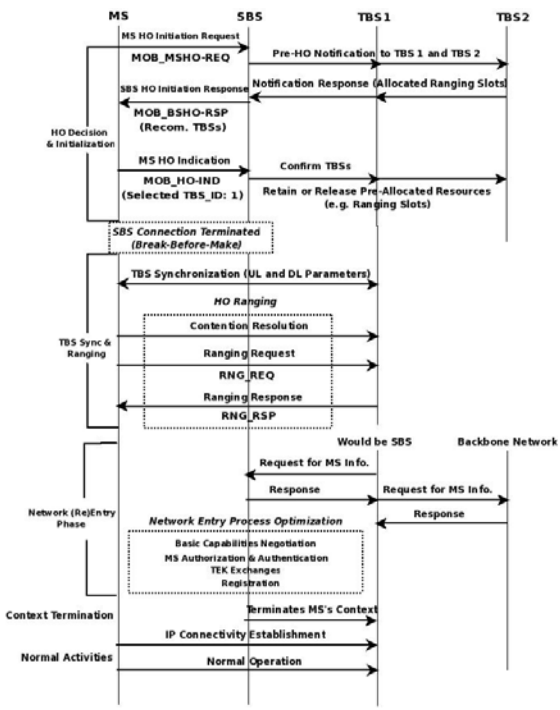
During AHOP (Figure 1(b)), once a particular TBS is selected from the list of the candidate BSs, the MS informs the current SBS about the beginning of the HO activity by sending a MOB_HO-IND (Mobile_Handover-Indication) message. It is at this point that the MS terminates its connection with the current SBS. Appropriate synchronisation and ranging activities take place once again to resume DL/UL re-transmissions. Next, the lengthy authorization and registration process of the MS with the TBS follows. It marks the onset of the network re-entry phase of this MS, after which it becomes fully functional with the new SBS.

IEEE 802.16e is not free from drawbacks related with relatively large handover delays and resource wastages. During NTAP, prolonged scanning and ranging related activities are the primary hindrances for satisfying delay-sensitive real-time applications. Recent 802.16e HHO-related research has focused mostly on attempts of reduction of the disruptive effects of these constraints. The schemes proposed in [6] and [7] suggest prediction of TBSs before the scanning and ranging activities. While [6] discusses a procedure for fast and hybrid BS-oriented selection of TBSs on the basis of such factors as coverage, MSs mobility direction and load of NBSs, [7] predicts TBSs on the basis of the required bandwidth and QoS. In both cases, scanning and ranging related activities are reduced, being limited only to the predicted TBSs. However, these schemes do not lower the overall handover delay significantly. Adaptive Channel Scanning Algorithm (ACSA) introduced in [8] focuses on minimizing the disruptive effects of channel scanning activities in case of different types of traffic.

Similar to NTAP, AHOP also suffers from lengthy CDT. This is because an MS undergoing handover should complete the network re-entry procedures with the TBS for resuming normal connectivity. Apart from the ranging process, the MS needs also to undergo security related authentication, authorization and registration processes, to successfully resume its IP connectivity with the new SBS. As mentioned before, the total CDT in case of an 802.16e HHO exceeds 200 ms, which makes the packet transmission delay perceivable to users in case of such real-time delay-sensitive applications like video streaming or voice-over IP. Considerable research has been focused on reducing the CDT, thus making the 802.16e HHO scheme suitable for real-time traffic. For example, in the case of delay-sensitive real-time applications, [9] and [5] propose to resume DL and UL transmissions prior to completion of the authorization and registration




(a) Control Messages during NTAP




(b) Control Messages during AHOP

**Fig. 1.** Control Messages during the 802.16e HHO Procedure

procedures. However, a possibility of unsuccessful authorization and registration while switching domains is not considered. An 802.16e cross-layer HHO scheme, in which the MAC layer CDT- related delays are reduced with support from Layer 3, is proposed in [10]. In that scheme, some of the messages exchanged between the MS and the TBS during the network re-entry phase can be relayed with the help of the SBS, to make the entire procedure shorter. However, there is still room for further reduction of the overall 802.16e HHO latency.

## 3 Proposed Scheme

In this section, we propose a new HHO scheme, which does not suffer from the drawbacks of the standard version. We will show that by merging and redesigning some steps of the standard version, one can significantly improve performance of that HHO. In particular, we reduce delays caused by HHO-related MAC layer messages during the scanning, ranging and authorization phases, with the help of the backhaul network. In the current work, the SBS is tasked with the bulk of the handover-related decision-making responsibilities. The proposed HHO procedure is described in the following subsections.

### 3.1 Handover Initiation

As in [6], we assume that an MS keeps track of its movement trajectory. However, we assume additionally that all MSs apply the mobility prediction scheme proposed in [11], in which a hexagonal cell structure is divided into three zones: the No Handover (No-HO) Zone, the Low Handover (Lo-HO) Zone and the High Handover (High-HO) Zone, as shown in Figure 2 [11]. The No-HO zone marks zero handover probability, while Lo-HO and High-HO zones mark medium to very high handover probabilities. This division subsequently reduces the actual area of tracking of MS's random movement during a potential handover activity. We assume that while in the Lo-HO zone an MS may receive mild beacons from neighbouring cells, the communicating signal from the current SBS is still strong enough (though not as strong as in the No-HO zone), so the chance that an MS in the Lo-HO zone performs a handover is small.

As per the IEEE 802.16e standard, an MS initiates handover activity at the time instant when it perceives that the communication signal strength has dropped below a certain threshold $L_0$. However, the handover activity can take a considerable time before the MS can actually resume communication with the new SBS. Long delays associated with handovers are unsuitable for real-time traffic handling as it may cause packet losses and call disruptions. To combat this, in our scheme an MS initiates a handover activity if the strength of a signal drops to $L_{Max}$, where $L_{Max} > L_0$. It is also assumed that a potential handover activity has to be finished before the strength of a given signal drops to $L_{Min}$, where $L_{Min} < L_0$ [12]. Otherwise, a call disruption would become highly probable. This probability of a call disruption at the time instant when the signals strength drops to $L_{Min}$ is much larger than at $L_0$, which is much larger at $L_{Max}$.

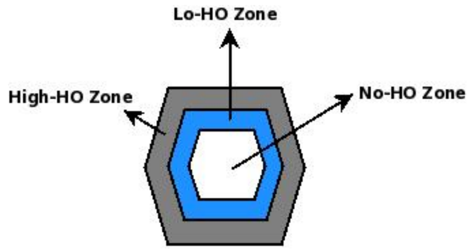



**Fig. 2.** Zone-wise Division of a Cell

Thus, in the time interval when the signal strength is between $L_0$ and $L_{Max}$, the MS is in a safe region, where delay-sensitive traffic is unlikely to suffer a disruption. On the other hand, the time interval when the signal strength is between $L_{Min}$ and $L_0$ represents a high-risk zone. To minimize the likelihood of call disruptions, we propose that the NTAP of the handover is completed within the safe zone and the AHOP within the high-risk zone.

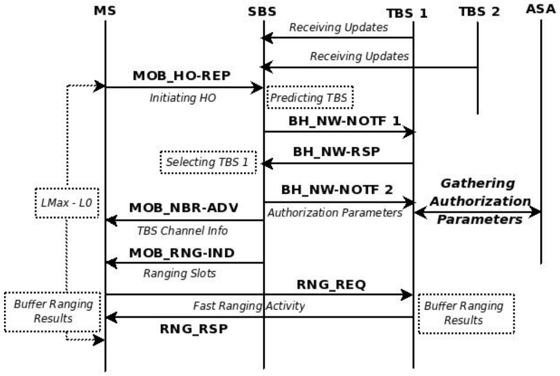
### 3.2 TBS Selection and Insinuation

***Step 1: TBS Prediction -*** The MS initiates a handover activity by sending a MOB_HO-REP (Mobile_Handover-Report) message [6] to the current SBS. On receiving the message, the SBS creates a list of potential TBSs by taking into account the MSs movement direction, load factor of NBSs, the areas of coverage of NBSs and the estimated time interval needed by the MS to travel from one cell to another. Details of the procedure are the same as in [6]. The topmost BS from the list is chosen as the TBS.

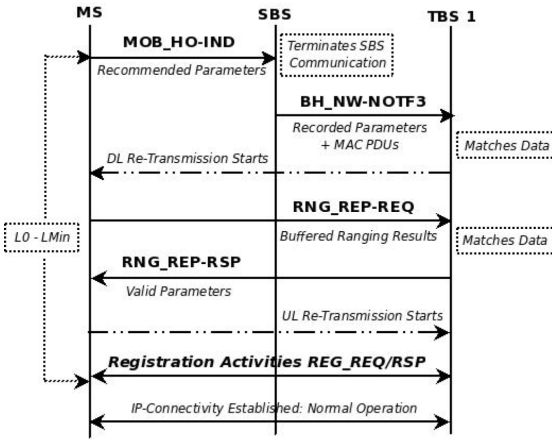
***Step 2: Pre-HO Notification -***After predicting the suitability of a particular BS as the TBS, the SBS uses the backhaul network for sending a pre-handover backhaul network notification (BH_NW-NOTF1) message (Figure 3(a)) addressed to the TBS with the MS ID, the required bandwidth, frequency, QoS and CQICH (Channel Quality Indication Channel) [1] parameters, which the SBS knows from its communication with the MS.

***Step 3: TBS Selection -*** On receiving this pre-notification message, the TBS assumes that a handover activity with the particular MS might occur soon. Provided it has the required resources, it replies to the SBS with a BH_NW-RSP (pre-handover backhaul network response) message containing such information as its ID, DCD, UCD, and other frequency-related information. The TBS also allocates dedicated ranging slots (fast ranging IE) in advance, anticipating a potential ranging activity. However, if this TBS fails to provide the required resources (it might get overloaded in the meantime), it will send an error report in the response. In that case, the SBS would try another candidate for TBS from the list of potential TBSs [6].

***Step 4: Authorization Information Exchange -***Successful selection of the TBS quickly prompts the SBS to channelize all network re-authentication related




(a) Control Messages in the Proposed NTAP




(b) Control Messages in the Proposed AHOP

**Fig. 3.** Control Messages in the Proposed HHO Procedure

information relevant for the particular MS to the TBS, which would help to achieve a more optimised network re-entry phase [13]. A BH_NW-NOTF2 message containing relevant connection IDs (CIDs), encryption keys and associated parameters, MS's digital certificate, MAC address and other relevant information is used for this purpose. During NTAP, the TBS also connects with the ASA server, to get more authorization related information for the particular MS [13].

***Step 5: MOB_NBR-ADV Message*** **-** Now, the SBS forwards all the TBS channel related information to the MS through the MOB_NBR-ADV message, indicating the availability of that TBS for handover. This allows the MS to get DL synchronised directly and be ready to perform ranging activities with the TBS, bypassing the time consuming scanning procedures.

***Step 6: Fast Ranging Interval Allocation*** **-** Anticipating probable ranging activities, the SBS allocates a time slot for the MS to perform fast ranging with the TBS. In this context, we propose a fast ranging interval allocation message, MOB_RNG-IND (Mobile_Ranging-Indication), specified in Table 1.

**Table 1.** MOB_RNG-IND Message Format

| Syntax | Size | Notes |
|---|---|---|
| MOB_RNG-IND_Message_format( ) { | - | - |
| Management Message Type=X | 8 bits | - |
| Ranging duration | 8 bits | In units of frames |
| Report Mode | 2 bits | Periodic Report |
| Initial Frame | 4 bits | - |
| Data Interleaving Interval | 8 bits | Duration in frames |
| Iteration | 8 bits | - |
| Recommended_TBS_Index | 8 bits | Selected TBSs=1 |
| Recommended TBS_ID | 48 bits | 48 bit BS ID of the selected TBS |
| Fast_Ranging_IE( ) { | - | - |
| Subcode | 4 bits | FRNG=0x01 |
| Length | 4 bits | Length=8 |
| Offset | 12 bits | TBD |
| Reserved | 4 bits | - |
| } | - | - |
| Rendezvous Time | 8 bits | In units of frames |
| TLV Encoded Information | Var | - |
| } | - | - |

### 3.3 Fast Ranging Activity

***Step 7: Fast Ranging Activity* -** The SBS, acting as a relay agent between the TBS and the MS, forwards the allocated ranging slots to the MS in the MOB_RNG-IND message so that the MS can undergo a fast ranging activity with the TBS using conventional RNG_REQ (Ranging_Request) and RNG_RSP (Ranging_Response) messages. This shortens handover delay and saves resources considerably, as the MS does not have to contend for ranging slots. The RNG_RSP message also contains the primary management CID [1] that the MS uses to send further MAC management messages to the TBS during the AHOP. As per our current scheme, both the MS and the TBS buffer the ranging result-related parameters to be used during future ranging activities. A timer maintained for that purpose remains valid until the underlying channel condition changes considerably.

### 3.4 HO Indication and DL Retransmissions

***Step 8: HO Indication* -** On accomplishment of the ranging procedure, the MS immediately indicates the handover activity to the SBS by sending the MOB_HO-IND message (Figure 3(b)). As per our scheme, the message also contains the assigned CIDs, TBS ID, the recorded UCD, DCD, and other PHY frequency-related parameters from the NTAP. At this point, the MS also releases its connection with the current SBS.

***Step 9: Channelization of MAC PDUs* -** Unlike the conventional 802.16e handover procedure, in which the SBS retains the MS MAC PDUs up to a certain instant of time, in our scheme, on receiving the handover indication message, the SBS quickly communicates a handover BH_NW-NOTF3 message to the backbone network indicating its disassociation from the MS. It also forwards the MAC PDUs of the MS to the TBS, having encapsulated them in this message. This actually reduces chance of packets buffered by the SBS being lost. The message sent via the backhaul network also contains the MS's recorded parameters indicated in Step 8, along with other MAC state related parameters [13]. Thus, the backhaul network channelizes any further traffic meant for that MS directly to the TBS, where it is buffered until DL transmission resumes.

***Step 10: DL Retransmission -*** On receiving the notification message via the backhaul network, the TBS matches the transmitted and the buffered data and can immediately start the DL retransmissions using the CIDs assigned during the NTAP.

According to our scheme, the interval between the time when the TBS generates the DL synchronisation parameters during the NTAP and the beginning of processing of BH_NW-NOTF2 message by this TBS lasts about 70 ms. Depending on the underlying hardware used, these parameters can remain valid for as long as 600 ms [1]. Moreover, since the time interval between termination of MS-SBS communication and TBS receiving the channelized MS MAC PDUs over the high-speed IP backhaul network is very short (few ms), intermediate packet loss is practically negligible. The uplink retransmission can only resume once the MS-TBS jointly comes to an agreement regarding the validity of the buffered result from the previous pre-coordinated ranging activity during the NTAP. In contrast to the schemes proposed in [5] and [9], ranging in our proposal is performed during NTAP rather than during AHOP, in order to reduce the overall CDT.

### 3.5 UL Retransmissions and Registration

***Step 11: Request for Ranging Data Matching -*** Using the allocated CIDs, the MS sends such relevant data to the TBS as the TBS ID, resultant service level prediction and ranging purpose indication parameters, along with the HMAC / CMAC tuple (message authentication codes) [2] buffered during the previous ranging activity. It is done by using a new MAC management message, RNG_REP-REQ (Ranging_Report-Request), specified in Table 2.

**Table 2.** RNG_REP-REQ Message Format

| Syntax | Size | Notes |
|---|---|---|
| RNG_REP-REQ_Message_format( ) { | - | - |
| Management Message Type = Y | - | - |
| TBS ID | 48 bits | Selected TBS |
| MAC Address | 8 bits | MS MAC Address |
| Ranging Purpose Indication | 4 bits | Bit#0=1 |
| Service Level Prediction | 4 bits | Encoding=2 |
| HMAC/CMAC tuple | - | - |

***Step 12: UL Retransmission*** **-** Next, the TBS matches the transmitted parameters with those already stored, and communicates the outcome in the RNG_REP-RSP (Ranging_Report-Response) message. A flag value is maintained for this and, provided the buffered ranging parameter-related timer is still valid, the value in the RNG_REP-RSP is equal to 1, implying a successful resumption of UL traffic. Otherwise it is 0. Through a valid response, the TBS also indicates the successful completion of all authorization related activities. On the other hand, if the response is 0 then this TBS allocates new fast ranging IEs [2] for a probable repeat ranging option. In our scheme, the interval between the previous RNG_RSP message and the time when the TBS receives the RNG_REP-REQ message is about 50 ms. So, according to [1] and [13], chances of values fluctuating significantly within such a short interval is very small. Thus, for a positive response message, UL transmission resumes immediately with the TBS.

***Step 13: Registration Activities*** **-** Registration activities follow next with the TBS communicating the updated CIDs to the MS.

The total handover procedure is accomplished before the signal strength drops down to $L_{Min}$ i.e. before a call disruption might occur. In order to prevent undesirable ping-pong activities the actual handover occurs only after the signal strength drops below the 802.16e threshold value $L_0$, i.e if the MS finds itself the High-HO zone. To identify such activities, the TBS maintains a timer right from the time instant when it receives the forwarded MAC PDUs from the SBS until the successful resumption of the UL traffic (the timer tracks round-trip delays along with sufficient processing times). For a failed UL retransmission, the TBS sends back all the MAC PDUs to the previous SBS, interpreting it as a ping-pong activity.

## 4 Simulation Scenario

The performance of our new scheme was evaluated in a moderately populated centralised architecture [14] consisting of 6 different BSs deployed in a multicell environment operating with different radio frequencies (2.4 GHZ–2.45 GHZ). Among these, one BS is the SBS. The latencies in the different phases of handover were studied using the IEEE 802.16e OFDMA model implemented in the Qualnet 4.0 simulator [15]. Table 3 lists the simulation parameters assumed according to the WiMAX forum specifications [16]. The BSs are connected to an ASN-GW (Access Service Network Gateway) via wired point-to-point links. Figure 4 shows the simulated topology with total of 25 nodes spread randomly over a terrain of 1500 m x 1500 m. BS 4 is the current SBS and BSs 5, 10, 13, 17 and 21 are the NBSs. Node 25 is the ASN-GW, while the remaining nodes are the MSs. For simplicity, we have considered that within a cell, each BS serves three different randomly placed MSs, and all the BSs are under the same administrative domain. Within each cell, all the MSs simultaneously communicate with their respective BSs. On the other hand, BSs also communicate amongst themselves through the

**Table 3.** The Assumed Key Simulation Parameters

| Parameters | Value |
|---|---|
| Number of BSs | 6 |
| Number of MSs | 18 |
| Bandwidth | 10 MHz |
| Cellular Layout | Hexagonal |
| Terrain size | 1500 m x 1500 m |
| FFT size | 1024 |
| No. of subchannels | 30 |
| Channel Frequencies | 2.40 - 2.45 GHz |
| Transmission Power | 20 dBm |
| MAC Propagation Delay | 1 $\mu s$ |
| Environment Temperature (K) | 290 |
| Noise Factor (K) | 10 |
| Antenna Height | 1.5 m |
| BSs Propagation Limit | -111.0 dBm |
| $L_{Max}$, $L_0$, $L_{Min}$ | -76, -78, -80 dBm |
| QPSK Encoding Rate | 0.5 |
| BS Link Propagation Delay | 1 ms |
| Frame length | 5 ms |
| MS speed | 60 km/h |

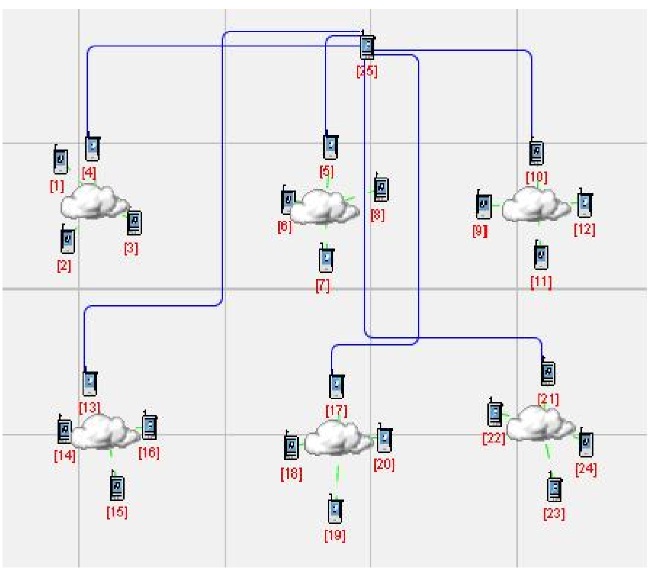



**Fig. 4.** Simulation Topology Consistig of Six BSs

backhaul network. We assume that the single round-trip delay plus the message-processing time over the backhaul network is not larger than 20 ms [2],[17]. We have modelled a single MS, initially under SBS 4, moving randomly between the different BSs and performing different numbers of handovers in each replication. A random waypoint mobility model [18] was used to modelling movements of MS. For simplicity of the performance analysis, we have considered only the data recorded during the first six handover activities in each replication. All graphs depict results based on multiple replications. The maximum relative statistical error is 3% at the 0.95 confidence level.

We have considered the following time-related parameters in order to analyse the performance of our proposed scheme:

- $\Delta T_{Ini}$: Mean duration of handover initiation time interval before the on-set of the scanning phase.
- $\Delta T_{Scan}$: Mean time required for an MS to complete scanning the different BSs. It depends on the number of BSs to be scanned.
- $\Delta T_{DL\_Sync}$: Mean DL synchronisation time.
- $\Delta T_{UL\_Sync}$: Mean UL synchronisation time.
- $\Delta T_{Cont\_Rang}$: Mean contention-oriented ranging time required. It was assumed that at least two ranging iterations occur before a successful ranging operation is accomplished.
- $\Delta T_{Fast\_Rang}$: Mean time required for a fast ranging opportunity with dedicated ranging slots.
- $\Delta T_{Cap\_Neg}$: Mean time required for performing capabilities negotiation.
- $\Delta T_{Re\_Auth}$: Mean time required for a successful re-authorization procedure through authorization hand-shaking framework during network re-entry [2].
- $\Delta T_{Reg}$: Mean time required for accomplishing a successful registration policy during network re-entry.
- $\Delta T_{Back\_Proc}$: Round-trip delay and message processing time in backhaul network equal 20 ms [2],[17].

### 4.1 NTAP HO Latency Analysis

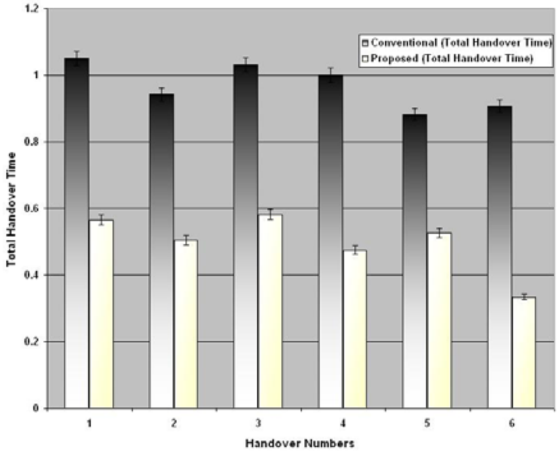
Our scheme can reduce the overall NTAP-related handover latency to as much as 50%. Note that handover latency in the conventional IEEE 802.16e NTAP is

$$\Delta T_{Ini} + \Delta T_{Scan} + \Delta T_{DL\_Sync} + \Delta T_{UL\_Sync} + \Delta T_{Cont\_Rang} \tag{1}$$

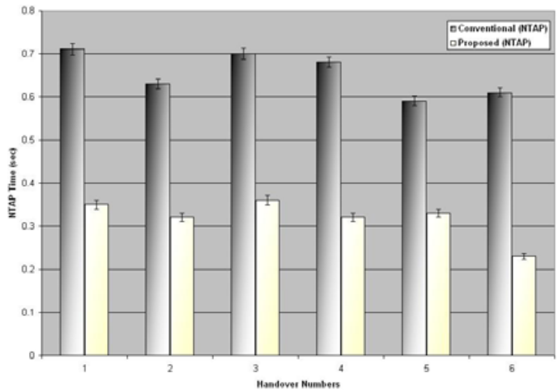
On the other hand, latency in our NTAP equals

$$\Delta T_{Ini} + \Delta T_{Fast\_Rang} + \Delta T_{Back\_Proc} \tag{2}$$

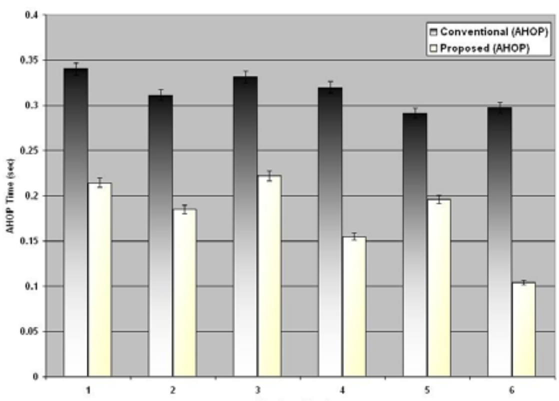
Figures 5(a) and 5(b), respectively, show the reductions in the overall handover latency and NTAP latency for individual BSs using our proposal. Depending on the load factor of different BSs, the latency for the conventional NTAP scenario can be over 0.7 seconds [6], whereas, the maximum NTAP latency in our scheme is about half of that.




(a) Overall Handover Analysis




(b) NTAP Processing Time




(c) AHOP Processing Time

**Fig. 5.**

### 4.2 AHOP HO Latency Analysis and CDT Analysis

Handover latency during the AHOP in the conventional IEEE 802.16e equals:

$$\Delta T_{DL\_Sync} + \Delta T_{UL\_Sync} + \Delta T_{Cont\_Rang} + \Delta T_{Cap\_Neg} + \Delta T_{Re\_Auth} + \Delta T_{Reg} \quad (3)$$

whereas the best case AHOP latency in our scheme equals:

$$\Delta T_{Reg} + \Delta T_{Back\_Proc} \quad (4)$$

and in the worst case scenario:

$$\Delta T_{Fast\_Rang} + \Delta T_{Reg} + \Delta T_{Back\_Proc} \quad (5)$$

As discussed in Section 3, DL retransmission can readily depend on the previously recorded data once the processing of the BH_NW-NOTF2 message is done, skipping the time-consuming DL synchronisation procedure. The same is valid for UL retransmission, which can resume immediately with the RNG_REP-RSP message, avoiding the time-consuming authorization procedure. Simulation results shown in Figure 5(c) indicate that the proposed scheme is capable of reducing the overall AHOP-related handover delays by up to 65%, in the best-case scenario.

Figure 6 indicates that, in the best-case scenario, our framework can reduce the conventional downlink service retransmission interval by up to 89% and the up link service retransmission interval to a maximum of 82%, with the average UL improvement range varying from 66% to 78%. Compared to the large CDT of over 200 ms in the conventional scheme, which is due to a series of lengthy network re-entry activities performed by an MS during each handover before it can resume normal activities, our scheme proves to be more efficient in handling delay-sensitive high-speed real-time traffic. Time-consuming ranging and re-authorization activities are omitted during the AHOP. This also results in significant reduction of the inter-handover packet loss and non-consecutive data flow.

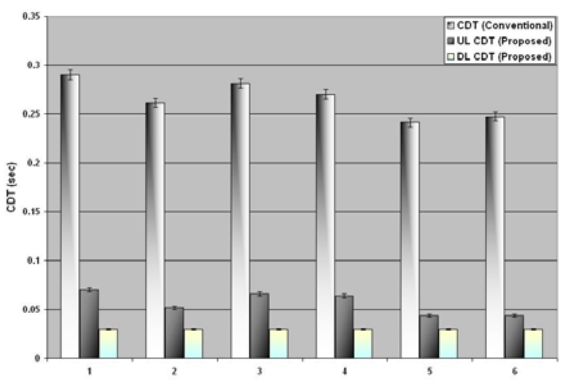



**Fig. 6.** Comparison of CDT in the Conventional and Proposed HO Procedures

There is scope for extending the current work to cross-layer scenarios, to see how the proposed scheme can cope with the network layer handover latencies. Further analysis of performance of our scheme in case of heavily loaded cells and different mobility models is planned in the near future.

## 5 Conclusion

In this paper, we have proposed a fast and seamless handover framework for IEEE 802.16e systems assisted by the backhaul network. The conventional 802.16e handover procedure impairs the service level processes for real-time delay-sensitive application, owing to high latency constraints resulting from time-consuming scanning and synchronisation activities along with a prolonged network re-entry phase. Our scheme has shown that, with the help of new handover messages and tunneling certain important information between the SBS and TBS over the backhaul network, the overall handover latency as well as the CDT of the 802.16e HHO procedure can be significantly improved, making it a realistic choice for delay-sensitive applications.

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