Dual-Trigger Handover Algorithm for WiMAX Technology

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Abstract
IEEE 802.16e is a Worldwide Interoperability Microwave Access (WiMAX) standard that supports mobility. Handover is one of the most important factors that affect the performance of a WiMAX network. Various handover schemes have been proposed and implemented. In this paper, we propose Dual-Trigger Handover (DTHO) algorithm for WiMAX networks. The proposed handover algorithm depends on the computation of signal to noise ratio (SNR) received at the Mobile Station (MS) from various Base Stations (BSs). Relying on SNR measurements and free capacity measurements of the serving BS and the target BS improves the accuracy of handover decisions. The handover is not triggered by the MS node or the BS node individually. Instead, it is a combined decision between the two nodes. The proposed algorithm is implemented in both MS and BS nodes. We implemented the proposed algorithm using OPNET Modeler version 14 running on Windows operating system. The algorithm was simulated using multiple scenarios with various channel parameters.

1. Introduction

Worldwide Interoperability Microwave Access (WiMAX) is the broadband wireless access standard based on the robust Orthogonal Frequency Division Multiplexing and Orthogonal Frequency Division Multiple Access (OFDM/OFDMA) physical (PHY) layer. Two categories of WiMAX are fixed WiMAX and mobile WiMAX, based on the IEEE 802.16 [1] and the IEEE 802.16e [2] standards, respectively. They support channel bandwidths between 3.5 MHz and 20 MHz, with up to 2,048 subcarriers. The first release of the mobile WiMAX system supports link adaptation using adaptive modulation and coding (AMC) and power control.

WiMAX PHY layer supports multiple-input multiple-output (MIMO) antennas to provide non-line-of-sight (NLoS) service and hybrid automatic repeat request (HARQ) for achieving good error correction performance [3]–[5]. In fixed WiMAX, no movement is supported and nomadic access is provided with no handover. In mobile WiMAX, additional features such as handover, flexible power management (sleep and idle modes), channel bandwidth scalability (also known as scalable orthogonal frequency division multiple access (SOFDMA)), fractional frequency reuse, and better NLoS performance and indoor penetration are supported. Three types of PHY layers for the IEEE 802.16e standard are defined by WiMAX Forum [6]: single-carrier transmission, OFDM, and OFDMA. Time Division Multiple Access (TDMA) is used in single-carrier transmission and OFDM as the multiple access technique. The OFDMA has been selected for portable and mobile communication.

In mobile WiMAX, handover is characterized as hard handover (also known as break-before-make) and soft handover. Soft handover consists of Macro Diversity Handoff (MDHO) and Fast Base Station Switching (FBSS). Soft handover improves the Quality of Service (QoS) performance while adding complexity and overhead to the system. Handover process is initiated based on the measurement of the signal strengths received by Mobile Station (MS) from multiple Base Stations (BSs). We consider only the hard handover, which we implemented in the WiMAX OPNET model. The only signaling we consider in this paper is the bidirectional signaling between the MS and the serving BS. We do not consider communication or signaling between MSs and neighboring BSs. However, we assume that the MS is aware of the neighboring BSs via the MOB_NBR_ADV message, which includes ID of the target BS, physical frequency, downlink channel descriptor (DCD), and uplink channel descriptor (UCD).

Handover occurs frequently because of the channel traffic load and the wireless environment that causes channel fading and shadowing. Most reported algorithms depend on various handover criteria such as signal to noise ratio (SNR) or the received signal strength indicator (RSSI). These algorithms may be divided into three categories [7]. In the first category, handover decision is initiated when the received signal strength of the serving BS is lower than the received signal strength of target BS. Repeated and unnecessary handovers may occur even if the MS receives a signal with acceptable SNR, which affects the performance of the system and degrades QoS of the connection. In the second category, the decision is based on relative signal strength and the threshold. This method may prevent the repeated handovers between two BSs, which occur in the algorithms in the first category when the MS reaches the cell boundary. However, an optimization of the threshold value is required because choosing a large threshold reduces the handover attempts and, consequently, delays the handover initialization and degrades the connection quality. The third category is based on the relative signal strength with a threshold and a margin. The handover is initiated only when the current received signal strength from the serving BS is lower than a certain threshold and the SNR of the target BS is higher than the SNR of the serving BS. In this case, the repeated handovers are prevented and the coverage area of the BSs is maximized. The drawback of this method is the optimization overhead of both the handover threshold and the margin: low threshold causes degraded connections due to late handover while high threshold causes premature handover. Both affect the coverage and the system throughput.

The remainder of the paper is organized as follows: The system model is introduced in Section 2. In Section 3, we present the description of the proposed handover algorithm. Simulation scenarios and results are described in Section 4. We conclude with Section 5.

2. Network Model

SNR Calculation: We consider the sample network shown in Figure 1, where BS1 and BS2 are separated by distance D. In this simple scenario, the signal strength is a dominant factor for a handover decision. The power received from BS1 at the MS node is [7]:

$$P_r[mW] = \frac{P_{t_{BS1}} G_{t_{BS1}} G_r}{PL(d)L}. \quad (1)$$

The power received from BS2 is:

$$P_r[mW] = \frac{P_{t_{BS2}} G_{t_{BS2}} G_r}{PL(D-d)L}, \quad (2)$$

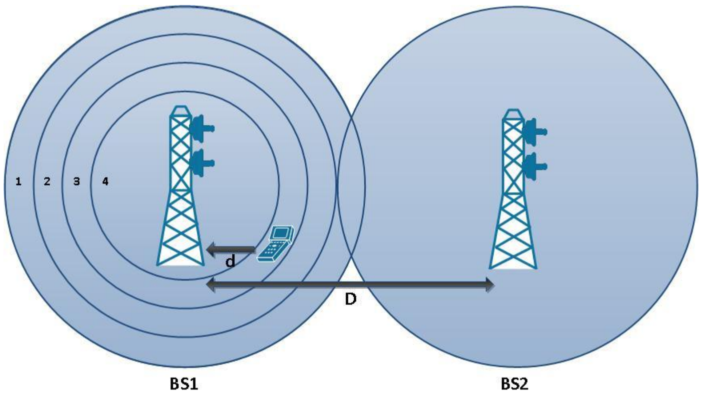

Figure 1. Network model for SNR calculations**.**

where $P_{t_{BS1}}$, $P_{t_{BS2}}$, $G_{t_{BS1}}$, and $G_{t_{BS2}}$ are the transmitted powers and the transmitter gains from BS1 and BS2, respectively. G_r is the receiver gain, L is the system loss factor, and $PL(d)$ and $PL(D-d)$ are the path losses at distances d and $D-d$ from BS1 and BS2, respectively. Equations (1) and (2) may be expressed in dBm units as:

$$P_r[dBm] = 10\log(P_r[mW]) \\ = P_{t_{BS1}} + G_{t_{BS1}} + G_r - PL(d) - L. \quad (3)$$

$$P_r[dBm] = 10\log(P_r[mW]) \\ = P_{t_{BS2}} + G_{t_{BS2}} + G_r - PL(D-d) - L. \quad (4)$$

We assume that transmitted powers from both BSs are equal and that the loss factor $L = 1$. By using (3) and (4), the relative signal strength at the MS may be written as [2]:

$$y(d) = 10n\log(d) - 10n\log(D-d) + u(d) - v(D-d), \quad (5)$$

where n is the path loss exponent, which is equal to 2 for free space and is usually larger for wireless channels. Its value may be calculated as $n = a - bH_{bs} + c/H_{bs}$, where a, b, and c are constants for a specified terrain category [8]. H_{bs} is the height of the BS. Processes $u(d)$ and $v(D-d)$, where $d \in (0, D)$, are independent and identically distributed zero mean stationary Gaussian random processes representing the shadow fading components of received signals from BS1 and BS2, respectively. We model the autocorrelation of the shadow fading as an exponential function [9]:

$$E[u(d_1)u(d_2)] = E[v(d_1)v(d_2)] \\ = \sigma_s^2 \exp(-|d_1 - d_2|/d_0), \quad (6)$$

where σ_s^2 is usually between 3 dB and 10 dB and d_0 determines the correlation decay with distance. We define the first threshold in the proposed handover algorithm by averaging the received signals (6).

Capacity Calculation: The second threshold in the proposed handover algorithm is the free capacity of the target BS. In OFDMA systems, time is divided into time slots while the bandwidth is divided into number of sub-channels [3]. There are three types of OFDMA subcarriers used for guard bands and data carriers (DC): data subcarriers for data transmission, pilot subcarriers for various estimation and synchronization purposes, and null subcarriers for no transmission. The OFDMA scalability parameters for mobile WiMAX (IEEE 802.16e) are shown in Table 1.

Table 1. OFDMA scalability parameters.

Attribute	Value (s)				
System bandwidth (MHz)	1.25	2.5	5	10	20
Sampling frequency (Fs, MHz)	1.42	2.85	5.71	11.43	22.86
Sample time (1/Fs, ns)	700	350	175	88	44
FFT size (NFFT)	128	256	512	1,024	2,048
Subcarrier frequency spacing	11.160 kHz				
Useful symbol time (Tb=1/f)	89.6 µs				
Guard time (Tg=Tb/8)	11.2 µs				
Symbol time (Ts=Tb+Tg)	100.8 µs				

The area covered by BS1 is divided into multiple regions as shown in Figure 1. Each region corresponds to an area where users may transmit data using specific coding and modulation scheme. The available BS capacity is shared among multiple MSs on a per-demand basis [10], [11]. Mobile WiMAX employs AMC, which dynamically selects the coding and the modulation scheme based on the channel status. When SNR of an MS channel is high, MS selects higher AMC (i.e., 64QAM). However, when channel SNR is low, MS switches to lower AMC (i.e., QPSK). The coding rates and modulation schemes for the four regions are shown in Table 2.

Table 2. IEEE802.16 AMC configurations.

Region #	Modulation	Coding rate	SNR (dB)
1	BPSK	½	6.4
2	QPSK	½ ¾	9.4 11.6
3 3	16QAM 16QAM	½ ¾	16.4 18.2
4	64QAM	½ ¾	22.7 24.4

In this paper, the BS free capacity refers to the free capacity of the upload link. It is equivalent to the complement of the capacity consumed by the MSs downlinks. Link capacity is measured in Mega symbols per seconds (Msps).

3. Proposed Handover Algorithm

The proposed algorithm is a combination of existing handover mechanisms. It falls into the second category of handover algorithms. It is a hybrid of MS initiated and the BS initiated (*capacity* [12]) handovers. The main difference between the proposed and the currently implemented WiMAX criteria is that the proposed algorithm prevents an MS from performing the handover if the target BS has no free capacity. To the contrary, the *capacity* handover permits an arriving MS to perform the handover to a target BS that already operates at full capacity (zero free capacity). The drawback of the *capacity* handover is that the target BS will then force one of the connected MSs to perform handover to one of the available neighboring BSs. Hence, the arriving MS gets resources to perform the handover while the departing MS may suffer poor quality of the new connection.

Scanning Process: The serving BS periodically provides the PHY layer parameters of neighboring BSs to its connected MSs using the MOB_NBR-ADV message. Such parameters include: the number of neighboring BSs, DCD/UCD, and available radio resources of neighboring BSs [7]. Once an MS reaches the scanning threshold, it sends MOB_SCN-REQ message to the serving BS and starts the scanning process, as shown in Figure 2. The MS uses these parameters to compute the QoS of the neighboring BSs and sends it in a MOB_MSHO-REQ message to the target BS during the handover process.

Handover Process: The decision regarding handover criteria (threshold) may be made either by the MS or the BS. The proposed handover algorithm defines a new hybrid triggering mechanism based on computation of the SNR and the estimation of free capacity. This approach reduces the probability of call loss since no call will be dropped even if the BS is operating close to its capacity limit. The proposed triggering condition is defined as:

$$SNR_{maxDT} - SNR_{DS} \geq H_1 \quad (7a)$$

$$AND$$

$$C_{EF} \geq H_2 \times C_{max} \ , \quad (7b)$$

where SNR_{maxDT} denotes the maximum downlink SNR of the target BS, SNR_{DS} corresponds to the downlink SNR of the serving BS, H_1 and H_2 are the first and the second handover threshold hysteresis, respectively, and C_{EF} and C_{max} are the estimated free and the maximum free capacities of the serving BS, respectively. The handover threshold hysteresis specifies the minimum difference between the SNR of a neighboring BS and SNR of the serving BS before triggering a handover to replace the serving BS with a neighboring BS. Equation (7a) implies that if the difference between the SNR of the target and serving BS is larger than H_1 (6 dB is chosen heuristically), the MS will send a list of the neighboring BSs using MOB_MSHO_REQ message to the serving BS to initiate the handover process, as shown in Figure 2. The serving BS will negotiate via the backbone with the neighboring BSs to check the resource availability of these BSs, as shown in Figure 3. We implement (7b) by modifying the *wimax_mob_bsho_response_msg_process* function, as shown in Figure 4. When the serving BS receives the HO_Rsp messages from the neighboring BSs, it checks their free capacity (7b). The free capacity of the candidate BS should be not less than H_2 (40% is chosen heuristically) of its maximum capacity. If the estimated free capacity of the neighboring BS is less than H_2 of the maximum free capacity, the serving BS flags this neighboring BS as an invalid candidate for the handover. The list of valid BS candidates is sent in the MOB_BSHO_RSP message back to the MS.

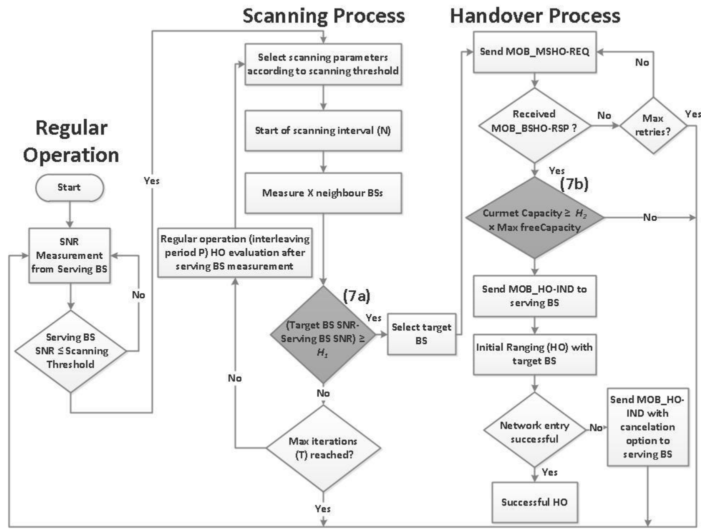

Figure 2. Flow chart of the proposed handover algorithm [12].

If the filtered list of BSs is not empty, the MS sends MOB_HO_IND message to confirm the handover and reconnect with the first listed valid target BS, as shown in Figure 3. Otherwise, it keeps scanning for a new target BS. The proposed algorithm is most effective in the highly overlapped BS cells where the MS can perform handover to multiple neighboring BSs. The serving BS also triggers the handover if the free capacity falls below the value of H_2. It chooses a candidate MS to perform handover among the connected MSs.

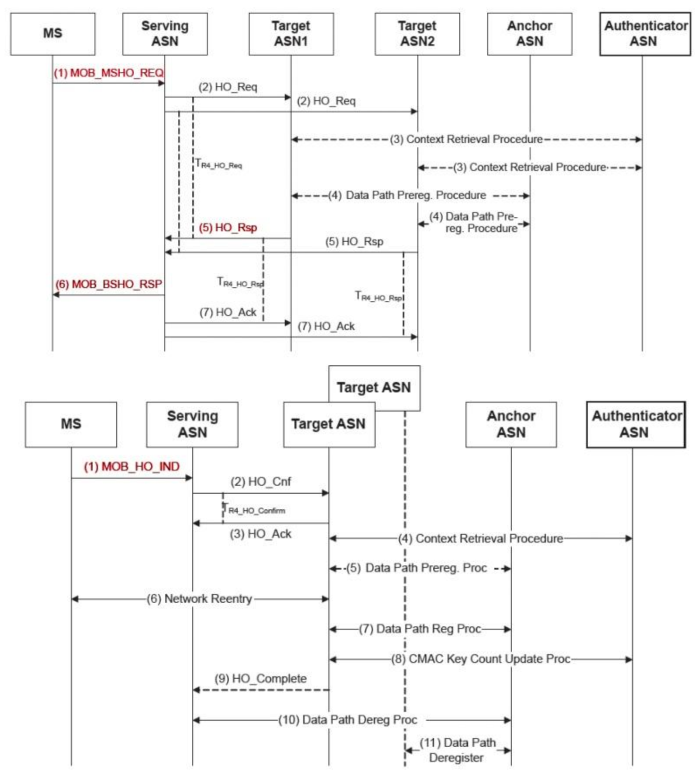

Figure 3. Flow chart of MS-initiated handover: preparation phase (top) and action phase (bottom) [7].

```
wimax_mob_bsho_response_msg_process{
…
for ( i=0 ; i < list_size ; i++)
{
target_list_element_ptr = (WimaxT_Ho_Target_List_Element*)
op_prg_list_access (target_bs_list_lptr,i);
nbr_list_elem_ptr = (WimaxT_Nbr_Bs_Scan_List_Element*)
op_prg_list_access (ms_scan_module_ptr->nbr_list_lptr,
target_list_element_ptr->target_list_index);
/* Obtain the capacity currently used at this BS.*/
tmp_capacity_spf = nbr_list_elem_ptr->nbr_bs_info_ptr-
>nbr_info_ptr->bs_params_ptr->capacity_spf;
/* Obtain the maximum expected capacity in this BS.*/
tmp_max_capacity_spf = nbr_list_elem_ptr->nbr_bs_info_ptr-
>nbr_info_ptr->bs_params_ptr->max_capacity_spf;
if(wimax_mob_opnk_alert_capacity_reached(tmp_capacity_spf,tmp_
max_capacity_spf))
target_list_element_ptr->target_response=OPC_FALSE;
}
…
}
```

Figure 4. Supplement code to the BS handover response process function.

4. OPNET Simulation Scenarios and Results

To validate the proposed algorithm, we used the WiMAX OPNET model. To simplify the simulation scenarios, each BS is assigned a Media Access Control (MAC) address (BS ID) corresponding to its name: MAC i for BS_i, i = 0, 1, 2, and 3. The OFDMA frame has 512 subcarriers and 5 ms duration. Each MS nodes has a constant downlink traffic flow of 64 kbps to a server throughout the uplink of the target BS. The handover messages are negotiated through the backbone links between the serving BS and the neighboring BSs. The mobility parameters for simulations scenarios are shown in Table 3 and Table 4. The network topology has identical object's attributes configurations for all simulation scenarios. Each BS initially has 0.704 Msps free upload link capacity.

Table 3. Scanning parameters.

Scanning Threshold (dB)	35
Scan Duration (N) (Frames)	3
Interleaving Interval (P) (Frames)	255
Scan Iteration (T)	5
Maximum Scan Request Retransmissions	8

Table 4. Handover parameters.

Handover Threshold Hysteresis H_1 (dB)	6.0
MS Handover Retransmission Timer (ms)	30
Maximum Handover Request Retransmissions	6
Multitarget Handover Threshold Hysterias (dB)	0.0
Maximum Handover Attempts per BS	3

Simulation Scenario A: The network topology shown in Figure 5 consists of four WiMAX cells with fourteen MS nodes located between BS_0 and BS_1, an MS labeled MS_0, a server, and a backbone router. MS_0 is moving based on a predefined trajectory between BS_2 and BS_3. BS_0 and BS_1 each have 33% free capacity (< 40%) by initially assigning MS_1, …, MS_7 to BS_0 and MS_8, …, MS_14 to BS_1. Once MS_0 enters the overlapping area, it exceeds the scanning threshold (35 dB in the scanning configuration)) and at 194 s it begins scanning, as shown in Figure 6 (top). Based on the proposed handover criteria (7a) and (7b), MS_0 does not initiate handover to either BS_0 or BS_1 and, instead, it initiates handover to BS_3 at 317 s, as shown in Figure 6 (middle). Regardless of whether or not (7a) is satisfied, (7b) is not satisfied. Hence, MS_0 does not perform handover. MS_0 repeatedly cancels the handover requests and remains in the scanning process until it reaches the BS_3 cell boundary. Downlink SNRs of the three BSs are shown in Figure 6 (bottom).

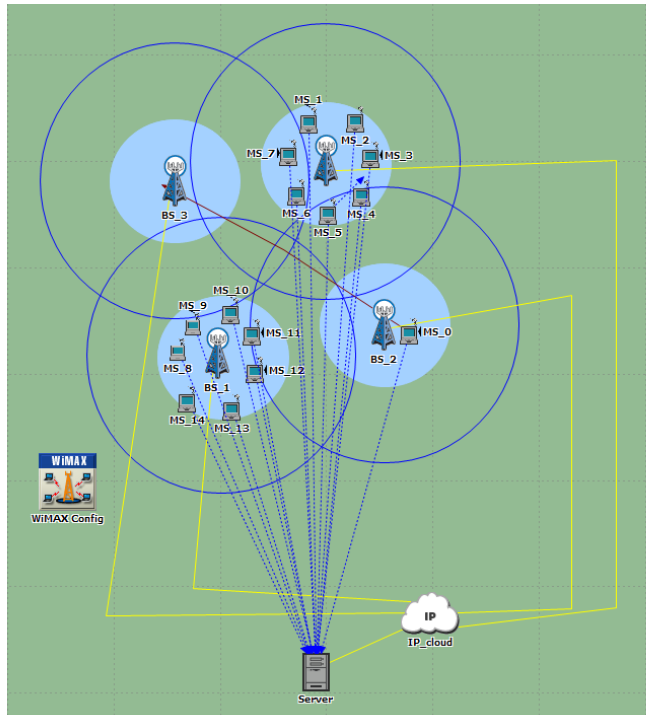

Figure 5. OPNET network model: Simulation Scenario A.

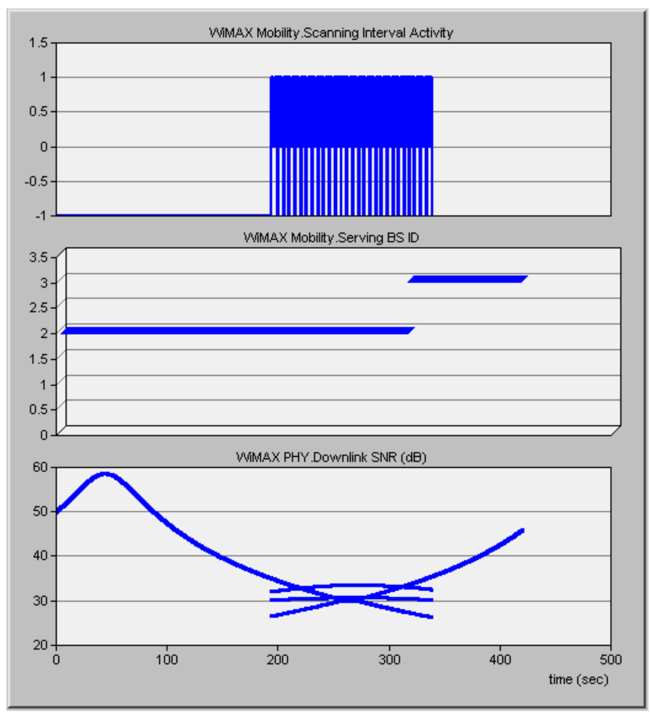

Figure 6. Scanning interval (top), serving BS ID (middle), and downlink SNRs (bottom) for MS_0.

Simulation Scenario B: In this scenario, the free capacities of BS_0 and BS_1 are identical as in Scenario A. With a newly defined trajectory, MS_0 passes close to BS_1 and $(SNR_{maxDT} - SNR_{DS})$ reaches 8.9 dB. In this scenario $(SNR_{maxDT} - SNR_{DS})$ is equal or larger than H_1 (7a).

Even if (7a) is satisfied, no handover will be performed unless the free capacity of the target BS is not less than 40% (7b). To validate the proposed threshold trigger, we simulated the network shown in Figure 7. As shown in Figure 8, MS_0 waits until 333 s to perform handover to BS_3.

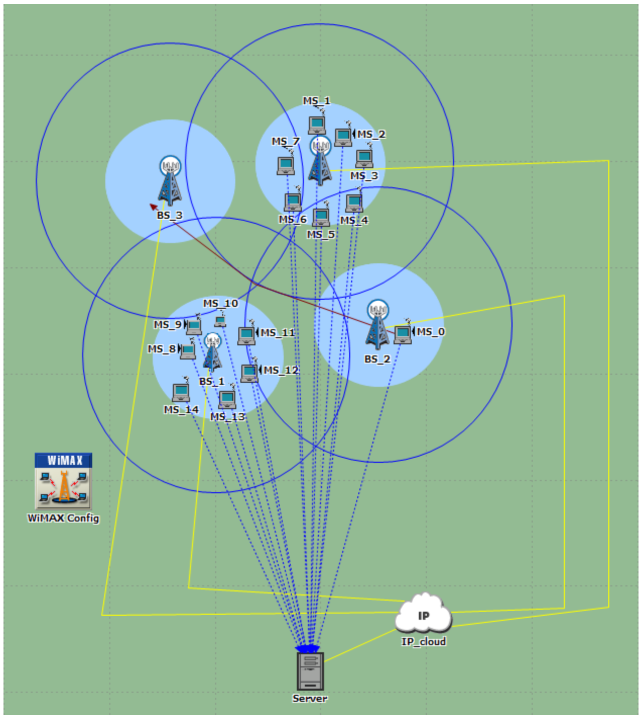

Figure 7. OPNET network model: Simulation Scenario B.

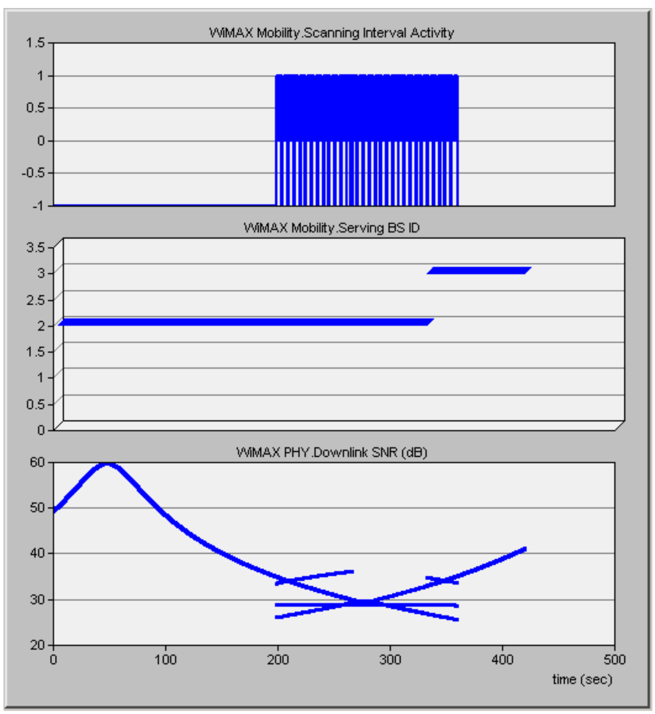

Figure 8. Scanning interval (top), serving BS ID (middle), and downlink SNRs (bottom) for MS_0.

Simulation Scenario C: We increased the free uplink capacity of BS_0 to 52% (≥ 40%) by assigning MS_1, …, MS_5 to BS_0. BS_0 may now offer resources to an arriving MS. The trajectory has been redefined so that MS_0 passes close to BS_0 and $(SNR_{maxDT} - SNR_{DS})$ reaches 6.7 dB, as shown in Figure 9.

Both (7a) and (7b) are satisfied. MS_0 initiates handover at 262 s and 380 s to BS_0 and BS_3, respectively, as shown in Figure 10. Figure 10 (top) illustrates the change in the upload free capacity of BS_0 from 0.368 Msps (52%) to 0.3008 Msps (43%) and back to 0.368 Msps (52%) as MS_0 arrives and departs.

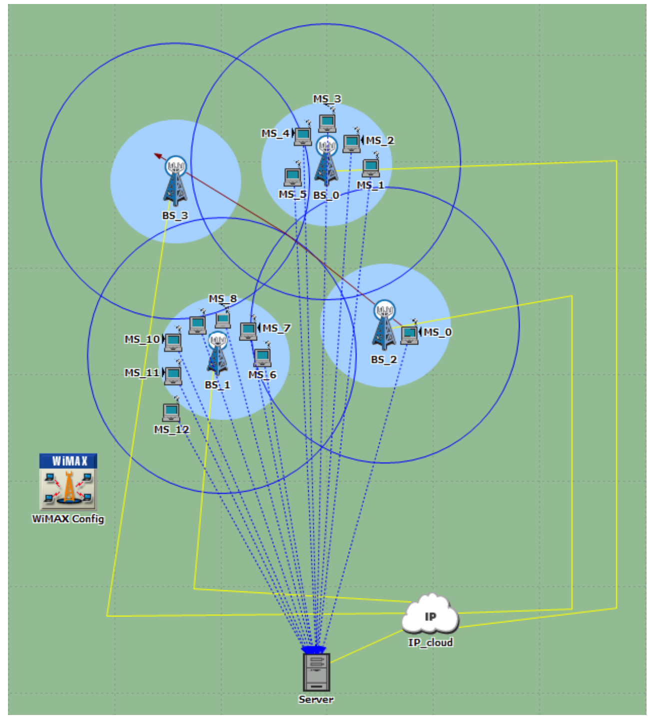

Figure 9. OPNET network model: Simulation Scenario C.

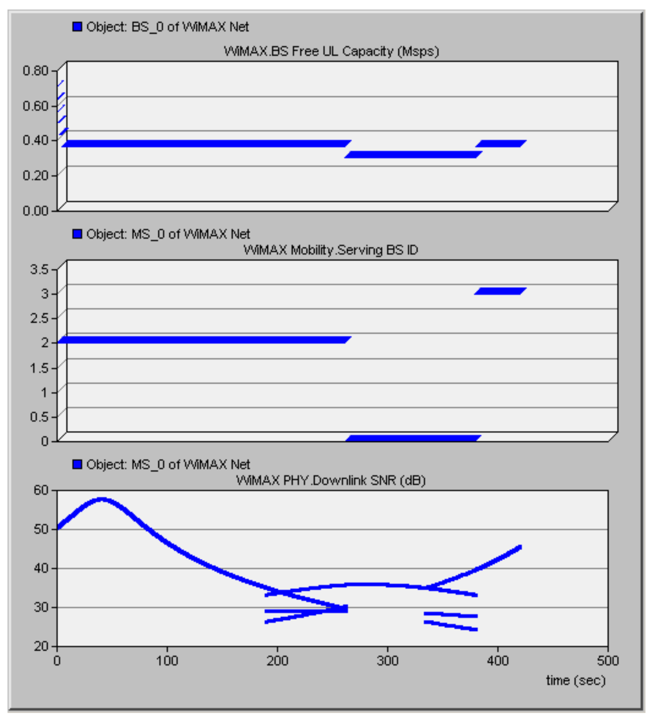

Figure 10. BS_0 free upload capacity (top), serving BS ID for MS_0 (middle), and downlink SNRs for MS_0 (bottom).

Simulation Scenario D: To verify that the proposed handover algorithm also performs the *capacity* handover, we increase the free capacity of BS_0 to 42.7% (≥ 40%) by assigning MS_1, …, MS_6 to BS_0, as shown in Figure 11. BS_0 may handle only one additional MS. However, its free capacity falls below 40% (32.2%). The BS executes the *capacity handover* and forces MS_6 to perform handover to BS_3. As shown in Figure 12, MS_0 initiates handover to BS_0 at 262 s. Consequently, MS_6 performs handover to BS_3. At 380 s, MS_0 initiates handover to BS_3. By performing the *capacity handover*, BS_0 maintains its free capacity above 40%.

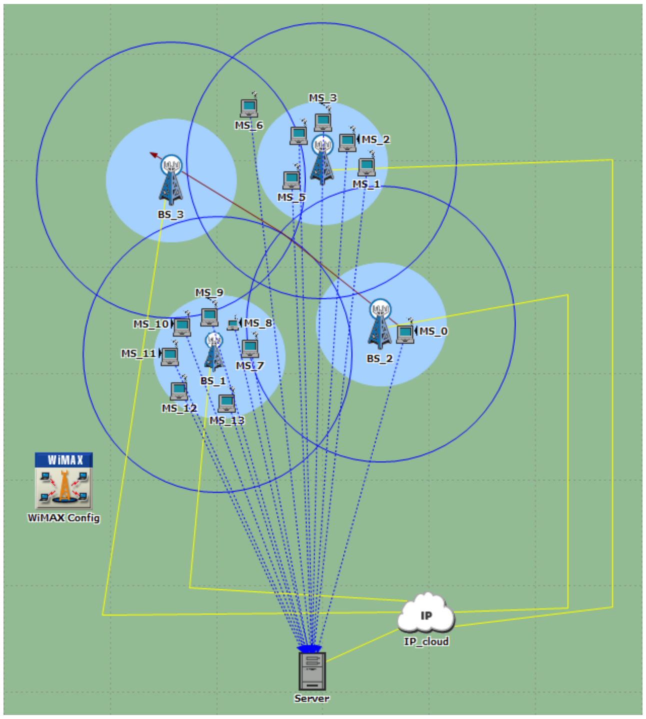

Figure 11. OPNET network model: Simulation Scenario D.

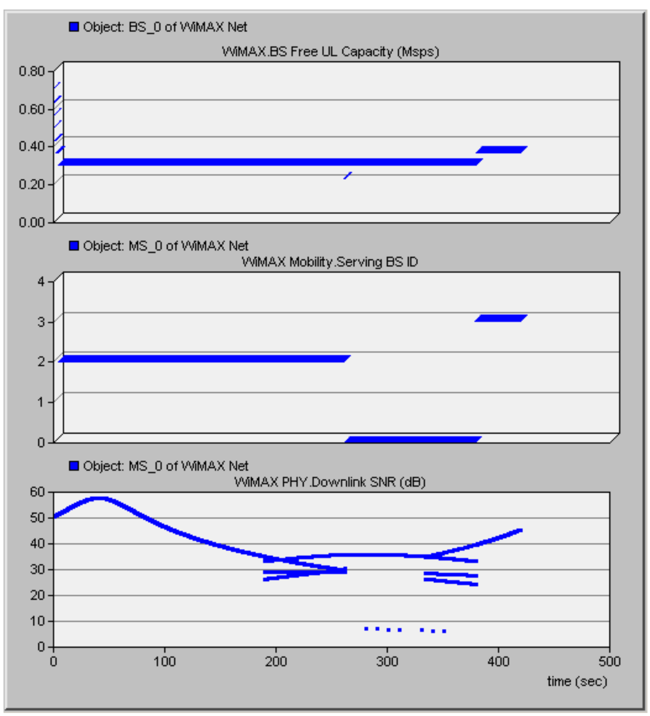

Figure 12. BS_0 free upload capacity (top), serving BS ID for MS_0 (middle), and downlink SNRs for MS_0 (bottom).

5. Conclusions

In this paper, we employed OPNET Modeler as a simulation tool for testing and developing WiMAX handover algorithms. We validated the proposed handover triggering algorithm for mobile WiMAX in various simulation scenarios and demonstrated that the algorithm shows significant performance improvements in WiMAX designs with highly overlapped BS cells. The SNR measurements for handover triggering mechanism combined with estimation capacity reduce the probability of call loss and maximize the overall system throughput. We also introduced handover heuristic values to avoid repeated handovers while trying to balance users across the cells. The future work calls for implementation of an adaptive mechanism for optimizing thresholds for the handover hysteresis values.

References

[1] IEEE standard for local and metropolitan area networks part 16: air interface for fixed broadband wireless access systems, *IEEE Standard 802.16*, 2004.

[2] IEEE standard for local and metropolitan area networks part 16: air interface for fixed and mobile broadband wireless access systems, *IEEE Standard 802.16*, 2005.

[3] H. Yaghoobi, "Scalable OFDMA physical layer in IEEE 802.16 wireless MAN," *Intel Technology Journal*, pp. 201–212, Aug. 2004.

[4] L. Nuaymi, *WiMAX: Technology for Broadband Wireless Access*. New York, NY: Wiley, 2007.

[5] J. G. Andrews, A. Ghosh, and R. Muhamed, *Fundamentals of WiMAX: Understanding Broadband Wireless Networking*. Upper Saddle River, NJ: Prentice Hall, 2007.

[6] WiMAX Forum [Online]. Available: http://www.wimaxforum.org.

[7] B. G. Lee and S. Choi, *Broadband Wireless Access and Local Networks: Mobile WiMAX and WiFi*. Boston, London: Artech House, 2007.

[8] V. Erceg, L. Greenstein, S. Tjandra, S. Parkoff, A. Gupta, B. Kulic, A. Julius, and R. Bianchi, "An empirically based path loss model for wireless channels in suburban environments," *IEEE Journal on Selected Areas in Communications*, vol. 17, no. 7, pp. 1205–1211, July 1999.

[9] M. Gudmundson, "Correlation model for shadow fading in mobile radio systems," *Electronics Letters*, vol. 27, no. 23, pp. 2145–2146, Nov. 1991.

[10] M. R. Ashayeri and H. Taheri, "Mobile WiMAX capacity estimation in various conditions," in *Proc. 18th Iranian Conference on Electrical Engineering, ICEE 2010*, May 2010 pp. 483–488.

[11] C. Tarhini and T. Chahed, "On capacity of OFDMA-based IEEE802.16 WiMAX including adaptive modulation and coding (AMC) and inter-cell interference," in *Proc. 15th IEEE Workshop on Local and Metropolitan Area Networks, LANMAN*, Evry, France, June 2007, pp. 139–144.

[12] Understanding WiMAX Model Internals and Interfaces [Online]. Available: http://coloftp.opnet.com/x/69eeff7ffd6dbeb8af5eacb13975bd08/1579/1579_pres.pdf.