International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463
Vol. 4 Issue 1, January-2015, pp: (98-115), Impact Factor: 1.252, Available online at: www.erpublications.com

Handover Schemes for Mobile WIMAX Networks: Review, Challenge and the State of Art

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Abstract: Handover (HO) mechanism is one of the critical operations in Mobile WIMAX. It takes place when a mobile station (MS) moves from a serving base station (BS) to another BS.The handover procedure is comprised of several stages; network topology advertisement, MS scanning, cell selection, handover initiation and decision and network re-entry including ranging, authorization, authentication and re-registration. During these stages, still some issues, such as unnecessary scanning, handover delay and MAC overhead, ping-pong handover and handover failure which may affect real-time applications. In this article, we present mobility features in WiMAX systems and survey the handover mechanism along with their schemes, strategies and protocol categories, and elaborate in each stage upon the classification and comparison among various handover schemes. Furthermore, it identifies and discusses several issues and challenges facing mobility management along with an evaluation and comparison of several relevant mobility studies.

Keywords: WiMAX, Handover, Mobility, Scanning, Cell selection, Decision, Network re-entry.

1. Introduction

WIMAX stands for worldwide interoperability for microwave access by the WiMAX Forum[1]. It is based on IEEE 802.16 standard, officially known as Wireless- MAN, it aims to provide wireless data coverage over a metropolitan area like a city. The forum describes WiMAX as "a standards-based technology enabling the delivery of last mile wireless broadband access as an alternative to cable and DSL". Although the WiMAX standard supports both fixed and mobile broadband data services, the latter has a much larger market. The WiMAX system comprises of a radio tower, similar to a cellular base station, and a WiMAX antenna and receiver at the customer end, which can be a modem, PC data card or even a mobile handset[2]. WiMAX network promises to support different user application and meet their QoS requirements during and after the handover. Today it is one of the most outstanding standards capable of providing quadruple play technologies — data, voice, video and mobility — on a single network [3]. The IEEE 802.16 family of standards is currently being developed to meet this demand.

The initial version of the standard (802.16d) provides high data rate but only supports fixed terminals, and the subsequent version of the standard (802.16e) provides support for mobile terminals[4]. Another standard, 802.16j introduces a relay station (RS) entity to extend the coverage and improves the performance[5], particularly at cell edges and shadowed areas of the cell. The most recent version of the standard, 802.16m promises to meet the IMT-Advance requirements to provide high performance improvements to support future advanced services and applications. This is done by providing high data rates of at least 1Gbps for fixed stations and 100 Mbps for MSs at a vehicular speed of up to 350 km/h

The series of standards specify physical (PHY) layer and medium access control (MAC) layer functionalities with many advanced features to provide ubiquitous broadband access and flexible networking for all kinds of terminals[6], [7]. The basic characteristics of the various IEEE 802.16 standards are summarized in Table 1.

Table 1: Basic characteristics of the various IEEE 802.16 standards

	802.16d Fixed WiMAX	802.16e Mobile WiMAX	802.16j Multi hop relay	802.16m IMT-Advanced
Operating frequency	2 - 11 GHz	2.3, 2.5, 3.5, 5.8, 6.75 GHz	2.3, 2.5, 3.5, 5.8, 6.75 GHz	<6 GHz

Channel bandwidth	5, 7, 8.75, 10, 20 MHz	5, 7, 8.75, 10, 20 MHz	5, 7, 8.75, 10, 20 MHz	5, 7, 8.75, 10, 20 MHz
Multiple access method	OFDM	OFDMA	OFDMA	OFDMA, MIMO
Modulation scheme	BPSK, QPSK, 16QAM, 64QAM	BPSK, QPSK, 16QAM, 64QAM	BPSK, QPSK, 16QAM, 64QAM	BPSK, QPSK, 16QAM, 64QAM
Duplexing	TDD and FDD	TDD and FDD	TDD and FDD	TDD and FDD
Data Rate	Up to 75Mbps	Up to 75Mbps	Up to 75Mbps	1Gbps (Fixed) 100Mbps (Mobile)
Mobility speed	Walking speed	Up to 120 km/h	Up to 120 km/h	Up to 350Km/h
Mobility Supporting	No	Yes	Yes	Yes
Relay Supporting	No	No	Yes	Yes

Handover process can be divided into two main phases; the network topology acquisition phase also known as pre-handover phase, and the actual handover phase. The first phase includes the network topology advertisement with the neighboring BS scanning and association. The second phase consists of cell selection, handover decision and initiation, and network re-entry including ranging, authorization and re-registration [4]However, during these phases still there are some issues affects the handover performance such as as unnecessary scanning, handover delay and MAC overhead, ping-pong handover and handover failure which may affect real-time applications. A survey of these issues in scanning and cell selection, initiation and decision and network re-entry phases is presented along with discussion of the different solutions to those challenges. A comparative study of the proposed solutions, coupled with some insights to the relevant issues, is also included. The rest of this paper is organized as follows: Section 2 introduces the mobility feature in WiMAX in details. Section 3 presents the handover issues and solutions in Mobile WiMAX and provides comparative study of the proposed solutions. This paper is concluded in Section 4.

2. Mobility Feature (Handover) in WiMAX

In recent years, the number of mobile devices such as mobile phones, smart phones, tablets and laptops have increased exponentially by the day. This is partly driven by the advancement in electronics and computations power for the device. The burgeoning number of such devices also drive the demand for ever higher bandwidths to access to the many applications over the Internet, including ubiquitous emails, instant messaging, and the more bandwidth demanding applications such as multimedia streaming, web browsing, gaming and many more. However, the development of networks supporting mobility sets several requirements for mobile user. The main requirement is the ability of a mobile device to change the serving BS according to the movements of the user to new BS. This process is called handover. Additionally, the handover has to be performed without disturbances in the connection and maintaining the confidentiality between the MS and both old and new, BSs. Traditional WiMAX functionality supports only nomadic access. With nomadic access, a user can change the location of its MS without the support of handover. The mobility feature of WiMAX starts with IEEE 802.16e and later versions. It promises to support mobility fully in WiMAX[8], [2], [9]. The coming sections will describe the network architecture behind Mobile WiMAX and handover procedure.

2.1 WiMAX Network Architecture

IEEE 802.16 standard develops the air interface at medium access control (MAC) and physical (PHY) layers but does not define full end-to-end communication network architecture, while the scope of WiMAX Forum's Network Working Group covers higher-level network specifications above the radio interface specifications in the IEEE 802.16 air interface standard[10]. The combined specifications of IEEE 802.16 standard and WiMAX Forum's Network Working Group help define an end-to-end system solution[11].

There are multiple levels of mobility in WiMAX, they are namely IEEE 802.16 air interface mobility, access service network gateway (ASN-GW) re-anchoring mobility, and connectivity service network (CSN) mobility, as shown in

Figure 1. The IEEE 802.16 air interface mobility covers functions to complete the migration of MAC and PHY layers from one serving BS to a target BS. As long as the serving BS and target BS are served by the same ASN-GW, the handover can be completed through MAC state migration and packet forwarding from the serving BS to the target BS. ASN-GW re-anchoring happens when the MS is transferred to a target BS belonging to a different ASN-GW. This is IP based and it involves a mobile IP registration with the home agent in the core network[12].

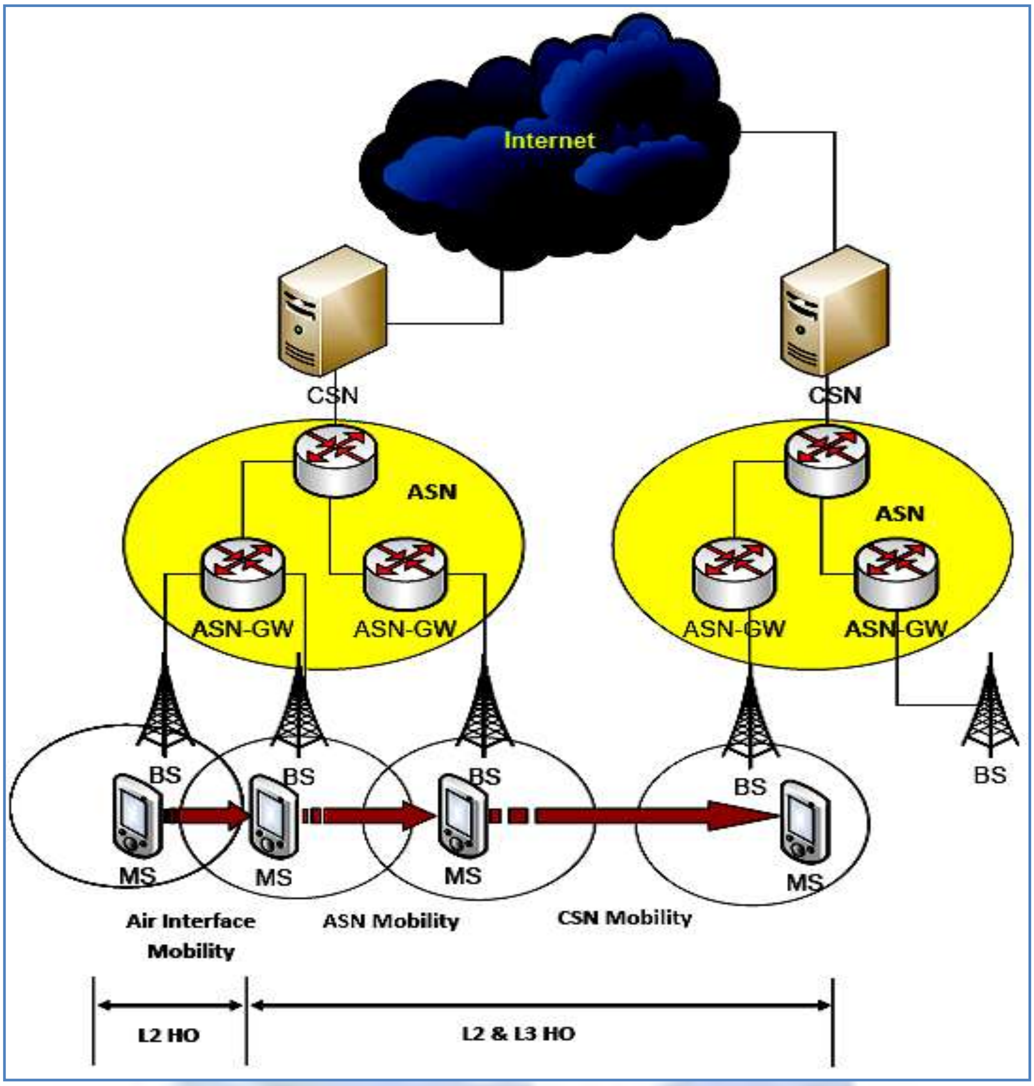


Figure 1: Mobility levels in WiMAX network

Network reference model (NRM) is the Architecture of WiMAX network defined by WiMAX Forum to describe the multiple level of handover or mobility in WIMAX. The mobility management considered by the WiMAX Forum for mobile WiMAX supports both IPv4 and IPv6 mobility management protocols. Besides the handover between BSs, two types of mobility are considered: ASN-anchored mobility and CSN-anchored mobility. ASN-anchored mobility, or micro-mobility (intra-domain mobility), performs mobility procedures that occur without the need for an MS Care-of-Address (CoA) update, since the MS moves its point of attachment between BSs of the same ASN. CSN-anchored mobility, or macro-mobility (inter-domain mobility), considers IP mobility between ASN and CSN. Different types of mobile IP (MIP) implementations are considered to support macro-mobility. The first type is aimed at MIP-enabled clients; and the second, for those nodes that do not support MIP and therefore need assistance from the network to perform handover. The latter approach is based on proxy mobile IP (PMIP)[13], [14]. With the MIP-aware approach, the MS is compliant with MIPv4 if deployed in IPv4 networks; or MIPv6, if deployed in IPv6 networks, respectively [15].

Therefore, intra-domain mobility is considered as layer2 (L2) handover, because it does not need any IP address updating, while inter-domain mobility is considered as layer3 (L3) handover, because it has to consider IP mobility between ASN and CSN. Although the L3 handover causes higher delays because of the IP mobility, layer 2 handover is more frequent. This is because L3 handover happens only when the MS roams between two cells that belong to different network subnets, and usually the subnet covers a large area that consists of many BSs. The NRM of WiMAX is shown in Figure 2 and described in Table 2[16].

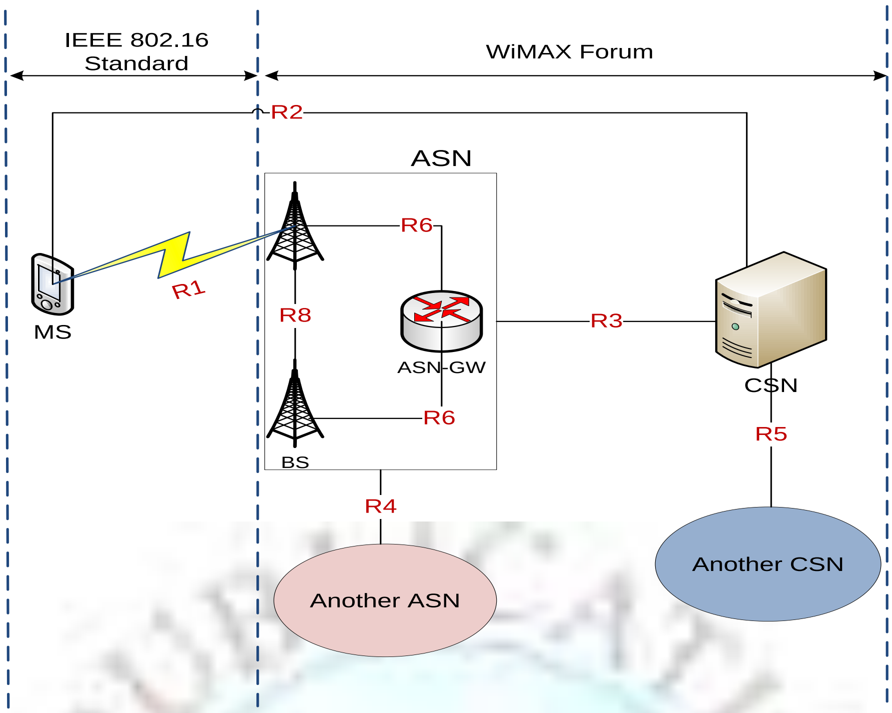


Figure 2: Network reference model (NRM) of WiMAX

Table 2: Network reference model interfaces

Interface	Description	Functionality
R1	Interface between the MS and ASN.	Air interface.
R2	Interface between the MS and CSN.	AAA, IP host configuration, mobility management.
R3	Interface between the ASN and CSN.	AAA, policy enforcement, mobility management
R4	Interface between ASNs.	Mobility management.
R5	Interface between CSNs.	Internetworking, roaming.
R6	Interface between BS and ASN gateway.	IP tunnel management to establish and release MS connection.
R8	Interface between BSs.	Handovers.

WiMAX Forum defines three profiles for ASN — A, B and C[17] — as described inTable 3. Profile C is the last ASN profile defined by WiMAX Forum, but profile B has been withdrawn. Profile C consists of one or more BSs and one or more ASN GWs. The BSs shall be connected to the ASN-GWs with R6 interfaces. The neighbor BSs are interconnected with R8 interfaces. The ASN GWs are interconnected with R4 interfaces. In addition to R1, the other mobility interfaces (R8, R6, R4) have to be considered during the handover process[12], [16].

Table 3: Access Service Network (ASN) profiles

Profile	Key features
A	Hierarchical model, with more intelligence located at the ASN gateway. The ASN gateway is involved in the Radio Resource Management (RRM) and hosts the Radio Resource Controller (RRC). It also handles handovers between BSs. The open interfaces: R1, R3, R4, R6.
B (withdrawn)	Flat, distributed model, with BSs playing a more substantial role in managing traffic and mobility. The ASN network acts as a black box, with R6 being a closed interface. The open interfaces: R1, R3, R4.
C	Centralized model similar to A, but BSs are responsible for all the RRM, including the RRC and Radio Resource Agent (RRA), and the handovers between BSs. The open interfaces: R1, R3, R4, R6.

2.2 Types of Handover in Mobile WiMAX

As mentioned earlier, handover is a mechanism to maintain uninterrupted user communication session during a user's movement from one location to another. Handover mechanism handles MS switching from one BS to another. Mobile WiMAX supports three types of handovers: Hard handover (HHO), fast base-station switching (FBSS) handover and macro-diversity handover (MDHO). Of these, the HHO is mandatory, while FBSS and MDHO are two optional modes[9].

In HHO, the connection with a BS is ended first before the MS switches to another BS. It means all connections with the SBS will be broken before the connection with a TBS is established. Hence, there is a short delay due to the short connection break between MS and SBS. Handover of HHO will be executed when the RSSI value from neighbors' cell exceeds the current cell RSSI threshold level and its margin. This type of handover also called as break-before-make. On the contrary, soft handover uses a make-before-break approach, wherein a connection to the next BS is established before an MS leaves an ongoing connection to a BS.

The other two types of handovers, MDHO and FBSS are known as soft handover or make-before-break, where a connection to the TBS is established before MS leaves the connection from SBS. Both MDHO and FBSS support a list of candidate BSs called diversity set which are involved with the handover procedure. In the MDHO approach, the downlink data are transmitted to MS by two or more BSs such that diversity combining can be performed at the MS. For uplink MDHO, the MS transmission is received by multiple BSs such that selection diversity of the received information could be performed. In the FBSS approach, the MS continuously monitors the BSs in the diversity set and defines an Anchor BS (A-BS), which is the chosen BS that the MS will communicate with[2], [8].

Error! Reference source not found.shows the WiMAX handover types.Although hard HO (HHO) is more bandwidth-efficient than soft HO, it causes longer delay and greater loss of packets [9]. Thus optimization of HHO mechanism becomes one important research areas for mobile WiMAX. The objective of this optimization is to reduce HO latency so as to make it suitable for real-time applications. Soft HO such as MDHO or FBSS normally is more complex and adds significantly to the hardware costs in IEEE 802.16e. Although the mandatory handover technique in WiMAX is HHO [18], the study of spectral efficiency of downlink traffic in multi-hop relay system (802.16j) as simulated in [19] shows that MDHO has better spectral efficiency compared with FBSS and HHO in a well-designed overlay cells system. A summary of the characteristics of various handovertypes is listed inTable 4.

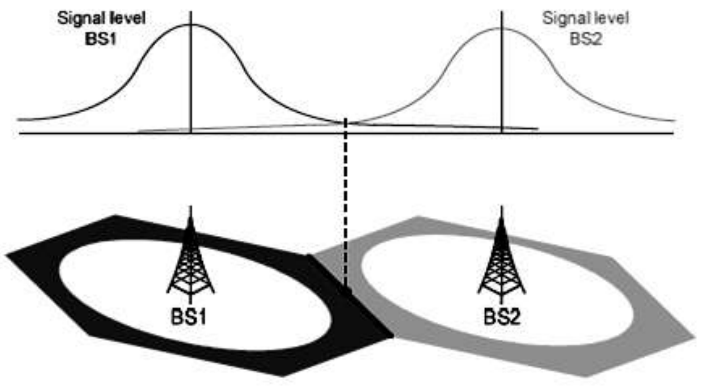
Table 4: Characteristics of hard handover vs. soft handover

	Hard Handover (HHO)	Soft Handover (SHO)
Complexity	Less	High
Disruption time	High	Less
Packet loss	High	Less
Network resources	Use less resources	Use more resources
Additional hardware	Not required	required
Extra radio link	Not required	MS consume extra radio link

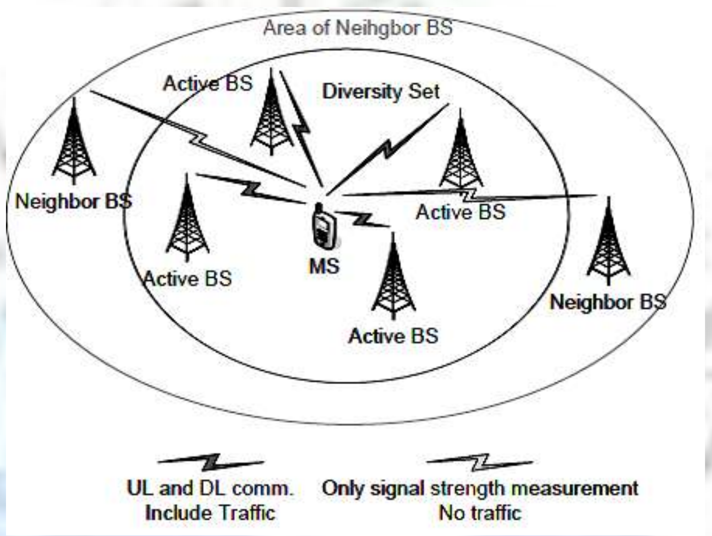
2.3 Handover Procedure

In network reference model (NRM) of WiMAX, there are multiple level of handover or mobility, they are namely intra-domain mobility and inter-domain mobility respectively. The intra-domain mobility performs mobility procedures that occur without the need for Layer 3 (network layer) handover, since the MS moves between BSs of the same Access Service Network (ASN) gateway, which consider a layer 2 handover. On the other hand, the inter-domain mobility considers IP mobility when the MS moves between BSs belonging to different ASNs, which considers a layer 3 handover.

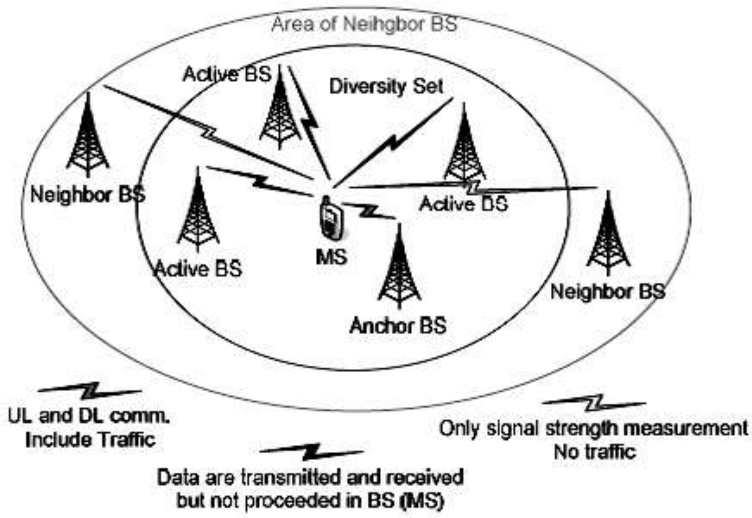
Therefore, based on the research scope this section will focus on the intra-domain mobility [10], [15]. The inter-domain mobility handover process can be divided into two main phases; the network topology acquisition phase also known as pre-handover phase, and the actual handover phase. The first phase includes the network topology advertisement with the neighboring BS scanning and association. The second phase consists of cell selection, handover decision and initiation, and network re-entry including ranging, authorization and re-registration [4]. Both phases of handover procedure can be summarized as in Figure 4.



(a) Hard Handover (HHO)



(b) Macro-Diversity Handover(MDHO)



(c) Fast Base-Station Switching (FBSS)

Figure 3: Types of Handover in Mobile WiMAX

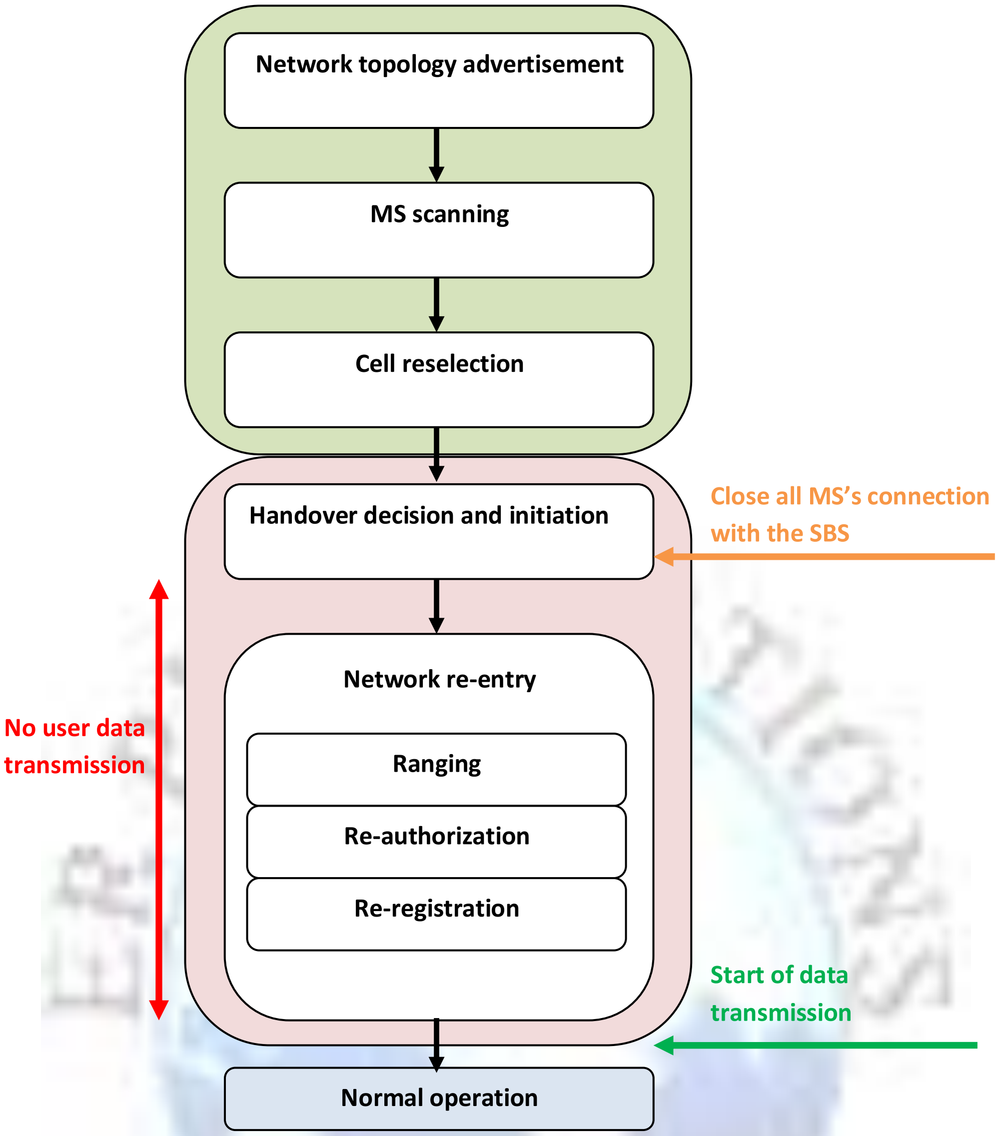


Figure 4: Handover procedure phases in mobile WiMAX system

2.3.1 Network topology advertisement

In this stage, the SBS gets the information about the nBSs through the backbone, and broadcasts this information periodically with an advertisement message MOB_NBR-ADV to the MSs for potential handover or initial network entry. The BS stores the MAC addresses and indexes of neighbor BS(s) with their information such as the BS ID, radiation power, frequency assignment, the scheduling service supported (UGS, nrtPS, rtPS, BE), mobility and handover support, and finally their UCD and DCD information. The information contained in the MOB NBRADV message facilitates faster handover to one of these BSs. Once the MS becomes aware of the neighbor BSs, it can start the scanning and association procedure in order to select a final target BS as will be discussed in the next section [20].

2.3.2 MS Scanning

After receiving the MOB_NBR-ADV message, the MS synchronizes with nBSs and starts the scanning process with all the advertised nBS to select the BS candidate for handover when the trigger condition is met. During the scanning phase, the signal quality of all nBS will be measured in order to determine the most suitable nBS as a TBS for the coming potential handover. However, during the scanning interval, all data transmission will be paused and this causes delay. The scanning process can be categorized as scanning without association or scanning with association, which is optional [8]. In the scanning without association which is shown in Figure 5, the MS starts the scanning process by sending and receiving the MOB_SCN-REQ and MOB_SCN-RSP messages respectively to or from the SBS. This scanning process is essentially to determine the time duration (in frames) for scanning, the interleaving interval duration for sleep scanning, and the number of iterations to repeat the scanning process, in other words to complete all nBSs scanning and evaluate their PHY channel information. Without terminating the connection between the SBS and MS, the SBS will schedule the scanning intervals or interleaving interval to MS. Finally, the MS sends MOB_SCN-

REP as a report message to the SBS[8]. In the scanning with association category, besides the MS scanning, some initial ranging must be done as shown in

Figure 6, hence the network re-entry process could be shortened further. The scanning process with association can be categorized into three types [8]:

- Association L0: Scan/association without coordination. The MS performs contention based ranging. If successful, the MS will receive success RNG-RSP.
- Association L1: Scan/association with coordination. The SBS informs MS the ranging code and transmission interval from each of the neighbours. Then, the MS will perform unicast ranging. If successful, the MS will receive success RNG-RSP.
- Association L2: The network-assisted association reports (same as L1 but MS does not wait for response). The nBSs send their responses to SBS. The SBS then aggregates these messages and sends one message to MS.

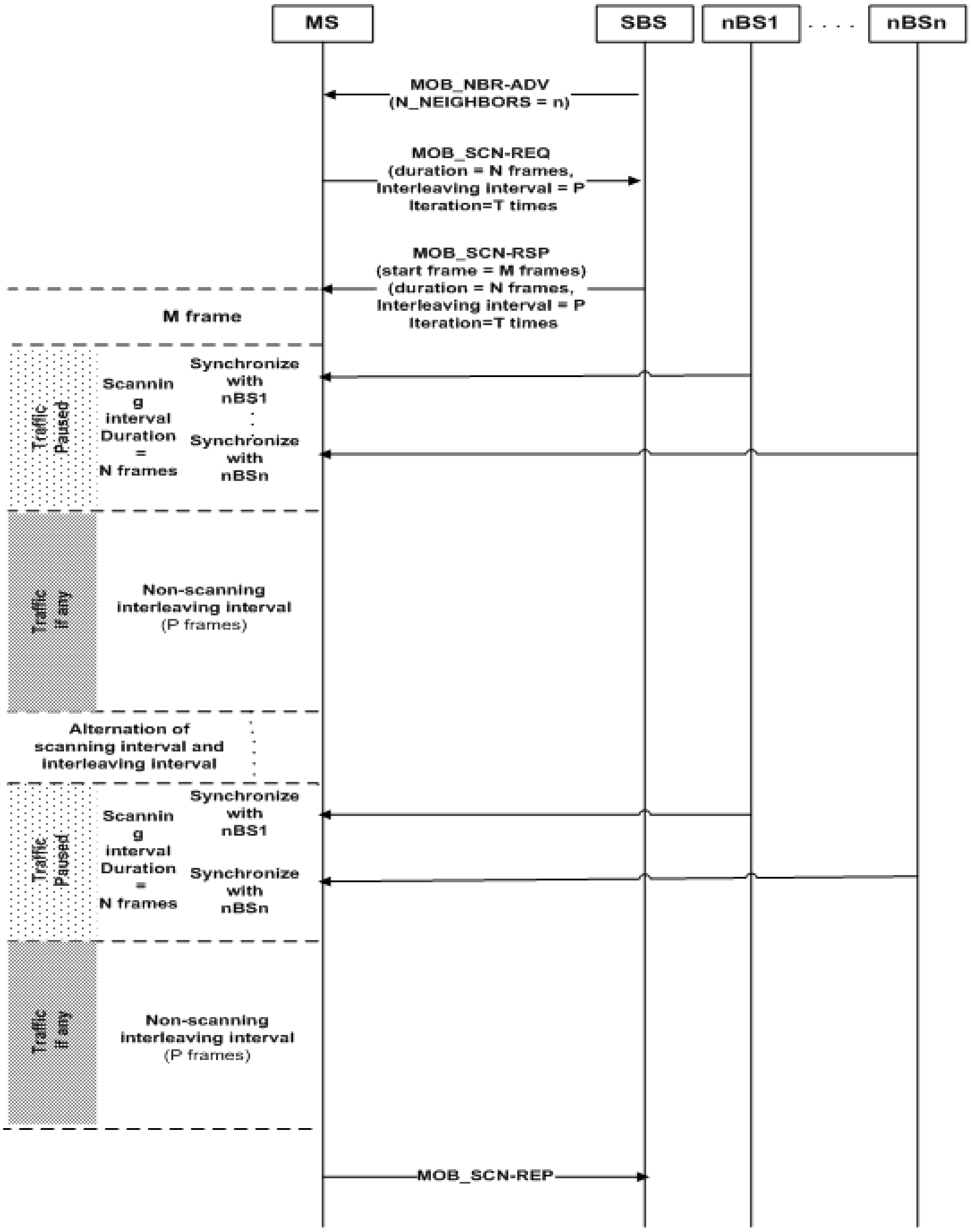


Figure 5: Scanning process without association procedure

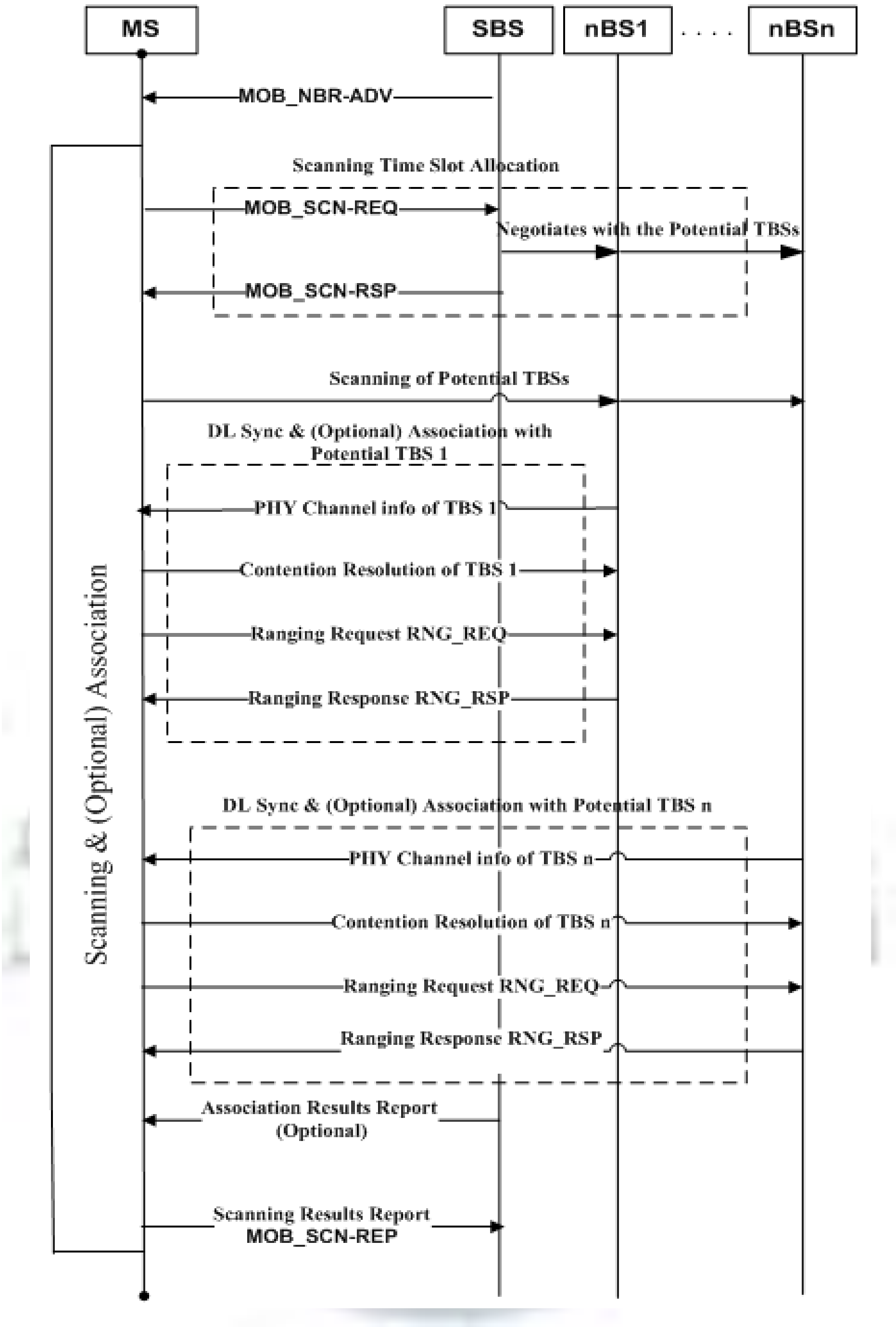


Figure 6: Scanning process with association procedure

2.3.3 Cell Selection

Cell reselection is a process to find a potential BS for handover. The MS has several possibilities to use while evaluating the possible change of the serving BS. It can exploit the information in neighbour advertisement messages (MOB_NBR-ADV). Additionally, the MS and the SBS can retrieve more information about the nBSs after the MS scanning stage. The conventional scheme of cell selection in mobile WiMAX is based on a single criteria which is signal quality. The nBS which has the best signal quality (e.g. RSSI or CINR) will be considered as the TBS for the coming handover [8].

2.3.4 Handover Decision and Initiation

The actual handoff begins when a decision is made that the MS changes the serving BS. The decision can be made at the MS, the BS, or on the network. However, the WiMAX profile defined MS triggering the handoverdecision as a mandatory process[2]. The goal of the handover decision phase is to check whether a handover is necessary or not.

After the scanning report is returned to the SBS, which includes some channel parameters such as CINR, received signal strength indicator (RSSI) and round-trip delay (RTD), the TBS will be selected in the cell through the reselection procedure based on these channel parameters. Nevertheless, RSSI metric is usually used as a handover trigger [2]. The conventional handover decision algorithm in mobile WiMAX is a single criterion approach which is usually based on the quality of signal or the received signal strength indicator (RSSI) while other handover parameters being fixed, handover threshold and handover margin [21]. The "margin" is used by the MS to make a decision whether a neighbour BS is suitable to be TBS. If the SBS's RSSI drops below the handover threshold, the neighbour BS is selected as a possible TBS, if its RSSI is larger than the sum of the RSSI of the current SBS plus a margin.

The start decision and initiation MAC message, MOB_MSHO-REQ which contains the information of the TBSs is sent out through either MS or SBS. After that, the SBS communicates with the TBS over the backbone to initiate the ranging opportunity for the MS. The MOB_BSHO-RSP message will then be sent by the SBS to the MS after the SBS receives the acknowledgement of handover from the TBS. The handover decision is confirmed with a MOB_HO-IND message[8]. The MOB_HO-IND is sent by the MS and it tells the BS whether the MS is really proceeding with the handover or not as shown in Figure 7.

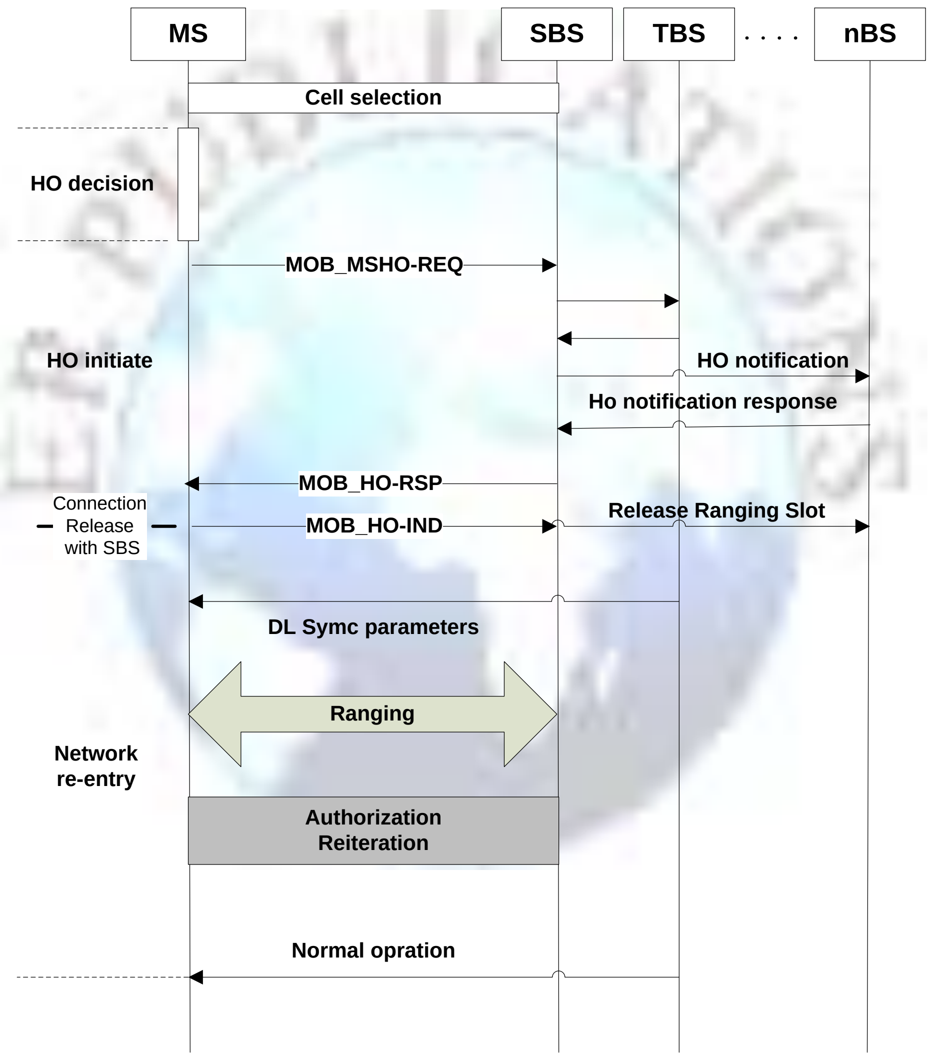


Figure 7: Handover decision and initiation procedure

2.3.5 Network Re-entry

After the TBS is chosen and the MS sent the MOB_HO-IND message to the SBS, the network re-entry process begins as illustrated inFigure 8. The network re-entry process includes ranging, re-authorization and re-registration. The MS needs to synchronize with downlink transmission and obtain downlink and uplink transmission parameters with TBS. Then the MS starts exchanging Ranging Request message (RNG-REQ) and Ranging Response message (RNG-RSP) to complete the initial ranging process[8]. This may be done contention-based or non-contention based. If RNG_REG contains the serving BSID, the target BS may obtain MS information from the serving BS through backbone network.

In addition, if MS is already associated with the target BS at the previous stage, some process may be shortened and we can avoid contention-based ranging. Therefore neighbouring BS scanning and association should be done close enough to handover initiation timing to utilize pre-obtained information before channel condition changes[6].

After the channel parameters have been adjusted, the MS can communicate with target BS to negotiate channel capability, perform authorization and conduct registration. The target BS requests MS authorization information from the Authorization server (AS) via backbone network. Then the new BS registration is performed with REG-REQ/RSP message. Processes including capabilities negotiation, MS authorization, key change, and registration can be abbreviated based on the association level[6].

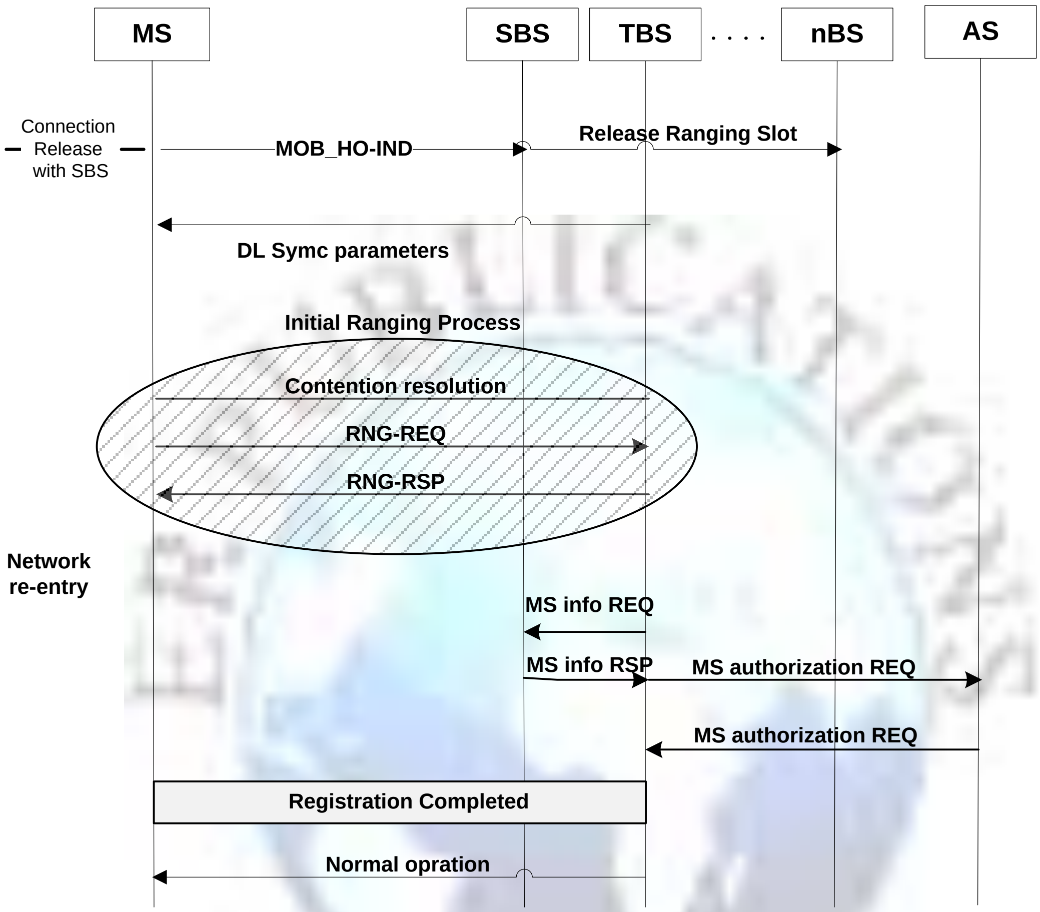


Figure 8: Handover network re-entry

3. Handover Phases Issues and Solution in Mobile WiMAX

As mentioned earlier, handover process can be divided into two main phases; the network topology acquisition phase also known as pre-handover phase, and the actual handover phase. The first phase includes the network topology advertisement with the neighboring BS scanning and association. The second phase consists of cell selection, handover decision and initiation, and network re-entry including ranging, authorization and re-registration [4] and each phase has some issues[11]. Some proposals to enhance these handover phases will be discussed in the following sub-sections and will be summarized inTable 6.

3.1 Excessive Handover Scanning Activities

In the conventional scanning scheme, the MS scan all the nBS to determine the most suitable nBS as a TBS for the coming potential handover. Due to the redundant or unnecessary scanning activities in the scanning phase, data transmissions will be paused, and this may cause handover delay and throughput degradation and signalling overhead. The scanning period, which is measured in terms of the number of frames, depends on the number of nBSs that must be scanned. This means that when the number of nBS increases the scanning period will increase proportionately. This issue will affect the continuity of multimedia application sessions [22]. To evaluate and analyse the effect of the number of nBS for the conventional and the proposed scanning schemes, an analytical model that has been utilised by [23] will be exploited. From the abovementioned expressions, it is noted that the handover scanning time is a proportional relation with the number of potential TBSs in all scanning types.

Several papers in the literature have proposed methods to optimize the scanning operation. The solutions can be categorized into two main research areas; either focusing on the scanning interval has to be performed [24-27], or reducing the frequency of scanning operations[22, 23, 28-38]. For the first category, An Adaptive Channel Scanning (ACS) algorithm has been introduced in [24] for IEEE 802.16e to estimate the total required scanning time by an MS. The scanning intervals are allocated to multiple MSs by interleaving them with the data transmission intervals. In addition, it maintains the QoS of the application traffic in the system. However, use of unlimited channel buffers in order to make the packet loss smallgives rise to the problem of channel resource wastage. In this scheme, rather than minimizing excessive scanning activities, it actually focuses on minimizing the disruptive effects of excessive scanning activities on the different application traffics.

Another paper in [25] proposes to reduce the time required for scanning operation. It is based on the history of the previous rounds of scanning and handovers and select only the most likely neighbour BSs for scanning based on historical records. However, this scheme is only applicable for the handover scenarios when the MS travels in some repeated paths, it is not applicable for the scenarios when the MS moves randomly. [26] proposes a scanning algorithm to optimize the scanning parameters, scan duration, interleaving interval and scan interval. It optimizes the scanning parameters value based on the MS velocity and BS density. Authors in [27] used movement prediction using fuzzy logic which allows the MS to perform pre-scanning before the actual handover. With the help of this prediction, the required amount of resources will be reserved for the upcoming handover at the TBS before handover initiation and execution.

For the second category, the effect of the redundant scanning activities has been analyzed and evaluated in [22], [29]-[30]. All these schemes try to minimize the scanning delay and reduce packet loss. Handover prediction techniques to reduce effect of redundant scanning have been introduced in a number of published works [31]-[37, 38]. They are mainly based on mobile location prediction to enhance the overall handover scanning performance. Mobile location prediction it is either consider the history records of the mobile movement during a schedule time like in [31], [32], [33] or consider some mobility parameters such as velocity, angle or direction to select the coming TBS [34], [35], [37], [36]. However, using history records to predict the mobile movement is only suitable for the handovers when the MS travels in some repeated paths and it is not general for the scenarios when the MS moving in irregular paths.

In some proposed aapproaches [22], [29], [23], [30], consider only a single nBS to be scanned and fast range in order to reduce the handover delay. The scheme in[31] suggest a single nBS scanning and fast ranging to reduce the handover delay. It suggests a fast and hybrid BS that controls the TBS selection based on MS movement history records and cell load. The scheme in [23] selects the a single nBS to be scanned based on the mean of "carrier to interference and noise ratio" (CINR) and the arrival time difference (ATD) of each nBS, before the handover scanning and association activities are made. In this scheme, an IEEE 802.16e-supported MS can get the nBS-related information from the broadcasted advertisements of SBS.

Also [30] predicts TBSs based on the required bandwidth and QoS. In both cases, scanning and ranging related activities are reduced, being limited only to the predicted TBSs. However, as this scheme does not consider the MS's movement direction, it might lead to unwanted ping-pong effect. In addition, scanning a single BS could lead to a problem when the TBS channel condition is changed and could not meet the end-user requirements, this leads to handover failure. In [32], [33] the authors proposed a fast handover scheme using location based mobility pattern table. Each MS maintains information about the previous and target BS and send it to the current BS by MAC (MO-HO_IND) message. Based on this message the current BS will update mobility pattern table and chooses the TBS based on the parameters in the table. Therefore, the MS will only scan for the possible BSs that meet the QoS in the table instead of scanning all the BSs. However, the BSs channel conditions and their respective QoS could have changed after the MS sent the information to the current BS.

Authors in [34], [35] proposed MS controlled fast handover based on self-tracking. It is based on the estimation of the distances between the MS and its nBSs based on RSS. However, this scheme may add computational cost in the MS to calculate the distance between its location and the nBSs. In addition, the authors in [28] and [37] proposed a location-aware scanning to reduce the number of scanning rounds. They used the arrival-time-difference (ATD) of DL-MAP messages from three nBSs to estimate the MS location. However, this scheme has to scan at least three nBS assuming that all nBS are synchronized. Moreover, authors in [36] proposed MS movement direction prediction based handover scanning algorithm. Based on the cell sectoring-zoning structure, and the MS position, the SBS will calculate the distance between the MS and the nBS. Using an accumulative distance (AD) function, the SBS can predict the MS movement direction. In this scheme, only two BSs can become candidates; the two that the MS moves toward them will be chosen as the candidate for the handover scanning purpose. However, this scheme did not evaluate the probability of the situation when real target BS is not scanned and handover fails.

3.2 Cell Selection

In the past, the earlier cellular systems concentrated on voice calls as the main application that has to be considered to fulfil end-user requirements. However, nowadays with the variety of the user application and their requirements, the new 3G/4G systems have to consider many applications such as voice calls, video streaming/conference, online gaming, peer-to-peer application and many other application and their different requirements as shown in Table 5[39], [2].

Table 5: WiMAX Application Types

	Application	Type	Bandwidth	Delay
1	Multiplayer Interactive Gaming	Real-time	50-85 kbps	<100 ms
2	VoIP & Video Conference	Real-time	4-64 kbps (VoIP) 32-384 kbps (Video call)	<150 ms
3	Streaming Media	Real-time	5-128 kbps (music) 20-348 kbps (video clip) >2 Mbps (movie streaming)	<300 ms
4	Web Browsing & Instant Messaging	Non real-time	<250 kbps (instant messaging) >500 kbps (email/web browsing)	N/A
5	Media Content Downloads	Non real-time	>1 Mbps	N/A

Cell selection is one of the main phases which may affect the user requirements after the handover process. The conventional cell selection scheme in Mobile WiMAX is based on signal quality, i.e. the nBS that has the best signal quality in terms of Received Signal Strength, will be considered as the TBS for the coming handover [8]. However, a single criterion like signal quality is not sufficient as a basis to choose the best BS for different end user application's requirements. As an illustration in Figure 9, suppose the MS is in an overlapping area of two or more BSs that have similar signal quality, there will be an ambiguity on which one will the MS choose for different user application requirements? Putting a cell selection criterion on signal quality entirely may make an MS choose a TBS with a good signal quality but one which may have high delay or smaller bandwidth, this may affect some real-time applications.

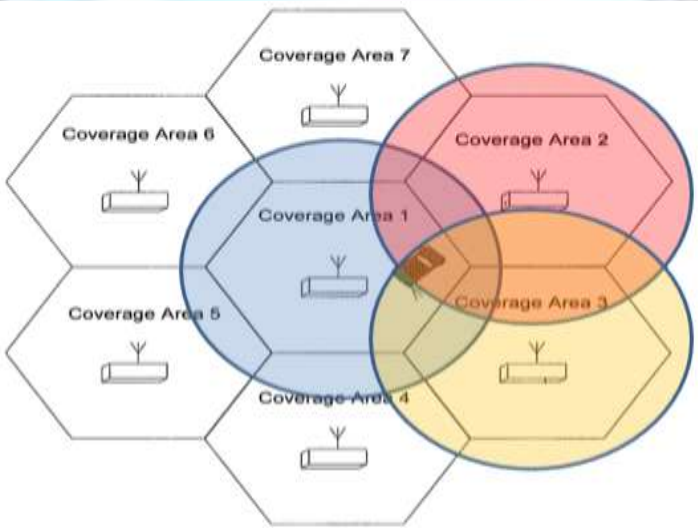


Figure 9: Cells overlapping

As mentioned earlier, some authors [23], [30], [35] proposed to identify the cell or the target BS before the scanning operation. However, choosing the TBS before scanning could lead to incorrect decisions, because the MS does not have all the information of the channel condition, QoS, and other physical information of the nBSs. On the other hand, the authors in[40], [41], [42]introduced an enhanced handover target cell selection algorithm based on the effective capacity estimation and neighbour advertisement. The algorithm let each BS to estimate its idle capacity and broadcasts its effective idle capacity via the MAC management message, MOB-NBR_ADV, to help each MS to select the handover target cell. Therefore, the cell selection algorithm uses two criteria, idle capacity and signal strength as a weighted cost function to select the target cell. However, other criteria such as the BS congestion delay or cell load are not considered as introduced in[43]. Because of the increasing number of MSs and the support of high speed Internet and multimedia data services, the base station (BS) of WiMAX often works at a data rate close to maximum capacity. Therefore, it is not proper to let the signal strength to be the only reference criteria to choose the next cell. The MSs should decide intelligently to switch to another idle cell to get the best channel in order to select a TBS that best meets the end-user application requirements.

3.3 The Efficiency of the Handover Decision

Mobile WiMAX supports small cell size and high mobility across the base station (BS) coverage in which MS will experience frequent handovers between BSs. Since handover criteria and handover decisions are key factors that determine a handover system efficiency, limited intelligence handover schemes may cause unnecessary handover (referred to as "ping pong" handover), handover failure, and handover delay which can affect some application sessions such as video conferencing, media streaming, and multiplayer interactive gaming. Some proposal have been introduced to optimize the handover decision scheme. MS velocity effect show a significant improvement in the handover performance. In [44], the mobility improved handover (MIHO) algorithm was presented, in which it causes the velocity-based handover decision with the assistance of a logarithm function. The results show that the velocity factor has an important influence on handover process. However, the presented logarithm function self-tunes the handover threshold, which is based on the MS velocity only, without considering the RSSI and handover margin. [45] proposes adaptive mobility handover (AMHO) scheme, based on the MS velocity the proposed scheme detect the suitable time for the handover trigger for each specific MS velocity.

Fuzzy logic is a useful approach to control and make decision in a situation when the system model and its behaviour are not clearly known. This has been adopted in [46] to enhance the handover decision to choose the best TBS. However, the paper only suggested the fuzzy logic approach to provide efficient switching between BSs but did not report any result. However, authors in [47] proposed fuzzy based self-adaptive handover to self-tune the handover parameters, threshold and margin based on multiple criteria, RSSI and MS velocity. [47]shows a significant enhancement of the WiMAX handover performance in terms of ping-pong handover and handover delay. [48] and [49] propose uplink and downlink channels quality based handover decision trigger. A handover process is triggered once the two signal strengths exceeds some pre-determined thresholds. The outage probabilities are reduced significantly. However, using multiple received signal strength indication (RSSI) thresholds for downlink and uplink signals have to be self-tune based on the user application. To maintain VoIP application quality over WiMAX, [50] proposes handover decision based on two criteria -- Carrier to Interference plus Noise Ratio (CINR) and an MS's queue length. It provides a better voice quality (MOS score) compared with conventional schemes but is does not consider the MS velocity effect and the handover parameters.

3.4 Network Re-entry

This is a critical phase in the handover procedure. In this phase, the connection between the MS and the SBS is totally disconnected after the MS sent the MOB_HO-IND message to the SBS. It should be as fast as possible to avoid service interruption. Many researches focus on handover execution and network re-entry phase, and how to perform the execution process with a small number of messages involved. [51] proposes an enhanced link-layer handover scheme for Mobile WiMAX, it reduces data transmission delay and packet loss probability for real-time downlink service during the handover. In this scheme, the downlink packet could be transmitted just after synchronization to the new downlink by introducing a Fast DL MAP IE MAC management message that enables an MS to receive downlink traffic even before the completion of the uplink synchronization phase. This proposal is efficient for downstream data such as video streaming. However, it is inefficient with uplink traffic, because it cannot reduce handover latency in the uplink (from MS to BS) direction, which is sensitive to interactive applications (e.g., VoIP).

A similar idea, [52] proposes a scheme to reduce handover latency for both downlink and uplink services. It proposes a fast handover scheme called Passport Handover by introducing a new Transport CID mapping strategy for real-time applications. In this scheme the connection CIDs assigned by the serving BS will be accepted by the handover target BS during the process of handing over until new CIDs are assigned, just as a passport used by a passenger when passing through the territory of a country. Therefore, the MS could resume the DL retransmissions with the TBS before the completion of the authorization procedures by using the CIDs of the previous SBS. However, this scheme assumes that the target BS allocates Fast Ranging IE for the MS handover and ignore if the MS fails to receive Fast-Ranging IE message. It should conduct contention based ranging process by transmitting the CDMA codes that introduce extra latency and they did not consider potential possibilities of unsuccessful authorization activities while switching domains.

Crossing-layering has also been introduced to speed up the network re-entry process [53], [54]. The authors in [53] propose cross-layer solution to reduces scanning/ranging latency and eliminating the network re-entry latency through cross-layer in mobile WiMAX. It uses layer 3 to transmit MAC control messages between the MS and the BS during the handover. It proposes the layer 3 to speed up the layer 2 handover. Although [53] uses layer 3, but it does not consider the IP handover (when the MS is going to be transferred to a target BS belonging to a different ASN-GW). Also [53] does not solve the predicating of the best target BS, so MS still has to execute scanning/ranging with every neighbouring BS and this adds to handover latency. Unlink [53], the authors in [54] considers the network handover (Mobile IP handover). They propose the so called "fast intra-network and cross-layer handover" or FINCH which performs intra-domain mobility management.

Table 6: Summary of some of the handover methods

Papers	Objective	Key Idea	Limitations
Rouil [24]	Optimizing Scanning Interval	In a multiple MSs andnBSs canexchange configuration parameters to figure out theideal scanning interval required	Temporary suspension of data exchange between the MS and the SBS during scanning degrade the overall handover performance.
Boone [25]	Reducing the time required for scanning operation	Exploiting the history of the previous rounds of scanning and the handovers and select only the most possible neighbour BSs.	It is only suitable for the handovers scenarios when the MS travel in some repeated paths.It is not general for the scenarios when the MS moving randomly
Ray [31]	TBS selection and reducing the number of the scanning activities.	MS can selectthe potential TBS before the scanning operations based on MS trajectory and load of nBSs	Scanning a single BS could lead to a problem when the TBS channel condition is changed and could not meet the end-user requirements, which leads to handover failure
Lee [23]	TBS selection and reducing the number of the scanning activities.	MS can selectthe potential TBS before the scanning operations based on the mean of CINR and ATD	Scanning a single BS could lead to a problem when the TBS channel condition is changed and could not meet and does not consider the MS's movement direction, it might lead to unwanted ping-pong effect
Choi [30]	TBS selection and reducing the number of the scanning activities.	MS predicts TBSs before the scanning operations based on the required bandwidth and QoS	Scanning a single BS could lead to a problem when the TBS channel condition is
Ray[34],[35]	Reducing the number of the scanning activities	MS controlled fast handover based on self-tracking, It is based on the estimation of the distances between the MS and its nBSs	This scheme may add computational cost in the MS to calculate the distance between its location and the nBSs.
Ben-Mubarak [36]	Reducing the number of the scanning activities	Using an accumulative distance (AD) function to predict the MS movement direction.	This scheme did not evaluate the probability of the situation when real target BS is not scanned and handover fails.
Lu[28], [37]	Reduce the number of the scanning rounds	Location-aware scanning to reduce the number of the scanning rounds. They used the arrival-time-difference (ATD) of DL-MAP messages from three nBSs to estimate the MS location	this scheme has to scan at least three nBS with assuming that all nBS are synchronized.
Shen [40]	Enhanced handover target cell selection algorithm	cell selection algorithm uses two criteria, idle capacity and signal strength	Other criteria are not considered such as the BS congestion delay
Anwar [44]	Optimize the handover decision	Velocity-based handover decision with the assistance of a logarithm function	Based on the MS velocity only, without considering the RSSI and handover margin
Ben-Mubarak [47]	Optimize the handover decision	RSSI and MS velocity based handover decision using fuzzy logic	Additionalcriteria could be used to optimize the handover decision.
Sunghyun [48] and Ji-Su [49]	Optimize the handover decision by Efficient Exploitation of DL and UL Signals	Propose uplink and downlink channels quality based HO decision trigger	Using multiple received signal strength indication (RSSI) thresholds for downlink and uplink signals have to be self-tune based on the user application
Niswar [50]	Optimize the handover decision	Proposes handover decision based on two criteria, CINR and MS's queue length.	does not consider the MS velocity effect and the handover parameters.
Choi [51]	Enhance Downlinks Streaming	Introduced a Fast DL MAP IE MAC management message, that enables an MS to receive downlink traffic even before the completion of the uplink synchronization	Inefficient with uplink traffic,
Jiao [52]	Reduce the HO Latency (Downlink Traffic & Uplink Traffic)	Passport Handover by introducing a new Transport CID mapping strategy for real-time applications.	Assumes the target BS allocates Fast Ranging IE for the MS handover and ignore if the MSS fails to receive Fast-Ranging IE message
Chen [53]	Eliminate the network re-entry latency	Cross-layer solution to reduces scanning/ranging latency	Executing scanning/ranging with every neighbouring BS and this issues a HO latency

4. Conclusion

Mobile WiMAX has been designed at the outset as a broadband access technology capable of delivering triple play services (voice, data and video). However, the HO operation is one of the critical operations in mobile WiMAX, which can influence the continuity of real-time applications over WiMAX. The HO mechanism is one of the most important research areas in the field of mobile WiMAX, and the goal of reducing the HO latency to support real-time applications should be pursued. This paper discussed the mobility feature in WiMAX and the handover procedure including the different phases, network advertisement, scanning, cell selection, handover initiation and decision, and network re-entry have been described in detail. It also reviewed related works from the literature on various handover mechanisms for WiMAX and discusses several issues and challenges facing mobility management along with an evaluation and comparison of several relevant mobility studies.

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