A Fast and Simple Scheme for Mobile Station-Controlled Handover in Mobile WiMAX

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Abstract. A Mobile Station (MS)-controlled fast and simple scheme of handover (HO) in Mobile WiMAX network has been described. An MS can roughly estimate its present distance from any neighbouring Base Stations (BS) using the Received Signal Strength (RSS) and an appropriate pathloss formula. From the Mobile Neighbor Advertisement (MOB_NBR-ADV) broadcasts, the MS periodically monitors the RSS of its Serving BS (SBS), chooses the appropriate times to perform few scanning of selected Neighbouring BSs (NBS) and estimates their changing distances to compute their respective angles of divergence from its own line of motion. The MS selects the NBS having the minimum angle of divergence (AOD), coupled with satisfactory quality of service and bandwidth capability, as its Target BS (TBS) and requests the SBS for executing this HO. Simulation studies show fairly reduced HO latency. MS-controlled HO promises greatly increased scalability for the Mobile WiMAX network.

Keywords: Handover in Mobile WiMAX; MS-controlled fast handover; distance estimation and lookahead handover; MS self-tracking; scalability improvement in Mobile WiMAX; Angle of Divergence; RSS-based Distance Estimation.

1 Introduction

Attractive features like high data rate, spectral efficiency, extended area coverage, and low cost are steadily increasing the deployment of Mobile WiMAX (IEEE 802.16e) networks. However, designing improved processes of HO remains an important area of research. HO is the process of transferring an ongoing connection of an MS from its current BS (SBS) to its next or would be SBS. It must be carried out fast, without causing any call break, and also efficiently, without consuming much of the network resources. After the various recommendations that were made in the Mobile WiMAX standard [1] and WiMAX Forum documents [2] regarding the parameters to be used,

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types of mobility to be considered, etc., in designing HO algorithms, a large number of different approaches toward performing HO have been suggested in the literature. A brief review of these will be provided in the next section.

In the present paper, we propose a fully MS-controlled fast and efficient Hard HO (HHO) scheme in Mobile WiMAX, by following the broad approach adopted by its precursor paper [3]. It is based on the concept of an MS estimating its present distances from its NBSs by utilizing their RSS and performing, using these distance estimates, an appropriate lookahead algorithm for selecting its TBS. Actually, with the knowledge of the RSS of its SBS and the NBSs and also knowledge of its own absolute velocity, the MS can itself ascertain its need of a HO, determine its relative velocity with respect to its NBSs, select the TBS and, finally, just request its SBS for handing it over to its selected TBS. This approach of RSS-based distance estimation followed by an appropriate lookahead technique was originally developed in connection with a Modified Distance Vector Routing (MDVR) algorithm [4] for use in Mobile Ad-Hoc Networks (MANET), which have no infrastructures like BSs, Access Points etc. Recently, this idea was used in a MS-controlled fast MAC-layer HO scheme [3] in Mobile WiMAX. The chief attraction of such simple MS-controlled HO techniques in Mobile WiMAX lies in the possibility of achieving enhanced scalability of Mobile WiMAX networks by distributing much of the HO-related work of each BS to the large number of MSs being served by it, without the MSs being much burdened either. As a matter of fact, the MS selects its TBS by virtue of two criteria: (i) meeting the bandwidth (BW) and quality of service (QoS) requirement for its ongoing call and (ii) showing the highest relative velocity with respect to it (i.e. the MS). Hence those NBSs that either do not meet the QoS-BW requirement or do not show at least a progressive or approaching relative velocity with respect to the MS are not even considered for (further) scanning. Because of greatly reduced scanning and ranging activities in this scheme, as compared to that in the Mobile WiMAX standard or many of the proposed HO schemes, the overall HO delay here is considerably reduced, thus improving the expected call drop performance.

The rest of this paper is organised as follows. The IEEE 802.16e HHO procedure and the HO-related research works are briefly reviewed in Section 2. Section 3 discusses the principle and implementation methodology of our new scheme. Section 4 presents the simulation details and the numerical results that have been obtained. Finally, the paper ends with some conclusions drawn in Section 5.

2 Mobile WiMAX HHO and Related Research Work

Although the Mobile WiMAX standard supports three types of HO procedures, namely, the HHO, the Macro Diversity HO (MDHO) and the Fast Base Station Switching (FBSS), the HHO is the default and the most commonly used procedure. The two main phases in the Mobile WiMAX HHO procedure [1] are the Network Topology Acquisition Phase (NTAP) and the Actual Handover Phase (AHOP). In Mobile WiMAX, the HO process is triggered when the strength of the signal received by the MS from its SBS drops below a certain threshold level. During the NTAP, the MS and the SBS, with the help of the backhaul network, jointly gather information about the underlying network topology before the actual HO decision is made. The

SBS, using MOB_NBR-ADV messages, periodically broadcasts information about the state of its neighbouring BSs. Based on these information, the MS performs repeated scanning and ranging activities with different available NBSs (irrespective of MS's movement direction and QoS and BW availabilities of the NBSs) before finally a suitable TBS is selected, with the active help of the SBS, for a potential HO activity. Several MAC management messages are exchanged between MS and SBS in the whole process. In AHOP, after the TBS has been finalized, the MS terminates its connection with the SBS by informing it with the help of a MOB_HO-IND (Mobile Handover Indication) message. Next, following a series of MAC management procedures between the MS and the TBS, involving synchronisation, ranging, authorization and registration, the MS becomes fully functional with the new SBS. A detailed description of the HO procedure can be found in [1].

The conventional Mobile WiMAX HO procedure has some important limitations. Prolonged scanning and ranging-related activities during NTAP cause much delay and create primary hindrances for delay-sensitive real-time applications. On the other hand, AHOP suffers from lengthy inter-HO gap because of the extensive network re-entry activities of an MS [5]. Recent 802.16e HHO-related research has focused mostly on attempts to reduce the disruptive effects of these constraints. The schemes proposed in [6-7] suggest prediction of TBSs before the scanning and ranging activities on the basis of different factors like BSs' coverage, MS's mobility direction, required bandwidth and QoS for HO, etc. In all cases, scanning and ranging related activities are sought to be reduced. Schemes proposed in [8] and [9], focus on minimizing the disruptive effects of Mobile WiMAX channel scanning activities during HO in case of different types of traffic and noise levels. Works related to reducing the handover latency by shortening the inter-HO gap during the AHOP were proposed in [10-12]. Recently, a cross-layer HO scheme based on the mobility prediction of the MS using the signal strengths of the BSs was proposed in [13]. The total HO latency here was reduced by initiating the layer-3 HO activities prior to the layer-2 HO activities. However, this movement prediction scheme did not reduce the MAC layer HO time.

It may be pointed out here that most of these proposed HO schemes in Mobile WiMAX are largely controlled by the SBS with possible assistance from the MS, the only exception probably being the cross-layer HO scheme [13], which is "MS-initiated". It must be recognized that an SBS controlling the HO of all MSs being served by it, creates the important problem of scalability owing to excessive load on the SBS. An MS-controlled HO arrangement where the MSs can themselves select, with acceptable power consumption, their respective TBSs (next SBSs) and then request the present SBS for effecting the actual HO process, via the backbone network, may provide a better alternative. In the MS-controlled HO scheme [3], the MS can, at any time, obtain a rough estimate of its present distance from any NBS using the measured value of the relevant RSS in an appropriate pathloss formula. Through periodic monitoring of the RSS of the SBS, the MS ascertains the need of a HO and then starts scanning only those NBSs, which have been chosen as "potential" TBSs. With a few scanning cycles, each yielding the latest distance estimates of the NBSs, the MS selects the NBS for which it has the highest relative velocity and requests the SBS to hand it over to this selected TBS.

3 Proposed MS-Controlled Fast HHO Scheme

Since the present paper shares the same broad approach towards achieving a fast HO in Mobile WiMAX that had guided its precursor paper [3], we first present a recapitulation of the salient points of this broad approach before describing the new lookahead technique for TBS selection that is proposed in this paper. The key idea [4] is that any station, fixed or mobile, in a wireless network can, at any time, roughly estimate its present distance from any neighbouring station, fixed or mobile, by measuring (after suitable and adequate signal processing like filtering etc.) the strength of the signal received from the latter and using this RSS information in an appropriate pathloss formula [14]. It may be pointed out here that the parameter Received Signal Strength Indicator (RSSI) used in conventional Mobile WiMAX handover framework is actually obtained after some filtering of the received carrier signal (to reduce the effect of random noise and fading) followed by computing its logarithm. However, in this paper we propose to use as the RSS the received carrier signal, only after the appropriate signal processing (to take care of random noise, fading, shadowing etc) but before computation of the logarithm. The idea of distance estimation using the RSS has also been recently investigated [15] for use in localization in WiMAX networks [16] and this study has yielded, along with a new empirical pathloss formula, encouraging results to establish RSS-based distance estimation as a viable alternative to the existing two methods, namely, use of (i) GPS-enabled receivers (expensive and power-hungry) and (ii) round-trip delay (RTD)/relative delay (RD) measurement (needs synchronization between BSs) [16]. Though a relatively inaccurate approach, the RSS-based distance estimation is simple and entails no cost. In this context, it was suggested in [3] that pre-computed values of the estimated distance d, for all possible values of the RSS and for several different pathloss formulae, can be pre-stored as RSS-Vs-d Tables (RSSVDT) in the memory of the computer inside the MS. This would allow the stored values of the estimated distance d to be retrieved immediately, without wastage of any computer time and battery power.

In order to efficiently manage its own HO process, the MS creates four conceptual zones by partitioning the dynamic range $[0, P_m]$ of the RSS through a suitable choice of 3 different levels of RSS power P, viz. P_1, P_2 and P_3 as shown in Figure 1. These zones are called the Zone of Normalcy (ZN), the Zone of Concern (ZC), the Zone of Emergency (ZE) and the Zone of Doom (ZD). The MS periodically monitors the RSS of its SBS via the MOB_NBR-ADV broadcasts [1] for identifying the zone it is presently in. Very little HO-related activity is needed in the ZN and, additionally, all HO-related activities (including those carried out by the BS after the MS has selected the TBS) should preferably be completed before the ZD is entered so that any call drop owing to poor RSS in the ZD and/or excessive HO delay becomes highly improbable.

Now, we are in a position to describe the proposed RSS-based distance estimation-cum-AOD-based lookahead technique that the MS performs for controlling its own HO. For the purpose of explanation, we assume that the MS has six NBSs, A, B, C, D, E and F, clustered around its SBS S and the MS is moving along the straight line XY (Figure 2) at any speed up to 120 km/hr. How the MS selects its TBS may now be explained as follows:

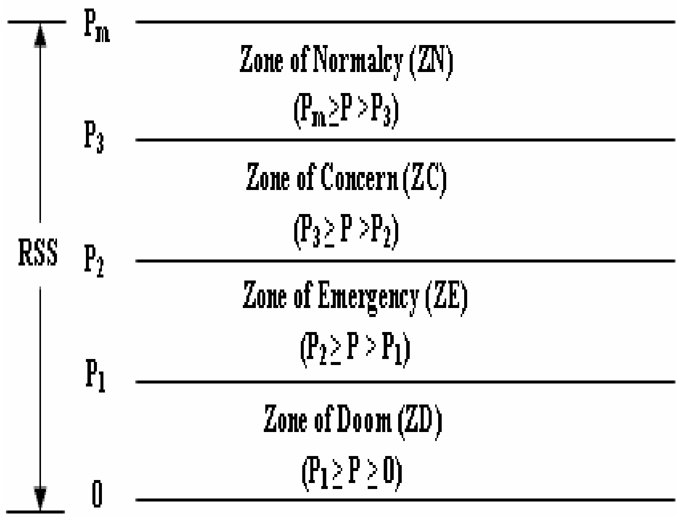

Fig. 1. Zones based on RSS levels

Step 1: During its stay in the ZN ($P_m \geq P > P_3$) where the MS receives high RSS P from its SBS, the MS creates, from the MOB_NBR-ADV broadcasts made by the SBS S, its set {A, C, D, E} of Potential TBSs (PTBS) by excluding those NBSs (B and F in our example) which do not have adequate QoS-BW capability to become a TBS. This screening not only reduces the number of PTBSs to be scanned but also removes any unfortunate possibility for the MS to receive a poor quality service after HO.

Step 2: When the MS enters the ZC ($P_3 \geq P > P_2$) after leaving the ZN, it starts receiving a power P from the SBS, which is "less than normal but still much higher than the Minimum Acceptable Signal Level (MASL)". So, in anticipation of the possible need for a HO, the MS, when it is at the point x (see Fig. 1) during its journey, it starts a scanning iteration for the four short-listed PTBSs in order to obtain the RSSs from them for the purpose of estimating their respective current distances d_A, d_C, d_D and d_E from it (i.e. from point x). Next, after the appropriately chosen period of time T seconds (this time T should be chosen depending on the current velocity of the MS) when the MS is at the point y on its line of motion, the MS starts a second scanning iteration for the four PTBSs (or less, if the RSS from any one was below the MASL) to estimate their respective changed distances d_A', d_C', d_D' and d_E'. At this point, we make an assumption that the motion of the MS is linear at least from the beginning of the first scanning iteration till the completion of the entire process of HO. This is probably not an unreasonable assumption for drives on the highways or important roads in urban areas, which are relatively straight, rather than being curved or zigzag over short stretches.

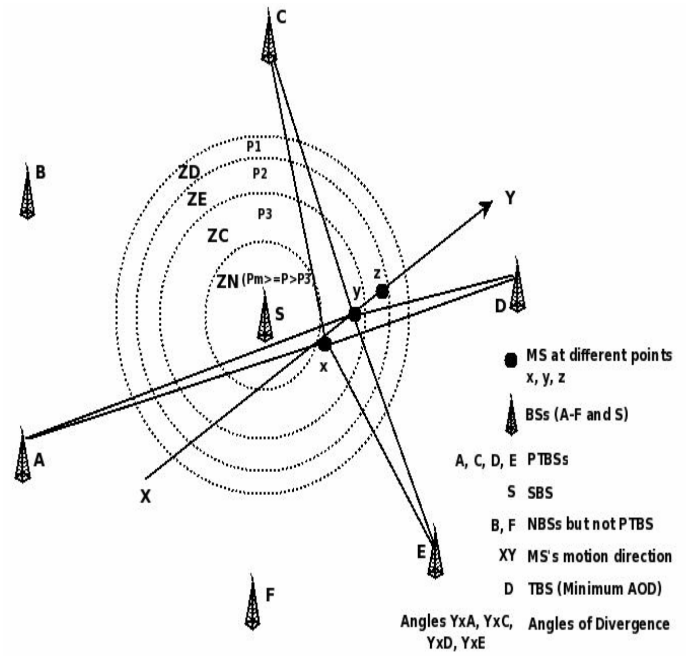

Fig. 2. Distance estimation-based lookahead scheme

Now it may be observed from Figure 2 that after the two scanning iterations, which have yielded a pair of distance samples for each PTBS, e.g. (Cx, Cy) for C, a triangle has been formed for each PTBS (e.g. Δ xCy for C), with all the four triangles standing on the same common side (base) xy which lies on the line of motion of the MS. More importantly, it should also be observed that the line of motion XY of the MS has created, at the point x, an AOD θ (e.g. angle Cxy) with each PTBS on each triangle. The AOD θ (0º ≤ θ ≤ 180º) characterizes the motion of the MS relative to the four (static) PTBSs as detailed in Table 1. W.r.t the table it should be mentioned that for value of θ = 0º and 180º, the concept of a triangle vanishes at these angles as the triangle becomes a straight line.

From the above, a looking ahead makes it obvious that the PTBS with the lowest value of θ promises to offer the strongest RSS to the MS in the near future and hence should be selected as the TBS. However, to do this, some means of identifying the PTBS having the minimum value of θ must be found out. This problem has been solved with the following three observations.

1. In each triangle, lengths of all the three sides are known. While lengths of two of the sides have been estimated through scanning and RSS measurement, length of the third (common) one can be computed as

$$\text{Length (xy)} = vT \tag{1}$$

where v, the average velocity of the MS during T, can be easily measured with simple instrumentation.

Table 1. θ Vs Characterization of MS's motion

Value of θ	Characterization of the motion of MS w.r.t. the PTBS
0º	MS is moving absolutely towards the PTBS, i.e. it has the highest possible progressive or forward movement towards the PTBS.
0º<θ<90º	The MS is moving towards the PTBS.
90º	Movement of the MS is tangential and cannot be characterized as either progressive or regressive w.r.t. the PTBS.
90º<θ<180º	The MS is moving away from the PTBS.
180º	The MS is moving absolutely away from the PTBS, i.e. it has the highest regressive or backward movement away from the PTBS.

2. If, inside each triangle, we build a right-angled triangle by making the common side xy its hypotenuse and dropping a perpendicular from y upon the side joining x with the PTBS, then, obviously, the PTBS with the lowest value of the AOD θ will have the highest value for COS θ.
3. From the well known "Law of Cosines" in Trigonometry, cosine of any angle of a triangle, whose all three sides are known, can be determined. For example, considering Δ Dxy in Fig. 2 (inspection tells us that D has the smallest θ = angle Dxy among the four PTBSs) and applying the Law of Cosines, we have

$$\text{COS}\ \theta = \{(Dx)^2 + (xy)^2 - (Dy)^2\} / \{2(Dx)(xy)\} \qquad (2)$$

Thus with four computations of Equation (2) and three comparisons between the four values of COS θ, the MS can select the TBS out of the four PTBSs. However, the MS does not make the final selection of the TBS at this time in keeping with the well known "look before you leap" dictum, which requires a last minute check. In the present case, the check is necessitated by the possibility that the selected MS may change its direction of motion even at the last moment so that a good standby PTBS would be welcome. Accordingly, two PTBSs, to be called Candidate TBSs (CTBS), are selected. The two must have the largest values of COS θ, show a progressive movement ($0^\circ \leq \theta < 90^\circ$) and have a signal level greater than the MASL.

Step 3: After reaching the ZE ($P_2 \geq P > P_1$), the MS finalizes its selection of the TBS from among the two CTBSs and then requests the SBS, through a MOB_HO-IND message [1], for executing an urgent HO by passing the ID of the selected TBS. As stated earlier, the HO process should preferably be completed before the MS enters the ZD. Now, in order to carry out the final selection of the TBS, the MS carries out a final scanning iteration for CTBS1 and CTBS2. CTBS1 is selected if it shows both a progressive movement (compared to its previous distance) and a signal level greater than MASL. Otherwise, CTBS2 is selected. The implicit assumption is that at least one of the two will hopefully maintain the trend that both had shown in the previous scanning. Figure 3 shows the implementing flowchart of the scheme.

4 Performance Evaluation

4.1 Simulation Scenario

The performance evaluation of the proposed HO scheme was done using the IEEE 802.16e OFDMA [14] model implemented in the Qualnet 4.5 Simulator [17]. The

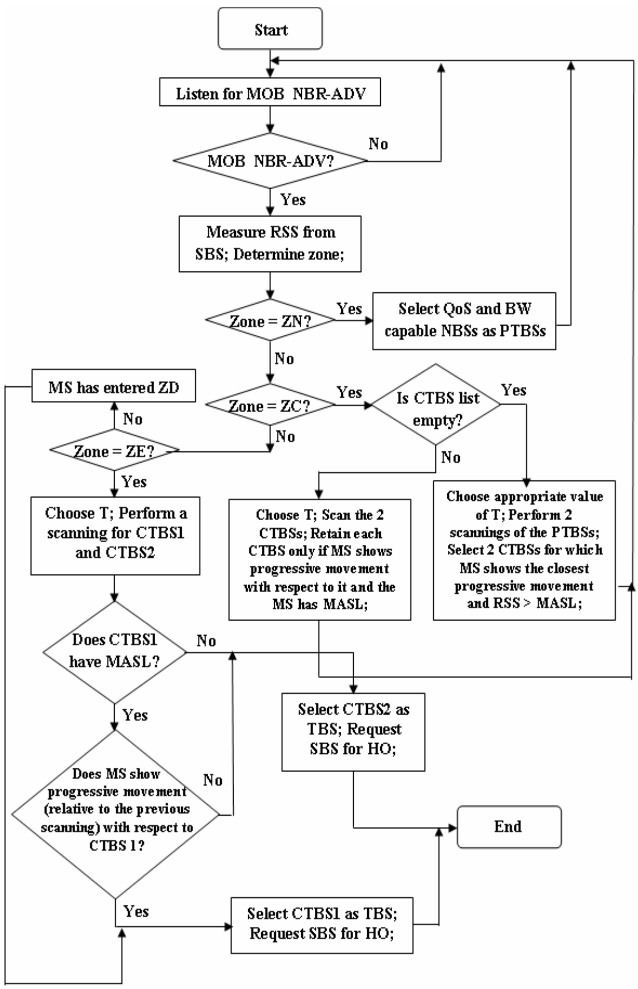

Fig. 3. Flowchart of proposed MAC-layer HHO scheme

simulation topology consists of 25 nodes spread over a 1500 m x 1500 m terrain. 6 of the nodes are the BSs (1 SBS and 5 NBSs) that are deployed in a multi-cell environment operating in the 2.4 GHz – 2.45 GHz band with different radio frequencies. One node is the Access Network Gateway (ASN-GW) whereas the remaining 18 nodes are the MSs, with 3 MSs per cell under each BS. The nature of traffic used in the simulation is CBR. As per our simulation model, a single MS, initially controlled by its SBS, is modelled to randomly move around between the BSs thereafter and perform a HO whenever needed during the course of the simulation. A Random Waypoint Mobility model [18] was used to model movements of the MS during simulations for different speeds, varying from 20 km/hr to 120 km/hr [13]. The two-ray path loss model [14] is used to incorporate the path loss effects during simulation. Table 2 lists the important simulation parameters that have been assumed according to the WiMAX forum specifications [19]. For our scheme, the BS signal values (in dBm) were converted to milliwatts. All the graphs shown in this Section depict results based on the method of multiple independent replications, on an average, each of which lasted for approximately 20 minutes (real time). The maximum relative statistical error is 7% at the 0.95 confidence level.

Table 2. Key simulation parameters

Parameters	Values
Number of BSs	6
Number of MSs	18
Number of cells	6
Bandwidth	10 MHz
FFT Size	1024
No. of Sub channels	30
MAC Propagation Delay	1 μs
VoIP Application Exists?	Yes
Environment Temperature (K)	290
Noise Factor (K)	10
Default Frame Length	20 ms
Signal Values (in dBm)	-76, -78, -80
BS Antenna Height	15 m
MS Antenna Height	1.5 m
QPSK Encoding Rate	0.5
BS Link Propagation Delay	1 ms
Scan Interleaving Interval	6 frames
Scan Iterations	3
MS's movement speed	20 kmph – 120 kmph

4.2 HO Latency Analysis

As was stated in Section 2, the overall HO time comprises of the sum of the NTAP time and the AHOP time. In contrast with the conventional Mobile WiMAX scheme where the MS carries out scanning and synchronization activities with all the advertised NBSs before short-listing a few, the overall NTAP latency in our scheme is much reduced due to much less scanning activities performed by the MS (see Section 3). So far as the AHOP time in the conventional HO scheme is concerned, prior to the synchronization, ranging, capability negotiation and authorization-registration times between the MS and the selected TBS, a major amount of time is consumed for HO preparation. The latter is concerned with the finalization of the ultimate TBS before the MS and the SBS jointly go for the HO. During this HO preparation time, the SBS exchanges a significant number of MAC management messages with the MS as well as with all the PTBSs to ensure that the MS would receive adequate QoS, BW and other relevant resources from its next SBS after HO. However, in our scheme, because the PTBSs are selected through inter-BS communication over the backbone network and, that too, prior to the scanning, the actual HO preparation time is omitted. This has led to a large reduction in AHOP time. Thus, there has been a significant reduction in the overall HO time.

Preliminary simulation results show that, in comparison with the conventional method, our scheme can reduce the NTAP delay by as much as 53% as shown in Figure 4. Also, as shown in Figure 5, for the overall MAC-layer HHO latency in our scheme, the reduction is as much as 49% compared to the conventional Mobile WiMAX scheme. Both for the pre-HO (i.e. NTAP) latency analysis and for the total HO latency analysis, simulations have been carried out for six different speeds of the MS, lying in the range of 20 - 120 km/hr.

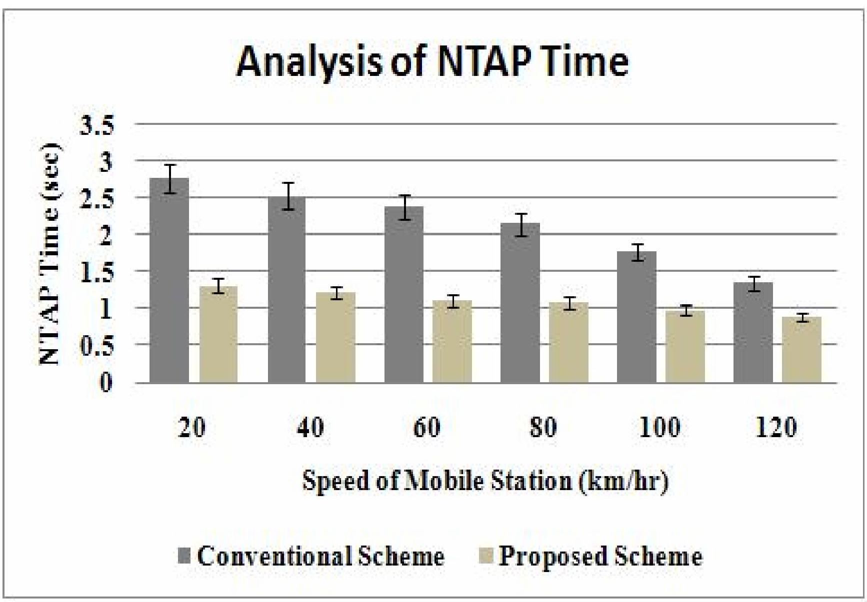

Fig. 4. Comparison of NTAP time

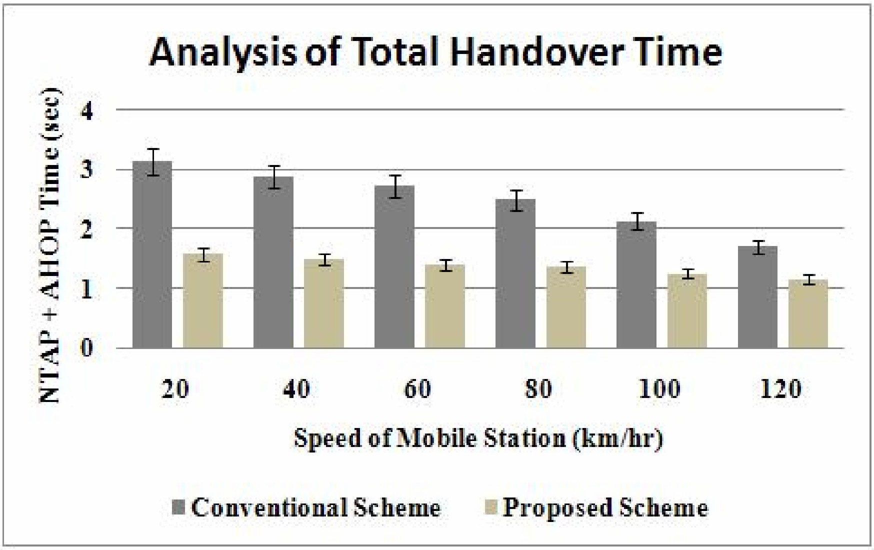

Fig. 5. Comparison of overall handover latency

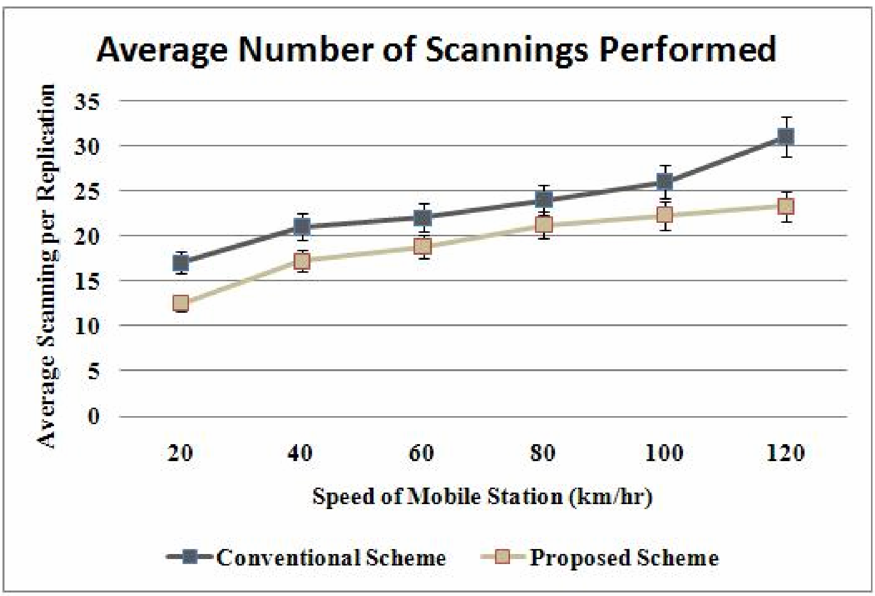

Fig. 6. Comparison of scannings per replication

4.3 Analysis of the Number of Scanning Performed

Figure 6 shows the result of comparison of the average number of scanning performed per replication, at different speeds of the MS. Clearly, scanning is much fewer in our scheme in comparison to the conventional Mobile WiMAX HO scheme. Again, this is because of avoidance of unnecessary scanning in our scheme.

5 Conclusion

An MS-controlled MAC-layer scheme for achieving a fast HHO in Mobile WiMAX networks, based on RSS-based distance estimation and relative velocity-based lookahead, has been described. There is a marked reduction in the overall HO latency because of the intelligent management by the MS of both NTAP and AHOP – the two main phases in the Mobile WiMAX HHO procedure. Aided by the concept of four zones, a good part of the HO-related jobs are completed even before the RSS from the SBS reaches the HO-threshold level. Intelligent short-listing of NBSs as PTBSs has considerably reduced the scanning overhead. Finally, the RSS-based estimation of the relative distances of the PTBSs from the MS and the lookahead based on angle of divergence from line of motion of the MS has enabled very authentic selection of the TBS. Besides a fast and efficient HO, an important contribution of the proposed MS-controlled HO scheme is the promise of enhancing the scalability of the Mobile WiMAX networks allowing each BS to serve a much larger number of MSs.

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