

A Novel Downlink Handover-Based Priority Scheduling for Providing Seamless Mobility and QoS in IEEE 802.16 BWA System

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Article Information	Abstract
Received: 27 April 2024 Revised: 18 June 2024 Accepted: 20 August 2024 Published online: 12 May 2025	In IEEE 802.16 wireless metropolitan area networks, users can take their broadband connections with them as they move from one location to another with different speeds. Thus, providing seamless handovers and QoS (Quality-of-Service) is challenging, especially for mobile subscribers at vehicular speeds. On the other hand, time variability and unpredictability of the wireless channel may cause QoS degradation and handover losses for these users. This paper proposes a new downlink handover-based priority scheduling scheme for different scheduling services which is providing lossless handovers and QoS. Taking the power degradation rates into consideration that enables monitoring users' locations, speeds and accelerations, this scheme assigns higher priority to the users having higher probability performing handover in the near future. An AMC (Adaptive Modulation and Coding) scheme and a pre-selection method are also proposed for providing high system performance, i.e., higher system throughput and lower packet dropping rate. The analytical results show the efficiency of proposed scheme.
Keywords AMC Handover IEEE 802.16 Quality of service Scheduling	
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1. Introduction

IEEE802.16 broadband wireless access (BWA) systems are providing multiple services for both fixed and mobile users [1]. In December 2005, the IEEE group completed and approved IEEE 802.16e-2005, an amendment to the IEEE 802.16-2004 standard that added mobility support [2]. The IEEE 802.16e-2005 standard defines a framework for supporting mobility management. In particular, the standard defines signaling mechanisms for tracking subscriber stations as they move from the coverage range of one BS (Base Station) to another when active or as they move from one paging group to another when idle. The standard has been developed in years, as in March 2018, this standard enables rapid worldwide deployment of innovative, cost-effective, and interoperable

multivendor broadband wireless access products, facilitates competition in broadband access and encourages consistent worldwide spectrum allocation [3].

In IEEE 802.16, the HO (Handover) process is defined as the set of procedures and decisions that enables an MS (Mobile Subscriber) to migrate from the air interface of one BS to the air interface of another. The standard also has protocols to enable a seamless handover of ongoing connections even for users at vehicular speeds up to 120kmph. IEEE 802.16 suggested a process in which BS allows each MS to monitor and measure the radio condition of the neighboring BSs called scanning. Three levels of associations can be performed for hand-over during scanning process, association level 0, 1 and 2. Association is an optional initial ranging procedure occurring during scanning interval with respect to one of the neighbor BSs. Also, the two optional handover mechanisms are FBSS (Fast BS Switching) and MDHO (Macro Diversity Handover). In both mechanisms the MS and the BS shall maintain a list of BSs that are involved in handover with the MS called the diversity set. During MDHO, MS communicates on the downlink and the uplink with all the BSs in the diversity set while in FBSS an MS communicates with one of the BSs in the diversity set called anchor BS.

Up to now, different handover schemes had been proposed. In [4, 5], fast handover schemes are presented. [4] proposed that a mobile subscriber station can receive downlink data before synchronization with uplink during handover which reduces data transmission delay and packet loss for real-time downlink service. In [5], it was proposed that algorithm can reduce handover operation delay by reducing unnecessary neighboring BS scanning. But [4] and [5] have not presented an efficient algorithm for other scheduling services; moreover, the optimization of delay performance is not the only object. Related investigations can be found in [6-8]. In [9], it was proposed performing different handover mechanisms for different scheduling services in order to guarantee delay and traffic performance during handover. However, it does not work on other QoS requirements such as handover failure and handover packet dropping rate. Finally, [10] proposed a handover priority scheduling algorithm which takes buffer occupancy and channel conditions into account. Thus, the system is able to provide low handover packet dropping rate. Nevertheless, [10] does not have a powerful mechanism detecting users mobility behaviors, e.g., employing power degradation level [11]. On the other hand, [12-15] proposed location management schemes, which studied random model for mobility estimation in wireless networks. In [16], a dynamic Mobility Anchor Point (MAP) discovery and selection scheme were proposed that adjusts the network topology structure to fit the vehicles' mobility environment better. A dual-connectivity handover scheme to enhance the transmission rate of the wireless links for a 5G-enabled ambulance is investigated in [17]. Although the mentioned schemes can enhance the successful probability of handover call, they have some complexity which may result in signaling and computational overhead.

In this paper, a downlink handover-based scheduling algorithm is proposed which is aiming at providing lossless handovers by reducing packet dropping probability and handover failures, while, guaranteeing users QoS necessities and high downlink throughput, concurrently. In this scheme, each MS using a scheduling service flow is monitored by its received power, speed and acceleration, as well as its QoS parameters. The scheduler gives higher priority to users who have more chance of performing handover process in the near future. Another scheduling algorithm is also proposed, namely, the optimized version of the first algorithm, which is picking high priority users more precisely by employing an averaging method. The second scheme provides lower handover packet dropping rate and reduces handover failures, since it decides on the users with transitional power fluctuations patiently with a careful scrutiny of these users' mobility behavior. An AMC scheme and a pre-selection

method are also proposed for providing high system performance, e.g., high downlink throughput. The pre-selection method guides the main scheduler selecting high priority users among the users with more packets in their queues. Therefore, the system provides low dropping probability and high through-put at the same time.

The remainder of this paper is organized as follows. The next section describes the handover procedure in IEEE 802.16. In section 3, we describe the implemented model used in this paper. The proposed scheduling algorithms are introduced in section 4. The AMC scheme and pre-selection method are described in section 5. In section 6, the simulation scenarios and results obtained by computer simulation are presented and discussed. Finally, we present our conclusion in the last section.

2. Handover Procedure in IEEE 802.16 System

The handover procedure in IEEE 802.16 has several steps as shown in Figure 1. The handover process in IEEE 802.16e is a multi-step procedure geared toward preserving seamless mobility and ensuring QoS during transfers between BSs. This entire process is, in general, subdivided into three major phases: cell reselection, hand-over preparation and handover execution.

2.1 Cell reselection and scanning

Under normal operating conditions, the MS is continuously monitoring the radio environment while scanning for its neighboring BSs. In fact, the serving BS regularly transmits MOB_NBR-ADV messages informing the MS about its neighboring BSs, including identifiers, channel parameters, and QoS capabilities. Using this information, the MS assesses the characteristics of alternative BSs for possible handover.

In the cell reselection phase, the MS scans and associates itself with neighboring BSs to determine their signal quality and service parameters. This enables the MS to ascertain its interest in triggering a handover to a candidate target BS. Once this evaluation has been completed, the MS resumes its normal traffic with the serving BS until it finally comes to a decision on whether to initiate a handover.

2.2 Handover decision and preparation

A handover is initiated when a decision is made for the MS to change from the serving BS to a target BS. This decision originates within either the target BS or the serving BS. The MS indicates its intention through a MOB_MSHO-REQ message to the serving BS; likewise, the serving BS could also initiate a handover by issuing a MOB_BSHO-REQ to the MS. Upon receipt of this request, the serving BS conducts negotiations with the candidate target BSs and gives feedback to the MS with a MOB_BSHO-RSP message that presents the options for recommended target BSs. In this preparation phase, the MS would also be able to initiate initial ranging with candidate BSs to help save time in the subsequent handover execution. As a final show of its intent to undergo handover, the MS sends a MOB_HO-IND message. This message has multiple usages: it executes the confirmation of handover initiation even though the handover could be cancelled/rejected if considered necessary. This guarantees that the MS was given a choice to cancel the whole conversion course until its execution.

2.3 Handover execution

Once the target BS is selected, the MS synchronizes itself to new downlink transmission. It performs initial ranging using the ranging channel for aligning its uplink timing and power levels with the target BS. If during the scanning period the MS has already associated with the target BS, the step would be shortened/ omitted. After ranging has

3. System Model

The model adopts an IEEE 802.16 BWA system. In having five handover mechanisms, it also accommodates five scheduling services to guarantee effective resource allocation and seamless mobility. This section provides a concise overview of the systems with respect to these mechanisms and services, illustrating their characteristics as well as contributions to system performance.

3.1 Handover mechanisms

The following are the handover mechanisms considered in the system model for ensuring continuous connectivity for mobile stations:

- **Hard Handover (HHO):** this means switching from one BS to another BS at once with an intersegment service interruption.
- **Fast Handover (FHO):** by pre-authenticating against potential target BSs, handover latency is minimized.
- **Macro-diversity Handover (MDHO):** The MS establishes synchronous links to multiple BSs before switching its connection to the target BS.
- **Seamless Handover (SHO):** Two connections are established so that service continuity is ensured in transferring between both serving and target BSs.
- **Predictive Handover (PHO):** This mechanism captures the essence of predictive algorithms based on signal strength signal measurements for forecasting the need for handover and proactively initiating this process.

Table 1 presents a brief summary of these handover mechanisms with their distinguishing features.

Table 1. Handover mechanisms in the system model

Handover Mechanism	Description	Primary Benefit
Hard Handover (HHO)	Immediate switch from serving BS to target BS	Simple implementation
Fast Handover (FHO)	Reduces latency by pre-authenticating with target BSs	Lower handover latency
Macro-diversity Handover (MDHO)	The MS communicates with multiple BSs simultaneously before switching to the target BS	Reliability
Seamless Handover (SHO)	Maintains connections with both serving and target BSs to ensure continuous service	Zero downtime during handover
Predictive Handover (PHO)	Initiates handover proactively based on signal strength prediction	Reduced latency and improved QoS

3.2 Scheduling services

Five scheduling services are defined in the system model according to different application requirements: Unsolicited Grant Service (UGS), real-time Polling Service (rtPS), Extended rtPS (ertPS), non-real-time Polling Service (nrtPS), and Best Effort (BE). Each of these scheduling services has a different set of Quality-of-Service attributes that define certain aspects of its behavior.

- **Unsolicited Grant Service (UGS):** For real-time traffic streams carrying fixed-size periodic data packets, e. g., T1/E1 and VoIP with no silence suppression.
- **Real-time Polling Service (rtPS):** This service is for real-time service flows carrying periods during which variable-size packets of data traverse, such as MPEG video.

- Extended rtPS: This service builds on both the use of UGS and rtPS. It is a variable data rate real-time application, for instance, VoIP with silence suppression. Still, it has a guaranteed data rate and delay.
- Non-real-time Polling Service (nrtPS): Delay-tolerant data streams such as FTP could best use this service requiring variable data grants at a minimum guaranteed rate.
- Best Effort (BE). Supports data streams like Web browsing and P2P not needing minimum service level guarantees.

The aforementioned services are classified into four service classes as per their priority, as clarified in detail in Table 2. This traffic classes are referred to as classes A, B, C, and D.

Table 2. Scheduling service classes with their priorities

Scheduling Service Classes (from highest priority to lowest)	UGS	rtPS, ertPS	nrtPS	BE
Maximum Sustained Rate	Yes	Yes	Yes	Yes
Minimum Reserved Rate	No	Yes	Yes	No
Maximum Latency Tolerance	Yes	Yes	No	No
Class-of-Service	A	B	C	D

4. Handover-Based Priority Scheduling Schemes

IEEE802.16 BWA systems should support the Simple Mobility and Full Mobility features. The subscriber may move at speeds up to 60 kmph with brief interruptions during handover in simple mobility while the system provides a seamless handover for an MS at speeds up to 120 kmph in full mobility. To meet these challenges, the system should prevent handover failures and reduce handover packet dropping, especially for subscribers at vehicular speeds using high priority scheduling services.

Figure 2 shows a pedestrian mobile user, MS1 and a mobile user at vehicular speed, namely MS2, while they are leaving their cells. Let us assume the users have the same distance from cell margins. Obviously, MS2 will need to change its serving Base Station, BS2 sooner than MS1. Thus, the system should give higher priority to MS2 for handover procedure, since it will reach cells overlap and pass it shortly. Otherwise, MS2 may experience high handover packet dropping or handover failure. On the other hand, MS1 has enough time to change its BS, since he is walking and spending more time in cells overlap. Therefore, the system can perform MS1 handover at its leisure time. Furthermore, IEEE 802.16 supports variant scheduling services. This makes the situation more challenging. Imagine that MS1 uses a BE scheduling service while MS2 is using Voice over IP. Consequently, giving handover priority to users is indispensable. In the most of proposed scheduling algorithms, there is no handover precedence between users such as MS1 and MS2.

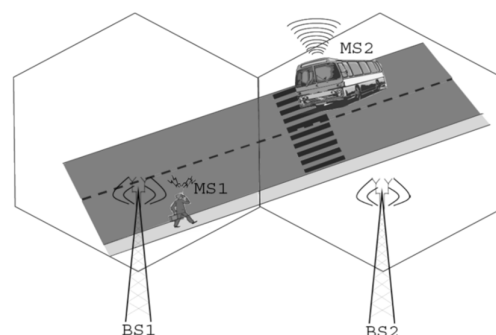


Figure 2. A two-cell IEEE802.16 system

Taking power degradation rate as an important parameter during handover process, this paper proposes a downlink handover priority scheduling algorithm, operating as follows:

A Handover Zone is defined, where the RSS (Received Signal Strength) received by an MS is between Handover Threshold and the MSL (Minimum Signal Level) value, as shown in Figure 3. By default, when an MS moving away from its serving BS e.g. BS1 to the target BS e.g. BS2, handover procedure is initiated a few moments, namely a guide time, after dropping the signal below the handover threshold. On the other hand, the system collects all the users who are transmitting or receiving at least one of MOB_MSHO-REQ, MOB_HO-IND or MOB_BSHO-REQ messages in handover zone. These users are collected and updated in Handover Zone Table. The update procedure for a given user is shown in Figure 4.

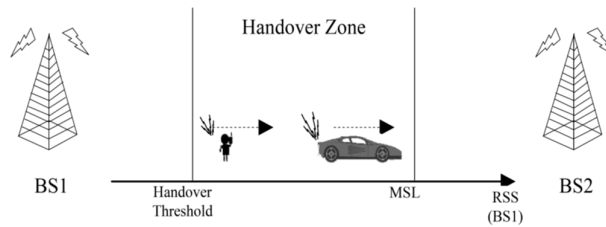


Figure 3. Handover zone

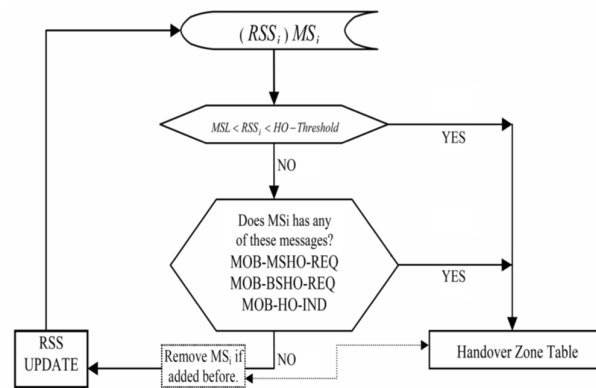


Figure 4. Update procedure of handover zone table

The handover procedure can be successful until the RSS is greater than MSL value; otherwise, link quality will not be acceptable and may cause handover failure, due to excessive packet loss. By default, the MSL value is greater in higher priority services and has direct relation with the expiration time of resource retain timer. Handover procedure is done with association level 2, which uses non-contention-based ranging. To provide the required QoS necessities of scheduling services, the Round Robin scheduling is applied.

4.1 Movement behavior function

In order to track received power transitions for a mobile user, e.g., MS_a using flow i , we define Movement Behavior Function as follows:

$$G_{i,n}^a(t) = \sum_{k=0}^n \alpha_{pk} \cdot \frac{d^k}{dt^k} RSS_i^a(t), \quad (1)$$

Where, $G_{i,n}^a(t)$ demonstrates the MBF (Movement Behavior Function) and $RSS_i^a(t)$ is the signal strength, received by MS_a at the time t . The coefficients α_{pk} are assumed constants and vary in different network

configurations and topologies. The MBF could locate MS_a by the first term ($\alpha_{p0} \cdot RSS_i^a(t)$), since $RSS_i^a(t)$ is a function of MS_a distance from its BS. Therefore, the MBF next two terms, namely $\alpha_{p1} \cdot d/dt(RSS_i^a(t))$ and $\alpha_{p2} \cdot d^2/dt^2(RSS_i^a(t))$, can detect the speed of MS_a and its acceleration, respectively, while the other terms declaring other movement characteristics. As it will be described later, we employ the users MBF in proposed scheduling scheme to analyze their movement behaviors, which helps the scheduler assigning proper priorities to service flows.

Note that the MBF will be more accurate if the coefficients α_{pk} are calculated more precisely. Increasing n will also enhance $G_{i,n}^a(t)$ precision. However, extensive computation is needed which increases system complexity. Since the proposed priority scheduling scheme has a *comparative basis*, the exact value of the users MBF is not requisite. Thus, a streamlined MBF structure with a few terms (reasonable n value) and constant coefficients (α_{pk}), is also applicable. We will use $G_{i,n}(t)$ for an unknown MS using flow i to show its MBF in the future.

4.2 Handover-based scheduling (HBS) algorithm

To provide lossless handovers, we propose a handover priority scheduling algorithm, which gives the priority value $P_i(t)$ to a given flow i , as follows:

$$P_i(t) = p_{SC_i} + G_{i,3}(t), \quad (2)$$

Where, p_{SC_i} is the service class priority of flow i , which can take different values for service classes A, B, C or D. By default, p_{SC_i} has greater value in higher priority services and has a principal effect on determining $P_i(t)$ in comparison with $G_{i,3}(t)$. That is, commonly, flows using higher level scheduling services, e.g., class B, have higher priority, $P_i(t)$, compared to those using lower-level scheduling services, e.g., class C, regardless of their $G_{i,3}(t)$ priority values. Since the scheduler operates under a *comparative basis*, setting $n=3$ will satisfy $G_{i,n}(t)$ precision. The scheduler serves service flow i with the highest $P_i(t)$, which is updated every T_p seconds. By default, T_p is equal to the expiration time of resource retain timer, called Resource_Retain_Time. Note that an MS is able to hold multiple flows at the same time. Assume that flows c and d belong to MS_a . We have:

$$G_{c,n}^a(t) = G_{d,n}^a(t). \quad (3)$$

Therefore, for a given user MS_a , the scheduler serves the flow with the highest p_{SC_i} first.

Considering three mobility behavior parameters, the scheduler assigns priorities to the flows, that is:

$$P_i(t) = p_{SC_i} + p_{RSS_i}(t) + p_{RSS_i'}(t) + p_{RSS_i''}(t), \quad (4)$$

Where, p_{RSS_i} , $p_{RSS_i'}$ and $p_{RSS_i''}$ are MBF priorities, which are calculated as follows:

$$p_{RSS_i}(t) = \alpha_{p0} \cdot RSS_i(t), \quad (5)$$

$$p_{RSS_i'}(t) = \alpha_{p1} \cdot \frac{d}{dt} RSS_i(t), \quad (6)$$

$$p_{RSS_i''}(t) = \alpha_{p2} \cdot \frac{d^2}{dt^2} RSS_i(t). \quad (7)$$

α_{p0}, α_{p1} and α_{p2} are prioritization constants, which cause (5) to (7) have greater impact on $P_i(t)$, respectively ($|\alpha_{p0}| > |\alpha_{p1}| > |\alpha_{p2}|$). They are currently chosen experimentally. The MBF priority terms $p_{RSS_i}, p_{RSS'_i}$ and $p_{RSS''_i}$ are multiplied by 0.1 for mobile users who are out of handover zone, called Normal Users. Thus, commonly the scheduler serves normal users with lower priority than users in handover zone. On the other hand, $G_{i,3}(t)$ has a vital effect on users in handover zone, while they are trying to obtain higher priority, compared to normal users and also each other. The proposed algorithm gives the MBF priorities to users in handover zone as follows:

- Giving higher $p_{RSS_i}(t)$ priority to users with lower RSS ($\alpha_{p0} < 0$).
- Users with higher speeds obtain higher $p_{RSS'_i}(t)$ priority.
- Higher $p_{RSS''_i}(t)$ priority is given to users who have higher growth of speed, i.e., higher accelerations.

Note that $RSS_i^a(t)$ can locate MS_a position and $d/dt(RSS_i^a(t))$ can monitor its speed in handover zone. The term $d^2/dt^2(RSS_i^a(t))$ helps with the priority expression to be more accurate by monitoring MS_a acceleration.

4.3 Average handover-based scheduling (AHBS) algorithm

As we know, power-level fluctuations can occur due to mobility, fast fading and shadow fading or any combination thereof. Generally, a user with these power fluctuations needs to perform a handover procedure in order to maintain its connection quality. However, in some cases, power fluctuations are momentarily and there is no need to perform handover procedures for such users since their RSS will become acceptable before long. In order to remove these users from high priority users, we replace the HBS scheme with Average Handover-based Scheduling (AHBS) scheme. The AHBS algorithm assigns the priority, $P_{i_{avg}}^n$, to the users which is calculated with the following formula:

$$P_{i_{avg}}^n = \delta P_i^n + (1 - \delta) P_{i_{avg}}^{n-1} = \delta \cdot \sum_{j=0}^n (1 - \delta)^j \cdot P_i^{n-j}, \quad (8)$$

where, n is a non-negative integer and P_i^n is calculated as follows:

$$P_i^n = P_i(t) \Big|_{t=nT_p}. \quad (9)$$

Here $P_i(t)$ is the priority assigned to the flows by the HBS scheme. Therefore, by substituting (4) to (8) we get:

$$P_{i_{avg}}^n = p_{SC_i} + \delta \cdot \sum_{j=0}^n (1 - \delta)^j \cdot p_{RSS_i}^{n-j} + \delta \cdot \sum_{j=0}^n (1 - \delta)^j \cdot p_{RSS'_i}^{n-j} + \delta \cdot \sum_{j=0}^n (1 - \delta)^j \cdot p_{RSS''_i}^{n-j} \quad (10)$$

where δ is a constant between 0 and 1, which depends on the amount of signal variation (e.g., kind of shadowing). It is currently chosen experimentally. $P_{RSS_i}^n, P_{RSS'_i}^n$ and $P_{RSS''_i}^n$ are the sampled values of (5) to (7) at $t = nT_p$, respectively. Note that p_{SC_i} remains unchanged during averaging, since it is time-invariant. Comparing (4) with (10) we can write $P_{i_{avg}}^n$ as follows:

$$P_{i_{avg}}^n = p_{SC_i} + P_{RSS_i}^n(avg) + P_{RSS'_i}^n(avg) + P_{RSS''_i}^n(avg), \quad (11)$$

That is, the optimized scheduling algorithm, AHBS, assigns averaged priorities considering mean values of $P_{RSS_i}^n, P_{RSS'_i}^n$ and $P_{RSS''_i}^n$. Therefore, it has more accuracy while selecting and prioritizing *handover zone users*, since:

- The AHBS algorithm eliminates normal users with transitional power-level fluctuations, which may cause little interruptions, from handover zone users by averaging their received powers and assigning $P_{rss(avg)}^n$ priority.
- Moreover, the handover zone users, who have high RSSs above Handover Threshold during a short period, are kept in handover zone table. The AHBS scheduler ignores these power transitions by giving $P_{rss(avg)}^n$ priority to users.
- Calculating the *averaged* speeds and accelerations, the AHBS scheduler assigns $P_{rss^l(avg)}^n$ and $P_{rss^f(avg)}^n$ priorities to handover zone users more precisely, compared to HBS. Thus, users with temporary high speeds/accelerations achieve lower P_{low}^n than real high speed/acceleration users.

Figure 5 shows the RSS of an MS while it is leaving its base station in an empirical IEEE 802.16 BWA system. Obviously, MS is entering the handover zone at the time t_0 for the first time. Although the received power fluctuates around the Handover threshold, but MS is often receiving acceptable power until t_1 . Using the averaging method, the AHBS scheduler assumes the link quality is admissible. Thus, the MS is not added to handover zone table over this time scale. The scheduler gives high priority to MS after t_1 , since the mean RSS is going down to handover zone after this time. The MS sometimes receives high power after t_1 and these transitions continue until the time t_2 . However, the MS is assumed to be a handover zone user over this time scale, since the AHBS scheduler considers previous values of P_t^n while assigning priorities. On the other hand, during t_0 to t_1 , the HBS scheme may add the MS to handover zone table several times, while some real handover zone users may be neglected getting lower priorities. Moreover, the MS may sometimes be removed from high priority users over the next time scale, t_1 to t_2 , which may cause high handover packet dropping rate or even handover failure. It is because; the HBS algorithm considers users current received powers.

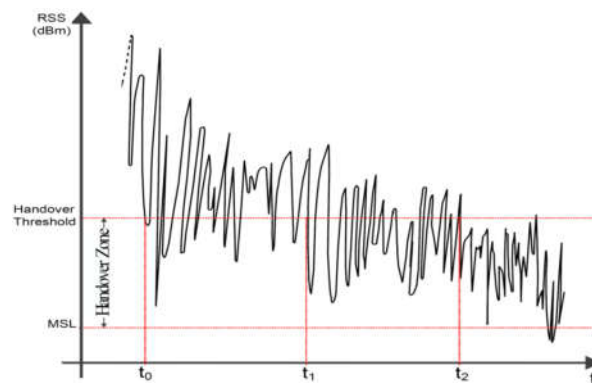


Figure 5. The MS received power in an empirical IEEE 802.16 model

Correspondingly, the AHBS scheduler monitors the averaged speed and acceleration of an MS after adding it to handover zone table. Since the vehicular mobile users in urban and suburban environments often have dissimilar speeds and accelerations, assigning $P_{rss^l(avg)}^n$ and $P_{rss^f(avg)}^n$ priorities could help deserving mobile users, e.g., vehicular users in freeways, getting higher priorities.

4.4 Implementation complexity and practical considerations

The proposed AHBS scheme needs to monitor received power, velocity, and acceleration for each mobile station parameters already monitored by the standard mobility management framework of IEEE 802.16e. The rest of the computation overhead mainly comes from computing the weight factors for handover priority score, which is the weighted sum of power degradation rate, velocity, and acceleration:

$$\text{Priority Score} = \alpha P_{deg} + \beta v + \gamma a, \quad (12)$$

where P_{deg} is the power degradation rate, v is velocity, a is acceleration, and α, β, γ are configurable weights. To reduce further complexities, the scheduler monitors only those users whose signal output exceeds a predetermined value, such as, RSSI $<$ -85 dBm and directs computational resources to those users since they are most likely to handover. Lookup tables are used for CQI thresholds and precomputed modulation boundaries to reduce real-time computations. In real scenarios, such operations can be easily accomplished using modern baseband processors; more acceleration can be achieved through hardware accelerators that use existing DSP or FPGA cores. From simulation profiling under a hundred-user scenario, it is evident that the AHBS algorithm raises CPU load by less than 15% when compared to traditional scheduling processes, which is manageable within today's conditions of base stations.

5. Adaptive Modulation and Coding Scheme and the Pre-Selection Method

In order to provide a high downlink throughput while reducing the packet dropping rate at the same time, we propose two schemes, namely an AMC and a pre-selection method operating as follows:

5.1 Adaptive modulation and coding

An AMC scheme is applied in order to compensate for downlink channel fluctuations during transmission. The scheme enables the system to transmit with higher data rates in good channel conditions and avoids excessive packet dropping in poor channel conditions by reducing data rate. Therefore, efficient bandwidth utilization and high throughput can be achieved.

Since the priority-based scheduling algorithms commonly reduce system throughput by prioritizing the users, the proposed AMC can compensate for the throughput reduction. It enables the scheduler to select the appropriate coding and modulation for each allocation. Thus, low packet dropping rates and better throughput are provided, especially for handover zone users, since they regularly have poor channel conditions.

Table 3. AMC Schemes and Receiver SNR Assumptions

Modulation	Coding Rate	Receiver SNR (dB)
BPSK	1/2	3
QPSK	1/2	6
	3/4	8.5
16-QAM	1/2	11.5
	3/4	15
64-QAM	2/3	19
	3/4	21

Several AMC schemes are proposed, namely, 16-state and 64-state Quadrature Amplitude Modulation (QAM), Quadrature Phase Shift Keying (QPSK) and Binary Phase Shift Keying (BPSK) with coding rates of 1/2, 2/3 and 3/4, as shown in Table 3. The system can achieve very high data rates by using 64-QAM with rate 3/4 in good channel quality while it can reduce data rate by using BPSK in poor channel conditions.

5.1.1 Implementation

An AMC function based on a 4-bit CQI index, as given in IEEE 802.16e, allows the efficient mapping of 16 modulations and coding states. The thresholds for switching between modulation schemes (e.g., QPSK to 16QAM at SNR = 14 dB; 16QAM to 64QAM at SNR = 20 dB) are stored in lookup tables. This operation is lightweight, and the base station's signal processing units can execute it in real time.

5.2 Pre-selection method

In order to provide a high system throughput and reduce packet dropping rate, low dropping probability (LDROP) scheduling algorithm [18], which considers buffer occupancy and channel conditions is applied. The LDROP algorithm assigns higher priority to the users, who (will) have more packets in their queues and eliminates the users with empty buffers. The system collects p percent of high priority flows picked by LDROP scheduler and consigns them to the main scheduler, namely HBS/AHBS, for final prioritization. The minimum value of p is set to 60. The pre-selection process is updated every T_p seconds. Therefore, the HBS/AHBS scheduler provides lossless handovers without reducing system throughput since it can only choose the users with copious packets in their queues or those who are prone to be in this situation in the near future.

6. Performance Results

6.1 Simulation model

A discrete event simulation program written in NS2 [19] and C++ has been designed for simulating IEEE 802.16 BWA networks. The system is a Time Division Duplexing (TDD) with frame length of 5ms. The model has 20 cells, supporting scanning, and handovers. Mobile users have different speeds of the range from 0 km/h to 120 km/h while using four scheduling services. Speed changing method is following a uniform distribution. Multipath fading and shadowing effect are also included. Total bandwidth is divided equally between four scheduling services. Simulation parameters are shown in Table 4.

Table 4. Simulation parameters

Parameter	Value
Channel Bandwidth	10MHz
Duplexing Mode	TDD
Frame Duration	5ms
Scan Iteration	2
Cell Radius	500m
Number of Cells	20
Number of MSs	0-90
User Mobility Speed	0-120kmph
Modulation Scheme	BPSK,QPSK,16QAM, 64QAM
Pathloss model	Suburban COST 231 Hata model
Shadowing	Log-normal zero mean, 8dB stdev

6.2 Simulation results

In order to evaluate the performance of proposed handover scheduling schemes, this paper studies two handover metrics, namely handover packet dropping and handover failure probability. We also investigate the performance of system throughput during simulation. For every 5s interval, performance results are updated and the mean value is calculated after the simulation progress.

Three simulation scenarios are performed. In the first one, we want to evaluate the impact of movement behavior function in providing lossless handovers. Therefore, we compare the performance of the proposed handover scheduling algorithm, namely HBS, and the Round Robin (RR) scheduling algorithm, while prioritization constants, α_{p0} , α_{p1} and α_{p2} , are set to zero for all mobile users in second algorithm. In the second scenario, we will compare HBS algorithm with a conventional IEEE 802.16 scheduling algorithm, namely Proportional Fairness (PF). Finally, we would like to investigate the performance of our optimized scheduling algorithm, namely AHBS, and also compare the throughput performance of the aforementioned scheduling algorithms together.

6.2.1 Scenario I

Figure 6 shows the performance of the handover packet dropping rate, which is defined as follows:

$$P_{HO-dropping} = \frac{\text{number-of-dropping-packets}}{\text{total-number-of-generated-packets}}. \quad (13)$$

Since, the HBS algorithm assigns higher priority to the users who are in the handover zone, decreasing the number of dropping packets is foreseeable. The RR scheme does not consider mobility parameters; thus, all mobile users are served in the same way, regardless of their locations, speeds and accelerations. Therefore, handover zone users are constrained to wait more time to be served, which causes higher packet dropping rate. When the instantaneous number of mobile users increases, there are many users in the handover zone and more handover procedures occur. The HBS algorithm assigns higher priority to users in handover zone, while there are many other flows with full buffers in system which may need to be handed over in the near future. Thus, the HBS scheme provides higher dropping rate in very high system load.

Figure 7 shows handover failure probabilities in mentioned scenario. The proposed algorithm, HBS, has better performance, since it gives higher priority to the users who are in handover zone. As the number of mobile users increases, more users get involved in handover procedures. Therefore, when the system load is very high, both algorithms have almost the same handover failure probabilities, because the system has to perform too many handovers at the same time, regardless of user's priorities. Note that high system loads do not occur regularly and the system may use other scheduling algorithms in such situations.

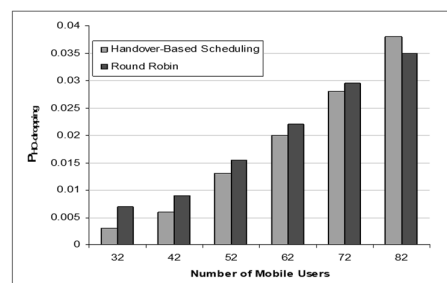


Figure 6. Handover packet dropping probabilities (scenario I)

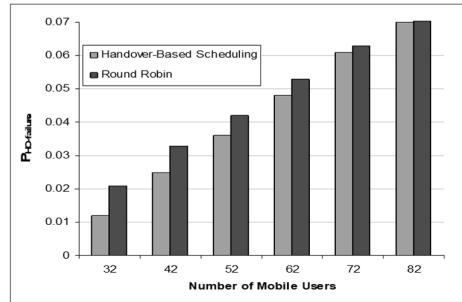


Figure 7. Handover failure probabilities (scenario I)

6.2.2 Scenario II

In order to evaluate the performance of the proposed scheduling algorithm, HBS, especially in an IEEE 802.16 BWA system, we would like to compare this algorithm with an IEEE 802.16 prevailing scheduling algorithm, namely PF [20, 21]. The PF scheduler selects MS_a if it has the highest $R_a(t)/T_a(t)$ for packet transmission. $R_a(t)$ denotes MS_a instantaneous data rate at time t . $T_a(t)$ is the average throughput of MS_a up to time slot t which is updated as follows:

$$T_a(t+1) = \left(1 - \frac{1}{t_c}\right)T_a(t) + \frac{1}{t_c}R_a(t). \quad (14)$$

Here, t_c is the latency parameter, which is set between 10 and 15. Figures 8 and 9 show the handover packet dropping rate and handover failure for the mentioned algorithms. The HBS algorithm outperforms the PF algorithm in both simulation results. Since the PF scheduler selects the user with the highest $R(t)/T(t)$, some of the users with bad channels, e.g., newcomer handover zone users, are unlikely to be selected. Moreover, the PF scheduler gives the mobile users fair priorities and does not consider the users received signal qualities, speeds and accelerations. On the other hand, the HBS algorithm assigns higher priority to handover zone users, especially vehicular users in overlap areas. Therefore, these users can discharge their buffers before performing handovers, which results in lower handover packet dropping rate and subsequently less handover failures. However, when the system has too many mobile users, namely high system load, the PF algorithm has better performance. The reason is that the HBS algorithm is a preemptive scheme and it gives high priority to handover zone users, while there are many other users with full queues who are waiting to be served. Whereas, the PF scheduler permits all users, e.g. users with full buffers, for packet transmission without considering they are inside or outside the handover zone. That results in a better performance with PF scheme in very high system load.

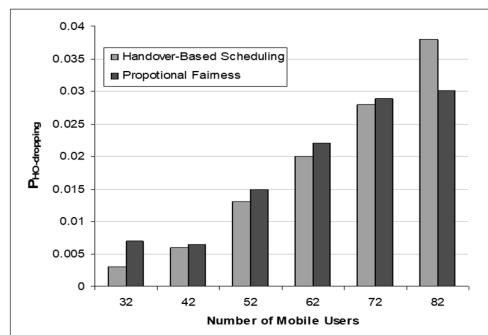


Figure 8. Handover packet dropping probabilities (scenario II)

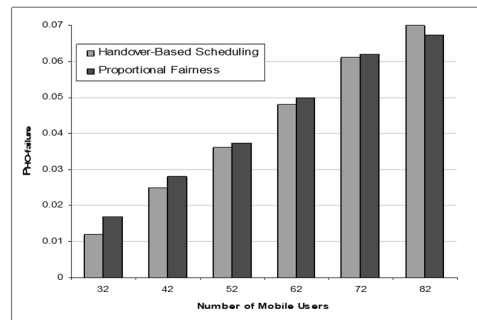


Figure 9. Handover failure probabilities (scenario II)

6.2.3 Scenario III

The impact of assigning averaged priorities on handover metrics are investigated in this scenario. As shown in Figures 10 and 11, the AHBS scheme has a better performance since it gives high priority to the deserving service flows by sifting out the real handover zone users from normal users. δ is set to 0.25, so that the AHBS scheduler could monitor the users power degradations in an extended period. Therefore, the scheduler eliminates normal users with transitional power fluctuations from high priority users. Moreover, it keeps the handover zone users with evanescent high RSSs in handover zone table. On the other hand, the HBS serves a small number of normal users hastily as it feels they are handover zone users. Further, it may eliminate some deserving users with temporary high RSSs from handover zone table. Consequently, some deserving users in handover zone may be neglected by the HBS scheme, since it considers the users instantaneous speeds/accelerations, while the AHBS algorithm assigns higher priority to these users by ignoring the users with temporary high speeds/accelerations, using averaging method. Accordingly, the AHBS scheme has lower packet dropping rate and fewer handover failures, compared to HBS. Finally, both of the algorithms have almost the same performance in very high system load, since there are too many handover requests at the same time. Thus, despite assigning handover-based priorities, the system is not able to serve all of the users at the same time. In this situation, the AHBS scheme is selecting users for transmission more strictly, hence it cannot serve a wide range of users, which results in more handover failures and higher packet dropping rate.

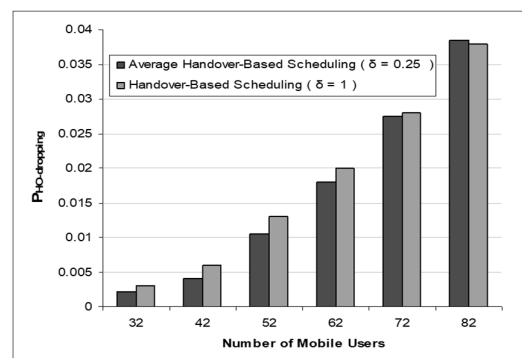


Figure 10. Handover packet dropping probabilities (scenario III)

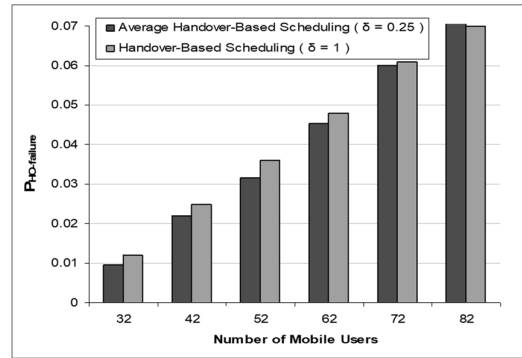


Figure 11. Handover failure probabilities (scenario III)

The performance of throughput is also evaluated in scenario III. Figure 12 shows the mean downlink throughput per sector for the proposed schemes and PF scheduling algorithm. Since we have used the AMC and pre-selection method in HBS and AHBS algorithms, both of the algorithms have reasonable throughput performance for different number of users. The PF algorithm gives the same priority to all users, regardless of their locations, speeds and accelerations. This means all the users with good channels can transmit and receive with high-level modulations and rates. On the other hand, the HBS/AHBS algorithm gives high priorities to a certain group of mobile users, namely handover zone users and accordingly a few users could achieve high data rates. That is because; many users with poor channel conditions have high priorities in HBS/AHBS scheme. Therefore, the PF algorithm has better performance in some cases, especially the high system load. It can be noted that unlike the AHBS algorithm, the HBS scheduler may assign higher priority to some normal users. This results in a little higher downlink throughput while using the HBS scheduling algorithm. Since the main goal of designing handover-based scheduling algorithms is to perform lossless handovers, the achieved throughput will be acceptable.

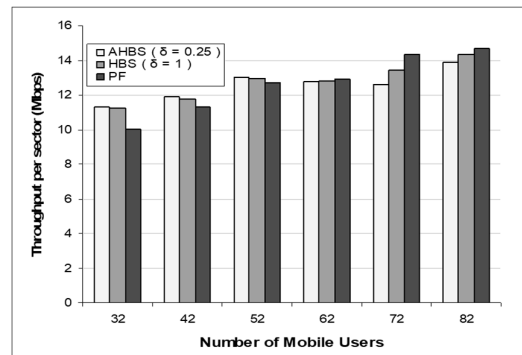


Figure 12. Performance of downlink throughput (scenario III)

6.3 Performance under high system load

To evaluate the robustness of the proposed algorithms under heavy traffic, we simulated scenarios with system load approaching 95% of total capacity. Table 5 shows that while the AHBS scheme has lower handover drop and packet loss rates than conventional methods, performance degrades during extreme load conditions. For instance, for loads of 95%, the handover drop rate for AHBS was 8.2% against 22.7% for conventional scheduling, and packet loss was 5.1% and 18.3% respectively.

Table 5. Simulation results at 95% load

Metric	AHBS	Conventional	Improvement
Handover Drops	8.2%	22.7%	63.9%
Packet Loss	5.1%	18.3%	72.1%
QoS Violations	9.8%	34.2%	71.3%

Several remedies are proposed to overcome these limitations:

- **Dynamic resource partitioning:** The scheduler will dynamically increase the fraction of bandwidth put aside for the handover traffic with an increase in the system load, for instance, from 30% to 50% when load exceeds 70%.

$$R_{ho} = \begin{cases} 0.3T_{total} & \text{if } \rho < 0.7 \\ 0.5T_{total} & \text{if } \rho \geq 0.7 \end{cases} \quad (15)$$

where ρ is system load and R_{ho} is bandwidth reserved for handovers.

- **Priority score compression:** Priority scores are mapped through a logistic function under high load to avoid an excessive resource concentration on a few users;

$$P' = \frac{1}{1 + e^{-k(P - P_0)}}, \quad (16)$$

where k is the steepness factor and P_0 is the cutoff threshold.

- **Preemptive resource reclamation:** Non-critical best-effort (BE) traffic is throttled or delayed when the system load exceeds 90% to ensure that real-time and handover-related flows are given priority.

Integration of these strategies with the AHBS framework further enhances the handover success rate and maintenance of QoS under congested conditions.

4. Conclusion

In this paper, we proposed a downlink handover-based scheduling system that provides lossless handovers while guaranteeing quality-of-service (QoS) requirements in IEEE 802.16 BWA systems. The proposed algorithm is adapted to monitor crucial parameters for mobile users such as received signal strength, speed, and acceleration while providing for the QoS requirements of the concerned users. The scheduler evaluates the power degradation rates and the movement behavior of all users involved, giving priority to those users with a higher probability of imminent handover through downgrading other users to reduce handover failure and packet dropping probabilities.

To enhance performance further, an optimized handover-based scheduling algorithm is developed to detect the users needing handover more accurately using their average received powers, speeds, and accelerations. The selective nature of the handover-based schemes is aided by adaptive modulation and coding (AMC) in conjunction with a method of pre-selection, thus enhancing throughput and improving packet dropping rates.

The analytical results have shown that these proposed algorithms lead to quite significant reductions in handover failures and packet loss, with performance always lying outside that of the traditional scheduling algorithms in various scenarios. The introduction of the handover-based scheduling does add a slight increase in computational complexities; however, the extra complexity can well be sustained by the modern base stations. The design is based on the existent mobility management scheme, and further alleviation in the computational load could be achieved through selective-monitoring and hardware acceleration. On top of that, the proposed

enhancements based on load-adaptation will ensure solid performance in heavy system loads, thereby making the solution ready for practical deployment in the real world.

The focus of future work will be on formulating scheduling schemes that can sustain excellent performance even under heavy system loads and optimizing the constants used in giving priority for more effective handovers and enhanced throughput. Also, the further enhancement of scalability and efficiency will include machine-learning-based predictive load balancing and hardware-accelerated implementations.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding this article.

Acknowledgements

The authors would like to thank Dr. Hoang Nam Nguyen and Mr. Ramtin Kazemi for their valuable comments and also the National Institute of Standards and Technology (NIST).

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How to cite this article: Fehri H, Monemizadeh M. A Novel Downlink Handover-Based Priority Scheduling for Providing Seamless Mobility and QoS in IEEE 802.16 BWA System. *Curr. Appl. Sci.*, 2025, 3(2):89-108. <https://doi.org/10.22034/cas.2025.220709>
