A New Seamless Handover Mechanism for IEEE 802.16e in WiMAX Networks

R. Bhakthavathsalam and Khurram J. Mohammed

***Abstract*—In IEEE 802.16e standard, mobility and handover are added as basic capabilities. It defines a framework providing specific methods or algorithm for handover that can be deployed in mobile stations to enable them for switching seamlessly from one base station to another. A mobile subscriber station (MSS) basically conducts hard handover operation when it moves to another base station (BS). Therefore, the MSS is not able to send or receive the data during handover process and these data should be delayed. As a result, real time packet could be dropped by handover delay. In this paper, we evaluate the performance of these handover schemes based on the metrics for delay and throughput. Then we enhance their performance by incorporating the principle of circularity. Circularity is a paradigm that allows the identification of specific groups of packets or events. This new paradigm reduces the collisions among request packets and thereby improves the performance in WiMAX networks. The evaluation and enhancement are performed through extensive simulation studies.**

***Index Terms*—IEEE 802.16e, MAC sublayer, contention resolution, handover ranging, circularity, network simulator 2.**

I. Introduction

The Institute of Electrical and Electronics Engineers (IEEE) 802.16 standard for Wireless Metropolitan Area Networks currently presents the most recent development of wireless technology. Originally intended for Fixed Broadband Wireless Access (FBWA) networks and as a wireless competitor for wire-line DSL and cable modem access in particular in rural and low-infrastructure areas, the most recent stage of the IEEE 802.16 standard also provides mobility support mainly intended for nomadic users or users with little mobility. Worldwide Interoperability for Microwave Access (WiMAX) is a consortium founded to enable the interoperability and foster the commercialization of products based on the IEEE 802.16 standard. The current IEEE 802.16-2004 standard with the extensions for mobility support amended in the IEEE 802.16e-2005 standard is the basis for two classes of WiMAX certified products [1]. The Orthogonal Frequency Division Multiplexing (OFDM) part of IEEE 802.16-2004 is known as Fixed WiMAX and the Orthogonal Frequency Division Multiple Access (OFDMA) part of IEEE 802.16e-2005 is known as Mobile WiMAX [2].

The MAC layer comprises three sublayers. The Service-Specific Convergence Sublayer (CS) on the top of sublayers accepts higher-layer protocol data units (PDUs) from ATM cell-based or packet-based network layers. The Common Part Sublayer (CPS) provides the core MAC functionality of system access, bandwidth allocation, connection establishment, and connection maintenance. The Security Sublayer provides authentication, secure key exchange, and encryption. The IEEE 802.16e [3] system is based on OFDMA physical structure, mobile subscriber stations (MSS) basically conduct three handoff methods: Hard Handoff (HHO), Fast Base Station Switching (FBSS) and Macro Diversity Handover (MDHO). The first method (HHO) is a mandatory while the other two methods are optional. In HHO, the Mobile Subscriber (MS) is connected to only one Base Station (BS) at any given time. If the MS decides to handover from the serving BS, it selects only one target BS from a subset of recommended BSs and starts connecting to it before disconnecting from the current serving BS. An important objective when designing a handover mechanism is to minimize the time spent in the handover transition to ensure that the MS does not experience service interruption during the handover.

A. Network Entry Procedure

A subscriber station has to complete the network entry process, in order to communicate on the network as illustrated in Fig. 1. The different stages in the network entry procedure are shown in the figure below [4]. The first stage of network entry is downlink (DL) channel synchronization. When an SS wants to communicate in a WiMAX network, it first scans to identify the available channels in the defined frequency list. On finding a DL channel, it tries to synchronize at the PHY level using the periodic frame preamble.

Information on modulation and other downlink (DL) and uplink (UL) parameters is obtained by observing the DL channel descriptor (DCD) and the UL channel descriptor (UCD) on the DL channel. In Initial Ranging (IR), the SS acquires the timing offsets and power adjustments from the base station. This enables the subscriber station (SS) to properly communicate with the base station (BS). The IR is a very important part of the network entry procedure and is dealt with in more detail in the next section.In Exchanging Capabilities,after successful completion of the initial ranging step, the SS sends capability request message indicating the supported modulation level, coding scheme and rates and duplexing methods. In Authentication, the BS authenticates the SS, determines the ciphering algorithm to be used, and sends an authenticationresponse to the SS. In Registration, the SS sends a registration request message to the BS and the BS sends a registration response.The registration response message includes the secondary management CID of the SS.

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Using this, a SS is allowed entry into the network and the SS is said to be manageable.

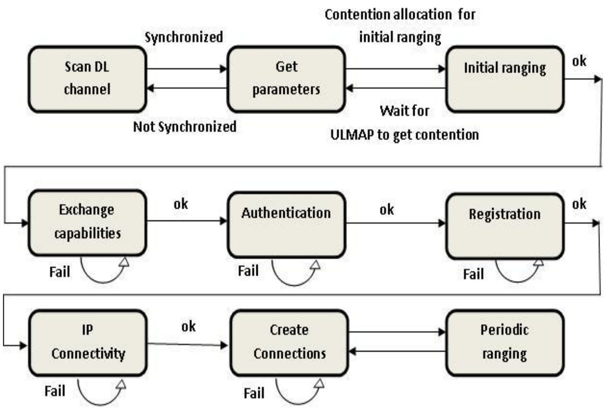

Fig. 1. Network entry process.

Next in Internet Protocol (IP) Connectivity, the SS gets the IP address via DHCP. The SS also downloads other operational parameters using TFTP. In Connection Creation, after completing the IP connectivity step, transport connections are created. For preprovisioned service flows, the BS sends a dynamic service flow addition request message to the SS and SS confirms the creation of connection. For non-preprovisioned service flows, connection creation is initiated by the SS by sending a dynamic service flow addition request message to the BS. The BS responds with the confirmation. During the process of network entry there are multiple SSs that are trying to send different request messages to the BS. In case of IR, the Ranging Request [5] messages will be sent on the Initial Ranging Intervals. Due to the presence of multiple SSs trying to compete in the IR procedure, there are bound to be collisions among the request packets. A similar phenomenon is observed in the steps of Exchanging Capabilities and Registration. A SS asks the BS to allocate resources so that it can transmit its Basic Capabilities Request and Registration Request messages. There exist (CDMA) codes that are sent by the different SSs for this contention among the Code Division Multiple Accesspurpose. In all these cases, due to collision among different packets sent by the SSs, the access delay of corresponding procedure increases. Thereby, the efficiency of utilization of the available resources decreases.

II. Handover Mechanism in 802.16e

The layer 2 handoff mechanism [6] has been defined and its procedure is divided into the following steps:

- Cell Reselection
- Handoff Decision and Initiation
- Synchronization to Target BS
- Handoff Ranging
- Termination of MS context

The Fig. 2 and Fig. 3 cursorily describe these steps.

Cell Reselection: A BS broadcasts network topology information by the MOB_NBR_ADV message. The message provides channel information for neighbor BSs such as each BS's DCD/UCD message. Any BS may obtain the information over the backbone network. This information facilitates MS synchronization with neighbor BS by removing the need to monitor transmission from the neighbor BS. After receiving the MOB_NBR_ADV message, the MS performs cell reselection to determine the target BS which the MS wants to switch to. The MS uses MOB_SCN_REQ and MOB_SCN_RSP messages to negotiate with its serving BS about the scanning interval, interleaving interval and the number of scan iteration.

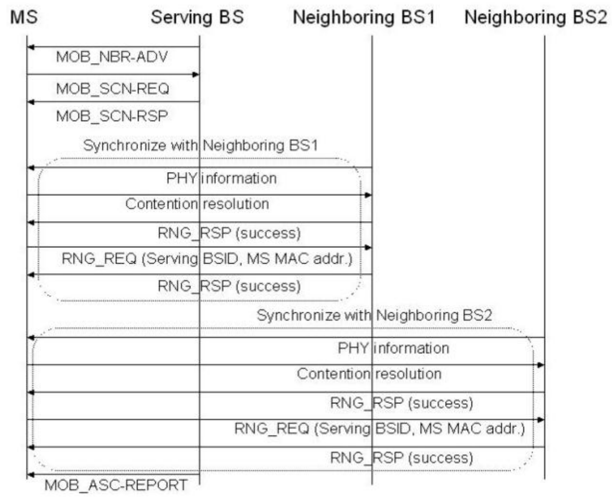

Fig. 2. Network topology acquisition.

After receiving the MOB_SCN_RSP, the MS starts the neighbor BSs scanning or scanning with association procedure. Association is an optional initial ranging procedure with respect to neighbor BSs occurring during scanning interval. The function of association is to enable the MS to acquire and record ranging parameters and service availability information for the purpose of proper selection of HO target and expediting a potential future handoff to a target BS. Recorded ranging parameters of an associated BS may be further used in future ranging events during actual handoff.

Handoff Decision and Initiation: Figure shows that a handoff starts at a decision for an MS to handover from a serving BS to a target BS. The decision may initialize either at the MS or the serving BS. The MS uses MOB_MSHO_REQ or MOB_BSHO_REQ message to negotiate with the serving BS to decide which target BS to select or not to perform HO [7].

Synchronization to Target BS: After making the decision to perform handoff the MS sends a MOB_HO_IND message to inform the serving BS to begin handoff and synchronize to downlink transmissions of target BS and obtain DL and UL transmission parameters. If MS had previously received a MOB_NBR_ADV message including target BSID, physical frequency, DCD, and UCD, this process can be shortened. If the target BS had previously received HO notification from serving BS over the backbone network, then target BS allocates a contention based initial ranging opportunities.

Handoff Ranging: The MS and the target BS conducts initial ranging or handoff ranging procedures. If the MS_RNG_REQ includes serving BSID, then target BS makes a request to serving BS for information on the MS over the backbone network and serving BS responds. Network reentry procedures are shortened by the target BS possession of MS information obtained from serving BS over the backbone network. Depending on the amount of that information, target BS decides to skip several network entry steps such as authentication or registration procedure.

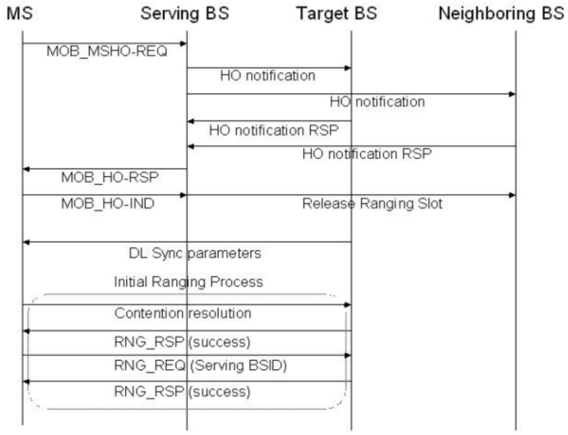

Fig. 3. HO decision, initiation, and ranging procedure.

Termination of MS Context: Termination of MS context is the final step of the handoff that the serving BS terminate the context of all connections belonging to the MS. The MS cancels the handoff before the expiration of Resource Retain Time interval after transmission of MOB_HO_IND message.

III. New Paradigm of Handover Mechanism

Circularity is a principle that aims to reduce the number of collisions between the request packets. It is defined as a number that allows us to identify specific groups of events or packets in the network [8]. The number of packets or events in one such group is equal to the circularity value. In each group, one of the packets or events is said to be circularity-satisfied. Here, we introduce certain control measures in case of circularity-satisfied packets. By doing this we achieve a decrease in the handover delay as well as an increase in the handover throughput. The circularity value is a positive integer. In order to identify the circularity-satisfied packets, we keep a count of the number of such packets. Whenever the value of this counter is a multiple of the circularity value, the packet is said to be *circularity satisfied*. If the counter is represented by C and the circularity value by k, then the mathematical representation for satisfying circularity is as follows:

$$C \text{ modulo } k = 0 \tag{1}$$

Now consider the Circularity 2, when the channel is treated as busy even though it is idle from the corresponding node for its second DATA packet transmission, and then select another random number with respect to backoff window. The numbers 1 to 11 and so on refer to the DATA packet number transmitted by that particular SS as indicated in Fig. 4. The above discussed circularity concept is used to treat the channel as busy selectively for particular DATA packets, irrespective of the consequences.

There arise a question that how this sensing mechanism for particular DATA packets irrespective of the network conditions result in improving the MAC performance of the IEEE 802.16e. Careful analysis and observation proved that the resulting consequences prove to be beneficiary. By treating the channel as busy for that particular DATA packet, we are refraining from initiating a data transfer, which may later prove to be costly if a DATA collision occurs due to contention. When a DATA packet collision occurs, the whole contention resolution phase is repeated.

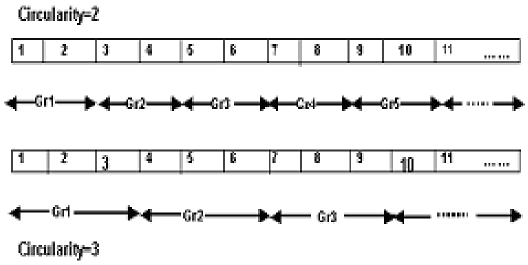

Fig. 4. Paradigm of circularity.

This leads to increase in access delay, which has the impact on the net throughput. Treating channel as busy avoids such situations and the concept of circularity is implemented for the above-mentioned reasons. With optimum value of circularity for low and high density of nodes in a network scenario lesser number of DATA packets is refraining from transmission thereby making the system coverage a steady state. An integer value is given to circularity and the value of counter is made to vary from 1 to C values as specified by the user. Initially Deferring process of transmission opportunities is checked and then as we need to treat the channel as busy for particular DATA packets based on circularity counter % circularity = 0 is checked. If the condition is true then that particular DATA packet refrained from the transmission by treating as channel busy else that DATA packet is send. After sending the DATA packet a further check is done to see if the DATA has been send successfully without collision. If no collision has taken place and ACK arrived for that particular node then transmission is successful, else the process again resumes from the beginning.In order to explain the effects of the principle of circularity on the handover request mechanism, we carry out a flow analysis as shown in Fig. 5 that depicts the events that occur during the mechanism. Network topology acquisition process consists of scanning neighboring BSs and association. The former refers to obtain DCD / UCD and DL-MAP / UL-MAP information of the neighboring BSs. The latter indicates to synchronize and associate with the neighboring BSs.

According to the existing draft standard, data transmission and reception is paused, which degrades system throughput. In the original handover process of the IEEE 802.16e system, the MSS can receive or transmit the data only in the normal operation mode after the handover process is completed. We introduce new management message to receive downlink data during the handover process and reduce the downlink packet transmission delay with the principle of circularity. In the case of Ranging [9], we introduce two modifications namely delay control for the request packets and window control for the Backoff Window. Firstly, a counter is kept for the RNG-REQ packets that are scheduled to be sent from the different SS. Whenever the counter value is an integer multiple of the circularity value, a finite delay is introduced. Secondly, a counter is kept of the number of RNG-REQ expire events that occur. Whenever this counter is a multiple of the circularity value, the Backoff Window is quadrupled (instead of the original doubling) we try to establish a more efficient usage of the resources assigned by the base station for the contention-based processes. This is what circularity aims to do. Although our main focus remains the enhancement of the Handover scheme.

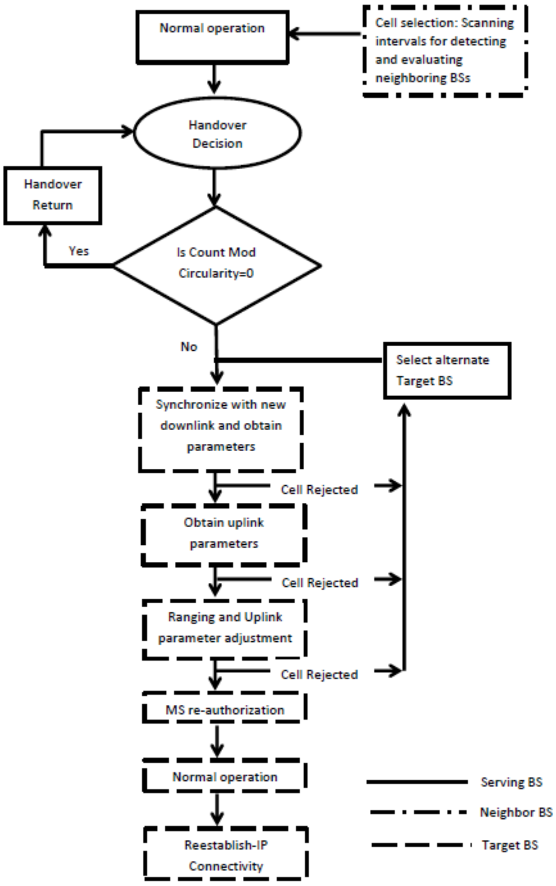

Fig. 5. HO Process with circularity.

IV. Simulation Studies

A. Simulation Setup

The simulations have been carried out using the Network Simulator 2 (ns-2) which is a discrete event simulator. We have added the WiMAX patch with mobility developed by the Advanced Network Technologies Division of the National Institute of Standards and Technologies [10], [11]. The simulation script is written in the Tool Command Language (Tcl) [12], [13]. The model supports layer2 mobility. Depending on the configuration, the MS may perform scanning and handover between BSs. To allow these different scanning modes and to perform fast handovers, the *WiMAXCtrlAgentis* required. The *WiMAXCtrlAgent* is an *Agent* performing 3 functions. The first one is to exchange DCD/UCD information between the neighbor BSs. The second is to trigger the sending of NBR_ADV messages to the MSs. The third one is to synchronize the serving BS and the target BSs when performing scanning level 1 or 2. The messages are exchanged over wired links using standard IP packets.

B. Simulation of Handover Scheme

The parameters mentioned are used in the Tool Command Language (TCL) script that we have written.This script also uses the WiMAX Control Agent in order to produce a detailed account of the activities going on during the simulations [14]. In the resulting output file, we search for the timing details of specific events in order to extract the Handover delay. The start and stop traffic times of the Handover procedure for all the Mobile Subscriber Stations (MSS) in the scenario are stored in files. Using a C program, we find the average Handover delay per node, after calculating the total time taken by all the nodes to complete their respective Handover processes. Such simulations can be carried out for different numbers of MSS each time by the use of shell scripts. Then the average Handover delay is recorded along with number of MSS involved in each such simulation [15].

In order to enhance the Handover Scheme, we make some modifications to the backend of ns-2, which is implemented in C++ language. The files that we need to modify are *bsscheduler.cc, ssscheduler.cc and contentionslot.cc.*During the Handover procedure, there will be many MSS contending to send their requests to join the network. The packets sent by different MSS may collide at some instants and they will have to be resent. We try to reduce the collisions between packets of different MSS by making the MSSs less selfish.

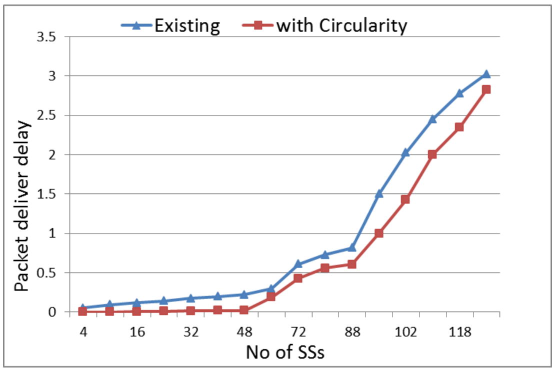

Fig. 6. Handover delay comparison.

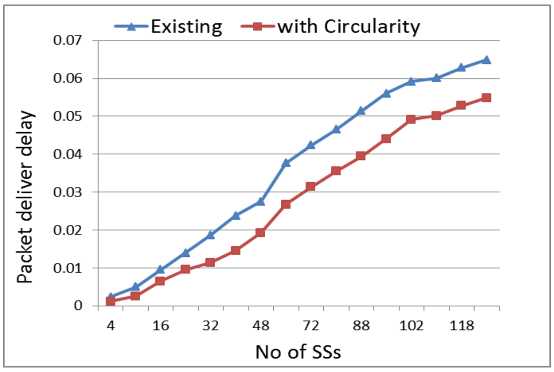

Fig. 7. IR delay comparison.

The following parameters shown in Table I are used for the simulation of the existing Handover scheme. In this section, we present the results of the simulations we have conducted using ns-2 [16]. In the first graph (Fig. 6), we compare the handover delay incurred in the handover mechanism in the existing and enhanced scenario. The circularity value used in MOB_SCN_REQ packet is 2. In the second graph (Fig. 7), we compare the delay incurred in the IR mechanism in the existing and enhanced scenarios. The circularity value used in selectively delaying the RNG-REQ packets is 3. Similarly in the third and fourth graphs (Fig. 8 and Fig. 9), we compare the drop occurring due to collisions and connection identifier. The fifth graph (Fig. 10) compares the success ratio [17] of handover mechanism between the existing and improved handover schemes.

TABLE I: LIST OF IMPORTANT PARAMETERS THAT HAVE BEEN USED DURING THE SIMULATION.

channel Type	WirelessChannel
Radio Propagation Model	TwoRayGround
Network Interface Type	Phy/WirelessPhy/OFDM
MAC Type	802_16e
Interface Queue Type	DropTail Priority Queue
Link Layer Type	LL
Antenna Model	OmniAntenna
Maximum Packets in Interface Queue	50
Routing Protocol	DSDV
BS coverage	20 meters
Number of SSs	4 to 126

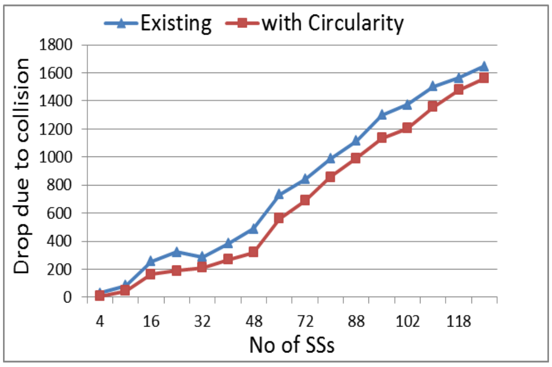

Fig. 8. Comparison of drop occurring due to cullusions.

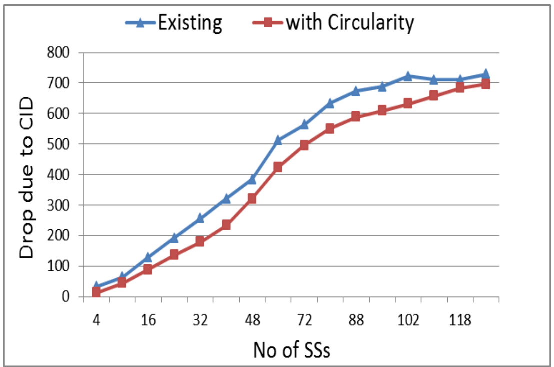

Fig. 9. Comparison of drop occurring due to connection ID.

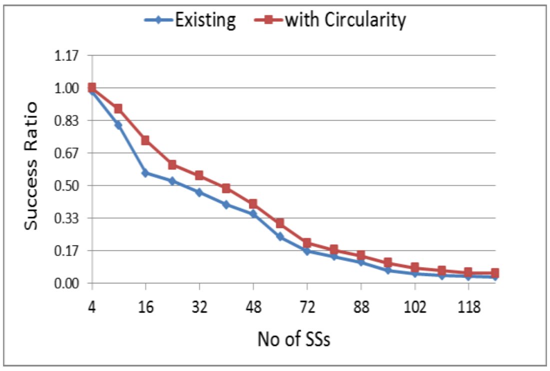

Fig. 10. Comparison of success ratio gained due to improved HO.

V. CONCLUSION

We proposed and analyzed the performance of a new handover scheme suitable for IEEE 802.16e wireless networks. According to existing draft version of standard, HO process consists of network topology acquisition, scanning, initial ranging, authorization, and registration. However there exists waste of channel resource and redundant work in the conventional algorithm. Therefore new scheme of circularity including target BS selection, fast synchronization and association, and optimized HO initiation timing are suggested. This will reduce the time required by the SSs to successfully transmit their requestpackets and hence complete both HO and network entry in lesser time. Also, reduction in number of collisions increases the success ratio of request packets sent. We have also analyzed the effect of the circularity value on the success ratio.

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