Strategies for Fast Scanning and Handovers in WiMAX/802.16

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***Abstract*—In WiMAX/IEEE 802.16 with mobility support, scanning for an available channel by a mobile station, at start up or when about to perform a handover must be done promptly in order to reduce delays in network access. We propose strategies that a mobile station can use to reduce the time required for scanning operations while attempting to establish network connectivity or perform a handover between neighboring base stations. We model and simulate an area of WiMAX coverage using real-world mobility trace data and show that there are strategies that reduce the time required for scanning operations significantly.**

I. Introduction

With the neverending growth of mobile communication systems today, mobile devices are becoming a central part of peoples lives. Applications such as VoIP, music downloads and streaming video, are being deployed that utilize an ever increasing chunk of the precious bandwidth available with current 3G systems. The next generation of 4G networks are under development and the WiMAX/IEEE 802.16e [3] standards are promising to provide the infrastructure for the future of the high-speed mobile internet.

When a mobile subscriber station (MS) wishes to join the network, it must follow the *network entry* procedure. This involves *scanning* for a frequency on a base station (BS). It is expected that the MS will be required to perform repeated scanning to maintain connectivity to the network by moving from one BS to another while moving throughout the coverage area. This process of changing BSs is called a *handover*. The impact of handovers between base stations is a serious problem in a mobile communication system that must be addressed. During a handover, packets may be delayed and connections may be dropped. Real-time applications such as VoIP and streaming video can be adversely affected by these delays.

We address two aspects of a MSs scanning, that of initially finding an available downlink frequency to a base station when entering a network, and that of the scanning a MS must perform when selecting a target BS when it is about to perform a handover.

A. Results of the Paper

We present several strategies that a MS may use in order to improve scanning times while searching for a downlink from a BS. The strategies attempt to provide faster network access during the network entry phase as well as reduce delay during the handover procedure. The first set of strategies incorporates the history of successful scanning frequencies in order to guide the MS in choosing frequencies for future scanning operations. A second type of strategy improves upon the use of the MOB_NBR-ADV messages sent to the MS from the serving BS that informs the MS of neighbouring BSs. A MS builds a history of handovers between BSs and uses this to determine which BS is the most likely neighbor target BS for a handover. Since the MOB_NBR-ADV messages gives the MS the list of neighbors and their parameters, knowing which BS is most likely the handover target improves the scanning operation.

Related works described in Section I-B either try to work around the required scanning by estimating how long it will take and then schedule the scanning operation efficiently or implement mechanisms such as new control messages or cross-layer handover techniques to improve upon the impact of scanning. We attempt to reduce the time required for the scanning operation. Our strategies require no additional network support and only limited memory and computational resources of the MS.

We evaluated our strategies by mapping real-world mobility data for a set of MSs obtained via the Automatic Position Reporting System (APRS) project [1] to simulate coverage area and performed simulations.

B. Related Work

There are two main complementary areas of research, that of efficiently scheduling the scanning operation and that of improving handover schemes. Neither attempt to reduce the number of frequencies checked during the scanning operation. Rouil and Golmie [9] recently introduced their Adaptive Channel Scanning (ACS) algorithm. ACS is primarily focused on when to perform scanning by estimating the time required for a MS to scan a list of neighboring BSs and then interleaving the scanning and data transmission intervals. Other work has been focused more specifically on improving handover performance. Choi et al. [5] have introduced a new management message to receive downlink data during the handover process and thus reduces the downlink packet delay. Kim et al. [8] proposed Last Packet Marking (LPM) that requires integrating the MAC layer (L2) handover and the network layer (L3) handover. LPM allows a MS to pre-notify a target BS for handover which the target BS can accept or reject.

An early work by Van de Berg [10] describes the storing information on the most probable used carrier frequencies in cellular networks on the MS . However, the term *most probable* is not defined and no mechanism is provided for determining the most probable frequencies.

The remainder of the paper is organized as follows. In Section II, we describe the WiMAX/802.16 network entry procedure and handovers. We focus in particular on the scanning process. In Section III, we present the current WiMAX/802.16 scanning operation and propose two new strategies. We provide a description of our simulation environment along with our simulation results in Section IV. Finally, we discuss ongoing work and conclude in Section V.

II. Network Entry and Handover Scanning in IEEE 802.16e

The WiMAX/802.16 standard defines a medium access control (MAC) layer as well as numerous underlying physical layer (PHY) specifications. The MAC protocol can be either time division duplex (TDD) or frequency division duplex (FDD) based. Communication between a mobile subscriber (MS) and the base station (BS) are established in a point-to-multipoint (PMP) architecture in a similar manner as traditional cellular networks.

The WiMAX/802.16 standard defines a network entry procedure, depicted in Figure 1, for a MS wanting to establish a network connection via a BS. The MS must first scan to find a frequency in use by a BS. It does this by listening to each possible frequency until it hears the frame preamble. This takes a minimum of two frames [3], [9], at each channel. After finding the channel, it must synchronize with the BS by waiting for the Downlink Map (DL_MAP). The DL_MAP is a map of the timeslot locations in use for the frame. The maximum time between DL_MAPs can be as high as 11 seconds [3]. Once the MS has synchronized with the channel, it then must listen for the Downlink and Uplink Channel Descriptors (DCD and UCD) that are periodically sent using broadcast by the BS. Then the MS must wait for a contention slot (determined from the UCD) in order to perform Initial Ranging with the BS. Initial ranging is used to determine the transmit power requirements of the MS in order to reach the BS.

Since the network entry process has many steps, if we can improve upon the time it takes for one or more of these steps to complete we can provide an improved access time for initialization or recovery of service. In this paper, we focus on *scanning*.

A. Scanning in WiMAX/802.16

Scanning is an activity conducted by a MS. The goal of scanning is to acquire a downlink signal from a BS. Scanning is done by monitoring each possible frequency until a downlink signal is received. The exact number of frequencies depends on the regulatory provisioned bandwidth (varies from one country to another), physical specification (several) and bandwidth per channel (several options available per physical specification). Scanning is performed during the initial network entry procedure and continues periodically to aid the MS in the selection of a suitable target BS for a handover to maintain network connectivity while in motion.

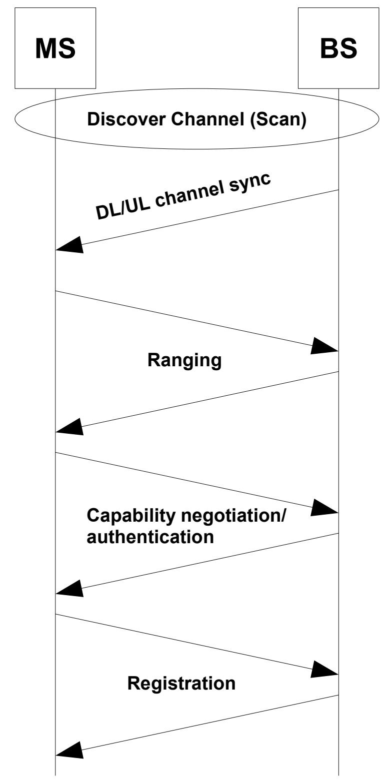

Fig. 1. IEEE 802.16e Network entry procedure.

The WiMAX/802.16 specifications provide support for network assisted handovers where the BS currently serving the MS can obtain the information of neighboring BSs over the network. The serving BS periodically sends using broadcast this information as a MOB_NBR-ADV message to the MS.

Even though there is support for network assisted handovers, there are still scenarios where the ability of a MS to make its own decisions on scanning would improve performance. These include the following.

1) Initial Network Entry: here, the MS is not aware of its closest BS and must determine which frequency to use.
2) Handover from one BS to another BS where there is no network handover assistance provided - either it is not available, or the MS is moving between different service providers.
3) Handover between different network types (i.e. IEEE 802.11 to IEEE 802.16).

B. WiMAX/802.16 Handovers

As a MS moves throughout the coverage area, maintaining connectivity is done via performing handovers between neighboring BSs. An example is shown in Figure 2, where a MS must choose one of six neighboring BSs, in this case neighbor six is chosen. Selection of the best handover target can be complex since the MS must scan for neighboring BSs to find a suitable target based on a number of criteria such as signal strength or error rates. Since a handover is an important function, a MS should perform the scanning and determine a target BS *before* beginning the handover. The IEEE 802.16e standard supports temporarily suspending the uplink and downlink communication between the MS and BS in order to allow the MS to perform scanning for neighboring BSs. While communication is suspended, the data streams must be buffered on either side. Any improvement on the time it takes for the MS to complete its scanning operation improves the performance of the communication, i.e. reduce delays.

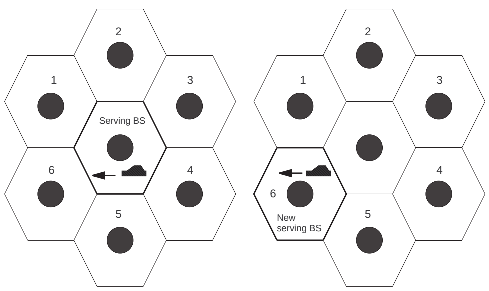

Fig. 2. Mobile station handover.

III. Scanning Strategies

In the following section, we describe the IEEE 802.16e default scanning strategy as well as two new strategies. The first new strategy, deals with reducing the number of frequencies checked during each scanning operation. The MS maintains information on the probabilities of the frequencies being used in order to make a choice. This strategy is further divided into the *Most Recently Used* and *Most Frequently Used* approaches. The second new strategy deals with the MS maintaining information on the history of performing handovers between BSs that were encountered under the assumption that patterns observed in handovers will be repeated.

A. WiMAX/802.16 Strategy

The IEEE 802.16e standard [3] specifies that a MS must keep a nonvolatile storage where it stores the last set of operational parameters. When a MS wishes to acquire a downlink channel, it uses this stored information. Whenever a MS fails to obtain the downlink channel, it then continuously scans the possible channels of the downlink frequencies until a time it finds a downlink signal.

B. Frequency Strategies

When a MS is turned on for the first time, all frequencies are equally likely since the MS has no history. That is to say if there are *n* frequencies, that the frequencies $f_1, f_2, \ldots, f_n$ have an initial probability distribution $p(f_1), p(f_2), \ldots, p(f_n) = \frac{1}{n}$. This can be defined as a random variable X assuming the values $f_1, f_2, \ldots f_n$ such that $Pr[X = f_i] := p(f_i)$. A MS only moves along a limited geometric planar region defined by the cells it traverses. This in turn gives rise to a random variable X_{MS} induced by the random variable X and having probability distribution $Pr[X_{MS} = f_i]$. It is clear that this probability distribution will depend on the mobility characteristics (the path) of the MS as well as the probability distribution of the frequencies in the subregion traversed by the MS during its movements. Given this random variable, we are interested in optimizing how the MS selects its frequencies.

From the initial setup, since a MS has no previous history, it must simply start scanning frequencies in increasing order. As the MS performs a number of successful scanning operations, it can determine an *order of frequencies* from its observations. This history can be used to make scanning more efficient.

In the following sections we will discuss two new strategies that utilize the MSs history of scanning operations to determine the frequency ordering.

1) Most Recently Used Strategy (MRU): In this first strategy, the MS must keep a certain number of the possible frequencies stored in memory. This information is independent of BSs or network topology. Initially, all frequencies are equally likely and will be chosen in increasing order (lowest frequency to highest frequency). For each successful scanning operation, the frequency discovered, f_{MRU_1}, is given the highest priority, that is, it is moved to the front of the list of frequencies. As the MS builds up a history of scanning operations, it will have a frequency of occurrence, *F*, distribution as follows

$$F(f_{MRU_1}) > F(f_{MRU_2}) > F(f_{MRU_3}) > \cdots > F(f_{MRU_k})$$

where f_{MRU_1} is the *most recently used* frequency, f_{MRU_2} is the second most recently used, and so on. The value of k is the number of frequencies stored in memory. There is a training period of time required to establish this order. In future scanning operations, the MS scans frequencies in order from the *most recently used* (MRU) to the least recently used. If the MS does not find the frequency from the MRU list, then it must scan the remaining frequencies.

2) Most Frequently Used Strategy (MFU): In this strategy, a frequency of occurrence distribution over the frequencies is built based on the history of the number of times each frequency is used. The frequency that is used the most has the highest priority. As the MS builds up a history of scanning operations, the frequency of occurrence, *F*, distribution will be as follows

$$F(f_{MFU_1}) \geq F(f_{MFU_2}) \geq F(f_{MFU_3}) \geq \cdots \geq F(f_{MFU_k})$$

where f_{MFU_1} is the most frequently used frequency, f_{MFU_2} is the second most frequently used and so on. The value of k is the number of frequencies stored in memory. The MS keeps an ordered list starting with the most frequently used frequency. In future scanning operations, the MS scans the frequencies from the most frequently used to the least frequently used frequencies.

C. Previous Handover Strategy

In this section, we describe a new strategy that utilizes the history of the MS handovers along with the information made available from the currently serving BS in the MOB_NBR-ADV message to improve the choice of a handover target neighbour BS to begin scanning.

We assume the MS is provided with the list of all neighboring BSs and the frequency advertised for each neighbor in the MOB_NBR-ADV message from the serving BS. Even though this information is provided to the MS, the MS must "guess" at which of the neighboring BSs it should attempt to perform a handover. The MS must perform a scanning operation to obtain the operational parameters and determine which of the neighboring BSs are suitable for a handover. The IEEE 802.16e standard does not define this operation. It is left to the MS to decide on which neighbor to attempt to communicate. A MS with no other information than the MOB_NBR-ADV must simply attempt to scan for the neighbors in the order given.

That is to say that the neighbors for each BS_i, n_{i1}, n_{i2}, $\ldots$, n_{id} have an initial probability distribution $p(n_{i1}), p(n_{i2}), \ldots, p(n_{id})$. This can be defined as a random variable Y assuming the values $n_{i1}, n_{i2}, \ldots, n_{id}$ such that $Pr[Y = n_{ij}] := p(n_{ij})$. We want to capture the probability that the MS currently served by BS_i will perform a handover to BS_is neighbor j. Similar to the frequency strategies, this probability distribution will depend on the mobility characteristics (the path) of the MS. Given this random variable, we are interested in optimizing how the MS selects its target handover BS. $p(HO_{i,j})$ is the probability that a handover will occur from BS_i to it's neighbor BS_j. n is the number of BSs, and d is the number of neighbors for BS_i.

The MS keeps for each BS_i it has visited, a list of most probable handover target of the neighboring BSs. For example, a commuter driving along a highway is highly likely to repeatedly perform the same set of handovers along the highway, from BS_1 to BS_2 to BS_3 and so on. This pattern can be captured and stored in the MS. This can be done by maintaining a frequency of previous handovers that have occurred from each BS_i. The frequency of occurrence, *F*, distribution is as follows

$$F(HO_{i,j_1}) \geq F(HO_{i,j_2}) \geq F(HO_{i,j_3}) \geq \ldots \geq F(HO_{i,j_k})$$

where we have non-increasing probabilities and $p(HO_{i,j_1})$ is the probability of a handover from BS_i to one of its neighbors BS_{j_1} which will be considered first when the MS performs scanning in preparation for a handover.

IV. Simulation

In order to evaluate our strategies, we implemented a simulation to compare the WiMAX/802.16 default scanning strategy with the *MRU* and *MFU* strategies. We then implemented a second simulation to test the *previous handover strategy*. We first describe important parameters concerning our simulation: 1) Network topology, 2) Metrics and measurements being used, 3) the Mobile Station Mobility Data used, and 4) Mobile Station scan times. Later we will discuss the results of the simulation.

A. Simulation Setup

The simulations are setup as summarized in Table I. A ten kilometres by ten kilometres area is defined and covered by WiMAX/802.16 base stations with a one kilometre range. The base stations are positioned based upon a cellular networking model [4] where each BS covers a hexagonal shaped region as shown in Figure 4. A total of 44 BS are required to cover the entire area.

Network Parameters	
Coverage Area	10 km x 10 km
No. Base Stations	44
Cell Radius	1 km
Cell Cluster Size	4
No. Frequencies	20
No. Channels	80
No. Channels per Cell	20
No. Frequencies per cell	5

TABLE I
SIMULATION PARAMETERS

The WiMAX/802.16 simulation parameters are chosen based on 100 MHz of bandwidth available for both uplink and downlink channels. Every channel is given 1.25 MHz of bandwidth for a total of 80 channels. A four cell cluster reuse clustering scheme, shown in Figure 3, is implemented on the underlying 44 BSs. This setup has 20 channels available for each cell for the 80 channels available in total. We use 20 different frequencies, assigning five to each BS, each of which has four channels for MS connections. Two MS scanning times are implemented in the simulation scenario.

In our model, the number of frequencies stored in memory is equal to the number of frequencies available in the coverage area.

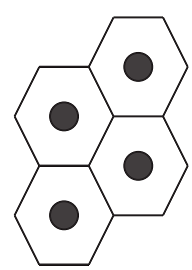

Fig. 3. Four cell cluster size for frequency reuse.

Metrics and Measurement: The purpose of this work is to improve upon (reduce) the number of frequencies a MS is required to check while scanning for a downlink connection to a BS. We measure the proportion of time that a MS can find the downlink with a certain number of frequencies checked. For our model, this is between one and 20 frequencies checked per scan. Ideally, we would like to have it so that 100% of the time a MS can successfully scan for a neighboring

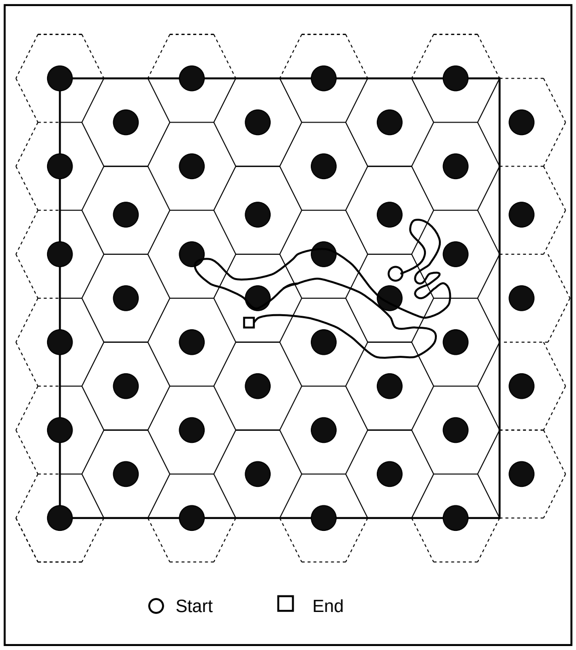

Fig. 4. Simulation area with sample path of a MS.

BS with only checking a single frequency, but the actual performance is dependent on the individual MSs mobility. From the observations of our simulations, we determine the expected number of frequencies required to be checked for a certain proportion of scanning operations. For example, $x\%$ of the time, the MS can find a downlink channel with only scanning a single frequency. Results were obtained with a 95% level of confidence.

MS Mobility Data: We used real-world mobility data collected by the APRS project [1]. The data included the mobility traces of 50 different MSs. The actual real-world coordinates of the data for each MS were mapped to the simulation coverage area. As an example, a partial path of a sample MS is shown in Figure 4.

MS Scan Times: Here we describe two different scanning times of a MS. The first represents how scanning would be performed as a MS is in motion and performs handovers in order to maintain a network connection. The second represents the cases where a MS is just being turned on and must find a downlink from a BS to enter the network.

1) *Scanning along the MS path*: In this scenario, we chose sampled locations that were *relatively* close in time to the *previous* scan attempt. This would closely follow the path taken by the MS and would cover scenarios where the MS is trying to re-acquire a channel, or is performing a handoff between cells. We expected that the *MRU* strategy would perform better in this scenario. Observe in Figure 4 that a MS may frequently move back and forth between the same series of two or more cells. It should be noted that the IEEE 802.16e default strategy is equivalent to the MRU strategy with a list of only one frequency.
2) *Scanning based on random locations*: In this scenario, we implement a series of randomly chosen sampled locations of each MS and perform a scan. This can be thought of to represent when a mobile station is turned on. It was expected that the *MFU* strategy would achieve the most reduced number of scans with this scenario since a user can be expected to perform this kind of operation in certain places (i.e. home, office, etc.)

We performed simulations for the IEEE 802.16 default, *MRU*, and *MFU* frequency strategies in order to compare their results.

Previous Handover Strategy: In this second simulation setup, the same area of coverage and mobility trace data were used. However, now the MS built a history of the previous BS handover pairs, and store for each BS, the list of neighboring BS in a *MFU* order. That is, for each BS, the list of neighboring BSs will be maintained in the order of most often chosen as the handover target to the least often chosen as the handover target. When a MS receives a MOB_NBR-ADV message, it will choose the neighbor that is most frequently used first. From our simulation model, a MS will have at most six neighboring BSs from which they can choose for a handover. We performed simulations for the IEEE 802.16 default and the *MFU* handover strategy in order to compare their results.

B. Simulation Results

The following sections show the simulation results of our frequency and handover strategies.

1) Frequency Strategies: Figure 5 gives the results of the *scanning along the path* scenario and shows the proportion of the time that a MS is required to scan a certain number of frequencies before finding the downlink signal from a BS. The results show that the *MRU* strategy performs the best of the three strategies. Table II summarizes the results and can be read as follows: for our network parameters, the WiMAX/802.16 default scanning strategey finds the downlink 51.9% of the time by checking 10 frequencies. The MRU strategy finds the downlink 86.9% of the time with the same number of frequencies checked. In order to meet the MRU number, the default strategy requires checking 18 frequencies.

Scanning along the path		
	5 Freq	**10 Freq**
Default	39.9%	51.9%
MRU	78.0%	86.9%
MFU	53.2%	79.5%

TABLE II
PROPORTION OF TIME SCANNING CAN BE COMPLETED WITH CHECKING 5, 10 FREQUENCIES

Similarly, Figure 6 shows the results for the *random locations* scenario. Here we observed that the *MFU* strategy performs best. The results are further summarized in Table III where we see that the MFU strategy successfully finds a BS frequency 79.5% of the time after checking 10 frequencies versus only 45.6% of the time for the WiMAX/802.16 default strategy. In order to meet the 79% of the MFU strategy, the default strategy is required to check 17 frequencies on average.

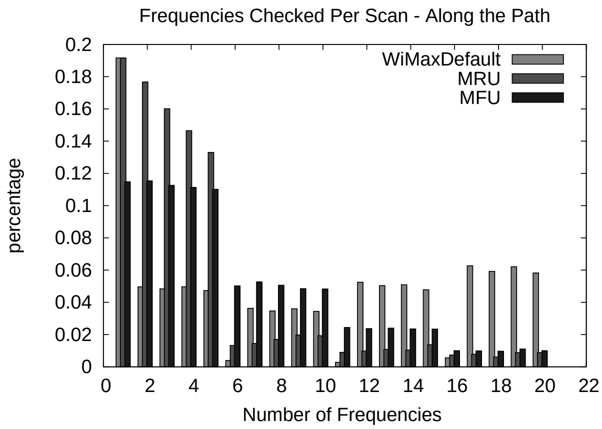

Fig. 5. Frequencies checked per scan - along MS path.

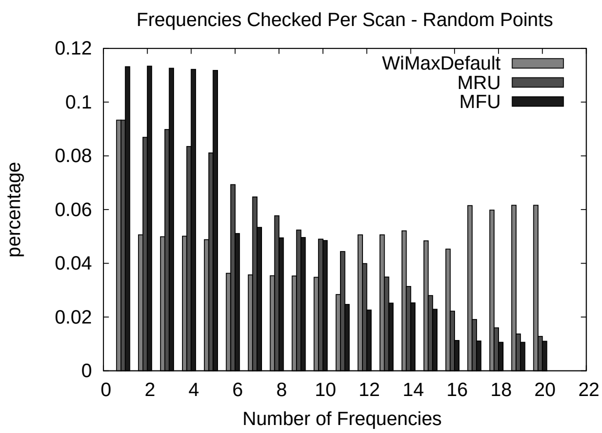

Fig. 6. Frequencies checked per scan - Random locations.

Random points scenario		
	5 Freq	**10 Freq**
Default	30.3%	45.6%
MRU	40.0%	70.7%
MFU	52.9%	79.5%

TABLE III
PROPORTION OF TIME SCANNING CAN BE COMPLETED WITH CHECKING 5, 10 FREQUENCIES

2) Previous Handover Strategy: In this simulation scenario, the WiMAX/802.16 default was to simply scan the neighbors in the order given by the MOB_NBR-ADV messages. By using information on the historical pattern of handovers from each BS, we obtain significant improvement in choice of neighbor BS frequency to scan. The results of the simulation are shown in Figure 7. We see that with the default strategy, slightly more than 20% of the time the MS picked the correct neighbor on the first attempt while with the MFU strategy this increases to over 70%. While the WiMAX/802.16 default was more evenly distributed, the MFU strategy successfully finds the correct handover target with only two attempts over 90% of the time.

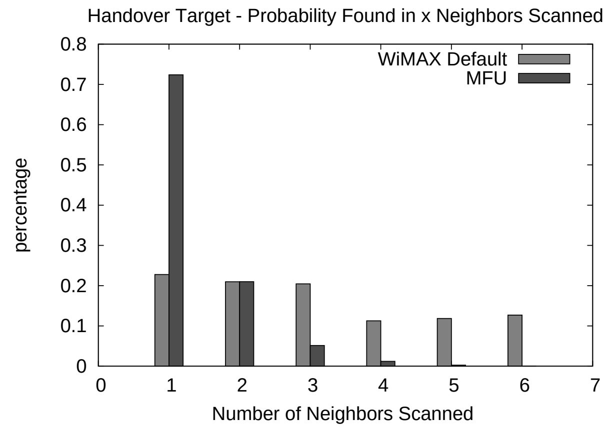

Fig. 7. BS neighbor scans per handover.

V. CONCLUSION AND FUTURE WORK

In this paper we have examined the scanning procedure for an WiMAX/802.16 MS. We have introduced two new strategies to aid in reducing the number of frequencies to check while scanning to find a downlink from a BS and provided some experimental results of a simulation based on real-world mobility traces. In the two scenarios we tested, *along the path* vs. *random locations*, we have shown that the *MRU* (*MFU* respectively) performed best when compared against the default WiMAX/802.16 scanning strategy. We introduced a second strategy to enhance the neighbor advertisement messages sent by the BS to assist the MS. In this strategy, the MS builds a history of previous handovers and uses this information to select which of the advertised neighboring BSs is most likely the correct one for a handover. Through our simulation, we have shown that this strategy improves performance significantly over that of the WiMAX/802.16 default strategy.

Our work is complementary to the other research mentioned such as that done by Rouil and Gomlie [9]. Future work includes extended the model to include such things as (1) time of day (heading to the office, or home) (2) day of the week (weekday vs weekend) and (3) change of city (frequent business travel) parameters to further enhance performance. Finally, an additional refinement to the model to investigate how different loads on the WiMAX/802.16 BSs may affect the scanning times.

VI. ACKNOWLEDGEMENTS

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