國立交通大學

網路工程研究所

碩士論文

評估在 Mobile WiMAX 的頻道掃描策略

Evaluation of Channel Scanning Strategies for Mobile WiMAX

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摘要

移動全球互通微波存取(Mobile WiMAX)在移動網路中已經成為寬頻無線存取(Broadband Wireless Access, BWA)的一項重要技術，它提供完全的分封交換(Packet-Switched)服務；而在移動的環境中支援分封交換的聲音與影像服務上，如何提供行動用戶端(Mobile Station, MS)在服務期間執行不同基地台(Base Station, BS)之間的無間隙換手(Seamless Handover)成為一項非常重要的議題。在移動全球互通微波存取的系統中，行動用戶端在真正執行換手之前，必須先掃描鄰近基地台，並做量程(Ranging)來調整與鄰近基地台的傳輸的功率以及時間同步；但這個過程會造成服務的中斷，使得通訊的服務品質(Quality of Service, QoS)受到影響。因此在本篇論文中，研究掃描及量程所需要的時間以及對執行中的聲音和影像通訊所造成的影響，以建立三種不同對於掃描及量程的策略和數學模型；此三種策略的執行效能也透過數值分析及模擬的方式來完成評估。

Evaluation of Channel Scanning Strategies for Mobile WiMAX

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ABSTRACT

IEEE Std 802.16e or Mobile Worldwide Interoperability for Microwave Access (Mobile WiMAX), which offers pure packet-switched services, has become one of the most important technologies for broadband wireless access (BWA) in mobile environment. One of the most important issues for supporting packet voice or video over a mobile environment is to provide seamless handover between base stations (BSs) during a voice/video communication session. In a Mobile WiMAX system, a mobile station (MS) has to scan the BSs, perform ranging procedures to adjust power and timing with neighboring BSs before handover, and these scanning/ranging procedures may introduce service interrupts and influence the QoS of a session. In this paper, we investigate the scanning and ranging latencies, and their interferences to the active voice/video sessions. The mathematical models for three different scanning and ranging strategies are developed and these strategies are evaluated through analytic and simulation analyses.

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Chapter 1 Introduction

In mobile network, a mobile station (MS) has to perform hanover (HO) while it moves from one base station (BS) to another. The HO introduces service interruption which is critical for real-time communication, such as voice over IP (VoIP). As the IEEE 802.16e specification [1] (the amendment version of IEEE 802.16/2004 [2]) has been established, the WiMAX network could support mobile users to access networks. Thus, the HO becomes one of the most important issues of 802.16e network.

The handover process of 802.16e network could be separated into two phases. The first phase is scan and ranging. The second phase is the HO procedure which is optimized by network side procedures. As for scan and ranging, passive scan of neighbors is fast. But if HO needs to be speeded up, ranging could be performed by an MS to adjust power and timing offsets for neighboring BSs. However, ranging may take long time and highly influence the quality of service (QoS) of VoIP sessions. Many studies have investigated how to reduce the service interruption time to keep good quality of service during handover procedures on Mobile WiMAX system.

[3]-[6] discussed the reserved-based ranging schemes and how to reduce the number of neighboring BSs to be performed scan by an MS. But all the schemes needed the serving BS perform precise coordination with neighboring BSs to allocate the reserved ranging resource for an MS in backbone network. In addition, the coordination process in backbone network is out of IEEE 802.16e standards. Therefore, contention-based ranging is the most popular strategy in ranging scenarios. Unfortunately, the contention-based ranging introduces uncertainty and influences QoS a lot.

[7], [8] discussed the contention-based ranging schemes. [7] proposed a scheme to schedule the scan and ranging operation for an MS to maintain the QoS of an MS while

performing scan. However, the overhead caused by performing contention-based ranging during scan was not carefully considered in [7], and it may result in additional delay. [8] proposed the statistic approaches for an MS to record the most frequent or the most recent ranging BSs in a certain location. For these strategies, the MS need to save a list of neighboring BSs in its local memory and keep updating the information while it moves around. The list helps an MS select suitable BSs for handover; it implies the number of BSs which the MS should perform ranging with could be reduced. However, the parameters of scan operations which influence the QoS directly still need to be carefully set even the list of BSs has be given.

The previous studies did not consider selecting suitable parameters of different BSs individually for an MS to minimize the duration of the first phase in the handover process. Thus, in this paper, we focused on the contention-based ranging during scan and derived performance models to evaluate the scan duration. By using the performance models, some scanning strategies that could minimize the overall scan duration or maintaining the QoS requirements of MSs during scan operation are also proposed.

The rest of this paper is organized as follows. The IEEE 802.16e handover procedures and scanning process are introduced in Chapter 2. The evaluations of scan operations and proposed channel scanning strategies are described in Chapter 3. The simulation environment, simulation results and analyses are described in Chapter 4. Finally, Chapter 5 concludes this study.

Chapter 2 IEEE 802.16e Scanning Process and Problem

2.1 Overview of IEEE 802.16e Handover Procedures

As the IEEE 802.16e standard has been established, the mobility across multiple BSs of an MS could be supported. While an MS travels between BSs, handover would be performed to keep the continuity of services. Figure 1 illustrates the procedures of the IEEE 802.16e handover. The IEEE 802.16e handover procedures could be separated into three stages, including network topology acquisition, actual handover process and network re-entry.

During the stage of network topology acquisition, the information of neighboring BSs would be delivered into the serving BS (1a. in Figure 1) over the backbone network. As following, the information would be broadcasted by advertisement messages (1b. in Figure 1) to their associated MSs. In addition, the MS could actively perform channel scan with neighboring BSs to retrieve the precise channel information.

Before an MS performs channel scan, it first negotiates scanning parameters with its serving BS (2, 3 in Figure 1). After negotiating, the MS references the negotiated scanning parameters to switch channels and passively listen to the channel information of neighboring BSs (4 in Figure 1). During scanning period, the MS could optionally perform ranging to retrieve further information, such as the timing, frequency and power adjustment about a neighboring BS (5, 6 in Figure 1). After performing scan, the MS reports the scan results of neighboring BSs to its serving BS (7 in Figure 1) for further use. As the above mentioned mechanisms are applied, the detailed network topology information of neighboring BSs could be derived by an MS in this stage.

While the signal strength of the serving BS decreases to a certain limit, the MS is trigger to perform actual handover to another BS. The MS sends the handover request message (8 in Figure 1) to the serving BS first. As the request is received by the serving BS, it references the information of neighboring BSs derived in former stage, and then replies the recommended target BSs by sending the handover responding message (9 in Figure 1). After the recommended target BSs are gotten by an MS, the MS decides the target BS from them and sends the handover indication (10 in Figure 1) to its serving BS. Thus, the handover process is finished and the serving BS releases the maintained MS information after receiving this indication message. Then the MS switches the channel to its target BS and prepares to perform network re-entry with it (11-13 in Figure 1).

The procedures of the network re-entry are similar to those of initial entry. If the target BS supports handover optimization or has negotiated with the MS in network topology acquisition stage, the network re-entry procedures could be reduced and the duration of service interruption would be shortened.

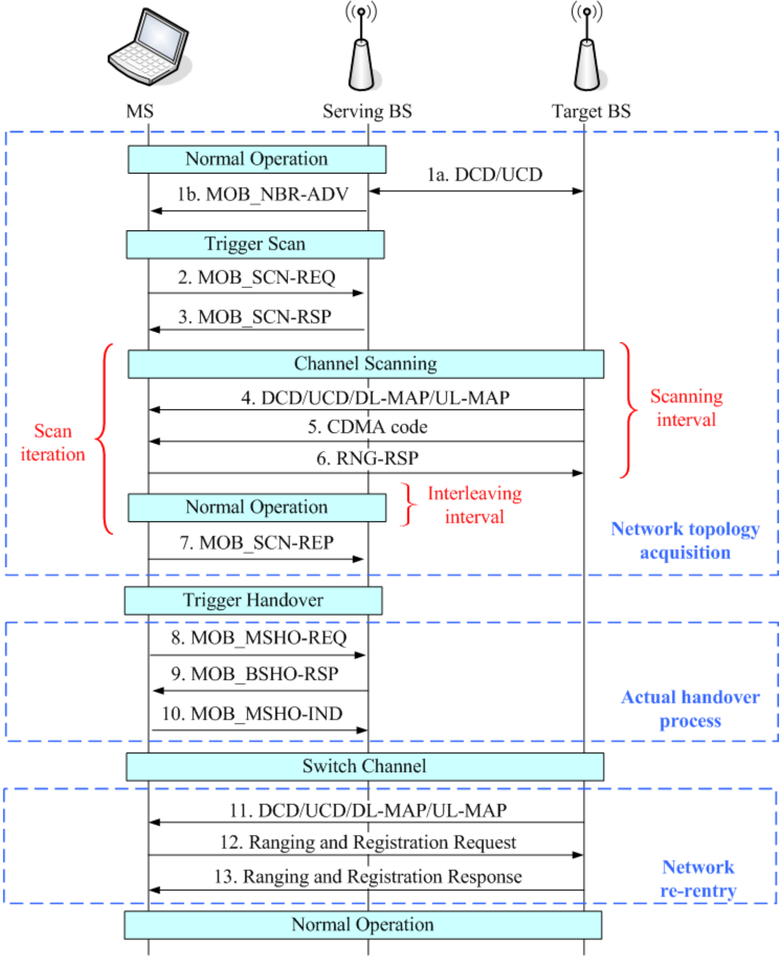

Figure 1. IEEE 802.16e handover procedures

2.2 The Channel Scanning Operations

As the network topology acquisition stage described in 2.1, an MS could perform passive scan and optional association during scanning time. The term, association, indicates that an MS performs ranging with neighboring BSs in scan duration. However, the IEEE 802.16e specification defines four modes of channel scanning with different association levels.

In scan without association, the MS synchronizes with the channels of neighboring BSs and just passively listen to get the channel information and estimate the channel qualities. After finishing scan, the MS switches to the original channel of the serving BS and continues its service flow.

In association level 0 (association without coordination), the serving BS allocates periodic scanning time for an MS to scan and range neighboring BSs. However, the target BS has no information about the scanning MSs and provides only contention-based ranging allocations for them. The ranging MS chooses randomly a ranging code and transmits it in the contention-based ranging slot of the target BS. The contention-based ranging process is applied by truncated binary exponential backoff (BEB) algorithm.

In association level 1 (association with coordination) and association level 2 (network assisted association reporting), the serving BS could coordinate association information between an MS and neighboring BSs, and then provide the dedicated ranging codes and ranging slots for the ranging MS. The MS could use them to perform reserve-based ranging which could shorten the ranging duration with neighboring BSs. Moreover, the difference between association level 1 and level2 is that for level 1, the MS needs to wait the ranging response after transmitting the dedicated CDMA code. However, for level 2, the MS does not need to wait the response after sending the CDMA code. The serving BS could retrieve all responses from neighboring BSs in backbone network and gather them as a message to send to the MS.

2.3 The Channel Scanning Problem

In association level 0, an MS performs contention-based ranging with a neighboring BS. Before the association process, the serving BS and the MS negotiate the association related parameters. The association parameters include two main periods for a ranging MS. The first is the scanning interval which is a period for an MS to switch channels and perform scan and association with neighboring BSs. The second is the interleaving interval which is a period for an MS to perform normal operation with the serving BS. Figure 2 shows the alternations of scanning and interleaving intervals along the time during the scan operation.

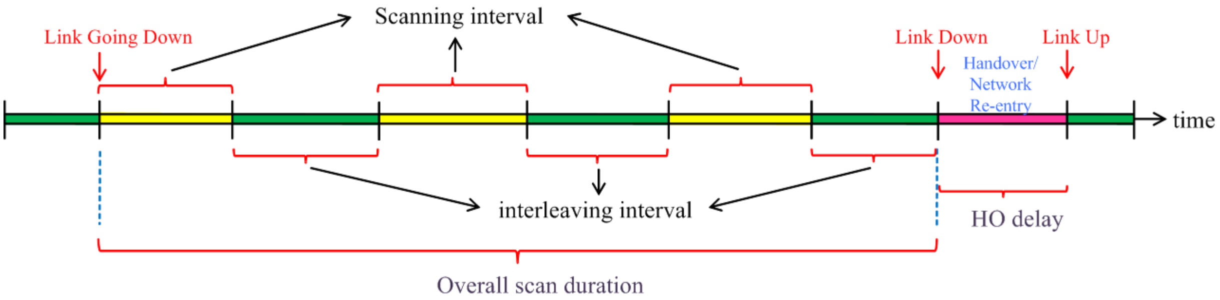

Figure 2. Alternation of scanning and interleaving intervals during the scan operation

In the scanning interval, while a serving BS or an MS has packets would be sent to each other, the packets are buffered in their local memories until the end of the interval. Then the buffered packets are sent in the interleaving interval. Thus, if the scanning interval is allocated too long, it would cause long packet delay and damage the QoSs of services. On the other hand, the association processes of an MS with neighboring BSs could only be performed in scanning intervals. If the scanning interval is allocated too short, the association process with a neighboring BS will be partitioned into several parts. In addition, the interleaving interval for normal operation would be allocated between scanning intervals. Therefore, the overall scan duration could be extended in this condition. Figure 3 shows the relationship as mentioned above. Allocation of long scanning interval causes long session interrupt but short overall scan duration. Oppositely, allocation of short scanning interval causes short session interrupt but long overall scan duration.

However, how the scanning and interleaving intervals for an MS are allocated by the serving BS is not specified in the IEEE 802.16e standard and is far from trivial. In this paper, the scan with association level 0 is focused. The issue of how to schedule the scan operation to shorten the overall scan duration of contention-based ranging without influencing the QoS of services will be discussed in following chapters.

Because the association level 0 is focused in this paper, in following article of this paper, the term, scan operation, indicates the scan with contention-based ranging operation.

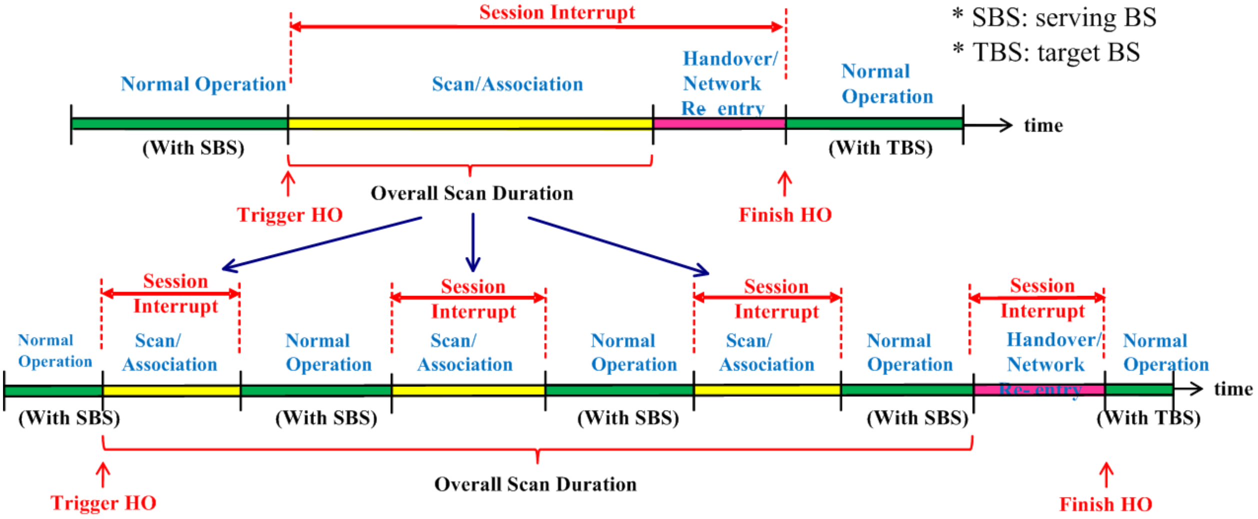

Figure 3. Relationship with overall scan duration, session interrupt and scanning interval

Chapter 3 Proposed Channel Scanning Strategies

3.1 Channel Scanning Without Partition

The first channel scanning strategy is to give an MS a long scanning interval to finish the overall scan operations without being partitioned by interleaving intervals. While the serving BS disconnects with an MS and the MS performs scan with neighboring BSs continuously, the overall scan duration could be the minimal. However, by using this strategy, the packet delay caused by buffering would be relatively large as mentioned before. Thus, this strategy is suitable for non-real-time applications. Figure 4 illustrates an example of scan without partition strategy for an MS.

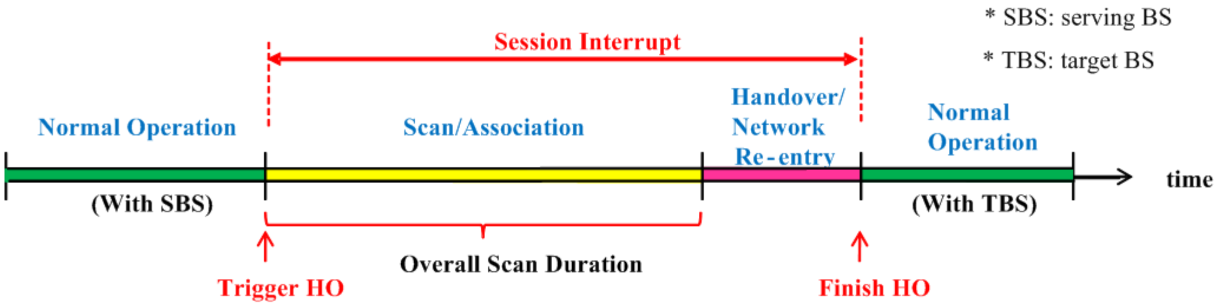

Figure 4. Scan without partition strategy

Before the serving BS allocates scanning time for an MS, it needs to estimate the duration that an MS requires to finish the scan and association operations with a neighboring BS. As mentioned before, an MS with association level 0 performs contention-based ranging with a neighboring BS. In IEEE 802.16e standard, the contention-based ranging applies the BEB algorithm. About BEB, [9] analyzed the performances of the exponential backoff protocol in detail. [10], [11] introduced the analyses of the contention resolution schemes in WiMAX networks. Based on these analysis results, the performance model of contention-based ranging delay is derived in this chapter. Then the serving BS could use this performance model to estimate the scan with association time from ranging related parameters of neighboring BSs.

Figure 5 shows the finite state machine of contention-based ranging in an MS. Before an MS performs contention-based ranging, it receives the ranging backoff start $B_{\exp s}$, ranging backoff end $B_{\exp e}$, and the ranging retry limit L of a neighboring BS. The MS could calculate the minimum contention window $W_0 = 2^{B_{\exp s}}$. Then the MS randomly chooses a backoff counter from $[0,1,...,W_0 - 1]$ and waits to transmit the chosen CDMA code. After the backoff counter is counted down to zero, the MS transmits the chosen code to a ranging slot provided by the neighboring BS.

After transmitting the CDMA code, if the MS waits over T3 duration and does not receive the RNG-RSP, it regards this request process as failed and then doubles its contention window and performs the random backoff again. The contention window size for *i*-th retrial could be calculated as:

$$W_i = \begin{cases} 2^i \cdot W_0, i \le m \\ 2^m \cdot W_0, m < i \le L \end{cases}, \text{ that } \ m = B_{\exp e} - B_{\exp s} + 1$$

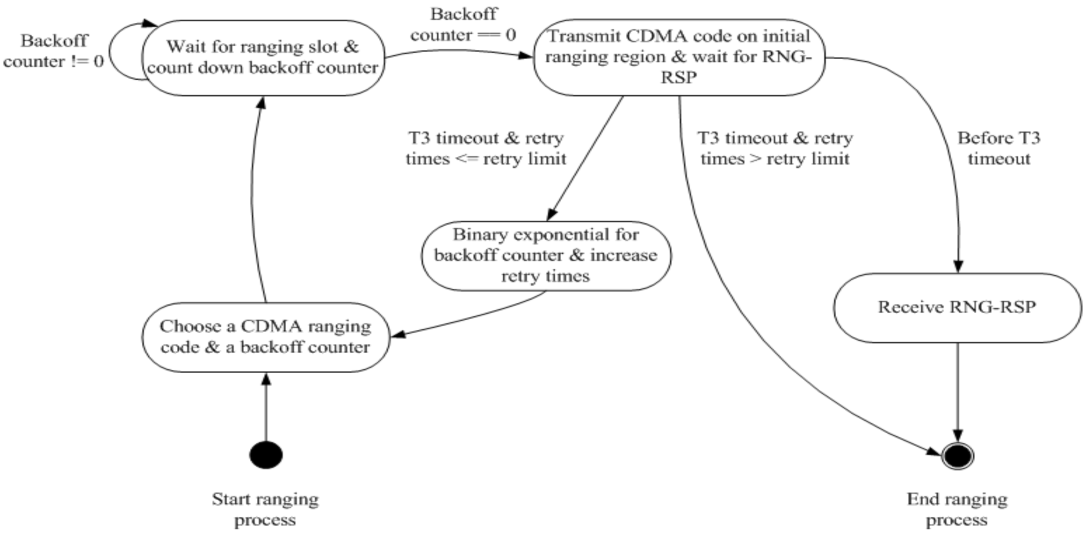

Figure 5. Finite state machine of contention-based ranging in an MS

Let d_i denotes the random variable of the delay in retrial state *i*, and the average delay in state *i* could be calculated as:

$$\overline{d_i} = E[d_i] = \begin{cases} \dfrac{2^i \cdot W_0 + 1}{2}, i \le m \\ \dfrac{2^m \cdot W_0 + 1}{2}, m < i \le L \end{cases}$$

The expected number of the backoff counter that an MS would need to count down after retrying *i* times could be calculated by cumulating the average delay until state *i*, and denotes as:

$$E[B(i)] = \begin{cases} \sum_{k=0}^{i} \dfrac{2^k \cdot W_0 + 1}{2}, i \le m \\ \sum_{k=0}^{m} \dfrac{2^k \cdot W_0 + 1}{2} + \dfrac{(2^m \cdot W_0 + 1) \cdot (i - m)}{2}, i > m \end{cases}$$

In this paper, the number of ranging MSs in a neighboring BS is regarded as steady. Thus, the collision probability of each MS in the neighboring BS is identical because each MS in the same BS uses the same protocol and ranging parameters. The collision probability is related to the number of ranging MSs, the size of contention window, the ranging retry limit, and the number of ranging CDMA codes. [11] derived the attempt rate β, which indicates the probability of an MS sending a CDMA code in a ranging slot, as $\beta = \dfrac{1}{T_{wait} + \dfrac{\overline{d_0} + P_c \cdot \overline{d_1} + P_c^{\,2} \cdot \overline{d_2} + \ldots + P_c^{\,L} \cdot \overline{d_L}}{1 + P_c + P_c^{\,2} + \ldots + P_c^{\,L}}}$ where T_{wait}, P_c indicate individually the time to wait RNG-RSP after sending a CDMA code and the collision probability. In addition, [11] also showed the equation of the collision probability as $P_c = \sum_{i=0}^{n-1} \binom{i}{n-1} \beta^i \cdot (1-\beta)^{n-i-1} \cdot (1 - \dfrac{1}{N})^i$ where *N*, *n* denote the number of ranging MSs and the number of CDMA codes. From these two equations, the collision probability P_c could be derived by solving the combined equations:

$$\begin{cases} \beta = \dfrac{1}{T_{wait} + \dfrac{\overline{d_0} + P_c \cdot \overline{d_1} + P_c{}^2 \cdot \overline{d_2} + \ldots + P_c{}^L \cdot \overline{d_L}}{1 + P_c + P_c{}^2 + \ldots + P_c{}^L}} \\ P_c = \sum_{i=0}^{n-1} \binom{i}{n-1} \beta^i \cdot (1-\beta)^{n-i-1} \cdot (1 - \dfrac{1}{N})^i \end{cases}$$

Assuming the channel condition is ideal, the ranging failure of an MS is caused from the collision of CDMA codes. Therefore, the probability of (i+1)-th successful transmission for the MS could be calculated as:

$$P_i = \frac{(1-P_c) \cdot P_c{}^i}{1 - P_c{}^{L+1}}$$

Finally, if an MS does not leave the ranging channel of the target BS before finishing ranging, the expected overall scan duration in slot time could be derived:

$$T_{assoc} = (1 - P_c{}^{L+1}) \cdot \left\{ \sum_{i=0}^{L} P_i \cdot [\frac{E[B(i)]}{\tilde{N}_{to}} + (T_{out} \cdot i + T_{wait})] \right\} + P_c{}^{L+1} \cdot [\frac{E[B(L)]}{\tilde{N}_{to}} + T_{out} \cdot (L+1)] \qquad (1)$$

$\tilde{N}_{to}$, T_{out} indicate individually the average ranging slots per frame of a BS and the T3 timeout duration. However, the delay of RNG-RSP sent by a neighboring BS is assumed as uniform distribution from 1 to T_{out} in this thesis, therefore the expected responding duration T_{wait} could be calculated as:

$$T_{wait} = \frac{T_{out}}{2}$$

After deriving the performance model (1), the first channel scanning strategy is described as follow. While an MS will perform the scan operation, the serving BS retrieves the information set $I_i\{B_{\exp s}, B_{\exp e}, \tilde{N}_{to}, L, T_{out}, N\}$ of the neighboring BS_i from the backbone network. Then the serving BS uses (1) to calculate the association duration T_{assoc_i} of the neighboring BS_i. If there are N_{nbs} neighboring BSs that the MS will scan, the serving BS would calculate the association durations individually from T_{assoc_1} to $T_{assoc\_N_{nbs}}$, and transmits the calculated information by MOB_SCN_RSP to the MS. After receiving the information, the MS could reference it and be aware of the expected overall scan duration and the service interruption duration while performing scan operations.

3.2 Channel Scanning With Partition

For real-time applications, the packet delay needs to be bounded below the QoS requirements. Therefore, the scan operations with neighboring BSs performed by an MS would need to be interleaved the normal operation durations to avoid packets buffered too long in scanning intervals. Figure 6 illustrates an example of the scan with partition strategy for an MS.

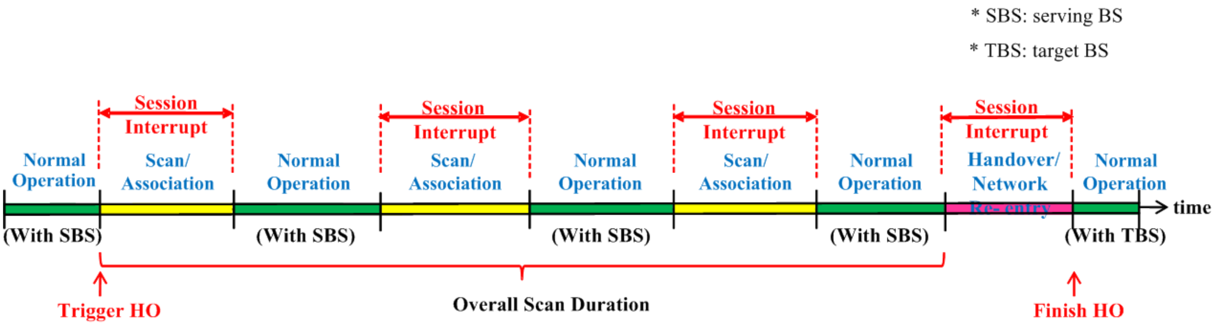

Figure 6. Scan with partition strategy

For the scan with partition strategy, while the serving BS provides certain scanning and interleaving intervals for an MS, how long the MS could finish the scan operation with a neighboring BS should be considered. Therefore, the performance model of association delay with different scanning and interleaving intervals will be derived in this chapter. Before deriving this model, there are two assumptions given in the scanning with partition strategy. The first is that if the backoff counter is not counted down to zero in a scanning interval, the MS will continue to count down the counter in next scanning interval. The second is that for an MS, after sending a CDMA code, the T3 counter for waiting RNG-RSP is counted down in both the scanning and interleaving intervals.

Figure 7(a) illustrates an example of the scan operation with partition. During scan, the processes of an MS include counting down backoff window, sending a CDMA code and waiting RNG-RSP. The counting down backoff window and sending a CDMA code processes only occur in the scanning interval but the waiting RNG-RSP process could occur in both scanning and interleaving intervals. However, for a neighboring BS, it has no idea about the scanning and interleaving intervals of a ranging MS and just sends the RNG-RSP after receiving the ranging code. Hence, comparing to the scan without partition strategy, in addition to collision of CDMA codes sent by different MSs, the ranging process could be failed from that the RNG-RSP is sent in interleaving intervals by the neighboring BS.

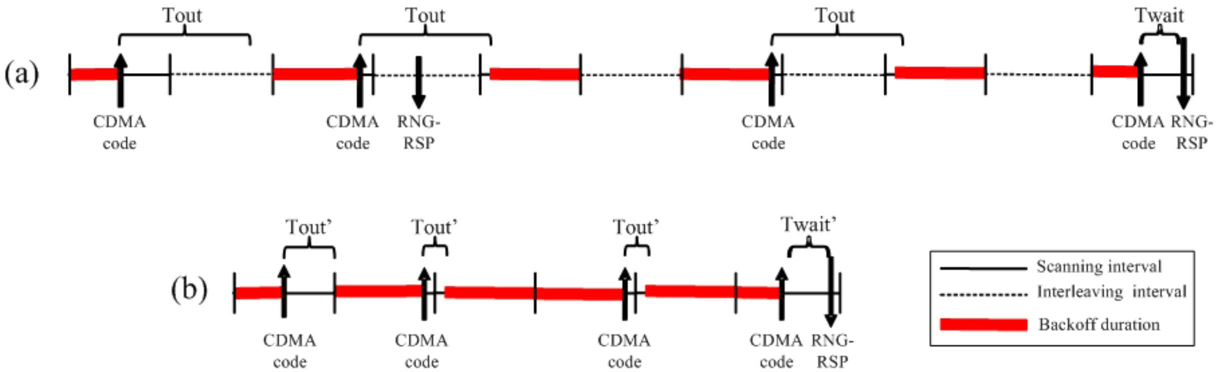

Figure 7. Scan with partition example

α denotes the probability which the RNG-RSP is sent during the interleaving interval. It relates to the lengths of scanning interval x, the interleaving interval y, and the RNG-RSP sending time of a serving BS. Assuming the number of ranging slots in every frame is the same, the probability of CDMA codes sent in each frame during the scanning interval by ranging MSs could be regarded as identical.

Figure 8 illustrates an example that indicates the probability of RNG-RSP sent in interleaving intervals. The x-axis denotes the time of an MS sending a CDMA code. However, because an MS could send a CDMA code just in the scanning interval, the sending time is bounded to the length of the scanning interval. The y-axis denotes the time of the serving BS sending a RNG-RSP after receiving the CDMA code from an MS. The maximum response duration of the serving BS is bounded to T3 timeout, because the ranging process would be regarded as failed if the response time exceeds the T3 timeout.

The sample space for the ranging process is within these two conditions as mentioned above. Therefore, as shown in Figure 8**,** the ranging results could be summarized into two situations. If the sum of sending CDMA code time *X* and sending RNG-RSP time *Y* is within the scanning interval *A*, the ranging process would be successful. Otherwise, if the sum of durations is within the interleaving interval *B*, the ranging process would be failed. These two situations could be expressed as:

$$\begin{cases} A < X + Y \le A + B \quad : ranging\ fail \\ A + B < X + Y \le 2A + B : ranging\ success \end{cases}$$

As shown in Figure 8**,** the slash region denotes the ranging failure situation within the sample space. The probability of ranging failure caused by RNG-RSP sent in interleaving intervals within the sample space could be calculated as:

$$\alpha = Ranging\_fail\_region / (A \times Max\_RSP\_Duration)$$

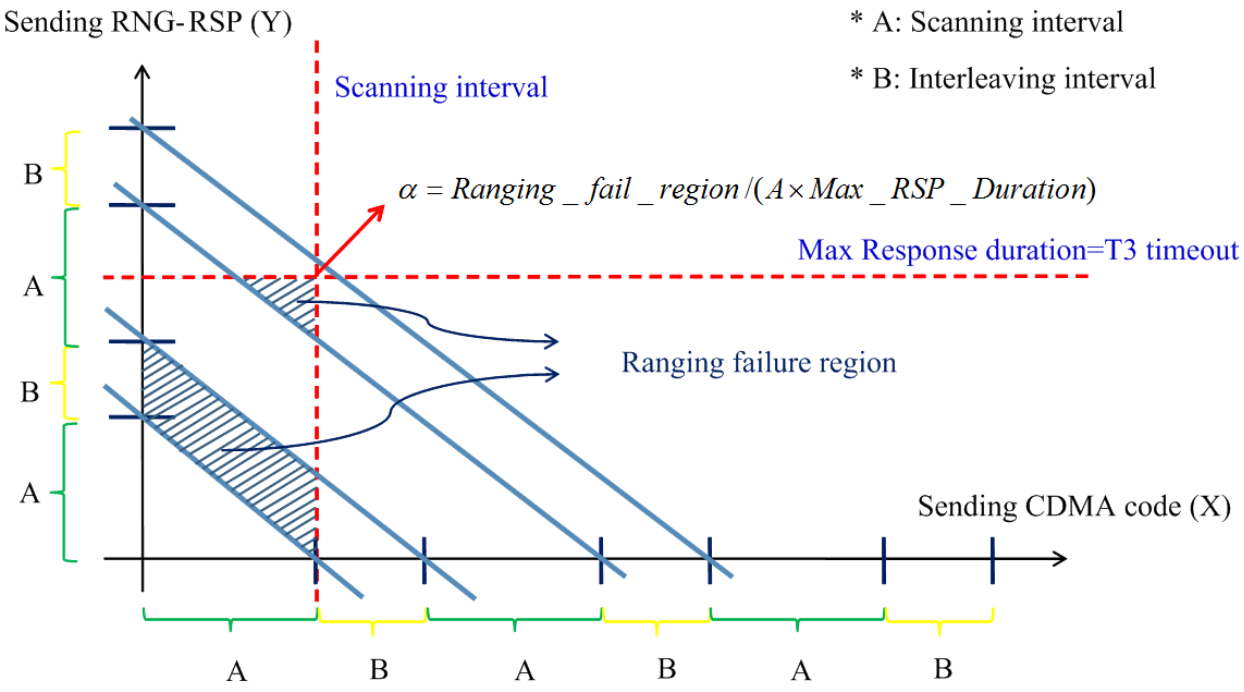

Figure 8. Probability of RNG-RSP sent in interleaving intervals

For the scan with partition strategy, the ranging process could be failed from the collision of CDMA codes or the RNG-RSP sent in the interleaving interval. Thus, the probability of ranging failure P_f could be derived as:

$$P_f = P_c + (1 - P_c) \cdot \alpha$$

The probability of (i+1)-th successful transmission of the scan with partition strategy for an MS could be derived as:

$$P_i^{'} = \frac{(1 - P_f) \cdot P_f^{\,i}}{1 - P_f^{\,L+1}}$$

Figure 7(b) shows the scan operation in only the scanning intervals. If the T3 timeout duration in scanning intervals $T_{out}\,'$, and the waiting RNG-RSP duration in scanning intervals $T_{wait}\,'$ could be estimated, the duration of Figure 7(b) could be calculated. Therefore, the overall scan duration as showed in Figure 7(a) would also be derived by adding the sum of interleaving intervals during the scan operation.

The T3 timeout duration in scanning intervals $T_{out}\,'$ is related to the scanning interval x, the interleaving interval y, and T3 timeout duration T_{out}. Figure 9 shows the five possible situations of T3 timeout in scanning intervals. The $T_{out}\,'$ in different cases are derived as:

Case 1. $T_{out} < x, T_{out} \le y$:

$$T_{out}^{\,'} = T_{out} \cdot \frac{x - T_{out}}{x} + \frac{(T_{out} - 1)}{2} \cdot \frac{T_{out}}{x}$$

Case 2. $T_{out} \ge x, T_{out} > y$ and $T_{out} \le (x + y)$:

$$T_{out}^{\,'} = \frac{(x - 1) + (T_{out} - y)}{2} \cdot \frac{x + y - T_{out}}{x} + (T_{out} - y) \cdot \frac{T_{out} - y}{x}$$

Case 3. $T_{out} \ge x, T_{out} \le y$:

$$T_{out}' = \frac{x-1}{2}$$

Case 4. $T_{out} < x, T_{out} > y$:

$$T_{out}' = T_{out} \cdot \frac{x - T_{out}}{x} + \frac{(T_{out} - 1) + (T_{out} - y)}{2} \cdot \frac{y}{x} + (T_{out} - y) \cdot \frac{T_{out} - y}{x}$$

Case 5. $T_{out} > (x+y)$:

Step 1: $\overline{T}_{out} = T_{out} \bmod (x+y)$

Step 2: Deriving $\overline{T}_{out}''$ from case 1 to case 4 based on x, y, and $\overline{T}_{out}$

Step 3: $T_{out}' = \left\lfloor \dfrac{T_{out}}{x+y} \right\rfloor \cdot x + T_{out}''$

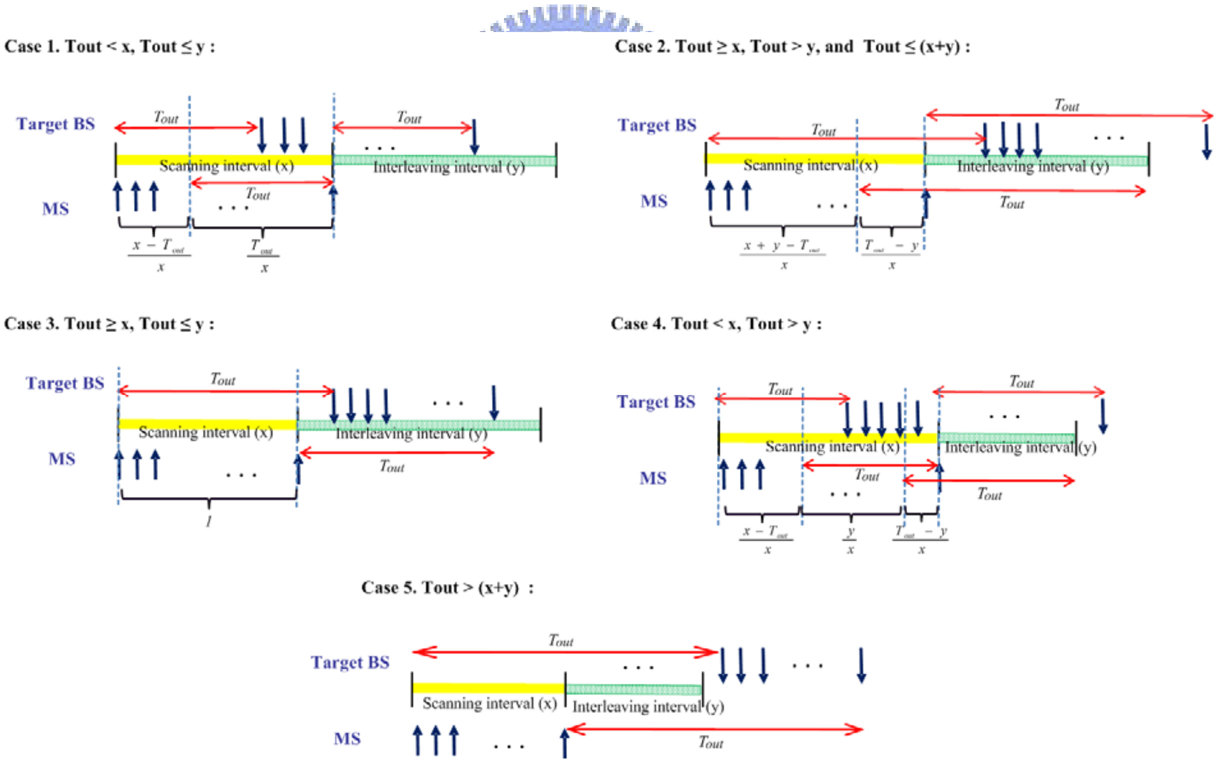

Figure 9. Five possible situations that T3 timeout in scanning intervals

Figure 10 shows the five possible situations that waiting RNG-RSP duration in scanning intervals. For waiting RNG-RSP duration, it is only discussed in ranging success cases. And the waiting duration T_{wait}' is related to the scanning interval *x*, the interleaving interval *y*, and waiting RNG-RSP duration T_{wait}. The T_{wait}' in different cases are derived as:

Case 1. $T_{wait} < x, T_{wait} \le y$:

$$T_{wait}' = T_{wait}$$

Case 2. $T_{wait} \ge x, T_{wait} > y$ and $T_{wait} \le (x+y)$:

$$T_{wait}' = T_{wait} - y$$

Case 3. $T_{wait} \ge x, T_{wait} \le y$:

The ranging process must be failed.

Case 4. $T_{wait} < x, T_{wait} > y$:

$$T_{wait}' = T_{wait} \cdot \frac{x - T_{wait}}{x - y} + (T_{wait} - y) \cdot \frac{T_{wait} - y}{x - y}$$

Case 5. $T_{wait} > (x+y)$:

Step 1: $\bar{T}_{wait} = T_{wait} \bmod (x+y)$

Step 2: Deriving T_{wait}'' from case 1 to case 4 based on *x*, *y*, and $\bar{T}_{wait}$

Step 3: $T_{wait}' = \left\lfloor \frac{T_{wait}}{x+y} \right\rfloor \cdot x + T_{wait}''$

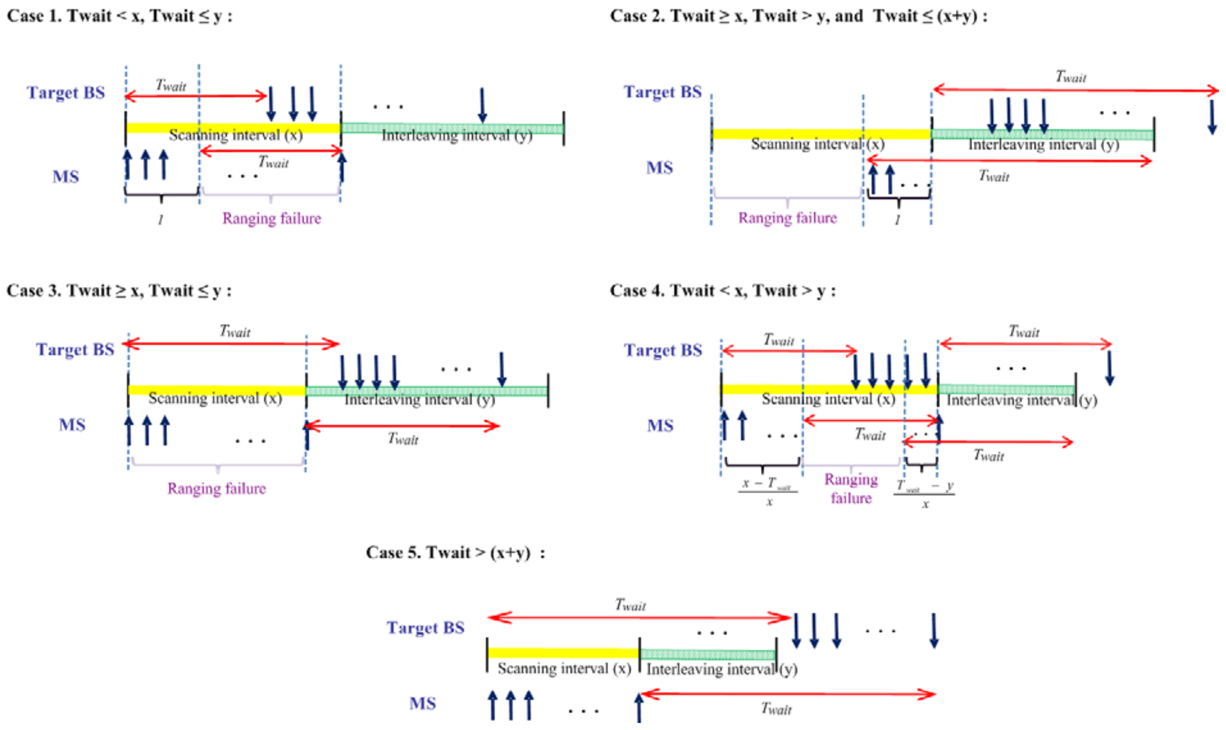

Figure 10. Five possible situations that waiting RNG-RSP duration in scanning intervals

After deriving the expected values of T_{out}' and T_{wait}', the expected overall scan duration in scanning intervals T_{assoc}' as shown in Figure 7(b) could be calculated as:

$$T_{assoc}' = (1 - P_f^{L+1}) \cdot \left\{ \sum_{i=0}^{L} P_i' \cdot \left[\frac{E[B(i)]}{\tilde{N}_{to}} + (T_{out}' \cdot i + T_{wait}') \right] \right\} + P_f^{L+1} \cdot \left[\frac{E[B(L)]}{\tilde{N}_{to}} + T_{out}' \cdot (L+1) \right]$$

Thus, the expected overall scan duration $T_{overall}$ with a neighboring BS as shown in Figure 7(a) could be derived as:

$$T_{overall} = \left\lfloor \frac{T_{assoc}'}{x} \right\rfloor \cdot (x+y) + (T_{assoc}' \bmod x) \qquad (2)$$

After deriving the performance model as shown in (2), while giving a scanning interval, an interleaving interval and ranging parameters of a neighboring BS, the expected overall scan duration of a neighboring BS could be calculated.

The second channel scanning strategy is that the serving BS provides a ranging MS static scanning and interleaving intervals to perform scan operations with all neighboring BSs. However, how long the scan operation would be finished could be calculated by the performance model (2).

The third channel scanning strategy is an advanced version of the second strategy. In this strategy, the quality of service (QoS) of each service in an MS would be considered. The serving BS attends to satisfy the delay constraint D_i and the bandwidth requirement B_i of MSi during the scan operation. Moreover, in the third scanning strategy, the serving BS could also find the optimal scanning and interleaving intervals for each neighboring BS that generates the minimal expected overall scan duration.

Because the scan operation in scanning intervals could interrupt the normal operation and cause the packet delay, the decision of the scanning interval should be bounded to the delay constraint of a ranging MS. The serving BS could derive the minimal delay constrain $Min(D_i)$ from all services in MSi. Then the serving BS could derive the maximum scanning interval X' that $X' \leq Min(D_i)$. In addition, the serving BS could retrieve the information of how much bandwidth B_i has been allocated to an associated MSi and how much the resource R has not been allocated. From the derived information, the serving BS could calculate the minimum interleaving interval Y' that $(X'+Y') \cdot B_i \leq Y' \cdot R$. After X' and Y' have been derived, the serving BS attends to find the minimal overall scan duration from applying particular scanning interval X and interleaving Y.

Figure 11 illustrates an example of finding the optimal scanning and interleaving intervals in the third scanning strategy. The slash region denotes the possible solutions which are bounded to the delay and bandwidth constraints. Moreover, the optimal scanning and interleaving intervals could be derived with these possible solutions.

Basing on these constraints, the third scanning strategy could be partitioned into three steps:

Step 1. The serving BS retrieves the information set $I_i\{B_{exps}, B_{expe}, \tilde{N}_{to}, L, T_{out}\}$ of the neighboring BS_i from the backbone network. Moreover, the delay constraint and the bandwidth requirement of an MS are also derived.

Step 2. For each neighboring BS, the serving BS calculates the maximum length of the scanning interval for an MS from the delay constraint. Then the serving BS uses the performance model (2) to calculate the overall scan duration from different scanning and interleaving intervals which are under the maximum length of the scanning interval. Moreover, the lengths of the interleaving intervals varied from different scanning intervals are calculated by the bandwidth requirement of the MS.

Step 3. The minimal expected overall scan duration with particular scanning and interleaving intervals for each neighboring BS would be derived. Then the serving BS provides the optimal scanning and interleaving intervals of each neighboring BS for ranging MSs to perform scan operations.

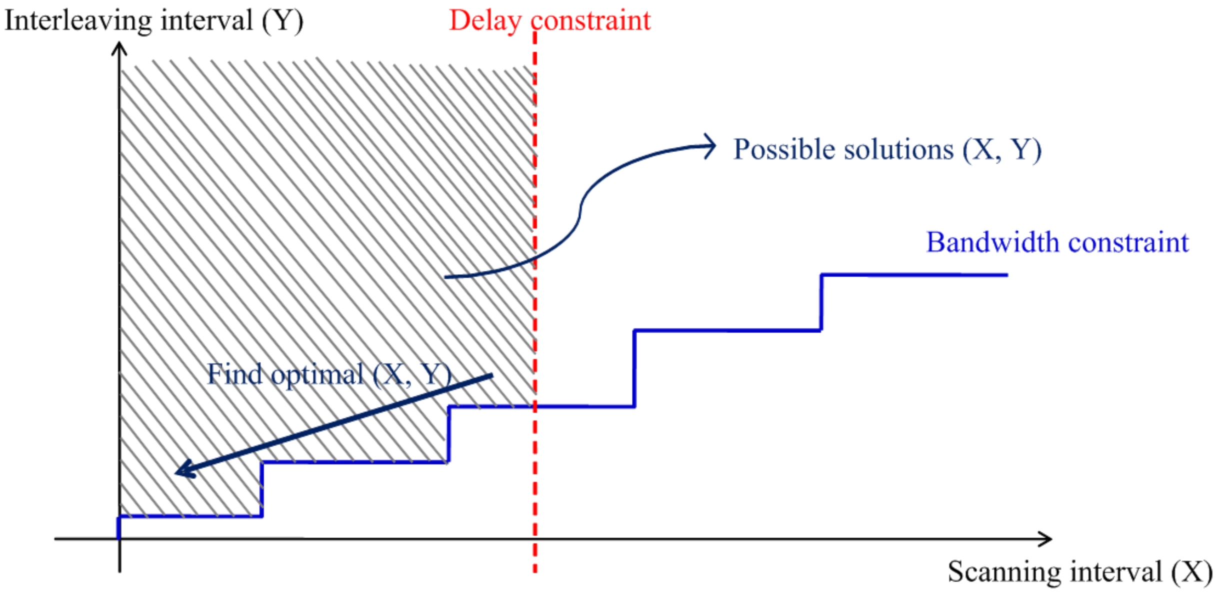

Figure 11. Finding the optimal scanning and interleaving intervals of the third strategy

Chapter 4 Simulation Results

4.1 Simulation Environments

The IEEE 802.16e MAC-layer simulator is written in C++ to evaluate the channel scanning operation performance by applying three proposed strategies. The simulation uses WirelessMAN-OFDMA profiles with 1024 FFT, 10 MHz frequency bandwidth, 5 ms frame length, and BPSK 1/2 modulation coding.

The simulation environment in this chapter is that there are an MS, a serving BS and neighboring BSs operating while the simulation starts. The serving BS and neighboring BSs periodically exchange their ranging parameters in backbone network. An MS connects with its serving BS and performs normal operations. While the MS is triggered to perform HO, it negotiates the scan parameters with its serving BS and then performs scan operations with neighboring BSs. The sending RNG-RSP delay after receiving the ranging code of a neighboring BS is uniform distributed from 1 to 10 frames. A neighboring BS in the simulator supports scan with association level 0 and its ranging parameters are listed in Table 1.

Table 1. Ranging parameters of a neighboring BS

Parameter	Value	Parameter	Value
$B_{\exp s}$ (Backoff start)	5	n (# of ranging CDMA codes)	2
$B_{\exp e}$ (Backoff end)	10	L (Retry timeout)	16
$\tilde{N}_{to}$ (Ranging slots per frame)	2	T_{out} (T3 timeout)	50 ms

In addition, the MS uses audio and video applications and the performances of these applications would be evaluated while performing scan. For audio application, it is applied the UGS service flow class; for video application, it is applied the rtPS service flow class. The detailed application parameters are listed in Table 2.

Table 2. Application parameters

Application	Description	Delay Constrain
Audio	G.711 codec with 64 Kbps and 20 ms frame length.	50 ms
Video	H.261 codec with 256 Kbps and 25 frames per second.	100 ms

4.2 Simulation Results and Analyses

There are four scenarios of the simulation in this chapter. The first is to observe the overall scan duration with different scanning and interleaving intervals. In addition, the calculated results by the performance model (2) will be validated with the simulation results. The second is to observe the overall scan duration considering the QoSs of services in an MS. While giving a scanning interval, the serving BS would calculate the corresponding interleaving interval basing on the bandwidth requirement of the application. The third is to observe the variations of packet delays for audio and video applications with different working loads of the serving BS. Finally, the last is to compare the overall scan duration with three mentioned scanning strategies for an MS by scanning multiple neighboring BSs.

In the first scenario, there are an MS, a serving BS and a neighboring BS in the environment. For the neighboring BS, there are two hundred MSs raging with it. Figure 12 shows the calculated results of overall scan durations by the performance model (2) with different scanning and interleaving intervals. The calculated results are validated by the simulation results and the mean deviation between them is 6.13%.

From these results, while the scanning interval is fixed, the longer the interleaving interval is given, the longer the overall scan duration is gotten. This result is trivial and could be easily realized from the performance model (2). Oppositely, while the interleaving interval in fixed, the longer the scanning interval is given, the shorter the overall scan duration is gotten. The reason is as the scanning interval is given long, the probability of RNG-RSP sent in interleaving intervals could be reduced. Then an MS could occur less times of ranging failures, so that the overall scan duration would also be reduced.

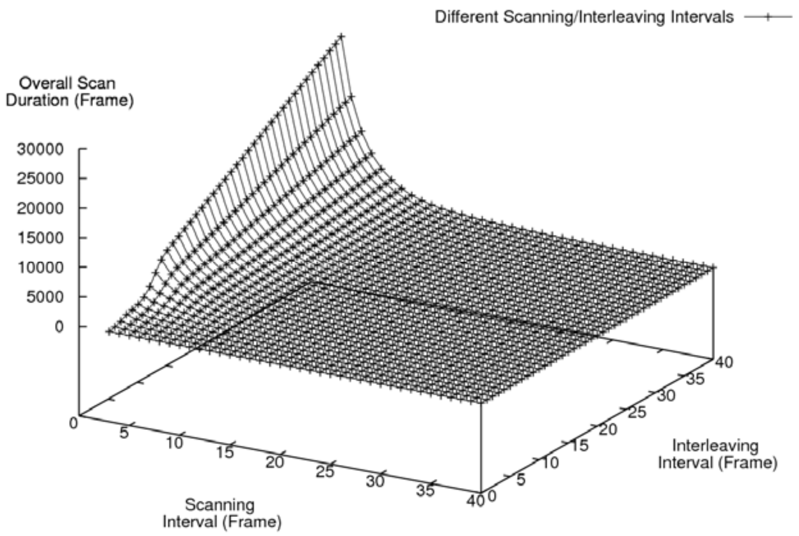

Figure 12. Overall scan durations for an MS by different scanning and interleaving intervals

In the second scenario, there are an MS with different applications, a serving BS and a neighboring BS in the environment. The performances of audio and video applications in an MS while performing scan are discussed. For the neighboring BS, there are one hundred MSs raging with it. Considering the application QoS, while giving a scanning interval, the interleaving interval could be derived by the bandwidth requirement of the application and the working load of a serving BS.

For audio applications, Figure 13 shows the overall scan duration derived by different scanning and interleaving intervals with different working loads of the serving BS. As the working load of the serving BS is 10%, the interleaving interval is kept the same while the scanning interval is increased. Moreover, the overall scan duration varies as monotone decreasing while the scanning interval is increased. However, if the load of a serving BS is up to 70%, the available resource would be less than that of 10% working load. Thus, as the scanning interval is increased to a certain length, the interleaving interval also needs to be increased to meet the bandwidth requirement. Figure 14 shows the results of the projection of the x-axis and z-axis in Figure 13.

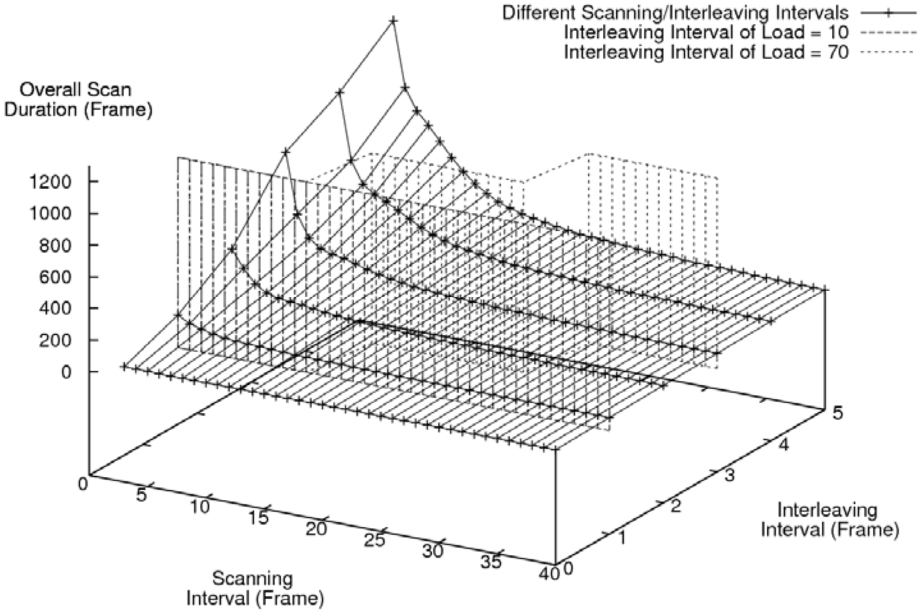

Figure 13. Overall scan durations for an MS supporting audio traffic by different scanning intervals

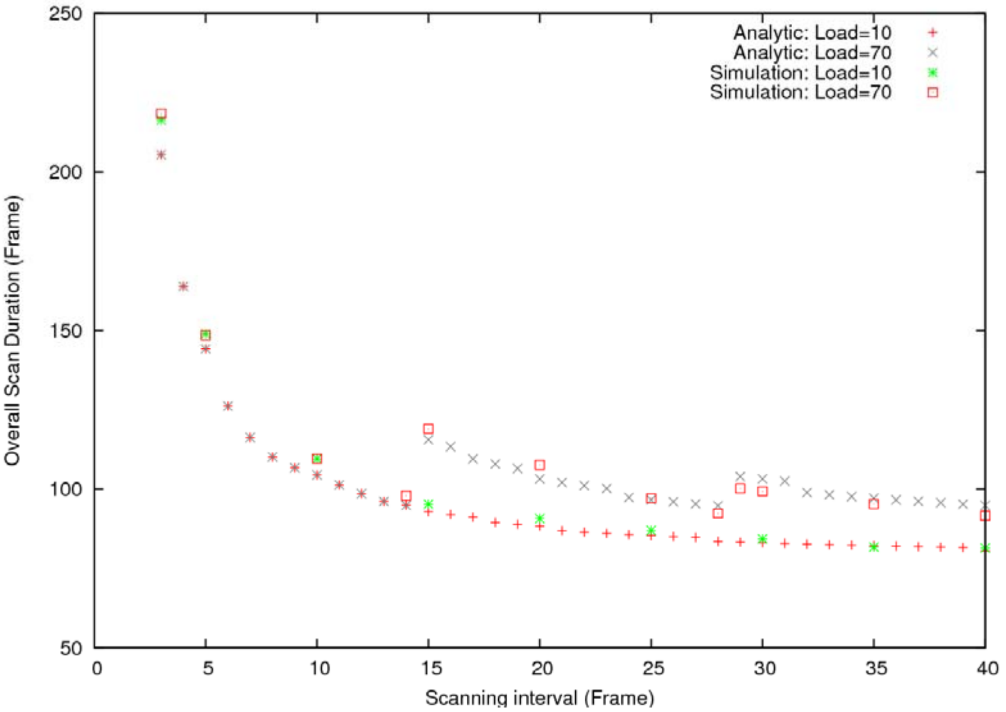

Figure 14. Overall scan durations for an MS supporting audio traffic by different scanning intervals

For video applications, the data rate is higher than that of audio applications as shown in Table 2. Thus, the increasing rate of the interleaving interval for the video application as the scanning interval is increased is faster than that for the audio application. Figure 15 shows the overall scan duration derived by different scanning and interleaving intervals with different working loads of the serving BS. While the load of the serving BS is 10%, unlike the audio application, the interleaving interval could be increased as increase of the scanning interval. However, while the load of the serving BS is up to 50%, the increasing rate of the interleaving interval is faster than that of 10% because of the less available resource of the serving BS. Figure 16 shows the results of the projection of the x-axis and z-axis in Figure 15.

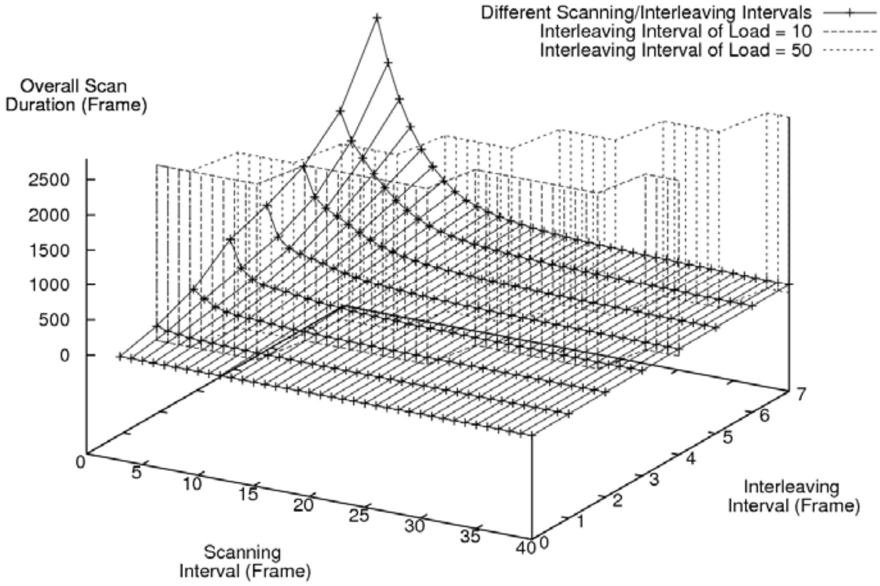

Figure 15. Overall scan durations for an MS supporting video traffic by different scanning intervals

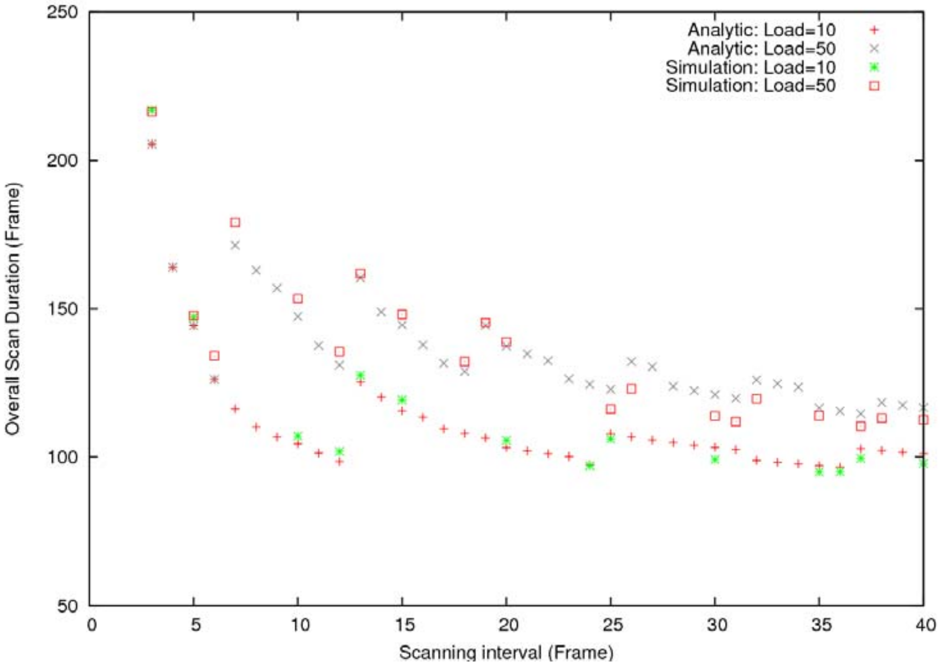

Figure 16. Overall scan durations for an MS supporting video traffic by different scanning intervals

In the third scenario, there are an MS, a serving BS applying the third scanning strategy and a neighboring BS in the environment. Figure 17 and Figure 18 show individually the variations of average packet delays of audio and video applications with different working loads of the serving BS.

For the audio application, the delay constraint is set to 50 ms. As shown in Figure 17, the average packet delay is still bounded to 50 ms while the working load of the serving BS is below 97%. Table 3 illustrates the optimal scanning and interleaving intervals which are derived by the third scanning strategy under different loads of the serving BS for audio applications. Because the interleaving interval is encoded as 8 bits which is specified in the standard, the maximum length of it is 255 frames. However, while the working is up to 98%, the remainder resource of the serving BS is not enough to be allocated for the MS in the interleaving interval. Thus, the packet delay of the MS could not be ensured to be under the delay constraint in this situation as shown in Figure 17.

Similarly, for the video application with 100 ms delay constraint, the average packet delay could be bounded to the delay constraint while the serving BS load is below 93% as shown in Figure 18. Table 4 illustrates the optimal scanning and interleaving intervals which are derived by the third scanning strategy under different loads of the serving BS for video applications.

Table 3. Scanning and interleaving intervals of different loads derived by the third channel scanning strategy for audio traffic

Load (%)	10	20	30	40	50	60	70	75	80	85	90	95	96	97	98
Scanning Interval (frame)	10	10	10	10	10	10	10	10	9	6	8	6	4	10	10
Interleaving Interval (frame)	1	1	1	1	1	1	1	1	1	1	2	4	4	20	255

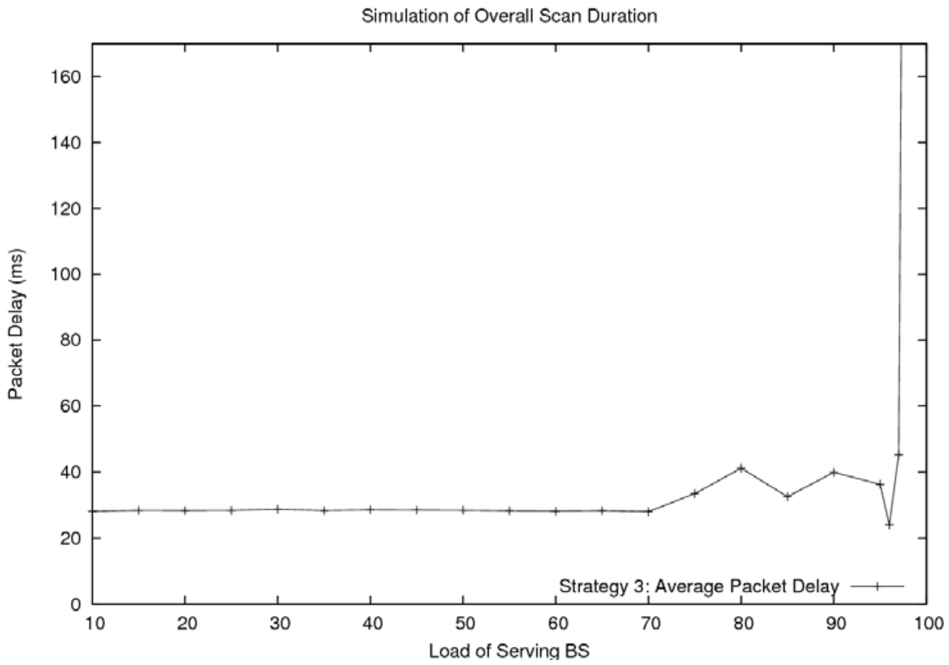

Figure 17. Average packet delays for an MS supporting audio traffic by the third channel scanning strategy

Table 4. Scanning and interleaving intervals of different loads derived by the third channel scanning strategy for video traffic

Load (%)	10	15	20	25	30	35	40	45	50	55	60
Scanning Interval (frame)	12	11	20	19	9	8	15	7	6	16	19
Interleaving Interval (frame)	1	1	2	2	1	1	2	1	1	3	4
Load (%)	65	70	75	80	85	90	91	92	93	94	95
Scanning Interval (frame)	20	20	20	20	20	20	20	20	20	20	20
Interleaving Interval (frame)	5	6	8	11	17	44	64	118	255	255	255

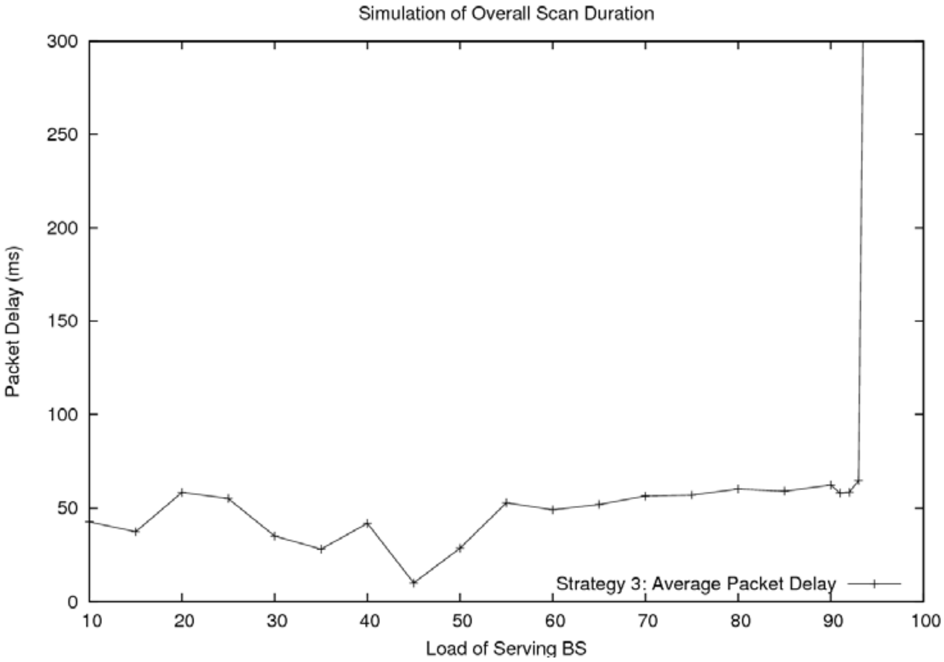

Figure 18. Average packet delays for an MS supporting video traffic by the third channel scanning strategy

In the last scenario, there are an MS, a serving BS and three neighboring BSs in the environment. The MS with video application performs scan operations with three neighboring BSs as shown in Figure 19. The MS individually applies three scanning strategies and compares their overall scan durations. There are total three hundred MSs performing ranging in this environment and the numbers of MSs in these three neighboring BSs are distributed as the Zipf skew model [12]. The skew factor in this scenario is considered from 0 to 1 and the numbers of ranging MSs of the three neighboring BSs are listed in Table 5. However, the number of ranging MSs is related to the collision rate in a neighboring BS. Figure 20 shows the overall scan durations after an MS scan all the neighboring BSs with different skew factors. For the second scanning strategy in this scenario, the serving BS provides an MS static scanning and interleaving intervals that are individually ten and two frames to scan all neighboring BSs.

From the simulation results, the overall scan durations of the third strategy are about sixty frames less than those of the second strategy with different skew factors. The results are caused from that the third scanning strategy could find the optimal scanning and interleaving intervals of different neighboring BSs for an MS. Besides, applying the first scanning strategy could always derive the minimal overall scan duration, because it needs not to interleave the durations for normal operations. Thus, the ranging failure rate in the first strategy with a neighboring BS would be the least, because the situation of RNG-RSP sent in interleaving intervals would never occur.

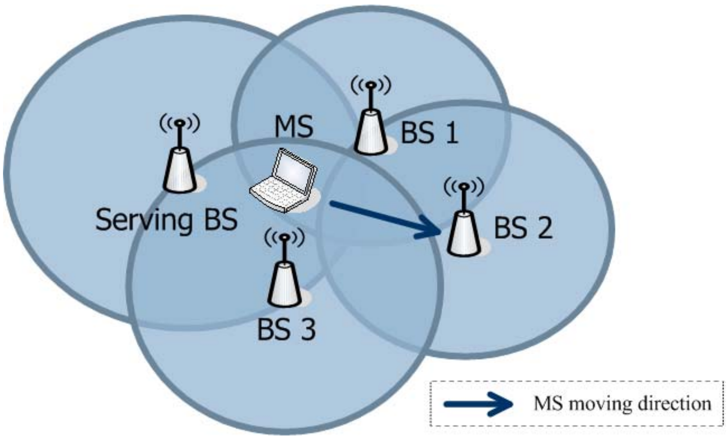

Figure 19. Scenario of an MS scanning multiple neighboring BSs

Table 5. Numbers of ranging MSs in neighboring BSs with different skew factors

Skew factor BSs	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
# of MSs in BS 1	100	95	90	85	80	76	71	67	63	59	54
# of MSs in BS 2	100	99	98	96	95	93	91	89	86	84	82
# of MSs in BS 3	100	106	112	119	125	131	138	144	151	157	164

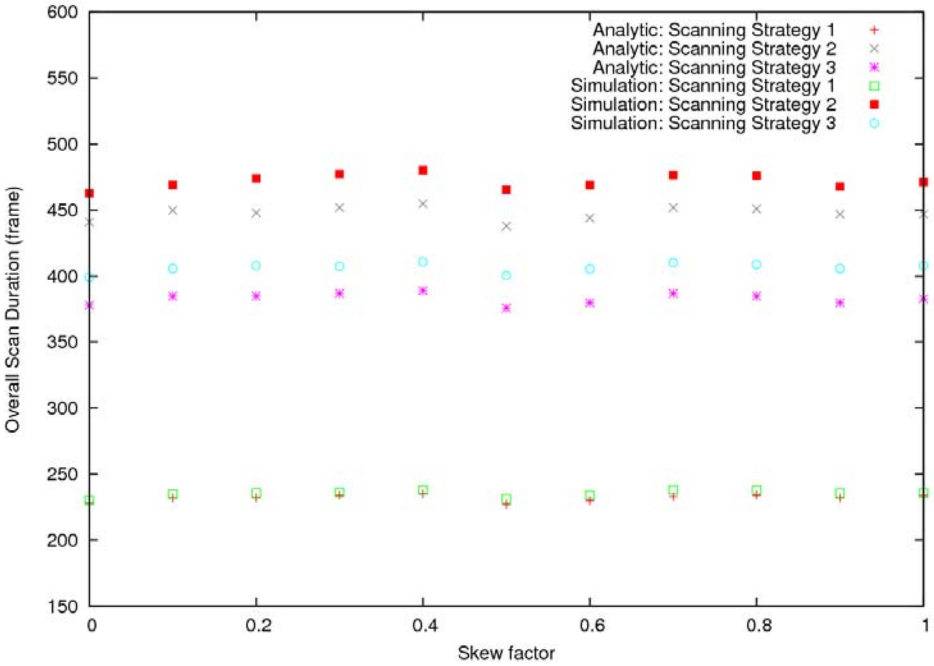

Figure 20. Overall scan durations for an MS applying three channel scanning strategies with different skew factors

Chapter 5 Conclusions

In this paper, the performance models of association delays for contention-based ranging during scan are proposed. From these performance models, while the scanning interval length, interleaving interval length and other ranging related parameters of a neighboring BS are given, the overall scan duration would be calculated. The calculated results are validated by the simulation results.

Moreover, there are three channel scanning strategies are proposed in this paper. As applying the first strategy, the minimal overall scan duration could be derived but the largest packet delay would be caused during scan. It is suitable for non-real time applications. However, the second and the third strategies consider the scan operations with partition for QoS requirements of different applications. They are suitable for real-time applications. Besides, the third strategy is an advanced version of the second strategy and could derive the minimal overall scan duration with considering the QoS requirement. From the simulation results, the overall scan durations of the third strategy are shorter than those of the second strategy in different skew situations.

The proposed approaches in this paper are all applied in the serving BS but the MS has no contribution to the decisions of the scan operations. The future work is to propose the MS assisted channel scanning approaches. The MS could report its ranging situation for the serving BS to improve the decision of scan operations. Thus, the ranging failure rate during scan could be further reduced and the overall scan duration could also be shortened.

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