Movement-Aware Vertical Handoff of WLAN and Mobile WiMAX for Seamless Ubiquitous Access

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Abstract — *This paper addresses a movement-aware vertical (MAV) handover algorithm between WLAN and Mobile WiMAX for seamless ubiquitous access. An MAV handover algorithm is proposed in this paper to exploit movement pattern for avoiding unnecessary handovers in the integrated WLAN and Mobile WiMAX networks. If a mobile station (MS)'s velocity is high and its movement pattern is irregular, unnecessary handovers likely occur more frequently. Therefore, the MS velocity and moving pattern are important factors for the handover decision procedure. To avoid unnecessary handovers, the MAV handover algorithm adjusts the dwell time adaptively and predicts the residual time in the cell of target base station (BS). Consequently, the adaptive dwell timer of MAV handover algorithm allows an MS a better connection as long as possible. Our simulation results show that the reduction of unnecessary handovers by leads to significant throughput improvements.*[1]

Index Terms — Vertical Handover, Movement-Awareness, IEEE 802.11 WLAN, IEEE 802.16e Mobile WiMAX, Ubiquitous Computing.

I. INTRODUCTION

Over the past few years, rapid advances in wireless broadband networks have been driving the evolution of communication and network technologies towards next-generation ubiquitous computing environments. To realize the ubiquitous environments, a seamless handover algorithm between heterogeneous wireless networks is one of the most critical techniques. The heterogeneous wireless networks include wireless personal, local, and broadband networks. Among several candidate technologies for the numerous wireless broadband networks, IEEE 802.16-operated WiMAX shows promising potentials. IEEE 802.16 Fixed WiMAX has beendeveloped by the IEEE 802.16 standard activities [1]. Because it cannot support the mobility of terminals, IEEE 802.16 Fixed WiMAX is not suitable for mobile computing environments [1][2]. Thus, to support mobility on terminal stations, IEEE 802.16e Mobile WiMAX standard is proposed. The handover procedure is described as "horizontal handover" in the standard document [2]. Due to the mobility in IEEE 802.16e Mobile WiMAX, an interworking scheme between heterogeneous networks, i.e., vertical handover [3], is essentially required. Under this requirement, this paper addresses a vertical handover algorithm for interworking between IEEE 802.11 WLAN [4] and IEEE 802.16e Mobile WiMAX. To date, not much attention has been paid to the handoffs between IEEE 802.11 WLAN and IEEE 802.16e WiMAX. In the literature, most research on vertical handover is for interworking between WLAN and 3G networks. The most well-known research on vertical handover for interworking between WLAN and 3G networks can be classified into radio signal strength (RSS) based approach [5] and policy-based approach [6]. However, to adopt the mobile computing environment, such as Mobile WiMAX, we need to consider movement pattern of mobile stations (MSs). Therefore, this paper proposes a movement-aware vertical (MAV) handover algorithm between IEEE 802.11 WLAN and IEEE 802.16e Mobile WiMAX. Our scheme to recognize the movement pattern of MSs is as follows. By measuring of the velocity of MS (v_t) and the direction of MS (d_t) at time t, the MS determines to remain associated with the current serving base station (BS) or to move to a new BS which is the most efficient among neighbor BSs. Also the MAV handover algorithm considers 'ping-pong effect' [7][8]. The ping-pong effect occurs if factors for vertical handover decision are changing rapidly and an MS performs the handover as soon as it detects a better BS. Therefore ping-pong effect can lead to inefficiency in network resource management. By using the MAV handover algorithm, we can avoid ping-pong effect by using a dwell timer.

The remainder of this paper is organized as follows. Section 2 reviews related work of vertical handover algorithms. Section 3 describes the proposed movement-aware vertical (MAV) handover algorithm between IEEE 802.11 WLAN and IEEE 802.16e Mobile WiMAX. In Section 4, the proposed movement-aware vertical handover algorithm is evaluated through simulation. Finally, the conclusions and future work are drawn in Section 5.

II. RELATED WORK

In the early vertical handover research, homogeneous networks have used the radio signal strength (RSS) as the

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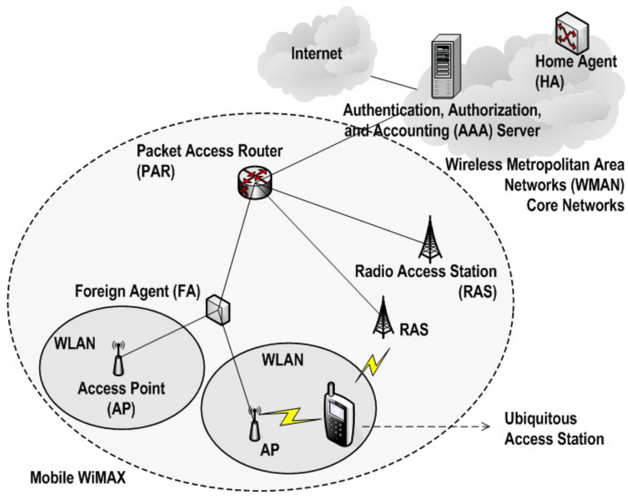

Fig. 1. Macro-View of Interworking Architecture for Integrated WLAN and Mobile WiMAX

main factor of the handover decision [5]. However, the vertical handover decision needs to consider more factors [6] because heterogeneous wireless networks have different characteristics. Therefore in [6], the policy-enabled handover decision algorithm using the utility function with various factors was proposed. It performs vertical handover to the best target BS determined by the utility functions. The factors used in vertical handover are service types, monetary cost, network conditions, system performance, mobile node conditions, etc. [9]. Such policy-based vertical handover decision algorithms can be used to provide QoS to BSs. In a homogeneous environment, the ping-pong effect is a phenomenon that rapidly repeats vertical handover between two BSs [5]. In a heterogeneous environment, the ping-pong effect occurs if factors for the vertical handover decision are changing rapidly and an MS performs handover as soon as the MS detects the better BS [10]. The dwell timer scheme has been used to avoid such ping-pong effects [7][8]. It starts to work when the vertical handover condition is first satisfied. If the vertical handover condition persists during the dwell time, the MS performs vertical handover to the target BS after the dwell timer is expired. Otherwise, the MS resets the dwell timer [11]. Consequently, the MS does not execute premature vertical handover until the target BS becomes stable. Ping-pong effect can also occur if the speed of an MS is high or the moving direction of the MS is irregular. Thus, the proposed scheme in this paper adjusts the length of the dwell time adaptively according to the ping-pong movement of MS. In [12], an MS selects a target BS with the least QoS level from neighbor BSs that can satisfy QoS requirement of the current application, i.e., an MS does not select the best BS as a target BS. Therefore, it remains with the serving BS as long as the BS satisfies the QoS requirement of the MS. When the type of the application used changes or an MS leaves the serving BS, the MS attempts to find another BS. The proposed vertical handover decision algorithm in [12] can avoid ping-pong effect since it is based on the need of the application, but not

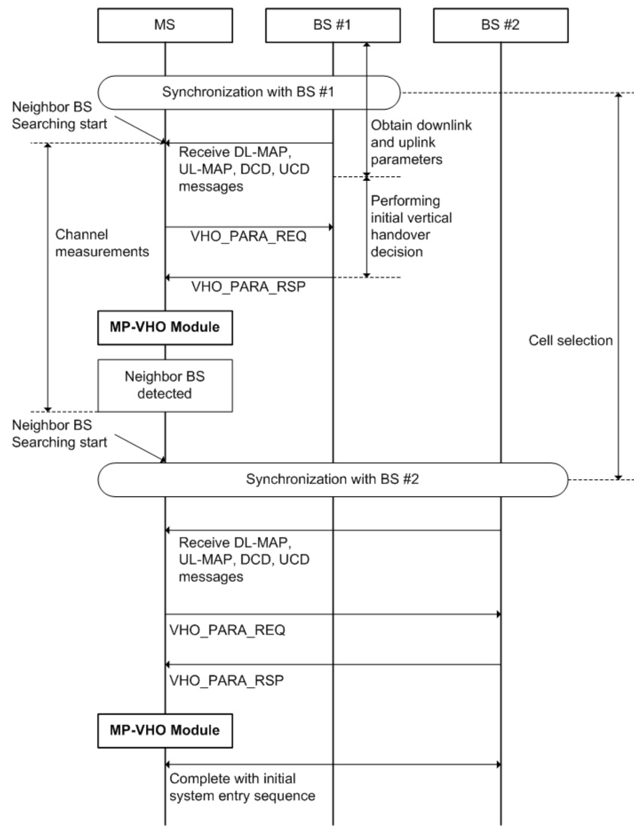

Fig. 2. Micro-View of Interworking Architecture for Integrated WLAN and Mobile WiMAX

the RSS of the BS. On the other hand, we propose a vertical handover decision scheme that can avoid ping-pong effect as well as select the best among neighbor BSs.

III. Movement-Aware Vertical Handover between WLAN and Mobile WiMAX

This section presents our proposed vertical handover algorithm named movement-aware vertical (MAV) handover. Section III.A addresses the interworking architecture by the MAV handover algorithm. Section III.B describes the detailed mechanism of the MAV handover algorithm.

A. Interworking Architecture between WLAN and Mobile WiMAX

Fig. 1 and Fig. 2 show the macro view and the micro view of interworking architecture of integrated WLAN and Mobile WiMAX, respectively.

1) Macro-View of Interworking Architecture: As shown in Fig. 1, the vertical handover adaptive mobile station (MS) has dual interfaces for both WLAN and Mobile WiMAX. If the WLAN network provides more efficient service for the MS, the MS uses the WLAN interface to use a WLAN connection link. Otherwise, the MS uses the Mobile WiMAX interface. The efficiency is determined by 'VHO module' in the MAC of the MS. To interconnect with WLAN or Mobile WiMAX, the MS connects an AP of WLAN with a RAS of Mobile

Algorithm 1. Movement Aware Vertical (MAV) Handover Procedure

```
loop
    if U_serv.BS > U_trgt.BS then
        if ((RSS_trgt.BS < thresh_trgt.BS) and (t_res < t_hd + t_mu) then
            //Beneficial Handover → Start Adaptive Dwell Timer
            Start(t_d);
            if (condition persists until timer expires) then
                //Handover to Target BS
                MAV-HANDOVER(targ.BS);
            else
                //Reset Dwell Timer
                Reset(t_d);
            end if
        else
            //Unbeneficial Handover → Stay in Current Serving BS
            Continue;
        end if
        //Current Serving BS is Weak
    else if (RSS_serv.BS < thresh_serv.BS) then
        //Start: Adaptive Dwell Timer
        if (condition persists until timer expires) then
            //Handover to Target BS
            MAV-HANDOVER(trgt.BS);
        else
            //Reset Dwell Timer
            Reset(t_d);
        end if
    end if
end loop
```

Algorithm 1. Pseudo Code: Movement-Aware Vertical (MAV) Handover Scheme

WiMAX. The AP and RAS provide an interface to communicate with the MS. In the subsequent section, the AP and RAS are called as base stations (BSs).

2) Micro-View of Interworking Architecture: Fig. 2 shows the detailed interconnection procedure between MS and BS. At first, the MS and BS have synchronization process to communicate for operating vertical handover. Next, the MS and BS exchanges parameters such as DL-MAP (Downlink MAP), UL-MAP (Uplink MAP), DCD (Downlink Channel Descriptor), UCD (Uplink Channel Descriptor), VHO_PARA_REQ (Vertical Handover Parameters Request), and VHO_PARA_RSP (Vertical Handover Parameters Response). The first four parameters are used for downlink/uplink synchronization and the next two parameters are used for VHO module. If a BS receives VHO_PARA_REQ, the BS sends VHO_PARA_RSP with its parameters to determine the efficiency of the serving networks. Upon the receipt of the received messages, the VHO module determines whether the MS needs vertical handover or not.

B. MAV Handover Algorithm

Our proposed movement-aware vertical handover algorithm (MAV)consists of three procedures as described in this section. The first procedure, location update procedure, detects the location of an MS periodically according to the velocity and movement pattern of the MS. Values used in the vertical handover decision are also updated periodically. The target BS selection process selects a BS providing the maximum utility and benefit among other candidates. Based on the information obtained from the above two procedure, the actual vertical handover is performed in the final handover execution procedure. In the MAV handover decision process, RSS-based vertical handover is triggered if the MS leaves the current serving BS, while utility-based vertical handover is triggered if the handover is beneficial based on predictive residence time in the target BS. The whole process of the proposed algorithm is described in Algorithm 1 as a pseudo code form.

1) Location Update Procedure: An MS's location can be detected periodically using either GPS or other location sensing techniques. Location Update Timeout (to_{lu}) is set based on the MS's current velocity. The higher the velocity leads, the shorter to_{lu}. Eq. (1) sets to_{lu} at time t.

$$to_{lu} = \min\left[ubound\,(to_{lu}), \varphi\right] \tag{1}$$

s.t.

$$\varphi = \max\left(lbound\,(to_{lu}), \frac{\hat{v}_t}{\tilde{v}_t} \cdot \hat{t}o_{lu} \right)$$

where $\hat{t}o_{lu}$ means the default value of to_{lu}. $ubound\,(to_{lu})$ and $lbound(to_{lu})$ mean the Upper and Lower Bounds of to_{lu}. v_t means the velocity of MS at time t. $\hat{v}_t$ and $\tilde{v}_t$ mean the default and average values of MS until time t. In addition to updating the location of MS, weighted average velocity, direction, and ping-pong movement flag are calculated for the handover decision every to_{lu} time as follows. An MS's weighted average velocity $\tilde{v}_t$ and direction $\tilde{d}_t$ at time t are used to obtain the predictive residence time in the handover decision process. In Eq. (2) and Eq. (3), $\tilde{v}_t$ and $\tilde{d}_t$ at time t are calculated by using the real values of velocity v and direction d for the previous intervals.

$$\tilde{v}_t = (1-\alpha)\sum_{i=1}^{t} \alpha^{i-1} v_{i-t+1} \tag{2}$$

$$\tilde{d}_t = (1-\alpha)\sum_{i=1}^{t} \alpha^{i-1} d_{i-t+1} \tag{3}$$

where d_t and $\tilde{d}_t$ are the direction and average direction of MS at time t. α is an exponential smoothing factor. An MS can seamlessly check the $\tilde{v}_t$ and $\tilde{d}_t$, and we can describe the above equations as follows.

$$\tilde{v}_t = (1-\alpha)\int_i^t \alpha^{i-1} v_{i-t+1} di \tag{4}$$

$$\tilde{d}_t = (1-\alpha)\int_i^t \alpha^{i-1} d_{i-t+1} di \tag{5}$$

Furthermore, to obtain the value of velocity, i.e., $\tilde{v}_t$, two methods can be used. The first one is

$$\tilde{v}_t = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} \tag{6}$$

where Δx and Δt mean the difference of distance and time, respectively. The other one is the method which uses integration value of acceleration ($\tilde{a}$) under

$$\frac{d}{dt}\tilde{v}_t = \tilde{a} \cdot \tag{7}$$

Hence,

$$\tilde{v}_t = \int_0^t \tilde{a}\,dt = \tilde{a}\,t \cdot \tag{8}$$

To detect an MS's movement pattern, direction $\tilde{d}_t$ at current time t is compared to direction $\tilde{d}_{t-1}$ at time *t-1* (i.e., previous to_{lu} times while storing the direction value at time t. In Eq. (9), Eq. (10), and Eq. (11), if there is a considerable change of more than 90 degree (i.e., $\pi/2$) between $\tilde{d}_t$ and $\tilde{d}_{t-1}$, flag f is set to 1 since the probability of a ping-pong movement is high. The flag $w.Avg(f_t)$ is set to the weighted average of f_t so that the ping-pong flag $\tilde{f}_t$ keeps a value of 1 during several subsequent intervals after $f_t = 1$ and presents ping-pong movement. $\tilde{f}_t$ is used to adjust the dwell timer adaptively in the handover decision procedure.

$$f_t = \begin{cases} 1, & d_t \geq d_{t-1} + \dfrac{\pi}{2} \\ 0, & otherwise \end{cases} . \tag{9}$$

$$w.Avg(f_t) = \sum_{i=1}^{t} \alpha(1-\alpha) f_{t-i+1} \cdot \tag{10}$$

$$\tilde{f}_t = \begin{cases} 1, & w.Avg(f_t) > 0 \\ 0, & otherwise \end{cases} . \tag{11}$$

2) Target BS Selection Procedure: The target BS is the BS that provides the maximum utility among detected neighbor BSs. After receiving QoS information from each neighbor BS, the utilities of BSs are calculated using MS's request level and available level in the BS_j in terms of QoS factors such as data rate, mobility support, and so forth. Eq. (12) presents $u_{j,i}$, which is the satisfied degree of MS's request level in the BS_j in terms of QoS factors named i.

$$u_{j,i} = \min\left[thresh_u, \frac{AL_{j,i}}{REQ_i} \right]. \tag{12}$$

where REQ_k, $AL_{j,k}$, and $thresh_u$, are the utility request level of MS, the utility available level of MS, and the threshold of utility (Defined as 1 in this paper). The importance of each QoS factor becomes different according to MS's application areas. Thus the utility of BS_j, named U_j, is computed using as weight w_i as follows.

$$U_j = \frac{1}{n}\sum_{i=1}^{n} w_i \cdot u_{j,i} \cdot \tag{13}$$

$$0 \leq U_j \leq 1 \cdot \tag{14}$$

3) Handover Execution Procedure: Although the target BS provides a better utility than the current serving BS, the handover to the target BS becomes unbeneficial if the predictive residence time in the target BS is smaller than the delay caused by the handover procedure. Thus, the handover decision has to take into account both utility and residence time. MS's predictive residence time in the target BS can be calculated by using MS's movement direction, velocity, and range of the target BS. On the other hand, although current

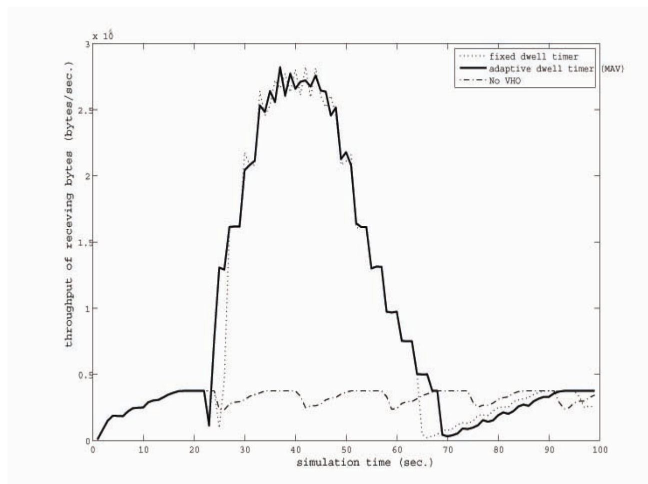

Fig. 3. Scenario 1: Throughput per Time (an MS passes over WLAN with radius 20m at 1 m/s)

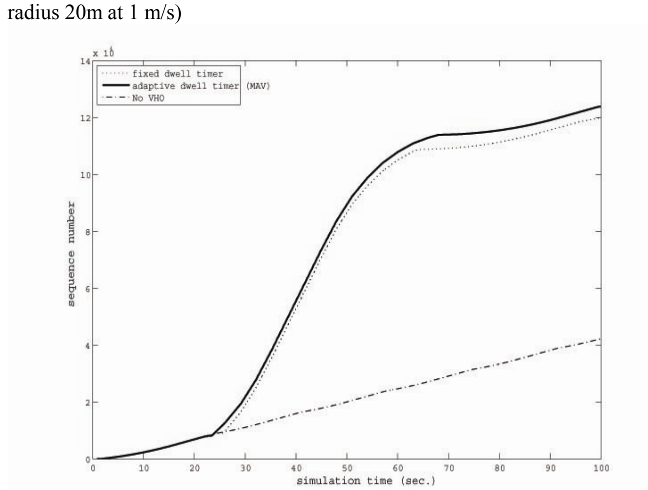

Fig. 4. Scenario 1: Sequence Number per Time (an MS passes over WLAN with radius 20m at 1 m/s)

serving BS provides maximum utility, handover to the target BS has to be performed provided the RSS of current one is lower than the threshold. Consequently, handover occurs when one of the following conditions lasts until the dwell timer expires. *serv.BS* and *trgt.BS* mean serving BS and target BS, respectively. $RSS_{trgt.BS}$ and $thresh_{trgt.BS}$ address the radio signal strength of target BS and the threshold of the signal strength of target BS. Finally t_{mu} and t_{hd} denote "Make Up Time" and "Handover Delay Time" respectively. "Make Up Time" means the amount of time needed to make up the loss due to handover delay.

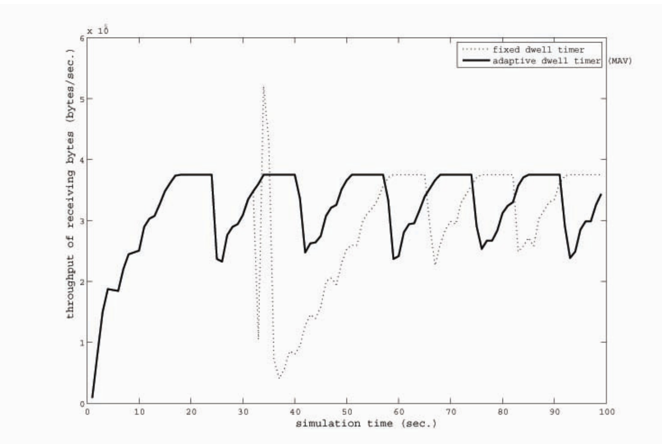

Fig. 5. Scenario 2: Throughput per Time
(an MS passes the point 19 – 20 m away from WLAN's AP at 5 m/s)

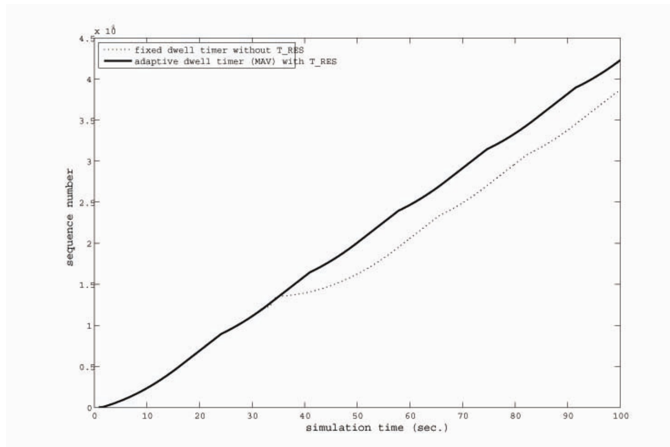

Fig. 6. Scenario 2: Sequence Number per Time
(an MS passes the point 19 – 20m away from WLAN's AP at 5 m/s)

The dwell timer provides smoothing and seamless handover to cope with ping-pong effect by alleviating sequential handovers evoked too frequently. It starts working if one of the following conditions is satisfied.

- $U_{serv.BS} < U_{trgt.BS}$
- $RSS_{trgt.BS} > thresh_{trgt.BS}$
- $t_{res} > t_{hd} + t_{hd}$
- $RSS_{serv.BS} > thresh_{serv.BS}$

The adaptive dwell timer, one of the contributions of the proposed scheme in this paper, can adjust the duration time according to the situation of MS and target BS. If the utility of target BS is far better than the current serving BS, the dwell timer is shortened, and if movement direction is irregular, i.e., ping-pong effect, the dwell time is extended. In consideration of utility and ping-pong movement, Eq. (15) sets the dwell timer as follows.

$$t_d = \min\left[ubound(t_d), \delta\right] \tag{15}$$

s.t.

$$\delta = \max\left(lbound(t_d), (1 + \tilde{p}p_t) \cdot \frac{U_{serv.BS}}{U_{trgt.BS}} \cdot \hat{t}_d \right)$$

where pp_t is the ping-pong flag at time t (0 or 1). $\tilde{p}p_t$ is an average ping-pong flag until time t (0 or 1). $ubound\,(t_d)$ and $lbound\,(t_d)$ are the upper and lower bounds of dwell timer (t_d). $\hat{t}_d$ is the default value of dwell timer.

IV. Performance Evaluation

We perform ns-2 simulations with three scenarios to test various aspects of the proposed scheme. In the first scenario, we compare a fixed dwell timer to an adaptive dwell timer using the utility ratio when an MS passes the center of WLAN slowly. In the second scenario, we compare a fixed dwell timer to an adaptive dwell timer when an MS passes through the edge of WLAN rapidly. When there are MS's quick ping-pong movements across the edge of Mobile WiMAX and WLAN, we compare RSS with an adaptive dwell timer in the third scenario. We assume that the utility ratio of WLAN to Mobile WiMAX is a fixed value of 2 in the simulation. The IEEE 802.11a standard is used for WLAN and a simple link adaptation is applied [13]. The traffic used in the simulation is a non-real time data service with TCP. The simulation parameters of the scenarios used are shown in Table I.

TABLE I
Simulation Parameters of Each Scenario

Parameters	Scenario 1	Scenario 2	Scenario 3
WLAN Std.	802.11a	802.11a	802.11a
WLAN Max. Radius	35m	35m	35m
Radius to RRS Threshold (WLAN)	20m	20m	20m
Mobile WiMAX Std.	802.16e	802.16e	802.16e
Mobile WiMAX Max. Radius	1000m	1000m	1000m
Radius to RRS Threshod (Mobile WiMAX)	600m	600m	600m
MS's speed (m/s)	1m/s	5m/s	5m/s
Movement Pattern	Straight	Straight	Ping-Pong

A. Scenario 1: Adaptive dwell timer's behavior when MS passes the core of WLAN at slow speed.

In scenario 1, an MS passes the center of WLAN (802.11a) at a slow speed (1m/s). If fixed dwell time is 4 seconds, the adaptive dwell time of the MAV handover algorithm is adjusted to 2 seconds and 8 seconds during handover to WLAN and leaving WLAN respectively. Therefore, the adaptive dwell timer, i.e., the MAV handover algorithm scheme, can receive WLAN's service for a longer duration. Variations of the throughput are presented in Fig. 3 to observe the handover time according to handover decision algorithms.

At around 20 second, the MAV handover algorithm performs a handover to WLAN from Mobile WiMAX earlier than the fixed dwell timer scheme. At around 70 second, the MAV handover algorithm performs a handover to Mobile WiMAX later than the fixed dwell timer scheme. Because link adaptation occurs during in motion, the closer an MS is to WLAN's AP, the higher throughput the MS gains. The case of no handoff (No VHO) shows TCP behavior of receiving Mobile WiMAX service with constantly low throughput. Growth of the sequence number is shown in Fig. 4 to show the cumulative amount of received packets for certain elapsed time periods.

The MAV handover algorithm has the largest number of received packets since it has the longest service time of WLAN. The MAV handover algorithm has 3,900 packets more than the fixed dwell timer scheme after 100 second. No VHO scheme receives much smaller number of packets than the vertical handover schemes.

B. Scenario 2: use of t_{res} when MS passes over the edge of WLAN at rapid speed.

In scenario 2, an MS passes the point 19m away from WLAN's AP at 5m/s (18km/h). The predictive dwell time (t_{res}) in WLAN is 2.56 seconds. However, handover (delay + makeup) time is more than 10 seconds under the assumption that the vertical handover delay is 0.5 second and the packet loss fraction at handover is 0.5. If t_{res} is shorter than $t_{hd} + t_{mu}$, the MAV handover algorithm does not perform vertical handover to the preferred network because repeated handovers for short time cause ping-pong effects. The MAV handover algorithm is compared with the fixed dwell timer scheme (dwell time = 2 seconds without using t_{res}) as follows.

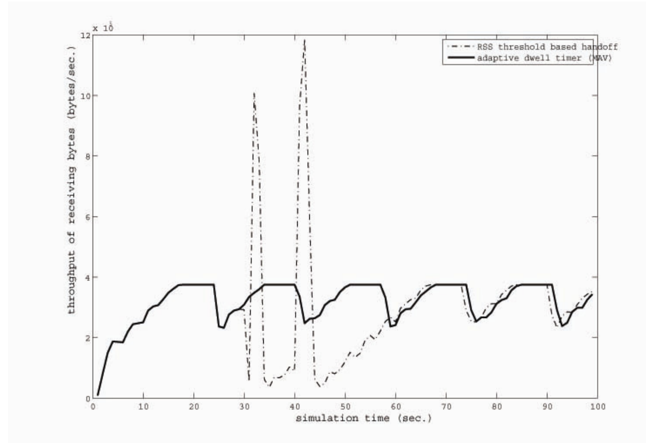

Fig. 8. Scenario 3: Throughput per Time (an MS's Ping-Pong Effect over the Edge of WLAN and Mobile WiMAX at 5 m/s)

In Fig. 5, the fixed dwell timer scheme performs a vertical handover to WLAN at 32 second after dwell time of 2 seconds. After receiving WLAN service for a very short time, the MS handovers to Mobile WiMAX again at 34.56s after dwell time of 2 seconds. However, the MAV handover algorithm does not handover to WLAN due to short t_{res}.

In Fig. 6, the fixed dwell timer scheme performs unbeneficial handovers, which results in significant packet loss. Therefore, the number of received packets using the fixed dwell timer becomes less than the MAV handover algorithm which avoids unnecessary handovers.

In Fig. 7, the number of cumulative received packets after 100 second is compared based on the total time of receiving WLAN service. No VHO scheme receives 42280 packets after 100 second regardless of the residence time in WLAN. The fixed dwell timer scheme without using t_{res} has smaller number of received packets than No VHO scheme where residence time

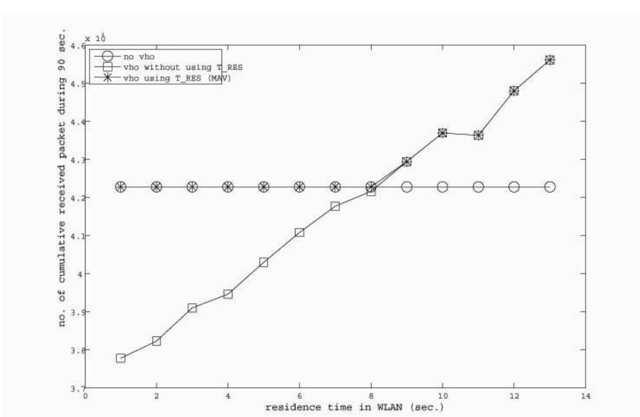

Fig. 7. Scenario 2: Number of Cumulative Received Packets (an MS passes the point 19 – 20 away from WLAN's AP at 5 m/s)

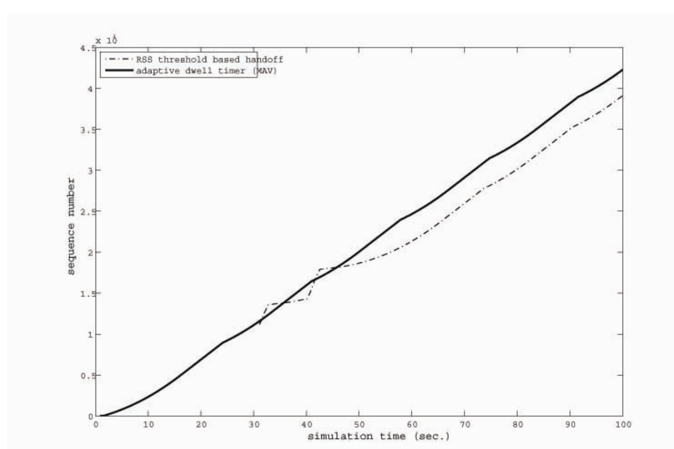

Fig. 9. Scenario 3: Sequence Number per Time (an MS's Ping-Pong Effect over the Edge of WLAN and Mobile WiMAX at 5 m/s)

in WLAN is less than 8 seconds. The MAV handover algorithm takes t_{res} into account for the handover decision. Consequently, the MAV handover algorithm does not perform handovers to WLAN if t_{res} is less than 8 seconds, and it performs handovers only if t_{res} is more than 9 seconds. As a result, it can avoid unnecessary handovers which causes performance degradation.

C. Scenario 3: adaptive dwell time's behavior when MS has ping-pong movement pattern and high speed.

In scenario 3, an MS has ping-pong movement before the MS enters WLAN with the MS's velocity of 5m/s (18km/h). An MS's residence time in WLAN RSS threshold is 3 seconds whenever the MS enters WLAN. If the change in the MS's direction is more than 90 degree, the MAV handover algorithm checks the ping-pong flag and makes the previous dwell time 2 times longer. Therefore, 2 second dwell time in scenario 2 is adjusted to 4 second and the MS does not handover in scenario 3. The fixed dwell timer and the MAV handover algorithm have the same performance if the dwell time is fixed to more than 4 second. However, the fixed dwell timer scheme performs handovers if dwell time is fixed to less than 4 second. The RSS-based handover decision scheme always performs handover whenever an MS exceeds the RSS threshold. The MAV handover scheme and the RSS-based schemes are compared as follows.

Fig. 8 shows the sudden changes of throughput of the RSS-based handover decision scheme that performs a total of 4 handovers. The RSS-based scheme receives WLAN's service for a very short time. The MAV handover algorithm avoids vertical handovers because of the ping-pong movement and continues to receive Mobile WiMAX's service. In Fig. 9, the RSS-based scheme receives packets quickly right after handover to WLAN. However, the RSS-based scheme receives fewer packets than the MAV handover algorithm after 100 seconds because it has more packet loss due to continuous handovers for the short duration.

V. CONCLUSION

This paper proposes a novel MAV handover algorithm for interworking between IEEE 802.11 WLAN and IEEE 802.16e Mobile WiMAX. Frequent handovers for a short time period mean a higher chance of packet loss/delay, adversely affecting the overall throughput. The ping-pong effect, which is a phenomenon that repeats handovers between two base stations, results from the short residence times in the preferred network. By investigating the cause of the short residence time (i.e., MS's high speed and ping-pong effect), we have proposed the MAV handover algorithm which is an improvement to avoid the ping-pong effect. This algorithm contrasts the existing fixed dwell timer schemes that cannot handover to a preferred BS quickly even if they have sufficiently long dwell times. On the other hand, our algorithm adjusts the dwell time adaptively according to MS's mobility. The dwell time doubles to reduce the probability of vertical handovers when an MS's ping-pong effect is detected. The dwell time is reduced if the target BS has better performance than current serving BS. Otherwise, it increases. As a result, an MS ends up being served by the preferred BS as long as possible. In addition, if the predictive residence time in the target BS is shorter than $t_{hd} + t_{mu}$, the MAV handover algorithm cancels handovers. Through our simulation study, we have demonstrated that the MAV handover algorithm outperforms the fixed dwell timer scheme by eliminating the ping-pong effect and reducing unnecessary handovers.

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