*U*biComm: An Adaptive Vertical Handoff Decision Scheme for Heterogeneous Wireless Networks*

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Abstract. Vertical handoff will be essential for the next generation heterogeneous wireless networks. We propose an *Adaptive Vertical Handoff Decision Scheme* called *UbiComm* to avoid unbeneficial handoffs in the integrated WiBro and WLAN networks. If the mobile node (MN)'s velocity is high and moving pattern is irregular, more unnecessary handoffs can occur. Therefore, MN's velocity and moving pattern are the important factors of our handoff decision scheme. In order to avoid unbeneficial handoff the *U*biComm adjusts the dwell time adaptively, and it also predicts the residence time in the target network. In addition, *U*biComm's adaptive dwell timer makes a MN receive service of a better network as long as possible. The simulation results show that the reduction of unnecessary handoffs proposed in *U*biComm improves the MN's throughput.

1 Introduction

Recent wireless networks have various characteristics in terms of latency, bandwidth, frequency and coverage. Wireless networks can be divided into two groups; one that provides high bandwidth and small coverage (e.g. WLAN), and one that provides low bandwidth and wide coverage (e.g. WWAN) [1]. The vertical handoff, which is the roaming technology among different types of networks, has been studied in order to satisfy the demand on QoS as well as wide coverage. For example, an MN equipped with both WWAN and WLAN interfaces can perform vertical handoff to WLAN hotspot while receiving the service of WWAN. As a result, the MN's overall throughput is improved. There has been little research on handoffs between WiBro and WLAN. In this paper, we deal with vertical handoffs between WLAN and WiBro (which is a type of WMAN).

For vertical handoff, it is important to determine when a MN should perform handoff and to which network a MN should perform handoff. Despite the increased in

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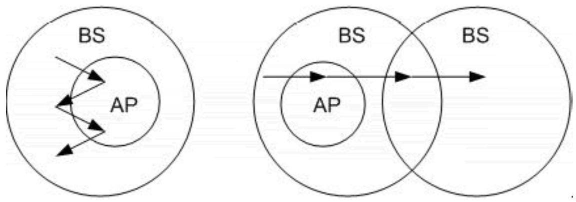
research on the received signal strength (RSS)-based and the utility-based vertical handoff algorithms in recent years, few have attempted to focus on factors on mobile node condition such as velocity and moving pattern. However, if factors on the MN's mobile condition are not considered, unbeneficial handoffs can be triggered frequently without any gain in such situations depicted in Figure 1.

In Figure 1, smaller circles are networks that provide better utility than larger ones. Hence, a MN prefers smaller networks. The first example shows a situation that a MN keeps handing off between the two base stations back and forth (ping-pong effect [3]) while keeping ping-pong movement [2] near the edge of two networks. Frequent handoffs cause packet loss/delay, decrease throughput, and increase the signaling overhead. The second example shows that a MN travels at high speeds around the edge of the small network. In these two cases, performing vertical handoff to smaller networks is unnecessary since a MN leaves it after a short period of time.



(a) (b)

Fig. 1. Unbeneficial vertical handoff: (a) MN's ping-pong movement and (b) MN's movement at high speed.

For the reasons stated above, we propose an *adaptive vertical handoff decision scheme for heterogeneous wireless networks*, called *UbiComm*, *not only* to avoid unnecessary and unbeneficial handoffs and ping-pong effect, but also to provide better service to loss and delay sensitive applications. The handoff decision algorithm of *U*biComm uses an *adaptive dwell timer* and *predictive residence time* in the target network to avoid unbeneficial handoffs. The adaptive dwell timer adjusts the length of timeout according to the ping-pong movement pattern. The predictive residence time in the target network is used to check if the target network could compensate for the handoff delay to the applications.

The remainder of this paper is organized as follows. Section 2 reviews related work. Section 3 describes the architecture for performing vertical handoff. In Section 4, an adaptive handoff decision mechanism, i.e., *U*biComm is proposed. In Section 5, *U*biComm is evaluated compared to previous handoff decision algorithms through simulation. Finally, the conclusion is drawn in Section 6.

2 Related Work

Traditionally, homogeneous networks have used the RSS as the main factor of the handoff decision. However, the vertical handoff decision needs to consider more factors other than the RSS because networks have different characteristics.

Therefore, the policy-enabled handoff decision algorithm using the utility function with various factors was proposed in [4]. Factors used with the RSS include service types, monetary cost, network conditions, system performance, mobile node conditions, etc. [5]. It performs handoff to the best network determined by the utility function. Such policy-based handoff decision algorithms can be used to provide QoS to users.

In a homogeneous environment, the ping-pong effect is a phenomenon that rapidly repeats handoff between two base stations [6]. In a heterogeneous environment, the ping-pong effect occurs if factors for the handoff decision are changing rapidly and a MN performs handoff as soon as the MN detects the better network [7]. The dwell timer scheme has been used to avoid such ping-pong effect. It starts to work when the handoff condition is first satisfied. If the handoff condition persists during the dwell time, the MN performs handoff to the target network after the dwell timer is expired. Otherwise the MN resets the dwell timer [8]. Consequently, a MN doesn't perform handoff until the target network becomes stable. Ping-pong effect can also occur if the speed of a MN is high or the moving direction of the MN is irregular. Thus, *U*bi-Comm adjusts the length of the dwell time adaptively according to the MN's ping-pong movement.

In [9], a MN selects a network with the least QoS level from networks that can satisfy QoS requirement of the current application, i.e., a MN does not select the best network. Therefore, the MN remains in the current network as long as the current network satisfies the MN's QoS requirement. When the type of the application used is changed or a MN leaves the current network, the MN attempts to find other networks. The proposed handoff decision algorithm in [9] can avoid ping-pong effect since it is based on the need of the application and not the RSS of the network. However, *U*bi-Comm provides the handoff decision scheme that can avoid ping-pong effect as well as select the best network.

3 Interworking Architecture between WiBro and WLAN

Previous vertical handoff studies have been mainly carried out over the integrated WLAN and WWAN networks. The next generation network will be a convergence of various wireless networks. Our approach described in this paper uses for the first time the integrated environment of WiBro and WLAN networks. WiBro (Wireless Broadband Internet), a type of WMAN (Wireless Metropolitan Area Network), has been proposed and standardized in Korea. WiBro is compatible with 802.16e and will become commercialized in 2006. WiBro has medium characteristics between WWAN and WLAN in terms of bandwidth (3Mbps/user), coverage (1km) and mobility support ($\leq$ 60km/h) [10]. Therefore, a MN can handoff to WiBro when leaving WLAN, and handoff to WWAN when leaving WiBro for maintaining connection during data communication. Figure 2 shows the proposed interworking architecture between WiBro and WLAN. It is a tightly-coupled architecture where WLAN is connected to WiBro core network. In this architecture, seamless vertical handoff is possible between WiBro and WLAN. A dual-mode MN has two interfaces; one for WiBro and the other for WLAN.

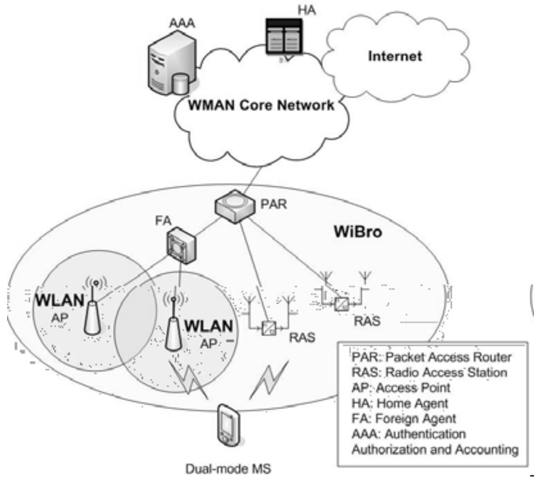


Fig 2. Interworking network architecture between WiBro and WLAN.

Figure 3 shows that we add process of requesting and replying network's information, i.e., QoS and location information, to existing handoff procedure in order to support *U*biComm. If a MN receives a beacon message from network2 during communication with network1, it requests range and QoS information of network2. A MN decides to perform handoff to network2 based on the information of network2 and the location of the MN. The MN needs to inform HA of the current network through PAR after handoff.

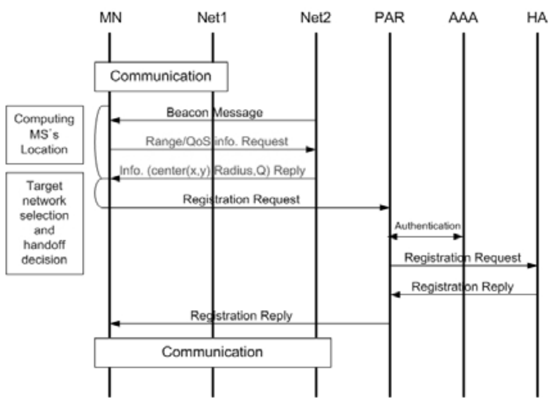


Fig. 3. Proposed handoff procedure.

4 *U*biComm: Proposed Vertical Handoff Mechanism

First, assumption and notations for *U*biComm are described in section 4.1 and 4.2 respectively. Section 4.3 shows three processes of *U*biComm in detail. The basic operation of handoff decision algorithm in *U*biComm is shown as pseudo code in section 4.4.

4.1 Assumption

We use the following assumptions for our proposed algorithm. Each network area is a circle. Each MN knows the degree of QoS factors of applications. Each network can provide information about its location (i.e., center location) and available resources (i.e., degree of QoS factors). How to detect a MN's location and its moving direction is not covered in this scheme.

4.2 Notations

The following Table 1 presents main symbols for describing *U*biComm.

Table 1. Symbols used for description of *U*biComm.

Symbol	Description
$LUTO$	Location Update Timeout
v_t	Speed of MN at time t
$V_{default}$	Default speed of MN
V_t	Average speed of MN until time t
d_t	Direction of MN at time t
D_t	Average direction of MN until time t
α	Exponential smoothing factor
f_t	Ping-pong flag at time t (0 or 1)
F_t	Average ping-pong flag until time t (0 or 1)
u_{ij}	The satisfied degree of MN's request (network j, QoS factor i)
U_j	Utility of network *j*
T_RES_{target}	Predictive residence time in the target network
DT	Dwell timer
γ	Utility ratio of current network to the target network

4.3 Algorithm

*U*biComm consists of three processes as described in this section. The *periodic location update* process detects the location of a MN periodically according to velocity of the MN. Values used in the handoff decision are also updated periodically. The *target network selection* process selects a network providing the maximum utility.

Based on the information obtained from the above two processes, the *handoff decision* process determines when a MN should perform handoff. In the *handoff decision* process, while utility-based handoff is triggered if the handoff is beneficial based on predictive residence time in the target network, RSS-based handoff is triggered if the MN leaves the current network.

4.3.1 Periodic Location Update

A MN's location can be detected periodically using either GPS or a location detection schemes, which use signals received from more than three networks.

Location Update Timeout (*LUTO*) is set based on the MN's current velocity. The higher the velocity is, the shorter the *LUTO* is. Equation (1) sets *LUTO* at time *t* using the default, upper bound, and lower bound values of *LUTO*.

$$LUTO_t = MIN[LUTO_{ubound},\ MAX(LUTO_{lbound},\ \ \beta \cdot LUTO_{default})] \quad (1)$$

where the current speed of a MN is v_t and $\beta = \frac{V_{default}}{v_t}$.

In addition to updating the MN's location, weighted average velocity, direction, and ping-pong movement flag are calculated every *LUTO* times for the handoff decision as follows.

A MN's weighted average velocity V_t and direction D_t at time *t* are used to obtain the predictive residence time in the handoff decision process. In (2), weighted average V_t and D_t at time *t* are calculated by using the real values of velocity *v* and direction *d* for the previous intervals. When a = 0.5, the weight affects the 4-5 latest *v* and *d* data. The length of interval between *t* and *t-1* equals $LUTO_{t-1}$.

$$\begin{aligned} V_t &= (1-\alpha)v_t + \alpha(1-\alpha)v_{t-1} + \alpha^2(1-\alpha)v_{t-2} + \cdots + \alpha^k(1-\alpha)v_1 \\ D_t &= (1-\alpha)d_t + \alpha(1-\alpha)d_{t-1} + \alpha^2(1-\alpha)d_{t-2} + \cdots + \alpha^k(1-\alpha)d_1 \end{aligned} \quad (2)$$

To detect a MN's movement pattern, direction d_t at current time *t* is compared to direction d_{t-1} at time *t-1* (i.e., previous *LUTO* interval) every *LUTO* times while storing the direction value at time *t*. In (3), if there is a considerable change of more than 90 degrees between d_t and d_{t-1}, flag f_t is set to 1 since the probability of a ping-pong movement is high. The flag A_t is set to the weighted average of f_t so that the ping-pong flag F_t keeps a value of 1 during several intervals after f_t =1 and presents ping-pong movement. F_t is used to adjust the dwell timer adaptively in the handoff decision process.

$$\begin{aligned} f_t &= \begin{cases} 1 & if\ \ d_t \ge d_{t-1} + 90^\circ \\ 0 & otherwise \end{cases} \\ A_t &= (1-\alpha) f_t + \alpha(1-\alpha) f_{t-1} + \alpha^2(1-\alpha) f_{t-2} + \cdots + \alpha^k(1-\alpha) f_1 \\ F_t &= 1 \quad if\ \ A_t > 0 \end{aligned} \quad (3)$$

4.3.2 Target Network Selection

The target network is the network that provides the maximum utility among detected ones except the current network. After receiving QoS information from each network, utilities of networks are calculated using the MN's request level (R_1, R_2, …, R_n) and available level in network j ($A_{j,1}$, $A_{j,2}$, …, $A_{j,n}$) in terms of QoS factor (1, 2, …, n) such as data rate and mobility support.

Equation (4) presents $u_{j,i}$, which is the satisfied degree of MN's request level in network j in terms of each QoS factor i.

$$u_{j,i} = \min[1, A_{j,i}/R_i] \tag{4}$$

The importance of each QoS factor becomes different according to MN's application. Thus, utility of network j, U_j, is calculated using weight in (5).

$$U_j = \frac{1}{n}\sum_{i=1}^{n} w_i \cdot u_{j,i} \tag{5}$$

where w_i is the weight of QoS factor i ($0 \leq w_i \leq 1$). As a result, $0 \leq$ utility of network j ≤ 1.

4.3.3 Handoff Decision

Although the target network provides better utility than the current network, the handoff to the target network becomes unbeneficial if the predictive residence time in the target network is smaller than the delay caused by the handoff process. Thus, the handoff decision has to take into account both utility and residence time. MN's predictive residence time in the target network (T_RES_{target}) can be calculated by using MN's movement direction, velocity, and the range of the target network. On the other hand, although the current network provides maximum utility, handoff to the target network has to be performed if RSS of current one is lower than the threshold. Consequently, handoff occurs when one of the following conditions lasts until the dwell timer expires. "Make Up Time" means the amount of time needed to make up the loss due to handoff delay.

- ($Utility_{current} < Utility_{target}$), ($RSS_{target} > TH_{target}$) and ($T\_RES_{target} >$ Handoff Delay Time + Make Up Time)
- $RSS_{current} < TH_{current}$

A dwell timer is a smoothing technique for ping-pong effect, cutting too frequent sequential handoffs [3]. It starts to work from the first time that one of above conditions is satisfied. We propose an adaptive dwell timer that can adjust timer duration according to the situation of MN and the network. If utility of the target network is much better than the current one, a dwell timer is shortened, and if movement direction is irregular (ping-pong movement), the dwell timer is extended. The dwell timer has the value of the upper bound $DT_{ubound,j}$, the lower bound $DT_{lbound,j}$ and the default $DT_{defualt,j}$ that depend on the MN's velocity. In consideration of utility and ping-pong movement, equation (6) sets the dwell timer.

$$DT_t = MIN[DT_{ubound}\ ,\ MAX(DT_{lbound}\ ,\ \ (1+F_t)\cdot\gamma\cdot DT_{default})] \quad \textbf{(6)}$$

where F_t is the ping-pong flag (0 is not ping-pong; 1 is ping-pong) and $\gamma = \frac{U_{current}}{U_{target}}$.

4.4 Basic Operations of *U*biComm Handoff Decision Algorithm

Algorithm 1 shows the whole structure of *U*biComm handoff decision algorithm in pseudo code. First of all, utilities of the current network and the target network are compared. Secondly, a dwell timer starts if the conditions such as RSS and *T_RES* are satisfied. A MN handoffs to the target network only if the condition persists until the dwell timer expires. Otherwise the MN stays in the current network.

Algorithm 1 *U*biComm Handoff Decision

```
loop
  location update periodically
  if Utility_current < Utility_target  then            /* detect better network */
    if RSS_target > Threshold_target and T_RES_target > handoff delay time + make up
      time then                                        /* beneficial handoff? */
       Start dwell timer                               /* adaptive dwell timer */
       if condition persists until timer expires then
          Handoff to target network                    /* handoff */
       else  reset dwell timer
       end if
    else stay in current network
    end if
  else if RSS_current < Threshold_current then          /* current network is weak */
    Start dwell timer                                  /* adaptive dwell timer */
    if condition persists until timer expires then
       Handoff to target network                       /* handoff */
    else reset dwell timer
    end if
  end if
end loop
```

5 Simulation Results

We have performed ns-2 simulation [11] with three scenarios for testing various aspects of the proposed protocol. In the first scenario, we compared a fixed dwell timer to an adaptive dwell timer using the utility ratio when a MN passes the center of WLAN slowly. In the second scenario, we compare a fixed dwell timer to an adaptive dwell timer using T_RES when a MN passes the edge of WLAN rapidly. When there are MN's quick ping-pong movements across the edge of WiBro and WLAN, we compared RSS with an adaptive dwell timer in the third scenario. We assume that the utility ratio of WLAN to WiBro 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 [12]. The traffic used in the simulation is non-real time data service with TCP (selective ACK). The simulation parameters of the scenarios used are shown in Table 2.

Table 2. Simulation parameters of each scenario.

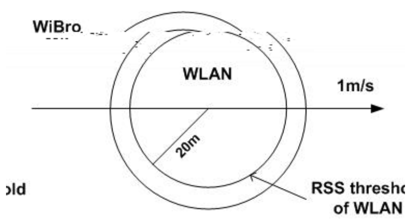
Parameter	Scenario 1	Scenario 2	Scenario 3
Radius to RSS threshold	20m	20m	20m
γ (utility ratio)	2	2	2
Link adaptation	802.11a	802.11a	802.11a
MN's speed (m/s)	1 m/s	5 m/s	5 m/s
Movement pattern	Line	Line	Ping-pong

5.1 Scenario 1: adaptive dwell timer's behavior when MN passes the center of WLAN at slow speed.

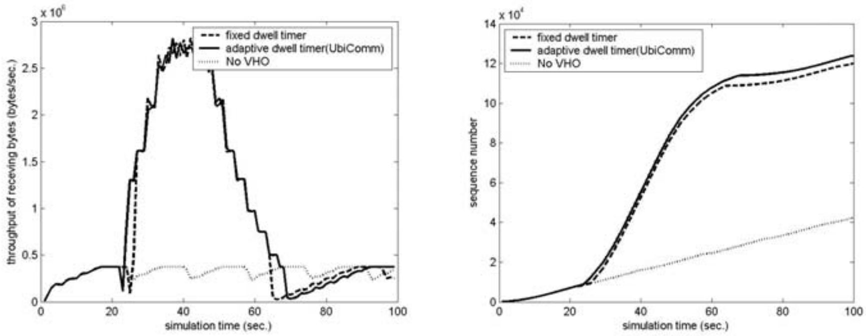
Figure 4(a) shows that a MN passes the center of WLAN (802.11a) at slow speed (1m/s). If fixed dwell time is 4 seconds, *U*biComm's adaptive dwell time is adjusted to 2 seconds and 8 seconds during handoff to WLAN and leaving WLAN respectively. Therefore, the adaptive dwell timer, i.e. *U*biComm scheme, can receive WLAN's service for longer duration.

Variations of the throughput are presented in Figure 4(b) in order to observe hand-off time according to handoff decision algorithms. At around 20 seconds, *U*biComm performs an earlier handoff to WLAN from WiBro than the fixed dwell timer scheme. At around 70 seconds, *U*biComm performs a later handoff to WiBro than the fixed dwell timer scheme. Because link adaptation occurs while in motion, the closer a MN is to WLAN's AP, the higher the throughput the MN gains. The No VHO (not to perform vertical handoff) scheme shows TCP behavior (selective ACK) of receiving WiBro service with constantly low throughput.

Variations of the sequence number are shown in Figure 4(c) to show the cumulative amount of received packets for certain elapsed time periods. *U*biComm has the largest number of received packets since it has the longest service time of WLAN. *U*biComm has 3,900 packets more than the fixed dwell timer scheme after 100 seconds. No VHO scheme receives much smaller number of packets than the other vertical handoff schemes.



(a)



(b) (c)

Fig. 4. Scenario 1: (a) a MN passes over WLAN with radius 20m at 1m/s, (b) throughput vs. simulation time, and (c) sequence number vs. simulation time.

5.2 Scenario 2: use of T_RES when MN passes over the edge of WLAN at rapid speed.

Figure 5(a) depicts the scenario 2 where a MN 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, handoff delay + makeup time is more than 10 seconds on the assumption that the vertical handoff delay is 0.5 second and the packet loss fraction at handoff is 0.5. If *T_RES* is shorter than handoff delay + makeup time, *U*biComm doesn't perform vertical handoff to the preferred network because continuous handoffs for short time cause a ping-pong effect. *U*biComm is compared with the fixed dwell timer scheme (dwell time = 2 seconds without using *T_RES*) as follows.

In figure 5(b), the fixed dwell timer scheme performs a vertical handoff to WLAN at 32 seconds after dwell time of 2 seconds. After receiving WLAN service for very short time, the MN handoffs to WiBro again at 34.56s after dwell time 2 seconds. However, *U*biComm does not handoff to WLAN due to short *T_RES*. In Figure 5(c), the fixed dwell timer scheme performs unbeneficial handoffs, and, as a result, has much packet loss without being able to make up the loss quickly enough. Therefore,, the number of received packets using the fixed dwell timer becomes less than *U*biComm that avoids handoffs.

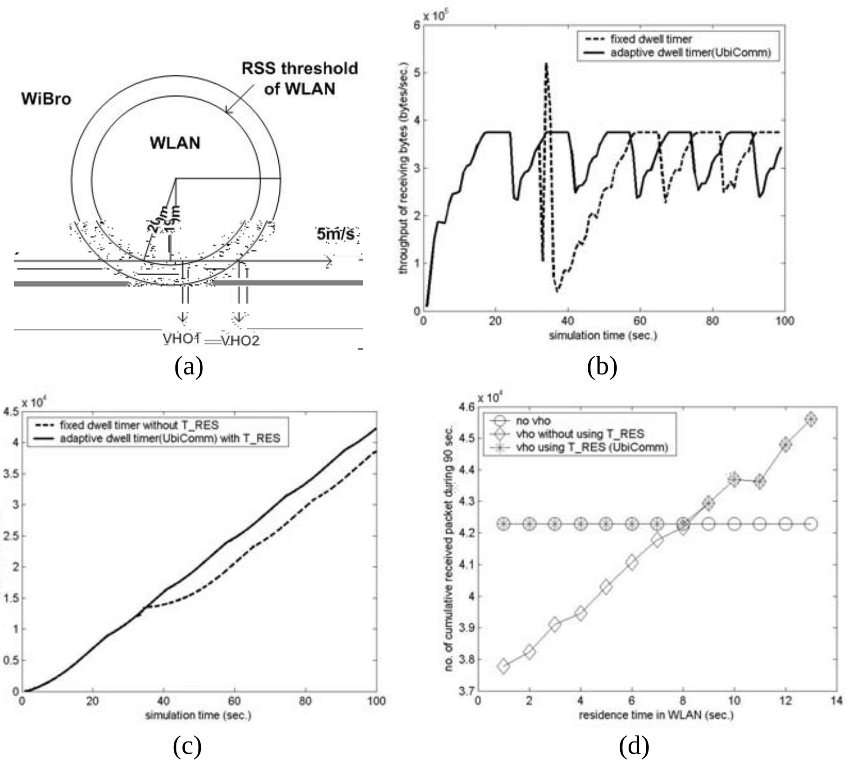


Fig. 5. Scenario 2: (a) a MN passes the point 19-20m away from WLAN's AP at 5m/s, (b) throughput vs. simulation time, (c) sequence number vs. simulation time, and (d) comparison of number of cumulative received packets with different *T_RES.*

In Figure 5(d), the number of cumulative received packets after 100 seconds is compared based on the total time receiving WLAN service. No VHO scheme receives 42280 packets after 100 seconds regardless of 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 in WLAN is less than 8 seconds. *U*biComm takes *T_RES* into account for the handoff decision. Consequently, *U*biComm does not perform handoffs to WLAN if *T_RES* is less than 8 seconds, and it performs handoffs only if *T_RES* is more than 9 seconds. As a result, it avoids unnecessary handoffs that can degrade performance.

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

Figure 6(a) shows scenario 3 where a MN starts to show ping-pong movement before the MN enters WLAN with the MN's velocity of 5m/s (18km/h). In scenario 3, a MN's residence time in WLAN RSS threshold is 3 seconds whenever a MN enters WLAN. If the change in the MN's direction is more than 90 degrees, *U*biComm 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 seconds, and the MN does not handoff in scenario 3. The fixed dwell timer and the *U*biComm have the same performance if the dwell time is fixed as more than 4 seconds. However, the fixed dwell timer scheme performs handoffs if dwell time is fixed as less than 4 seconds. The RSS-based handoff decision scheme always performs handoff whenever a MN passes the RSS threshold. The *U*biComm and the RSS-based schemes are compared as follows.

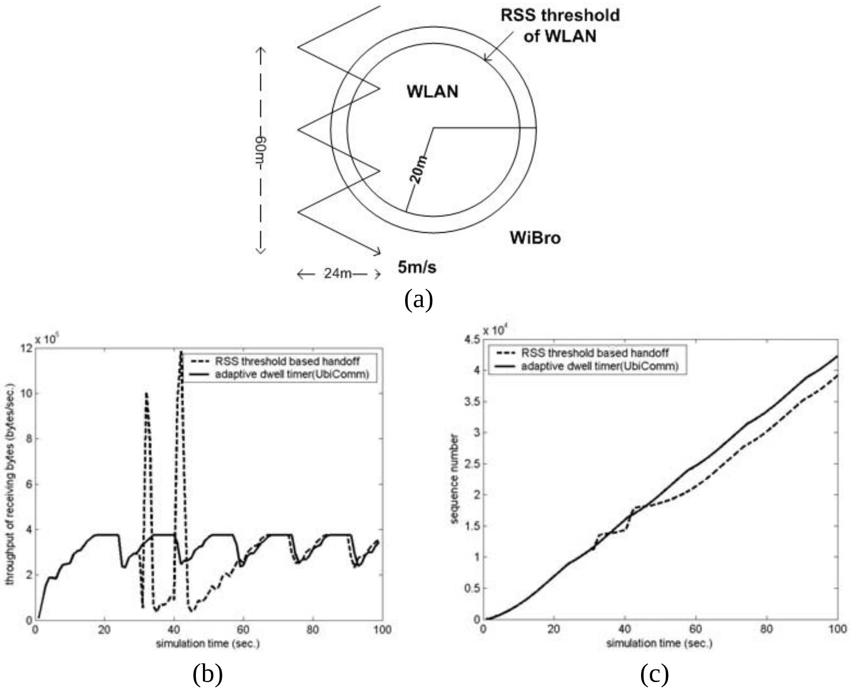


Fig. 6. Scenario 3: (a) a MN's ping-pong movement over the edge of WLAN and WiBro at 5m/s, (b) throughput vs. simulation time, and (c) sequence number vs. simulation time.

Figure 6(b) shows the sudden changes of throughput of the RSS-based handoff decision scheme that performs a total of 4 handoffs. The RSS-based scheme receives WLAN's service for very short time. *U*biComm avoids vertical handoffs because of the ping-pong movement, and continues to receive WiBro's service. In Figure 6(c), the RSS-based scheme receives packets quickly right after handoff to WLAN. However, the RSS-based scheme receives fewer packets than *U*biComm after 100 seconds because it has more packet loss due to continuous handoffs of for short duration.

6 Conclusion and Future Work

Performing vertical handoffs to the network of better performance results in better throughput. However, frequent handoffs of short time period cause more packet loss/delay, and, as a result, decrease the overall throughput. The ping-pong effect, which is a phenomenon that repeats handoffs between two base stations, results from short residence time in the preferred network. Therefore, we have investigated the cause of the short residence time (i.e. MN's high speed and ping-pong movement), and we have proposed *U*biComm which is an improved handoff decision algorithm that avoids the ping-pong effect. The fixed dwell timer scheme used to avoid the ping-pong effect cannot handoff to the preferred network quickly even if it has sufficiently long dwell time. On the other hand, the ping-pong effect occurs if it has short dwell time of receiving service from the preferred network early. However, *U*biComm adjusts the dwell time adaptively according to the MN's mobility. The dwell time doubles to reduce the probability of performing handoffs when a MN's ping-pong movement is detected. The dwell time is reduced if the target network has better performance than current network, and the dwell time is increased otherwise. As a result, a MN receives service of the better network as long as possible. In addition, if the predictive residence time in the target network is shorter than handoff delay + make up time, *U*biComm avoids handoffs. Through simulations, we have shown that *U*biComm is a more flexible scheme than the fixed dwell timer by increasing the overall throughput, avoiding the ping-pong effect, and reducing unbeneficial handoffs. In this paper, we focused on the handoffs between WiBro and WLAN, but *U*biComm can also be used for handoffs among heterogeneous networks, such as cellular networks, WiBro, WLAN, and other networks.

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