WISE: Energy-Efficient Interface Selection on Vertical Handoff between 3G Networks and WLANs

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***Abstract*— The integration of 3G networks and WLANs as complementary has begun to attract much attention in industry as well as academia. This topic is becoming a burning issue, and one of the key questions which it raises is how to support a seamless vertical handoff. This paper introduces a new interface selection algorithm for energy-efficient vertical handoff in tightly coupled systems capable of supporting seamless handoff. Our proposed scheme, *Wise Interface SElection* (*WISE*) switches the active network interface, after taking into consideration the characteristics of the network interface cards and the current level of data traffic, with the cooperation of the mobile terminals and network. Interface switching operates independently on both the downlink and the uplink for the purpose of energy conservation. We show through simulation that less energy is consumed with *WISE* than when only a 3G network or WLAN interface is used, resulting in a longer lifetime for the mobile terminals. In the case of TCP connections, additional throughput gain can also be obtained.**

***Index Terms*— Interface Selection, Vertical Handoff, Energy-Efficient, One-way Operation.**

I. INTRODUCTION

As networking trends move toward *ubiquitous computing*, it is expected that a user be able to connect to the Internet anywhere, at anytime and through any kind of device. In Korea, one Internet service provider, *KT* has recently started providing a particular type of high-speed Internet access called “NESPOT” in public places such as hotels, cafes and subway stations [1]. This service operates independently on CDMA2000 and WiFi (802.11b) networks.

Recently, the integration of diverse access network technologies is being discussed for the purpose of providing ubiquitous networking. Among these technologies, the integration of 3G networks and WLANs is becoming a burning issue in the academic and industrial worlds. 3G networks provide wide area coverage with high mobility. However, the bandwidth of 3G networks (in the case of *CDMA2000 1X EV*, about 2Mbps) is not sufficient for multimedia data services such as downloading large files, and the cost of transferring data through 3G networks is high. On the other hand, WLANs can provide high bandwidth. The two dominant WLAN standards, *IEEE 802.11* and *HiperLAN*, support data rates up to 54(Mbps) depending on channel conditions, and support for data rates greater than 100(Mbps) n *802.11n WG* is in the process of standardization. However, WLANs whose coverage range is from 30(m) to 300(m) cannot provide ubiquitous coverage, because WLANs are designed for local area coverage with low mobility.

Both WLANs and 3G networks are capable of providing higher data rates than the earlier cellular networks. However, 3G networks are best suited to wireless usage involving voice traffic, wide coverage and high mobility, whereas WLANs are optimized for data traffic, a small coverage area and low mobility. Therefore, because of the contrasting characteristics of these two types of network, 3G networks and WLANs are complementary rather than competitive.

Work is ongoing in both the 3G Partnership Project (3GPP) and 3GPP2 on the question of standards and there are many research projects being carried out in the academic arena on the integration of 3G networks and WLANs. Previous studies concerning integration strategies can be classified into (i) *loosely coupled systems* or (ii) *tightly-coupled systems*. The vertical handoff (*vho*) between 3G networks and WLANs is the most important problem to be resolved in the case of both these strategies. Ultimately, 3G networks and WLANs need to be integrated based on a tightly coupled strategy to support seamless handoff. Therefore, we propose *Wise Interface SElection* (*WISE*) to reduce the power consumption of mobile terminals and distribute the network load for vertical handoff in tightly coupled systems.

The rest of this paper is organized as follows. In section II, we provides a brief overview of the integration of 3G networks and WLANs in section III we describe the motivation for our work. Section IV describes our proposed scheme (*WISE*) for vertical handoff. A performance evaluation of *WISE* using simulation is presented in section V, and we conclude our work in section VI.

II. RELATED WORKS

Several strategies for the integration of 3G networks and WLANs have been studied. We can classify them into three categories: *protocol-based* approaches, *gateway-based* approaches, and *emulator-based* approaches. Firstly, the protocol-based approach supports inter-networking between

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heterogeneous networks, by reusing or slightly modifying existing protocols. 3GPP2 is currently studying a mobility management mechanism based on Mobile IP, and other groups are researching the extension of SIP to support mobility management [3]. Recently, [4] proposed a mobility management mechanism, utilizing the multi-homing functionality of SCTP under standardization process. Secondly, the gateway-based approach needs new equipment which can serve as a gateway to connect 3G networks and WLANs. In [5], the authors implemented a gateway called *IOTA*, which incorporates all the functionalities of 3G networks and WLANs. Both the protocol-based approach and gateway-based approaches can be regrouped into what is termed a *loosely coupled approach*. In the loosely coupled strategy, 3G networks and WLANs are separated, so as to allow the independent deployment and traffic engineering of each network. Lastly, in the emulator-based approach, WLANs are connected to a 3G core network, in order to act as access networks. Therefore, WLANs need to be able to emulate an RNC or an SGSN. This approach is called the *tightly coupled approach*, and both signals and data always pass through the 3G core network.

[6] mentioned several issues such as the AAA problem, and the question of seamless connectivity maintenance and QoS guarantee, which need to be considered when integrating 3G networks and WLANs. The authors in [6] pointed out that the interface selection problem in vertical handoff was the most important issue and proposed a simple switching algorithm based on the signal strength.

In [7], two new concepts, *Connection Manager* and *Virtual Connectivity*, were introduced to manage vertical handoff efficiently for mobile terminals. When a mobile terminal moves from a 3G network to a WLAN, CM detects the availability of the stable WLAN signal by physical layer sensing, and the network conditions of the WLAN system by MAC layer sensing. An FFT-based decay detection scheme was adopted to detect signal decay quickly and accurately. Then, the mobile terminal makes a decision as to whether it should trigger vertical handoff or not. VC supports transparency to applications.

Another approach, described in [8], controls voice traffic and data traffic in different manners. Suppose that mobile terminals can activate two types of network interface cards simultaneously, voice traffic is transmitted through a 3G network and data traffic through a WLAN in parallel. The authors in [8] claim that this strategy can provide high-speed best-effort data services.

III. Problem Statement

Generally, WLANs support more bandwidth than 3G networks. Therefore, most of the previous studied assumed that a mobile terminal should use a WLAN as long as possible. That is, when a mobile terminal can access both a 3G networks and a WLAN, it is always served by the WLAN regardless of the traffic characteristics of the network. However, switching to the WLAN in an overlapping area will not necessarily lead to an increase in performance. This operation may cause increased energy consumption and reduce throughput, contrary to the intention, which was to enhance performance.

Tables I and II show the energy consumptions of a *CDMA2000 1x EV-DO* wireless modem NIC and an *Orinoco IEEE 802.11b* NIC, which are the most popular interface cards for each type of network, respectively.

TABLE I
Energy Consumption in a CDMA1x Wireless Modem NIC [9]

Mode	Transmit	Receive	Idle
Consumed E.	2.8(W)	495(mW)	82(mW)

TABLE II
Energy Consumption in an Orinoco IEEE 802.11b NIC [10]

Mode	Transmit	Receive	Idle
Consumed E.	1.3(W)	900(mW)	740(mW)

When a mobile terminal is in *Transmit* mode, 3G network NICs consume approximately twice as much energy as WLAN NICs. However, WLAN NICs consume twice as much energy as 3G network NICs in *Receive* mode, and nine times as much energy in *Idle* mode. Let us suppose that most nodes require multimedia services, and that they tend to spend most of their time receiving data traffic, due to the download characteristics of multimedia traffic. Therefore, although the power consumption in *Transmit* mode is much higher in absolute terms, the power consumption in *Receive* mode cannot be neglected. If a mobile terminal has no data to transmit or receive, it will spend most of its time in *Idle* mode. In the case, since WLAN NICs consume far more energy than 3G network NICs in *Idle* mode, it would be more advantageous to activate the 3G network NIC for mobility management and to turn the WLAN NIC off. From the viewpoint of power consumption, 3G network NICs may be able to provide better performance than WLAN NICs depending on various network conditions, such as the traffic characteristic and network load.

In 802.11-based WLANs, medium access control on a shared wireless channel is contention-based. Increasing the number of mobile terminals in a WLAN causes increased contention overhead, resulting in the degradation of the total network throughput. In terms of the throughput, we should also consider the effect of contention overhead according to network load.

A Protocol-based or loosely-coupled approach is not appropriate for seamless vertical handoff due to the inherent high signaling latency. Therefore, we propose a novel scheme to support seamless handoff in tightly coupled systems.

IV. The Proposed Algorithm

A. Simple Abstraction Architecture

In the case of tightly coupled systems, the same service providers should serve both the 3G networks and the WLANs, or else there should at least be a contract describing the users' profiles for both networks. Therefore, it is possible to control the mobile terminals or to balance the network load using a centralized method. We introduce a new object called the *Virtual Domain Controller* (*VDC*) in a 3G core network. The *VDC* can control 3G access networks or WLANs through base stations (BSs) or access points (APs). The *VDC* is a conceptual and virtual object, so it can be physically constructed with several servers in a distributed manner.

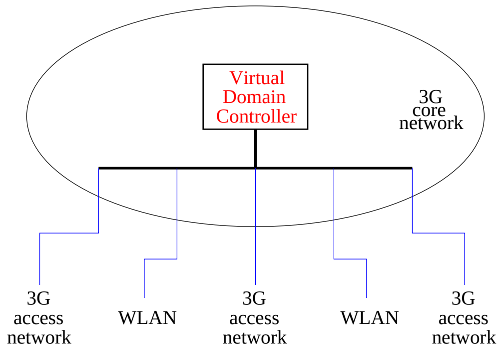

Fig. 1. Simple Abstraction Architecture

In contrast to loosely coupled systems which have no centralized component, the *VDC* can control both the 3G network and WLAN in tightly coupled systems, as shown in Fig. 1. The *VDC* has several functions, such as to trace the pattern of a mobile terminal in all of the networks, to transfer the context of a mobile terminal in advance in order to provide seamless vertical handoff, and if the mobile terminal can access both networks, the *VDC* can tell the mobile terminal which network has the better performance, irrespective of the question of good network load balancing.

One of the most important features of *VDC* is that it manages the uplink and downlink separately, in cooperation with the BSs or APs. The *VDC* can obtain information on the downlink load from a BS or an AP directly and information on the uplink load from a mobile terminal, indirectly via a BS or an AP. Therefore, based on this information, the *VDC* can balance the network load efficiently.

B. WISE

B.1 Basic Algorithm

The objective of our proposed algorithm, *Wise Interface SElection* (*WISE*) is to reduce the energy consumption in mobile terminals, without degrading the throughput. As seen in Tables II and I, the energy drain rates for each mode of each network interface are different. In detail, 3G network interfaces consume more energy in *Transmit* mode, but less energy in *Receive* or *Idle* mode. Therefore, *WISE* aims to dynamically switch an activated network interface to the other consuming the least energy, unless that operation degrades the throughput after taking into consideration the network load. *WISE* operates in cooperation with the mobile terminals and the network. A mobile terminal makes a decision as to which network interface will consume the less amount of energy under the current pattern of data traffic. If the selected network interface is different from the activated one, the mobile terminal sends a vertical handoff request to the *VDC*. The *VDC* accepts or rejects its request after taking into consideration both the 3G networks and the WLANs. Although in the view of the mobile terminal the vertical handoff is able to save its energy consumption, the *VDC* may reject the request if that operation makes the overall network degraded. By rejecting such requests, the *VDC* conserves the overall network state good. The mobile terminal should obey the decision made by the *VDC* because its throughput may also be reduced if the state of network becomes worse. Otherwise, the request is accepted and its vertical handoff is triggered by the *VDC*.

If a mobile terminal receives little data or has long idle period, using 3G network interfaces may be more energy-efficient. However, it makes sense to use WLAN interfaces when a lot of data needs to be sent, in order to prevent throughput from being limited by low bandwidth. In order to select an energy-efficient interface depending on data amount, each mobile terminal continues to monitor its input and output queues to measure how many data packets are being received or transmitted. If the current queue length exceeds over or falls below he predefined thresholds, the mobile terminal sends an appropriate request to the *VDC*. Of course, the cost of switching network interfaces should be considered when comparing with the queue lengths and thresholds.

The most important feature of *WISE* is that the operations on the uplink and downlink are independent. A mobile terminal measures the network load on the downlink based on the length of its input queue, and that on the uplink based on the length of its output queue. According to these measured values, it may independently request a one-way vertical hand-off to the *VDC*. In some cases, it can use asymmetric links for the uplink and downlink. For example, a mobile terminal receiving a lot of data on FTP connections using TCP may utilize WLAN interface on downlink for data packets and 3G network interface on uplink for ack packets.

If vertical handoff can be requested by only a mobile terminal, problems may arise. Suppose that many mobile terminals transmit or receive a small amount of data in a 3G access network. They already occupied the entire bandwidth of the 3G access network, whereas there is no data traffic in the WLAN. All additional mobile terminals will have to use their 3G network interfaces, even if they only transmit or receive a small amount of data, resulting in exceeding the maximum capacity of the 3G access network being exceeded. The opposite case produces a similar result. Therefore, the *VDC* needs to be able to trigger vertical handoff by itself, in order to balance the network load.

B.2 The Process of Vertical Handoff

The *WISE*-enabled mobile terminal is served from a 3G access network through initialize process. A mobile terminal periodically checks whether it can be served over a WLAN or not. If it can access to both a 3G access network and a WLAN, it measures the queue length of the input queue used for the downlink and the output used for the uplink. If each queue length exceeds the corresponding threshold, the mobile terminal sends *WISErequest*(*link*, *dest*) message to *VDC* for vertical handoff on each link in order to be served using the most efficient network interface. At this point, '*link*' means whether uplink or downlink, and '*dest*' means a target access network of vertical handoff.

When the *VDC* receives a request for vertical handoff, it first

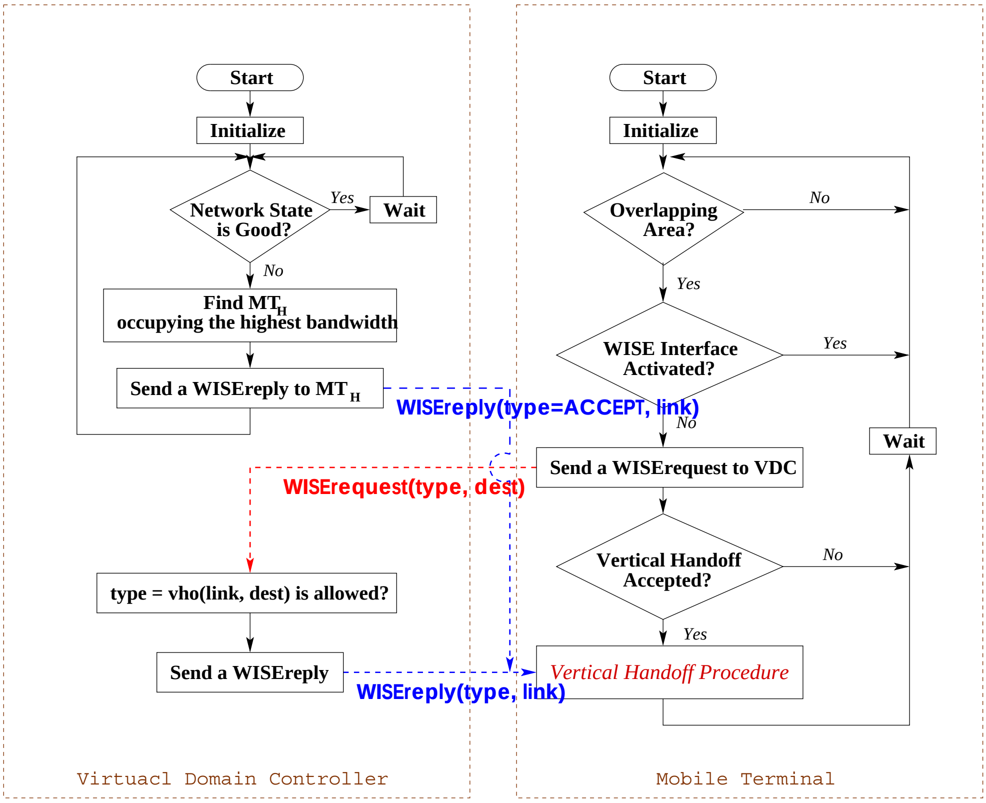

Fig. 2. Flow Chart of *WISE* Algorithm

checks the network load on the requested link on the target network by measuring the queue length of the associated BS or AP. Based on these information, the *VDC* makes a decision and sends *WISEreply*(*type*, *link*) message to the mobile terminal. '*type*' includes the information whether the request is accepted or rejected. If the request is accepted, '*type*' is '*typeACCEPT*' and otherwise, it is '*typeREJECT*' to reject vertical handoff. '*link*' in *WISEreply* means the target access network in the received *WISErequest* message. After receiving the message, the mobile terminal calls the vertical handoff procedure if the '*type*' is '*typeACCEPT*'. Otherwise, it waits for predefined time and repeats above process from testing overlapping area.

The *VDC* periodically checks the state of each BS and AP to test whether it is overloaded or not and, if so, the *VDC* selects and handoffs the mobile terminal occupying the highest bandwidth on the overloaded Network, in terms of either the uplink or the downlink. This process is repeated till the queue length of the BS falls below the threshold.

B.3 Operation Scenario

In order to explain the operation of *WISE*, consider an example scenario (Fig. 3). Suppose that a mobile terminal downloading a large multimedia file is served at *location A* through a 3G access network, and that it moves to *location B*, where it can gain access to both a 3G access network and a WLAN. The mobile terminal detects that it can use both types of access networks and it determines that WLAN service is more energy-efficient on download traffic by using *WISE* algorithm. Therefore, the mobile terminal sends a *WISErequest*(*downlink*, *WLAN*) message to the *VDC* for vertical handoff on downlink. The *VDC* receiving *WISErequest* message makes the decision considering the network load on WLAN by measuring AP queue length in order to determine whether it is overloaded or not. If sufficient bandwidth remains in the WLAN, the *VDC* sends *WISEreply*(*typeACCEPT*, *downlink*) message to the mobile terminal. The mobile terminal which received the message starts the vertical handoff procedure. If the *VDC* sends *WISEreply*(*typeREJECT*, *downlink*), then the mobile terminal repeats above process from testing overlapping area after waiting predefined time.

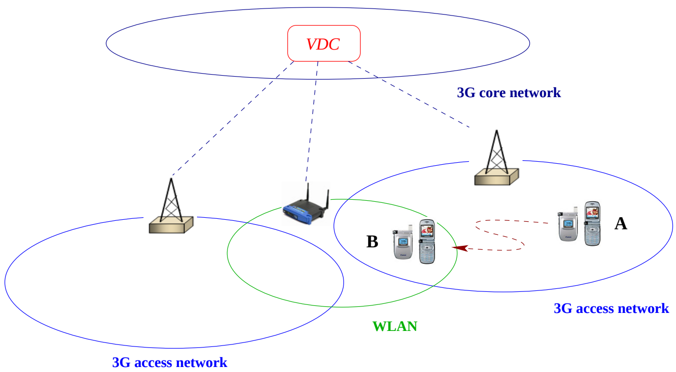

Fig. 3. Node movement in the integration of 3G networks and WLANs

At this point, it should be noticed that the direction of the vertical handoff is *one-way*, in that it only involves the downlink on the 3G access network. The mobile terminal con-

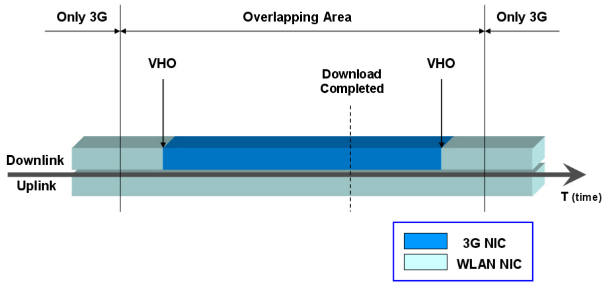

Fig. 4. Usage pattern of uplink and downlink

tinues to send packets on the uplink in the 3G access network, because the uplink in the 3G access network is not congested. In other words, the mobile terminal uses asymmetric links: a downlink in a WLAN and an uplink in a 3G access network.

If the queue length of the mobile terminal drops below the low threshold after it has finished its data download, it sends *WISErequest*(*downlink*, *3G*) to the *VDC*, requesting handoff from the WLAN to the 3G access network on downlink. On receiving the request from the mobile terminal, the *VDC* makes a decision as to whether vertical handoff is allowed or not, after considering the network load in the 3G access network. If possible, the *VDC* permits vertical handoff on the downlink by sending *WISEreply*(*typeACCEPT*, *downlink*). The mobile terminal is served through 3G access network again. Fig. 4 shows which access network is serving on download and upload in the mobile terminal.

C. Discussion

It is very important for battery-operated mobile terminals to reduce their energy consumption, in order to extend their lifetime. *WISE* which resolves this problem is an energy-efficient interface algorithm by selecting the active network interface dynamically, after taking into consideration of the power consumption of each NICs, the traffic pattern, and the network load. The basic concept involved is that a mobile terminal uses the WLAN interface on each *one-way* link when it has a large amount of data to send or receive, and the 3G network interface for small amounts of data, resulting in the total energy consumption being reduced, without degrading the total throughput.

In the case of bidirectional TCP connections, *WISE* may provide additional throughput gain compared to the case where only a WLAN interface is used via asymmetric links. Suppose that several mobile terminals are using a WLAN interface on both the uplink and downlink. While they are downloading large multimedia files using TCP, an AP attempts to send data packets on the downlink and the mobile terminal attempts to respond with ack packets on the uplink. Because the medium on the downlink and uplink is the same and is shared, the AP and the mobile terminals contend with each other, resulting in additional overhead such as packet delay and loss. On the other hand, *WISE* enables the mobile terminals to use two different networks simultaneously, a WLAN for the downlink, in order to receive a large amount of data packets, and a 3G access network for the uplink in order to send a small amount of ack packets. The AP can transmit data on the downlink in polling order, and the mobile terminals can transmit ack packets on the uplink in an assigned time slot. This operation is contention-free. Therefore, we expect additional throughput gain to be obtained by reducing competition overhead. A quantitative analysis will be provided in the next section.

V. Performance Evaluation

A. Simulation Environment

We simulated our proposed scheme, *WISE*, using the ns-2 simulator. Fig. 5 shows the internal structure of a mobile terminal. A *WISE* agent triggers a vertical handoff dynamically through the process of signaling with a BS or a AP. IFQ control modules signal feedback information such as queue length to a *WISE* agent.

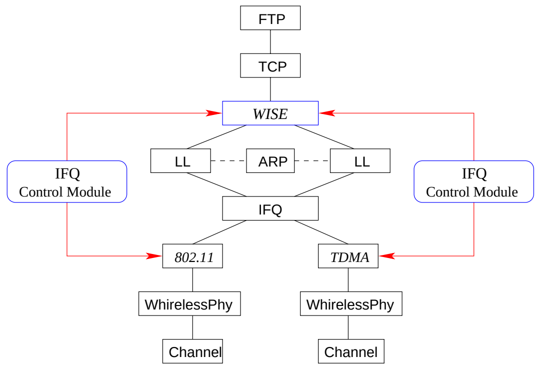

Fig. 5. Internal structure of a mobile terminal

In our simulation, two performance indices, power consumption and throughput for download or upload traffic, are measured and analyzed for three cases: (i) the case where a mobile terminal is served from only a 3G network, (ii) the case where it is served from only a WLAN, or (iii) the case where it can select the served network interface through *WISE*. The power consumption in each NIC is as described in tables II and I. The bandwidth is set to be 2.4Mbps for the downlink and 153.6kbps for the uplink in the 3G network, and 11Mbps for the WLAN links.

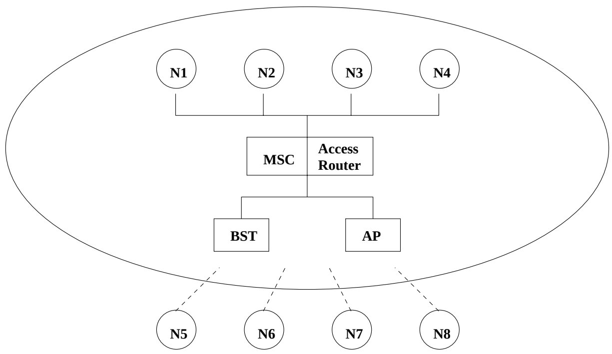

Fig. 6. Simulation topology

The topology used in our simulation is shown in Fig. 6. 8 nodes, consisting of 4 nodes in the wired link and 4 nodes in the wireless link, generate 4 download traffic flows or 4 upload traffic flows using FTP sessions. The TCP flows have a packet size of 1024 bytes and a window size of 1024 bytes. The total time in our simulation is 300(s), but the FTP agents try to send data only during the 5 active periods: 0∼20, 60∼80, 120∼140, 180∼200, and 240∼260(s).

B. Simulation Result

Fig. 7, 8 and 9 show the average remained energy, power consumption and throughput of the mobile terminals on download traffic and upload traffic. Each mobile terminal has an initial energy of 1000(J) and tries to transmit or receive data during 33% of the total simulation time. We plotted their average values every 10 seconds in Fig. 7, 8 and 9, and for the sake of convenience, referred to the case involving only the 3G network interface as Cellular, the case involving only the WLAN interface as WLAN, and the case involving dynamic interface selection based on *WISE* as *Dynamic*.

A similar tendency is shown in terms of the remained energy, power consumption and throughput on download and upload traffic. Fig. 7 shows the remained energy of a mobile terminal on download and upload traffic. The least energy was consumed for *Cellular* and the most energy for *WLAN*. This is because, in the simulation scenario, the mobile terminals spend 67% of their time in the idle state which is more energy-efficient state for *Cellular* than *WLAN* and less bandwidth is provided for *Cellular*, so that they receive a small amount of data. On the other hand, in the case of *WLAN*, they receive much more data, because more bandwidth is provided for *WLAN* and TCP connections can use as high bandwidth as possible. For *Dynamic*, the decreasing slopes in the active intervals are similar to those for *WLAN*, while those in the inactive intervals are similar to those for *Cellular*. That is because, during the active intervals, mobile terminals use a WLAN interface on the downlink when they have a large number of data packets to receive, and a 3G network interface on the uplink in order to send a small number of ack packets (Fig 7.a). During the inactive intervals, they use only the 3G network interface by powering their WLAN interface off.

Fig. 8 shows the energy decrease per time unit on download and upload traffic. *WISE* makes the mobile terminals perform handoff on only each *one-way* link if they transmit or receive large amounts of data, in order to take into consideration the network load, resulting in asymmetric links. In Fig 8.a, although *Dynamic* consumes a little more energy than *WLAN* during the active intervals due to the simultaneous use of two NICs, *WISE* has less total energy consumption without throughput degradation. *Cellular* has the least energy consumption, but limited throughput.

Fig. 9 shows the average throughput of the 4 mobile terminals on download and upload traffic. *Cellular* has the least throughput, due to the low bandwidth. In Fig. 9.a, *Dynamic* obtains higher throughput than *Cellular* by using a WLAN interface on the downlink. It should be noticed that *Dynamic* has higher throughput than *WLAN*. As mentioned in previous section, this is because an AP and mobile terminals contend with each other to transmit data and ack packets on both the downlink and the uplink in the WLAN, resulting in a degradation of the throughput. However, for *Dynamic*, an AP transmits data packets on the downlink in the WLAN and the mobile terminals transmit ack packets on the uplink in the 3G access network without any contention resulting in some decrease of total energy consumption. In Fig. 9.a and b, the difference of gaps between *WLAN* and *Dynamic* on the active periods shows the above fact explicitly. The gaps between *WLAN* and *Dynamic* for the download traffic during the active periods are larger than those for the upload traffic during the active periods. In the case of the upload traffic, although the WLAN interface on the uplink can provide high bandwidth for large amounts of data, the mobile terminals have to share the medium. Therefore, they contend with each other, resulting in a slight degradation of the throughput.

The simulation results confirm our assertion that *WISE* can reduce energy consumption without degrading throughput.

VI. CONCLUSION

In this paper, we proposed *WISE*, which adaptively selects the more energy-efficient network interface, by taking into consideration not only the energy consumption of each NIC, but also the network throughput. *WISE* utilizes *VDC*, which balances the network traffic load and takes the decision to perform vertical handoff, where this would reduce energy consumption, unless the operation would limit throughput due to low bandwidth. The process of performing vertical handoff operates separately on each link, uplink and downlink. This one-way operation eliminates contention between the uplink and downlink over the WLAN, potentially resulting in an additional throughput gain in throughput. The simulation results support our assertion that energy consumption and throughput can be improved through *WISE*, which dynamically selects which network interface to use, in order to conserve energy.

Future works involve the development of fast network detection in heterogeneous wireless networks. Detecting available networks in advance is important in an environment in which diverse access network technologies with different characteristics coexist.

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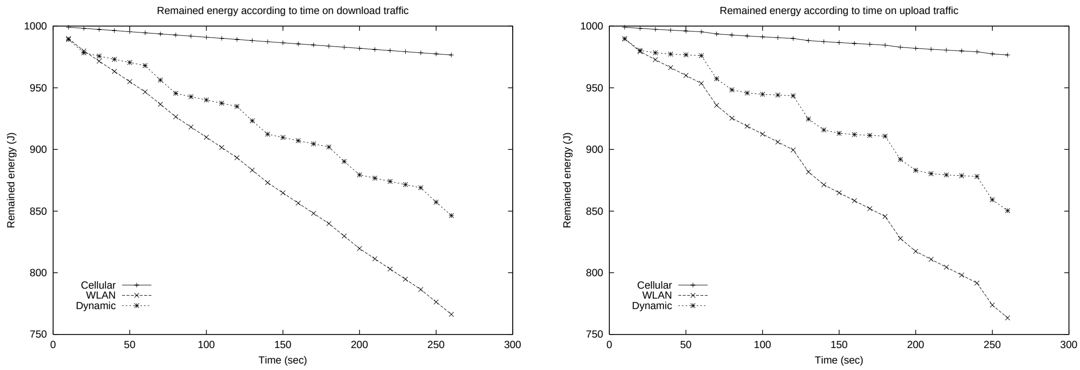

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Fig. 7. The Average Remained Energy

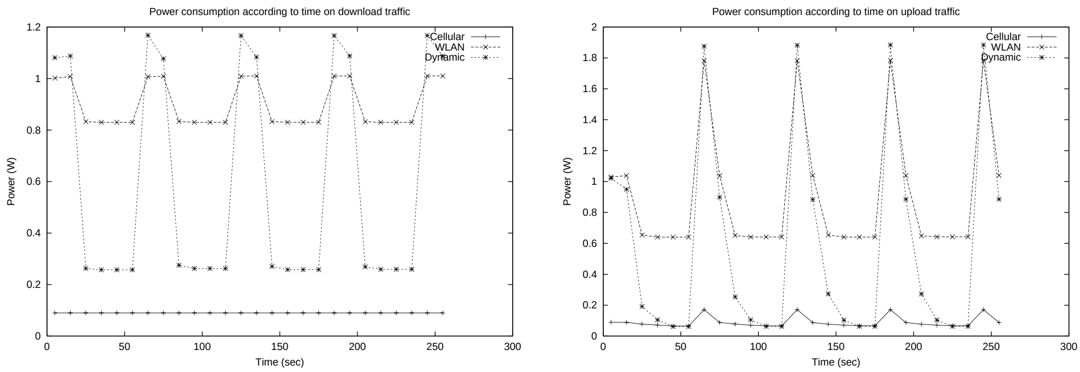

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Fig. 8. The Average Power Consumption

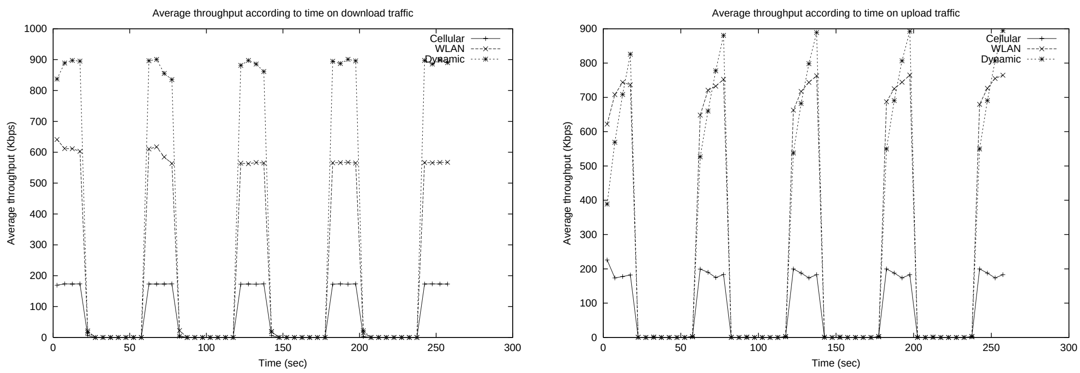

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Fig. 9. The Average Throughput

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