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An efficient wireless network discovery scheme for heterogeneous access environments

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Abstract

Purpose – Several new network types have emerged over the last couple of years. Many of these networks are being connected together to provide mobile users with the capability of staying always connected to the Internet which requires seamless transitions from one network to another without causing interruption to on-going connections. To maintain connectivity during handoff, all the networks that are accessible to the mobile station need to be known. The paper aims to propose a novel energy-efficient network discovery approach that enables fast discovery and selection of available access networks.

Design/methodology/approach – The performance of the proposed approach over an actual network testbed consisting of heterogeneous networks (such as wireless local area, cellular) is evaluated.

Findings – It was found that the approach yields between 12.4 and 19.1 per cent improvement in battery power consumption over other network discovery approaches.

Originality/value – The paper proposes and implements a novel scheme to discover wireless networks in a multi-access environment consisting of heterogeneous networking technologies.

Keywords Wireless, Computer networks

Paper type Conceptual paper

1. Introduction

Future generation wireless networks are envisioned to be a combination of several heterogeneous networking technologies including wireless local area networks (WLANs) such as IEEE 802.11a/b/g, wireless personal area networks (WPANs) such as Bluetooth and Zigbee, wireless metropolitan area networks (WMANs) such as WiMax, and wireless wide area networks (WWANs) such as general packet radio service (GPRS), universal mobile telecommunications network (UMTS), and code division multiple access (CDMA), etc. To support access to these varied technologies, complex multi-modal mobile devices are being developed which provide hardware and software support to enable users to access these networks. Most existing mobile devices such as laptops, personal digital assistant (PDAs), smart phones, etc. are already equipped with multiple network cards including WLAN, Bluetooth and, GPRS. These access systems and mobile devices are simultaneously developing to provide end-users with ubiquitous network connectivity, anytime, anywhere.

Mobile users tend to take advantage of the availability of various network types. These networks often vary in several characteristics, including their cost of services;

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bandwidth offered, security levels, and so on. In homogeneous networks (consisting of only one type of network technology), the choice of the access network is based upon the simple criterion of channel quality indicated by a measure of the received signal strength (RSS). On the other hand, in heterogeneous networks, the decision to select the right access network is more complex and is dependent on a combination of several criteria. Users benefit by selecting the most desirable network from the set of discovered available networks. However, currently available mobile devices are designed to discover the presence of various types of wireless networks only by switching on their respective network interfaces. For example, if a PDA is enabled with a WLAN network interface card (NIC), and a GPRS NIC, the device can detect the presence of these networks only by keeping these interfaces switched on. Since advanced wireless devices are being equipped with more and more network technologies, keeping every interface on at all times consumes a large amount of power in a mobile device.

In this paper, we propose a novel network discovery approach that enables a mobile terminal to efficiently discover available access networks with minimum power utilization, by eliminating the need to keep all interfaces on at all times.

The rest of this paper is organized as follows. In section 2 we discuss the concepts related to handoffs in wireless networks and highlight the main contributions of this work. In section 3, we present the design and implementation of our network-discovery method including the configuration details of our real networking testbed. Finally, in section 4 we make some concluding remarks and discuss future work.

2. Background

2.1 Handoffs

Handoff is the process by which a mobile terminal keeps its connection active as it migrates from the coverage area of one network to another. Handoffs can be categorized into various types depending upon various factors such as the type of networks, and devices involved. Handoffs that occur between the access-points of the same network technology and are termed horizontal handoffs or intra-system handoffs (Chakravorty *et al.*, 2003). In other words, horizontal handoffs occur between homogeneous cells of a wireless access system, example between two cells of a cellular system, etc. Handoffs that occur between different access-points belonging to different networks (example WLAN to GPRS) are referred to as vertical handoffs or inter-system handoffs. Thus vertical handoffs are implemented across heterogeneous cells of access systems, which differ in several aspects such as bandwidth, data rate, frequency of operation, etc. The different characteristics of the networks involved make the implementation of vertical handoffs more challenging as compared to horizontal handoffs. The terms horizontal and vertical follow from the overlay network structure that has networks with increasing cell sizes at higher levels in the hierarchy. The different characteristics of the networks involved make the decision to perform a vertical handoff more complicated as compared to horizontal handoffs (Figure 1).

A handoff can also be network-controlled or mobile-controlled. In a network-controlled handoff, the network is responsible for making the handoff decision. In a mobile-controlled handoff, the mobile node (MN) must take its own signal strength measurements and make the handoff decisions on its own. It may also take into account its own requirements as well as the characteristics of various networks available for access.

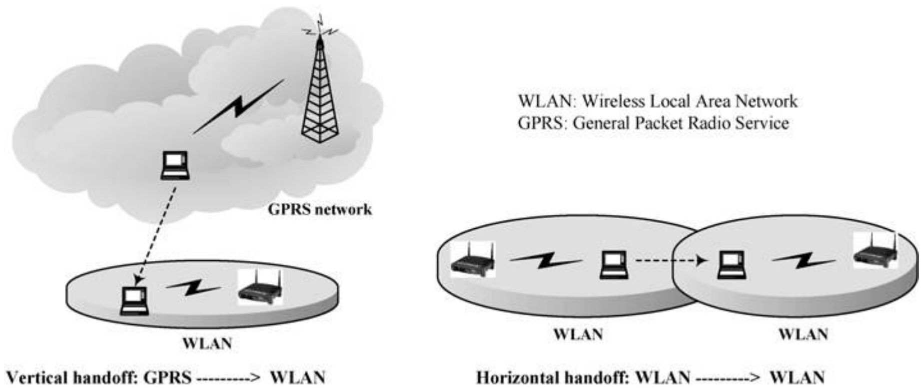

Figure 1.
Horizontal vs vertical handoff

Network controlled handoffs are unsuitable for vertical handoffs since each network will have to be aware of the characteristics of the other wireless networks to be able to make the handoff decision. Therefore, in this paper, we have implemented a mobile-controlled handoff decision method that enables a MN to select the most desirable network using various criteria such as network conditions, user preferences, costs, application requirements, etc.

2.2 Vertical handoff

The vertical handoff process can be divided into three phases:

Network discovery. The process in which a MN discovers reachable wireless networks.

Handoff decision. This is the ability to decide when to perform the handoff and to which network. A decision for vertical handoff may depend on several issues relating to both, the network to which the MN is already connected and to the one that it is going to handoff. The handoff decision may also include other factors such as the requirements of the mobile user, etc.

Handoff execution. This is the actual transfer of data packets to a new wireless link in order to reroute a mobile user's connection path to the new point of attachment. It requires the network to transfer routing information about the mobile user to the new (or target) access router for the proper forwarding of packets.

2.3 Contributions of this work

In this paper, we focus on the network discovery process. We propose and implement an energy-efficient network discovery method based on a simple cell-ID-based location-management technique. The approach eliminates the need to keep all interfaces on at all times for discovering available wireless networks. We also present an evaluation of the approach in a real networking testbed consisting of two heterogeneous wireless networks: WLAN and GPRS.

3. Network discovery

3.1 Related research

Discovery of the available access networks is the first step of any vertical handoff decision algorithm. Most of the decision algorithms proposed till date (Guo *et al.*, 2004; Jang *et al.*, 2005; Inayat *et al.*, 2004; Ormond *et al.*, 2006; Buddhikot *et al.*, 2003) have used an inefficient approach for discovering wireless networks. Most of these previous works have assumed the network interfaces to be active all the time and continuously scan (actively or passively) for signals arriving from one or more wireless access points in the vicinity. However, active interfaces consume battery power even in idle modes (Wen-Tsuen *et al.*, 2004). Thus, keeping network interfaces on all the time can reduce the battery time of a mobile device. Battery power is an important resource for mobile users and needs to be conserved with better network discovery techniques. Efficient utilization of battery power is even more important for small devices such as PDAs, smart phones, etc. which are already limited in their total battery capacity. Research studies (Takahashi, 2000) have predicted that, in the future, power consumption of wireless network interfaces will dominate total system consumption for mobile devices. Thus, power conservation for wireless network interfaces is becoming a significant issue.

A few decision algorithms proposed in the literature have shown a reduction in the power consumption while discovering available access networks by activating the network interfaces periodically instead of keeping them activated all the time. This method helps in reducing the power consumption, however, the power conserved is inversely proportional to the frequency by which the interfaces are activated and made to scan for available networks (Wen-Tsuen *et al.*, 2004). Also, the frequency of activation may affect the efficiency by which networks are detected. For example, a more frequent activation (example every 20 s) may be able to detect new wireless network coverage faster than a low frequency activation scheme (example. every 10 min). Moreover, interface activation done in the absence of actual coverage unnecessarily consumes extra battery power.

Tsuen *et al.* (2004) proposed an interface management technique to reduce power consumption by using a mobile positioning system called GPS (Sayed *et al.*, 2005) to discover wireless networks. However, using the GPS technology for network discovery has several limitations. First, embedding a GPS receiver into mobile devices leads to increased cost, and size. GPS receivers themselves consume additional battery power. This approach also requires the replacement of millions of mobile handsets that are already on the market. Furthermore, the accuracy of GPS measurements degrades in urban environments, and it does not work properly inside buildings. For these reasons, we argue that performing location-based wireless network discovery using GPS is not a very practical solution.

Several other research efforts have investigated the effect of using multiple network interfaces on the battery consumption of currently-used mobile devices.

Lorchat and Noel (2003) introduced a model for obtaining the upper bound for the power consumption of the wireless network interfaces. They studied three wireless network access technologies: IEEE 802.11a, 802.11b and Bluetooth. They found that Bluetooth has the lowest power consumption and a limited range and throughput. IEEE 802.11b has slightly higher power consumption with increased range and throughput. IEEE 802.11a has the highest throughput, however, the range is not as large as IEEE 802.11b. The higher frequency and throughput of IEEE 802.11a make it the highest power consumer among all three network access technologies (Table I).

Stemm *et al.* (1996) conducted measurement studies to determine the network interface power consumption on a PDA. Their work showed that network interfaces consume a significant fraction of the total power on a PDA, and that the power consumed when the interface is on and idle is more than the cost of receiving packets. Stemm's work also examined the power drain for different transport level protocols, and found that the critical factor is not the number of packets sent or received but the amount of time that the network interface is in an active but idle state.

Bargh and Peddemors (2006) investigated the energy consumption characteristic of different network interfaces in a multi-homed mobile device. They also conducted experiments to determine the energy-efficiency of GPRS and WiFi interfaces. Their studies showed that during idle-IP connectivity the GPRS Network Interface consume less or comparable amount of energy relative to the WiFi one. In order to be reachable at the IP level, a mobile device just needs to have idle IP connectivity. Thus, the GPRS interface is relatively more energy efficient for reaching the mobile device at the IP level. On the other hand, the WiFi network interface is energy efficient for sending/receiving large volume of IP data.

Pering *et al.* (2005) proposed the use of radio hierarchies for wireless service discoveries. An experimental evaluation of this technique demonstrated that radio hierarchies can significantly reduce power consumption (up to 40 times) while supporting "always on" radio connection models. By using lower capability radios to perform device discoveries high power radios can be shutdown until they are needed for an active connection. For example, the Bluetooth to WiFi connection process is similar to the Bluetooth connection process, but pushes the AP's WiFi configuration information instead, and performs the final connection request over the WiFi channel. The Bluetooth to WiFi configuration consumes considerably lower power than the WiFi only solution, but has increased latency due to the lengthy Bluetooth connection process. The connection time after obtaining the AP's WiFi configuration information is low because it only requires WiFi authentication and association. A significant advantage of this scheme is that both Bluetooth and WiFi are popular industry standards. Several laptops and PDAs are now equipped with these radios, and therefore this technique is directly applicable to a variety of commercial devices.

3.2 Proposed energy-efficient network discovery method

In this work, we propose and implement an efficient network discovery method based on a simple and inexpensive cell-ID-based location-management technique. Our method not only reduces power consumption by avoiding unnecessary interface activation, but also provides efficient and fast detection of wireless networks. Furthermore, this method does not require any upgrade of network or terminal equipments making it a practically deployable solution. We demonstrate the performance of the proposed technique by conducting tests in a real testbed consisting of a GPRS network and WLANs, and we present a comparison with conventional network discovery approaches.

3.3 Design and implementation of network discovery module

The proposed WLAN discovery approach is based on the concept of cell-ID-based location management (Trevisanai and Vitaletti, 2004) to discover the approximate

Table I.
Battery time of a PDA with various network interfaces

Network technology	Battery time
None	3 h 22 min
Bluetooth	3 h 16 min
IEEE 802.11b	3 h 8 min
IEEE 802.11a	3 h 3 min

Source: Lorchat and Noel, 2003

geographic location of the mobile device and use this information to determine if the MN is near or inside the coverage area of a WLAN hotspot (Figure 2). The cell-ID concept can be used in GSM, GPRS, and WCDMA networks. The base stations of these networks continuously broadcast certain information to their mobile clients in the network. The broadcasted information includes the following:

- Mobile country code (MCC).
- Mobile network code (MNC).
- Location area code (LAC).
- Cell ID (CI).

The value of MCC used by mobile network operators is unique to each country (for example MCC is 310 for the United States). The MNC value identifies the operator of the network and is unique to each mobile network operator (for example the T-Mobile network operator in the US has a MNC value of 260). The LAC is a group of cells managed by a mobile network operator in an area. A cell is the smallest geographical unit of a cellular network. Each cell has a base station that provides cellular network coverage within it. The CI value is unique to each cell of the network. The sizes of cells in a cellular network (example GPRS) may vary. However, the cell sizes are usually about 100 meters in urban areas.

The network discovery module monitors and collects the broadcasted information as well as the received GPRS signal strength using a Linux serial communication program called Minicom that communicates with the GPRS aircard using AT commands and extracts the required information. Table II lists the various AT commands used to interact with the aircard and read the broadcasted information.

The network discovery module transmits the values obtained for MCC, MNC, LAC, and CI (we refer to these as location identifiers) to a hotspot location server (HLS) on the wired network via the GPRS network interface. We assume the GPRS network to be an always-available network such that the GPRS connection can be used to monitor and receive information about the presence of smaller networks such as WLAN hotspots, Bluetooth networks, etc. In this paper, we have only demonstrated the dynamic discovery of WLAN hotspots using the cell-ID technique. In the future, we plan to extend this prototype to support discovery of other types of networks. The HLS maintains a database consisting of several hotspot locations and their corresponding location identifiers.

Whenever the MN enters a new cell (reflected by the change in the cell ID), it transmits the values of the location identifiers (MCC, MNC, LAC, and CI) to the HLS. The HLS checks its database to determine if the cell information received from the MN corresponds to any wireless hotspots inside the cell. The HLS also checks if there are any hotspots in the cells adjacent to the current cell of the MN. If any hotspots are found, the HLS returns the Cell-IDs of the cells containing the hotspots to the MN.

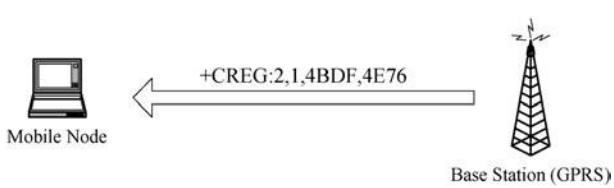

Figure 2.
Network discovery using cell-ID technique

Description	Command	Response	Response codes
Query registration status	AT + CREG?	+CREG:<mode>,<stat>,<lac>,<ci>	Mode = 2; enable network registration and location information Stat = 1; registered in home network Lac: 2 bytes location area code in hexadecimal format Ci: 2 byte cell id in hexadecimal format
Query RSS	AT + CSQ	+CSQ:<rssi>	Rssi = 0-99
Query IMSI value	AT + CIMI	IMSI value (example 15 310260411757705)	MCC: first three digits MNC: next three digits

Table II.
AT commands used for implementing network discovery

However, if no matches are found in the HLS database for the received location information, then the HLS returns a message to the MN with a NULL flag set.

When the MN receives a message from the HLS, it takes the following steps:

(1) If the message indicates the presence of wireless hotspots in the current cell, the MN activates its WLAN interface and starts active scanning for the WLAN.

(2) If the message from the HLS indicates no hotspots in the current cell, then the MN keeps its WLAN interfaces deactivated. This reduces power consumption as opposed to conventional techniques of network discovery that implement continuous WLAN network scanning, even if there might not be any WLANs in the vicinity of the MN. Furthermore, the MN transmits location information to the HLS only when it changes its cell (reflected by the change in the cell ID). Thus, information need not be transmitted continuously. This saves network bandwidth.

3.4 Performance evaluation of proposed energy-efficient network discovery approach

3.4.1 Heterogeneous network testbed. Figure 3 shows the experimental testbed used for our experiments. It consists of a user with a mobile device moving in a GPRS access network following the trajectory shown in Figure 3. This GPRS access network was found to have a MCC value of 310 (indicating country is USA) and a MNC value of 260 (indicating the mobile operator is T-Mobile[1]). The LAC of this area was determined to be “2BDF”. The LAC and CI values are generally specified in hexadecimal formats. Throughout the experiment, the mobile device moved at a speed of 15 miles/h. As the MN moved, it crossed several GPRS cells (“4E9A”, “335F”, “4F75”, “4FBB”, “4F95”, “4FC7”, and “4F76”) as shown in Figure 3. However, only cells with cell IDs “335F” and “4FC7” contained wireless hotspots in them. We determined the battery time of the MN as it moved along the shown trajectory and discovered the wireless hotspots. We also measure the wireless discovery time and compared the performance of our approach with previously proposed approaches by other researchers.

3.4.2 Performance evaluation. In this section we present an evaluation of the proposed network discovery approach in comparison with previous approaches. We used the following two performance metrics for evaluating the network discovery approaches:

- Battery time (min).
- Wireless network discovery time (s).

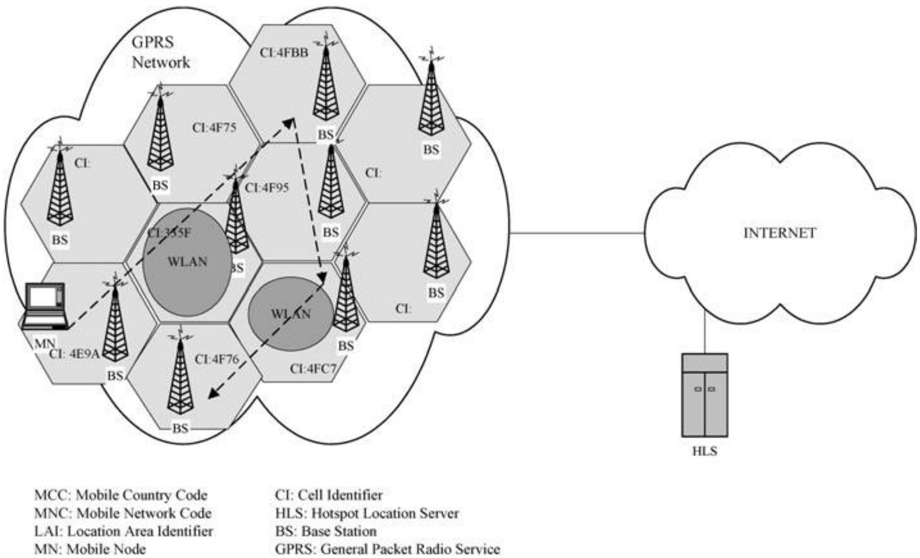

Figure 3. Experimental testbed for evaluating network discovery approach and implementation

Battery time is defined as the amount of time for which the battery of a mobile device lasts, beginning from the time is it fully charged to the time it is completely discharged. During this period the mobile device does not use a direct battery charger, but uses the stored battery power.

The wireless network discovery time is defined as the time taken by the MN to discover the wireless network after having entered into its coverage area. We also compare the rate of battery power consumption obtained for various approaches (Figure 4).

Figure 5 shows the decrease in battery time of the MN using different approaches. It can be observed (from Figure 5) that our proposed cell-ID-based approach achieves a higher battery time (118 min) as compared to the always-active (99 min) and periodically-active approaches. Figure 6 shows the exact battery time obtained with the different approaches. It can be observed that the cell-ID-based interface activation approach obtained a 19.19 per cent improvement over the always-active interface

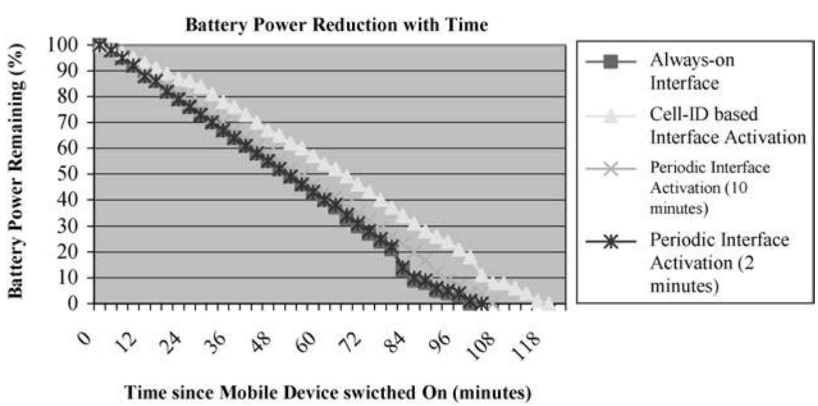

Figure 4. Power consumption for various network discovery approaches

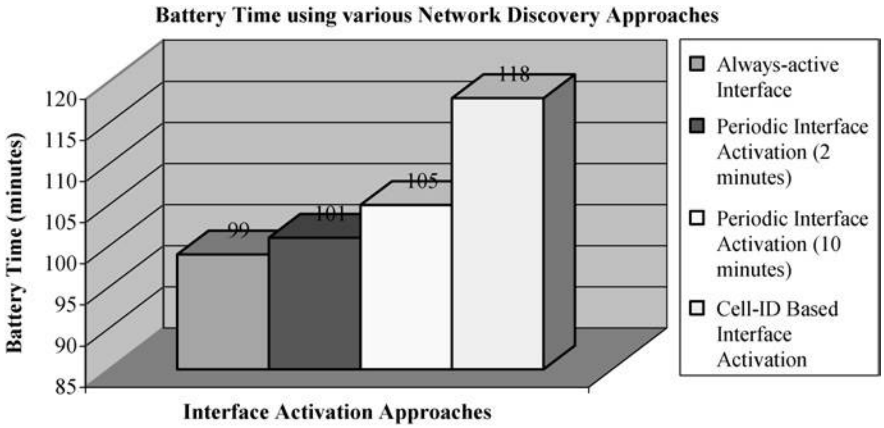

Figure 5.
Total battery time obtained for various network discovery approaches

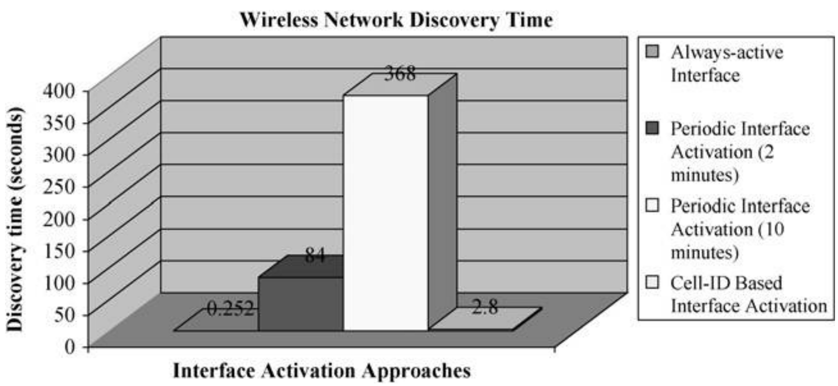

Figure 6.
Wireless network discovery time for various network discovery approaches

approach and approximately 12.38 per cent improvement over the 10-min periodic-activation approach. The reason for the improvement in battery time in the case of the cell-ID approach is because the WLAN interface is activated only when the MN is inside the GPRS cell containing the WLAN hotspot, as opposed to keeping the interfaces continuously activated even when there is no WLAN coverage in the vicinity.

We foresee that using our proposed cell-ID-based interface activation approach, the power savings will further increase in future when mobile devices will be equipped with more than just two wireless interfaces. The reduction in the power consumption will especially be significant for smaller devices such as smart handsets, pocket PCs, etc. These devices have limited battery capacity and require techniques that facilitate power conservation.

Figure 6 shows the WLAN discovery time using the different interface-activation approaches. The discovery time of the wireless network indicates the efficiency of the approach in detecting wireless coverage. It can be observed that the average discovery time our proposed discovery method is slightly higher (2.6 s more) compared with the always-active interface approach and is much lower than the 10-min periodic activation approach (368 s).

4. Conclusions and future work

In future heterogeneous access systems, network detection and handoff decision procedures will play a significant role in achieving efficient mobility solutions. In this paper, we have proposed and implemented a novel scheme to discover wireless networks in a multi-access environment consisting of heterogeneous networking technologies. The effectiveness of the proposed method has been evaluated via experiments done in a real networking testbed. We found that our cell-ID-based network discovery approach is energy-efficient and yields better performance compared to other network discovery approaches. Experimental evaluation and comparison of these approaches performed over a real heterogeneous network testbed showed that our proposed approach obtained 19.1 and 12.4 per cent improvements in battery power consumption over other always-active and periodic-activation methods, respectively.

Our future work will focus on the handoff decision process for vertical handoffs. We are currently developing a mobile middleware that implements automatic network selection based on several factors such as the conditions of accessible networks, requirements of active applications, and preferences of the mobile user. Furthermore, we plan to deploy this mobile middleware over a real network testbed and evaluate it by conducting real-world empirical tests in heterogeneous network environments.

Note

1. T-Mobile, available at: www.t-mobile.com

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