Ubiquitous map-image access through wireless overlay networks

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ABSTRACT

With the availability of various wireless link-layer technologies, such as Bluetooth, WLAN and GPRS, in one wireless device, ubiquitous communications can be realized through managing vertical handoff in the environment of wireless overlay networks. In this paper, we propose a vertical handoff management system based on mobile IPv6, which can automatically manage the multiple network interfaces on the mobile device, and make decisions on network interface selection according to the current situation. Moreover, we apply our proposed vertical handoff management with JPEG-2000 codec to the wireless application of map image access. The developed system is able to provide seamless communications, as well as fast retrieve any interested map region with any block size, in different resolutions and different color representations directly from the compressed bitstream.

Keywords: Vertical handoff, MIPv6, wireless overlay networks, wireless multimedia communications, JPEG-2000, map images

1. INTRODUCTION

Online access to map images is one of the most popular Internet multimedia applications. With the rapidly growing popularity and functionalities of wireless devices, such as laptop, PDA and mobile phone, and the significant increase of data transmission rate in wireless network infrastructure, wireless access to map images becomes possible and many systems have been developed.

Digital map images typically have huge volume in data size. For example, an uncompressed map image consisting of 5000×5000 pixels and 24 bits/pixel is about 75 megabytes. Hence, in a practical wireless map access system, each map image is usually pre-compressed and stored in a server. When a user sends a request to the server with his location information, the server will firstly decompress the entire map image, then find the corresponding sub-image according to the user location, re-encode the sub-image and finally send the compressed bitstream to the user through the bandwidth-limited wireless channels. A drawback of such a wireless map access system is that the entire map image must be decompressed before the sub-image can be fetched out. Obviously, this is not efficient and will result in a slow response to the user's request.

On the other hand, there are various wireless link-layer technologies, such as Bluetooth, WLAN and GPRS, coexist in the market. These technologies are diverse in terms of bandwidth, coverage area, cost and power consumption. It is not uncommon that a mobile device is equipped with multiple wireless network interface cards and can be connected to different wireless networks. Unfortunately, most existing wireless map access systems are only designed for a particular wireless network.

In this paper, we present our developed wireless map access system. In particular, we apply the latest image compression standard, JPEG-2000,[1] for map image compression and retrieval. The developed system is able to fast retrieve any interested map region with any block size, in different resolutions and different color representations directly from the compressed bitstream. Moreover, we also develop an intelligent middleware

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based on mobile IPv6[2] that can automatically manage the multiple network interfaces on the mobile device, and make decisions on network interface selection according to the current situation. This will free mobile users from the constraints of a particular wireless network and give them more flexibility to roam to any place they like.

The motivation for this research is to integrate some of the advanced techniques together and apply them to wireless multimedia applications. Our developed system is not specified for map application and it can be applied to any other wireless image access applications such as satellite weather images.

The paper is organized as follows. Section 2 introduces how we apply JPEG-2000 for map image compression and retrieval. Section 3 presents our proposed vertical handoff management system. Section 4 describes the system integration and finally Section 5 concludes this paper with remarks.

2. MAP IMAGE COMPRESSION AND RETRIEVAL

In this section, first, we will briefly introduce the JPEG-2000 standard and then describe how to apply JPEG-2000 for map image compression and retrieval. Note that, digital maps are usually stored in vector format[3] since it is convenient for zooming. However, vector format map images are not always available to the users and different vector formats are not compatible. Therefore, in this paper, we only consider the raster image format and use JPEG-2000 to compress the map image.

2.1. JPEG-2000 Introduction

JPEG-2000 standard is a new international standard for still image compression, which supports both lossy and lossless compression of single-component (e.g. grayscale) and multi-component (e.g. color) imagery. It is based on wavelet/subband transform. The coding and ordering techniques adopted by JPEG-2000 are based on the concept of Embedded Block Coding with Optimal Truncation (EBCOT).[1] It has numerous features, such as:

- Superior low bit-rate coding performance. This standard offers superior image compression efficiency especially at low bit rates, which is important when storage volume is limited or transmission delay is demanding.
- Highly scalable compression, including resolution scalability, distortion (fidelity) scalability, and spatial scalability. Combined with flexible code stream structure, this allows several kinds of progressive orders in the bitstream.
- Good error resilience. In former image coding schemes such as JPEG, the error resilient capability is very poor. A single bit error may cause the decoding collapse. JPEG-2000 has adopted more advanced error resilient mechanisms to provide robustness.

2.2. Map Image Compression and Retrieval Using JPEG-2000

The requirements for map image compression include

- Compact storage size: Map images are often of huge size, and thus high compression ratio is required in order to minimize the storage size at the map server.
- Fast map region retrieval: Large number of clients could request to access different regions of the map at the same time. To quickly generate the requested image region from the compressed image is necessary in order to reduce the service delay at the server.
- Multiple adaptation: Due to the diversity of wireless devices and users' needs, clients may request a map region with different quality, different resolution, and different color representation (grayscale or color). The compression scheme should allow the server to handle these requests quickly, i.e. without the need of decompression and re-compression.

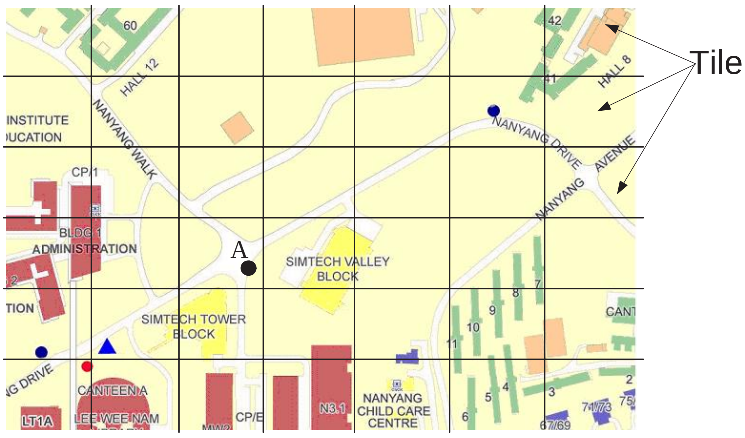

Figure 1. Tiling on a map image.

For fast map region retrieval, we partition a map image into disjoint rectangular regions called tiles, as shown in Fig. 1, and each tile is independently encoded in JPEG-2000. In this way, there is no need to decompress the entire compressed map image when we are only interested in certain tiles.

For obtaining gray scale image, according to JPEG-2000, a RGB image is transformed into YCrCb color space to reduce correlation between color components, and then each of the YCrCb component for every tile, called tile-component, is compressed independently. A gray scale image from the compressed bitstream can be easily obtained by dropping the Cb and Cr components from the JPEG-2000 bitstream since only the Y component contains the luminance information.

For providing resolution scalability, according to JPEG-2000, a tile-component is further split into frequency subbands through wavelet transform. The tree-structured subband decomposition results in several resolution levels, as illustrated in Fig. 2. A lower resolution version of a tile-component can be retrieved from the compressed bitstream without the need of decompression and re-compression.

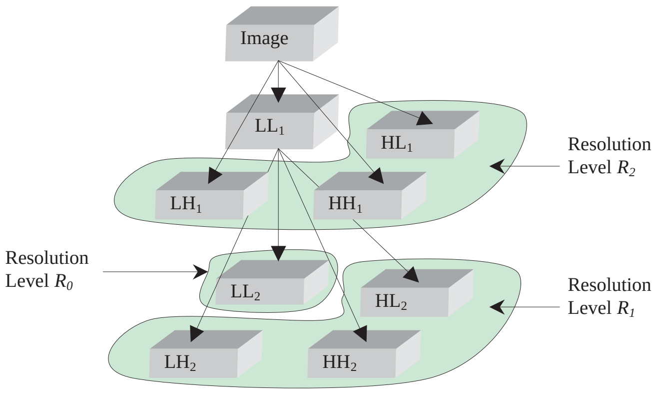

Figure 2. An example of three resolution levels.

For quality scalability, according to JPEG-2000, each subband is partitioned into small blocks called code blocks, and each code block is independently compressed using bit-plane coding. Due to bit-plane coding, each code block bitstream can be naturally divided into many layers, each of which contributes to a certain distortion level. A group of code blocks within a subband composes a precinct. The same quality layer from the code blocks within a precinct is then packetized together and forms a packet, which is the basic unit in JPEG-2000 bitstreams.

Fig. 3 shows the structure of the bitstream for a compressed map image. The bitstream is structured as a main header followed by a sequence of tile-streams and terminated by EOC (end of code stream marker). Each tile-stream consists of a sequence of packets and packets are ordered to provide different scalabilities. A tile-stream is allowed to be broken at any packet boundary. Packets belonging to a particular quality layer, a particular resolution level and a particular tile-component are combined together to form a tile-part starting with a tile-part header. With such a bitstream structure, any required partial data can be quickly retrieved from the original bitstream. All we need to do is to find the corresponding tile-parts, in which the user is interested, and use them to compose a new code stream. In order to quickly locate the interested tile-parts within the bitstream, we use the field of Tile-Part Length Marker (TLM) in the main header to specify the tile-index and tile-part length of every tile-part in the order in which they appear in the compressed bitstream. In this way, a tile-part can be quickly located and extracted from the bitstream by using only the information provided by TLM.

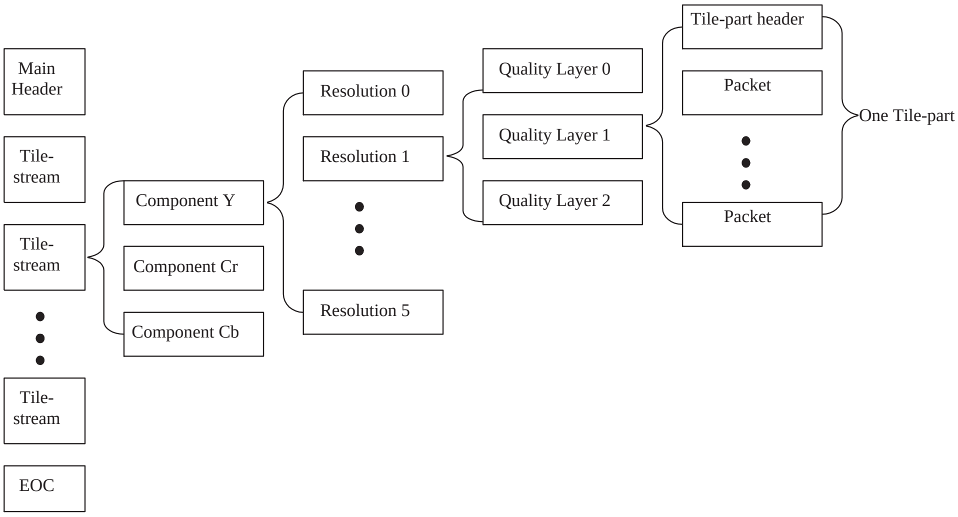

Figure 3. The structure of of a JPEG-2000 bitstream.

3. VERTICAL HANDOFF MANAGEMENT

As mentioned in Section 1, current wireless network technologies, such as GPRS, Bluetooth, and 802.11, vary widely in terms of bandwidth, propagation delay, coverage area, power consumption, etc. Different networks can coexist to compromise the different characteristics of each other, forming a heterogeneous wireless environment, which is also referred to as *Wireless Overlay Network*.[4] It is not uncommon that a mobile device is equipped with more than one wireless network interfaces. Under such a scenario of wireless overlay networks, in order to provide global connectivity, or not to break any ongoing connection, handoff among different types of wireless networks, called vertical handoff, is very important. It is desired to develop an intelligent system that can automatically manage multiple network interfaces on the mobile devices, and make decisions about which interface is the best to use at current situation, when the mobile node should switch to another interface, and etc.

The traditional Internet protocol (IP) does not support vertical handoff. This is because mobile device will have different IP addresses when connected to different wireless networks, which will cause the communication broken. This problem of connection mobility has been solved by Mobile IP[5] for the legacy IPv4 network, and by Mobile IPv6[2] for the future IPv6 network. A typical communication scenario in Mobile IP/IPv6 consists of three major components: *Mobile Node* (MN), *Home Agent* (HA) and *Correspondent Node* (CN, the node that the MN is communicating with). Fig.4 illustrates the scenario under wireless overlay networks.

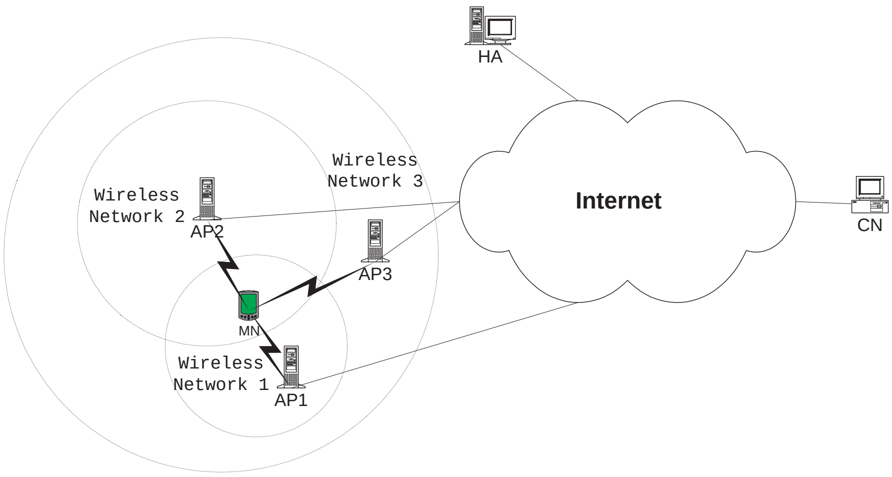

Figure 4. Mobile IP/IPv6 and wireless overlay networks.

Initially, MN uses its *Home Address* for network communication. When MN gets connected to a new network, it obtains a new IP address, which is called the *Care-of Address* (CoA). The MN then sends *Binding Update* (BU) packets to HA and CN to register the new address, so that they can maintain the {Home Address, CoA} *binding* of the MN. After registration is successful, subsequent data packets will use the CoA in the IP header so that they can be routed to the MN's new location, while the Mobile IP/IPv6 stack handles the CoA-to-Home-Address translation before passing the packets to upper layer protocols. From the transport protocols' point of view, the Home Address is still the unique identifier of the MN.

In Mobile IP, data packets have to be routed through HA after MN changes to another network, which behaves as *triangular routing*. In Mobile IPv6, the *route optimization* scheme eliminates the interception of HA so that data goes directly between MN and CN, which makes the communication more efficient. Our research is based on Mobile IPv6, using the implementation from MIPL.[6]

In this section, first, we will introduce some related work on vertical handoff and then we will describe our proposed system in detail.

3.1. Related Work on Vertical Handoff

The concept of vertical handoff is first defined in Ref. 4. The architecture of wireless overlay network is also defined, where different networks with various ranges of coverage areas overlay together to form a heterogeneous wireless network environment. Handoff from a small coverage network (in lower overlay) to a wider coverage network (in higher overlay) is called upward vertical handoff. Downward vertical handoff is in the other way round. Upward handoff is initiated when a certain number of beacons from the current network are not received. Downward handoff is initiated when several beacons are heard from the lower overlay network. In their proposed system, the CoA of MN is a multicast address. A group of base stations (BSs) is selected to listen to the CoA's multicast group. One primary BS is forwarding packets to MN, other listening BSs maintain buffers of MN's packets. During handoff, buffered packets are sent to MN from the listening BSs to reduce packet loss. Several enhancement mechanisms for reducing handoff latency are also proposed in that paper, such as fast beaconing, packet double casting and header double casting. Their system heavily relies on infrastructure, and it needs multicast support, requiring multiple BSs to listen and buffer packets for MN, which increases complexity for practical deployment. In Ref. 7, the authors proposed the P-Handoff protocol to complement vertical handoff. The protocol deals with ad-hoc links in peer-to-peer basis, where no infrastructure is required. HOPOVER[8] is a protocol designed to reduce the gaps in packet flows during handoff. This protocol aims at real-time applications that require resource reservation (e.g., via RSVP). HOPOVER defines a scheme to pre-reserve resource in the new path prior to handoff initiation. Before handoff, MN sends Handoff-Prepare messages to a group of BSs in the target network so that the target BSs can reserve resource and buffer packets for the MN. When handoff is triggered, MN sends a Handoff message to a selected BS, the new BS then starts forwarding packets to MN, and the other BSs release resource for MN. Additional handoff-preparation steps are required in this protocol, but it may fail if handoff is urgent or non-predictable.

There are a number of works that address the problem of when the MN should initiate handoff. In Ref. 9, the authors proposed an algorithm for predicting handoff from IEEE 802.11 WLAN to GPRS. When MN moves to the edge of WLAN, it takes samples of beacon signal strength from access point and compares them with a threshold c. During a predefined dwell time period, if all consecutive samples are below c, then MN initiates handoff to GPRS. Additional criteria are defined for handoff decision to optimize throughput and minimize delay. Ref. 10 proposed a similar algorithm that uses a threshold c to classify weak beacon signals. If a predefined number of consecutive signal strengths are lower than c, handoff will be triggered. Ref. 11 proposed a mobility management system to accomplish seamless handoff between Wireless Wide Area Network (WWAN) and WLAN. Handoff decision relies on Fast Fourier Transform (FFT) based decay detection. When MN is on the edge of WLAN and the signal strength is below a threshold $S1$, the system calculates the FFT fundamental term of the most recent N samples of signal strength $x(n)$. If the imaginary part of the fundamental term is negative, it implies that the signal sequence $x(n)$ is statistically decreasing, and handoff will be performed when signal strength goes below another threshold $S2$. Ref. 12 proposed to use fuzzy logic to make handoff decision based on signal strength. However, the computation complexity is too high for resource limited mobile devices.

3.2. Our Goals

The goals for our vertical handoff management system include

- Seamless: When the MN needs to switch from one network to another, the handoff process should cause no interruption on MN's current sessions, and the applications should not be affected. Seamlessness heavily depends on the handoff latency. Although in certain cases, handoff latency cannot be reduced to zero, the system should minimize the effect to the application as much as possible.
- Transparency: The various link layers should be transparent to the user and applications. Applications need not worry about handling multiple network interfaces. Instead, applications should perceive the system as a single integrated connectivity. All network management operations are hidden from the upper layers, so that no interference from the user and applications are necessary.
- Optimal network selection: The system should choose the best network to satisfy the requirements of active applications as well as to meet the various constraints, such as power consumption, cost, etc. Some networks provide high bandwidth but consume considerable power, while some provide low bandwidth but consume less power. The system should find the balance and make the optimal decision to take advantage of the wireless diversity.
- Generality: The system should not only handle specific types of network interfaces, it should be able to handle any or even future interfaces. The system should be network independent, and operate the same way whatever network cards the user plugs into the MN.

3.3. Proposed Vertical Handoff Management

When various networks are available simultaneously, it is possible to activate multiple interfaces and direct different network flows to different links. This will make the best use of the available bandwidth. However, it will increase the power consumption significantly and also make the system more complicated. In our design, only one network interface is active at a time, while other interfaces are turned off or kept in power saving mode.

A better seamless network service can be provided with cooperation of wireless Access Point (AP). For example, the APs can preserve packet buffers for the MN to reduce the number of lost packets during handoff. However, this requires modifications on the APs, and also imposes additional complexity in system implementation and deployment. Hence, in our design, all management operations are put on the MN alone, without modifications on the APs, so that the system can work under generic network environment.

The vertical handoff management system consists of six functional modules and two informational databases, as shown in Fig. 5. Each component will be described separately in the following subsections.

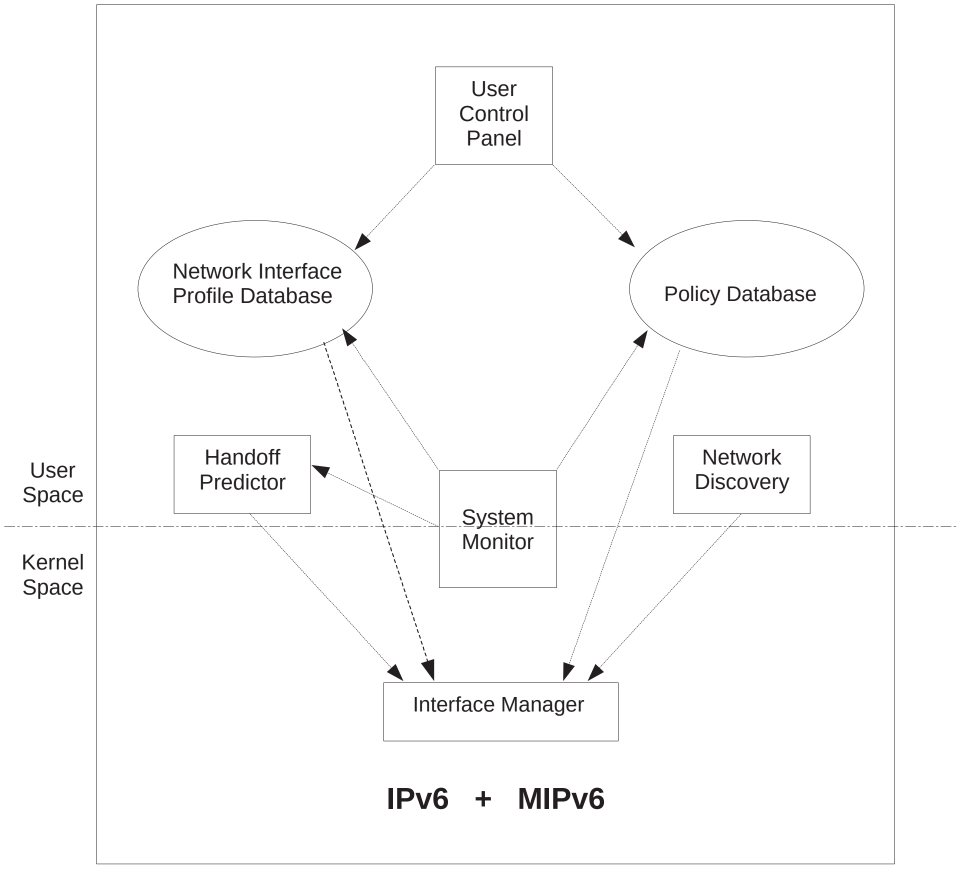

Figure 5. The architecture of the proposed vertical handoff system in Linux environment.

3.3.1. Network Interface Profile Database

Different network interfaces have different characteristics. Each type of interface needs a separate profile, which represents the performance specifications of the interface. A profile consists of several parameters that describe the characteristics of the respective type of interface. These parameters include:

- **Power consumption (P)**: Amount of battery energy that the device consumes when it is activated and operating, normally in terms of mw.
- **Available bandwidth (B)**: Current "idle" bandwidth available on the network that the interface is connected to.
- **Maximum capacity (M)**: Maximum bandwidth that the corresponding network can provide.
- **Signal strength (S)**: Radio signal strength that the device receives from the network. This parameter only applies for wireless interfaces.
- **Packet lost ratio (L)**: Percentage of lost packets on the networks. This provides useful information for handoff prediction.
- **Usage charge (C)**: Some wireless networks are free for use; some impose usage charge based on the time of connection or the amount of data traffic. This parameter specifies the price of using a network per unit of time or data volume.

Among these parameters, some are static information, which do not change with time, for example, the power consumption, maximum capacity and usage charge. Some are dynamic components, which will be updated at runtime, for example, the available bandwidth and signal strength.

The network interface profiles provide essential information for network selection decision and handoff prediction.

3.3.2. Policy Database

In the proposed system, interface selection is based on a cost-function policy model. The cost (not the usage charge) of using a network n at a certain time can be specified by a function as:

$$f(n) = w_b \times \frac{1}{B_n} + w_p \times P_n + w_c \times C_n \tag{1}$$

The computed cost is used for network interface selection (see Section 3.3.7). Parameters B_n, P_n and C_n are retrieved from the Network Interface Profile Database. The coefficients w_b, w_p and w_c are the weights, i.e. the degree of importance, associated with the respective parameters. These weights are stored in the Policy Database. These coefficients can be specified by the user, or default values are applied if the user leaves them blank. Some coefficients are dynamically updated at runtime, for example, w_p, which may increase as the battery energy level is going low.

3.3.3. User Control Panel

This is a simple user-space tool for the user to specify various parameters in Network Interface Profile Database and Policy Database. For example, the user can specify the usage charge (C) in the profile database, and w_b, w_p, w_c in policy database. This configuration is a one-time operation, so that user involvement is minimal. After the initial specification, interface management is automatic and no user interaction is necessary.

3.3.4. System Monitor

This module measures the system performance in various aspects. It consists of the following sub-modules:

- **Power monitor**: It monitors the battery power level of the MN. Power consumption is a critical issue for mobile devices. When the power is running low, the network selection policy may need adjustment. This adjustment can be reflected by changing w_p in the policy database based on the current battery status. When battery energy is running low, w_p will be increased so that the power consumption of a network interface has a greater contribution to its cost function, and thus becomes the dominant component that determines the network selection.
- **Network traffic monitor**: This sub-module monitors the data rate (R) of network traffic used by the running applications. This value can be used to dynamically update the parameter w_b in the policy database. When the data rate required by the applications is high, w_b will be increased so that the bandwidth of the network becomes the major consideration when selecting network interface.
- **Available bandwidth measurement**: There are various methods of measuring the available bandwidth of a network. Some requires probing messages to be sent so that bandwidth can be estimated based on round-trip time and inter-arrival variants. However, these methods increase the network load, which is not desirable in some low-bandwidth links. The MAC layer sensing mechanism in Ref. 11 estimates bandwidth based on link layer information, and no probing packets are injected to the network. That scheme can be employed in our system implementation. The bandwidth measurement result is then used to update parameter B in the profile database.

3.3.5. Network Discovery

This module discovers the available networks around the MN. The module periodically turns on the idle network devices, searches for wireless APs and requests for the router advertisements. Network discovery is also performed when a new network interface is plugged into the MN. If new networks are detected, the Interface Manager module will be informed to make a handoff decision. If handoff is desired, the preferred interface will be used as the current active interface, while the previous interface is shutdown after handoff. If no handoff is necessary, the non-current interfaces are turned off, while the collected network information (such as the address of APs and routers) is stored in database for later use, in case handoff is required in the future.

3.3.6. Handoff Predictor

Handoff prediction is especially important when the MN is moving. If the MN does not initiate handoff before it moves out of the coverage area of the currently connected network, the connection will be interrupted. The Handoff Predictor module is to detect the tendency of connection lost in the current network, and inform the Interface Manager module to perform handoff in advance. Such a tendency can be detected based on various hints from the current network status. For example, handoff will be triggered if current signal strength (S) is continuously dropping, or the packet lost ratio (L) exceeds a threshold value.

3.3.7. Interface Manager

This is the central module for making decision on interface selection, and performing handoff operation. Decision is mainly based on the parameters retrieved from Network Interface Profile database and Policy database. The cost function (Eq. 1) previously described is used to calculate the cost of using a network n. The lower the cost function value $f(n)$, the better network n is. If the cost value of a new network n is lower than the cost value of current network by a percentage threshold (say, 5%), the system will handoff to network n. Handoff can also be triggered by the Handoff Predictor module. When a handoff command is received from the predictor module, the Interface Manager module should perform handoff even if the current network has the lowest cost value, since the current network may become unreliable soon.

4. SYSTEM IMPLEMENTATION

We develop the vertical handoff management system based on MIPL v1.0 (conforming to Mobile IPv6 draft 24) for Linux kernel 2.4.22. In system implementation, the MIPL module is modified to allow more control on interface selection and handoff management. The Interface Manager is implemented as a Linux kernel module so that it can interface with the kernel space functions exported by MIPL module. The Network Interface Profile Database and Policy Database are stored as text files for simplicity. The Interface Manager kernel module also acts as a driver for a character device so that the user-space tool can pass the information in the databases to the kernel space via *ioctl* mechanism supported by Linux. The Network Discovery component is currently implemented as a Linux shell script so that it can manage network interface status and events using the user space commands provided by various Linux utilities.

We have conducted some experiments to test our developed vertical handoff system under the wireless overlay networks of Bluetooth, IEEE 802.11b and GPRS. We found that the system performs vertical handoff successfully without breaking existing TCP connections. However, when performing handoff from a fast network to a slow network, the receiver experiences a short latency in packet reception. When performing handoff from a slow network to a fast network, the receiver experiences out-of-sequence packet reception. Improved schemes are under investigation.

The application of map access is developed under Microsoft .Net framework. This is because the .Net framework provides numerous developing tools and libraries, which greatly simply the application development. In particular, we implement a client-server wireless map access system. We use a common PC as the map server and PDAs (HP iPAQ h3970) as wireless clients. The map server has the protocol stack of Application/TCP/MIPv6. The application layer in the map server has five modules: map image compression module, database server, client management module, communication module and retrieval module. The map image compression module has been described in Section 2. The database server stores all the map images, compressed by JPEG-2000, and the corresponding various information for different locations such as (X, Y) coordinates, unique identification numbers, addresses, categories and etc. The database is implemented using Microsoft SQL Server 2000. The client manager is to manage multiple concurrent PDA client sessions so that a single instance of the map server service program can serve multiple instances of PDA clients simultaneously. The retrieval module is to find the results of users' requests from the database, format the results into XML files and pass them to the communication module. The communication module is actually the interface between PDA clients and the retrieval module. Its tasks include interpreting the requests from PDA clients, send the interpreted requests to the retrieval module, obtain the results from the retrieval module and send back to PDA clients.

A PDA client is supposed to have the protocol stack of Applicaiton/TCP/MIPv6 (Integrated with proposed vertical handoff management). In the application layer, there are five modules: communication module, configuration module, graphical user interface (GUI), search module, bookmark module. The communication module is to handle the communications between the PDA client and the map server. The configuration module is to manage the individual user configurations and save the data into the memory. The GUI is to provide a user-friendly, hassle-free experience of accessing the online digital maps for PDA users. The search module is to handle the requests of location search. The bookmark module is to save some popular map images so that they can be reloaded later and there is no need to request from the server again. The developed GUI for PDA clients is shown in Fig. 6.

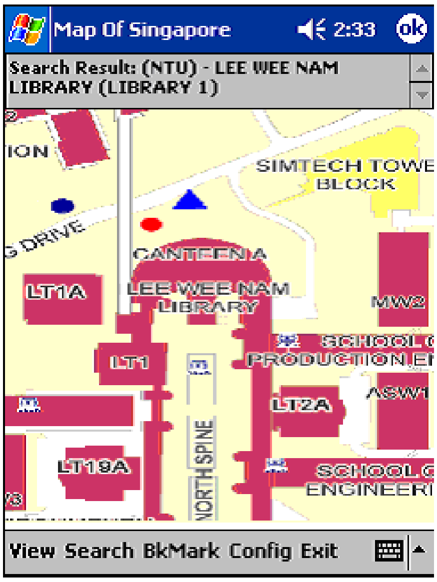

Figure 6. The GUI of the PDA client for wireless map access.

We would like to point out that due to the compatible problem between Linux and Window operating systems, we actually implement the vertical handoff system and the map access application in two different machines, which are connected together through high speed link.

5. REMARKS

In this paper, we have presented our developed wireless map image access system, which provides the functions of fast image access and ubiquitous communications. We have introduced the two major components, image compression and retrieval using JPEG-2000 and vertical handoff management, in detail. The prototype system has satisfied the basic requirements. In the future, we will further refine the system and extend it to other multimedia applications.

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