A Mobile-IP Based Mobility System for Wireless Metropolitan Area Networks

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Abstract

The real potential of broadband wireless networks lies with mobility. A hot debate is centered on building metropolitan area networks using WiMAX technology based on the IEEE 802.16 standards. Good mobility management schemes enable it to become the disruptive solution that fulfills the promises of ubiquitous computing with broadband access everywhere that was left unsatisfiable with the Wi-Fi and 3G cellular solutions. The wide area coverage and co-existence of multiple wireless access technologies pose a challenge to mobility in the metropolitan network. Complications arise from the hierarchical structure of the network and the seamless handoff requirement to maintain steady streaming media coverage without interruption. It also stems from the lack of cellular type infrastructure to support fast moving users. We study the issues associated with providing mobility in a wireless metropolitan network. We propose a mobility management scheme based on the integration of hierarchical micro-mobility, fast handoff, and vertical handoff. It is demonstrated that this scheme can perform well under traffic loads. The network is subjected to an application that provides public health informatics services to the metropolitan area. These experimental results can provide suggestion on how to construct the next generation wireless networks.

Keywords

WiMAX, Mobile-IP, Micro-mobility, Vertical Handoff, Fast Handoff, Metropolitan Area Network, IEEE802.16e, Public Health Network.

1. Introduction

The success of Wi-Fi network with IEEE 802.11x technology makes it possible to access broadband anywhere with low cost. However, WiFi suffers from two drawbacks: limited coverage and restricted scalability [6]. Existing propriety solutions to extend its coverage or interconnection are not scalable. Cellular based 3G network provide extended coverage, however, limitations on bandwidth and high costs on infrastructure equipments prohibit its growth. The introduction of broadband wireless WiMAX solution based on IEEE 802.16 technology makes it possible a standard based low cost solution for the last mile [7]. In particular, with its coverage of 30 miles and non line of sight technology based on OFDM, it will be able to construct a metropolitan network where broadband access from anywhere within the area is possible. The current version is based on IEEE 802.16a that specifies a fixed wireless environment. It is expected that within the next few years, we will observe an explosive growth in this area. It will be based on the IEEE 802.16e standard [8]. It extends the 802.16a specification with the capability to support mobile users in the region. Mobility is specified as a separated layer above the MAC layer. It has become the center of discussion as new findings in this area have the potential to influence the standard to come. With the inclusion of mobility, WiMAX could become the ultimate solution that provides a low latency, high bandwidth, and wide area connectivity to mobile users which is long sought after by the industry.

A metropolitan network will cover an area of up to 30 miles. Current study shows that the effective range for broadband coverage under IEEE802.16a is 4 to 5 miles. The eventual network might be composed of many base stations connected together to provide broadband connectivity to hundreds of stationary and mobile users. The intended applications of such a network are real-time media streaming and VOIP. The network must guarantee that the continuous services will not be disrupted while a mobile user switched its connectivity from one station to another due to signal fading or change of provider. The effectiveness of mobility depends on whether a moving node can maintain continuous connectivity with the base station without packet loss or delay during handoff. One characteristic is the handoff distance which specifies the minimum coverage between adjacent base stations for a moving node at maximum specified speed [9]. For example, to support users moving at 180km/hr with one-way packet delay on internet of 115ms, the handoff distance is more than 57 meters. Apparently, it is beyond the capability of Wi-Fi networks which can cover only a few meters. Another characteristic is the message delay due to handoff. It is reported that it usually takes up to 400ms of delay under current handoff mechanism. The WiMAX is required to support low latency of less than 100 ms and zero packet loss during handoffs at mobile speed of 120 km/hr or higher [1]. It is mandatory to find a better solution to fulfill these requirements.

Due to the proliferation of existing wireless technologies, a metropolitan network will consist of various wireless accessing technologies with different link speed and mobility support. It might include Wi-Fi for short distance WLAN, UMTS and CDMA2000 for broadband on 3G cellular networks, Bluetooth for personal area coverage, and wireless sensors [4]. It is bound to be a multimode environment. In case WiMAX becomes the major broadband service provider to the metropolitan area, users should be able to easily roaming among different technologies without interruption. Its success depends on the integration of mechanisms to deal with handoffs. A link layer handoff occurs when a mobile node's link layer connectivity is changed from one access point to another. A network layer handoff occurs when the user changes the IP address and connects to a new router. Existing solutions centered on the improvements to the Mobile-IP concept. These include hierarchical micro-mobility mechanism with low registration time, fast handoff mechanism that provides low latency over address resolution during handoff, and vertical handoff mechanism to provide a unified foreign agent service across technology boundaries. Full mobility require support for low packet loss and low latency make before break handoffs and idle mode with paging for extended low-power operation. We propose a unified solution to meet the requirements for WiMAX networks.

2. Related work

Micro-mobility solutions are considered to be effective mechanisms to implement fast and seamless handoff for intra-domain mobility. In particular, three main proposals with their strengths are discussed in detail [2, 14]. The hierarchical MIP scheme is one of the favorites among them. A seamless handoff mechanism that combines hierarchical micro-mobility and fast handoff mechanism is presented in [5]. It mainly considers a large indoor environment with 802.11 access technology. It shows that it is possible to optimize the handoff performance of Mobile-IP under the combined mechanism. Two approaches to integrate 802.11 WLAN with 3G cellular networks are presented in [3]. The loosely coupled approach is considered to be the preferred one and is adopted by this paper. The design of gateway has a strong influence on our design as well. Due to the proliferation of cellular networks and wireless LANs, it is well recognized the demand of co-existence of multiple wireless access technologies. The notion of vertical handoff was created for connection among those technologies [13]. The required functionalities between WLAN and cellular networks have been discussed in [12]. A metropolitan network consists of multiple technologies where various vertical handoff mechanisms are an integral part of such heterogeneous networks.

3. Architecture of WiMAX networks

A typical metropolitan network consists of one (or more) Base Station (BS) that is connected to the internet infrastructure and a group of Mobile Subscriber Stations (MSS). A base station can have several Base Station Sectors (BSS) each covers a single sector. Figure 1 shows the architecture of a WiMAX network.

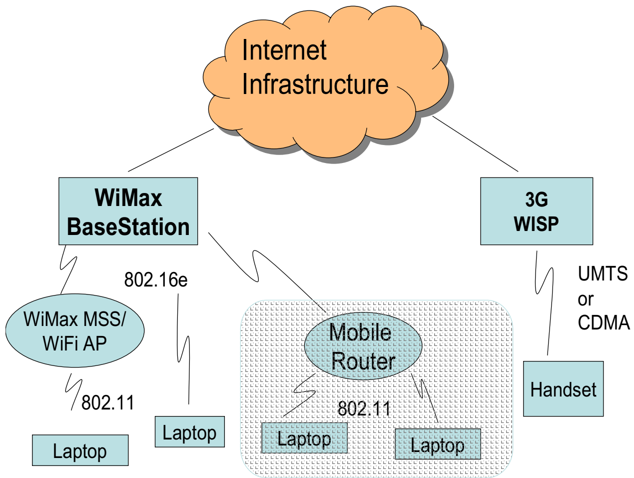

Figure 1. WiMax Network Architecture

Current standard under IEEE802.16a specifies the physical (PHY) and medium access layers (MAC) of the protocol. A lot of installations are underway that follows this standard to provide fixed wireless services as a replacement of wire-line broadband access technologies like ADSL or cable modem, especially in an area that lacks the infrastructure. A major revision under IEEE802.16e specifies the mobility operation of the metropolitan network. It includes a Mobility Agent (MA) layer on top of the MAC layer which allows a moving MSS to migrate from current Serving Base Station to a Target Base Station upon signal fading or changing of attached access points. The Mobility Agent acts as the termination points of the tunnel carrying data from the home network of the MSS, which includes de-capsulation of incoming data units and forwarding of data to and from the MSS. An MSS migrates from the air-interface provided by serving BS to the target BS upon receiving handoff indication from the MSS. The MSS will terminate the service with the serving BS and the associated context should be discarded or forwarded. Upon re-entry in target BS, the service flows belonging to the MSS are re-associated with the newly established connections. The handoff procedure includes the following major functions. The BS broadcasts the advertisements and keeps scanning for replies. The MSS initiates the handoff procedure and exchanges messages with BSs. It monitors the signal strengths and selects the target BS. In order to save energy, it will also alternate between sleeping and awakening mode [8].

4. Mobile-IP based handoff

There is a series of proposals over the years about different flavors of mobility management. Most of them are proposal to IETF standard committee following the Mobile-IP concept. In the Internet environment, it depends on the topological information embedded in the IP address to deliver the data to the correct end-point. Mobile-IP overcomes this restriction by providing a level of indirection at the network layer. Mobile-IP allows a mobile node to move from one place to another without changing its home address. Packets may be routed to the mobile node using its home address regardless of its current point of attachment to the internet. While away from home, a mobile node registers one of its Care-of-Addresses (CoA) with a router on its home network, requesting this router to function as the Home Agent (HA) for the mobile node. The home agent intercepts any packets destined to the mobile node and tunnels them to the mobile node's current location. The handoff latency in a Mobile-IP environment includes the time taken to register the mobile node's location at the home agent and the time taken to configure a new care-of address.

In case of WiMax, We can implement the mobility management system following the Mobile-IP proposal where the BS will function similar to Foreign Agent of Mobile-IP in "foreign agent care-of -address" mode. While Mobile-IP is recognized as a good solution for mobility in general, it suffers from several drawbacks in the metropolitan network. First, Mobile-IP is a network layer solution. It does not solve the problem related with link layer handoffs. Secondly, messages sent to the MSS in the visiting region will be tunneled through the home agent and long delay could be introduced due to the tunneling. Thirdly, it does not deal with handoffs due to discrepancies in the heterogeneous network supporting various technologies. In order to overcome these difficulties, we propose a unified mobility system for WiMAX

Figure 2 shows the various components of the unified mobility system.

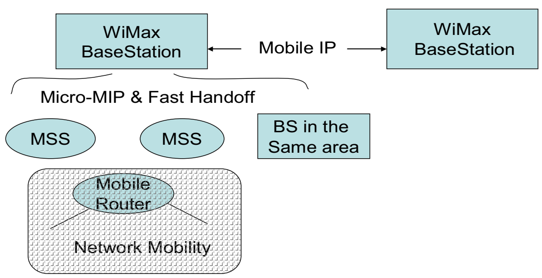

Figure 2. Hierarchical Mobility Management

4.1. Hierarchical micro-mobility

A metropolitan area network is intended to cover an area of 30 miles in radius. It will also accommodate various wireless technologies for accessing to the internet. The complexity of the network calls for a hierarchical mobility management scheme. Two kinds of mobility can be defined according to the mobile user's movement pattern. In case the mobile user move between Base Stations between different domains, a mobility scheme based on Mobile-IP is utilized. It provides a global mobility solution with full flexibility. In the case that the mobile user moves inside a domain, or inside a metropolitan network, a micro-mobility scheme is utilized. There have been a lot of proposals to reduce the handoff latency of mobile-IP. Hierarchical Mobile-IP (HMIP) is an IETF draft intended to reduce the registration time by using a hierarchical network management structure. It introduces a new entity called the mobility anchor point (MAP). The mobile node registers the MAP's CoA with its home agent. When the mobile node moves locally, it only needs to register its new address with its MAP. Nothing is to be communicated with the home agent.

4.2. Vertical handoff

Mobile-IP provides a mobility solution to mobile users. The handoff in Mobile-IP is horizontal handoff because the link layer technology remains the same and only the point of attachment changes. It is assumed that the link layer handoff is provided in the hardware layer as in the case of the 802.11 specification. For Mobile-IP to work for the metropolitan network, it should also provide a vertical handoff mechanism which covers handoff over different wireless technologies. Within a metropolitan network, a mobile user could switch between different access technologies due to coverage and provider changes, like GPRS, UMTS, 802.11, and 802.16. Each technology provides different support of mobility. The handoff mechanism must be provided in software consistently between the base station and mobile user. It will modify the Mobile-IP implementation to handle the vertical handoff, for example, to provide the foreign agent function for technologies that does not have this kind of support. It will monitor the signaling strength to decide the proper technology and time to switch over. It will also compensate the differences in link speed, quality of services, and reliability among the various technologies.

4.3. Fast handoff

The hierarchical micro-mobility reduces the home network registration time. It is observed that it still takes 300 to 400 milliseconds of delay time during handoff. The fast handoff scheme intends to reduce the handoff delay by minimize the address resolution delay time. It achieves this by pre-configuration of the care-of-address in the visiting network. This is done by letting the MSS to broadcast its knowledge to the potential target BSs so that they can decide the context of the car-of-address before the handoff is initiated, like the network prefix, configurations, etc

4.4. Network mobility

Besides individual mobile nodes, it is expected that a group of nodes will move altogether, which forms a Mobile network. Examples include cases where a person can own more than one mobile device, say a mobile phone, a laptop, and a PDA. These devices become a Personal Area Network (PAN) which moves with the user. Another example is the access points deployed on a public transportation, like ships, buses, and aircrafts. Devices attached to the access points forms a mobile network. The protocols like Mobile-IPv4 (MIP) and Mobile-IPv6 (MIPv6) are hierarchical based for supporting seamless connectivity of mobile hosts. They will be triggered upon link layer handoffs, which may not be sent by all nodes moving as part of a mobile network. IETF working group Network Mobility (NEMO) is developing a basic protocol [11] that ensures seamless mobility to the mobile network nodes. It introduce a special entity called the Mobile Router (MR) which acts as a gateway, all devices within the network can achieve global connectivity irrespective of their capability. The MR would act as the foreign agent (FA) and provide a foreign agent care-of address to the mobile nodes. Packets addressed to the mobile nodes within the mobile network go through the MR's Home Agent as well as the mobile node's Home Agent.

5. The prototype mobility system

5.1. Software modules

It follows the Hierarchical Mobile-IP designs to include the Mobility Anchor Point (MAP) node as the separation between macro and micro mobility. It can be collocated as the Base Station of the network. It can be at any level of the network if the Base Stations are arranged in a hierarchy. Handoff between the MAP follows the standard macro MIPv6 protocol and handoff within the MAP follow the unified micro-mobility and fast handoff protocol. There are six major components in the mobility manager: a Foreign agent module that hosts the MAP and holds the care-of-addresses, a Tunneling module that capsulate and de-capsulate the TCP messages, a Link Monitor module that detects signal strengths and decide on which target BS to switch to, a QOS module that governs the quality of the channels, a Security module to detect intruders and encrypt messages over the link, and a Billing module that does customer accounting. On the MSS side, it contains a mobile router that acts as the foreign agent for the subnet under its control.

5.2. Handoff procedure

Figure 3 show a typical message sequence during handoff on the unified mobility system.

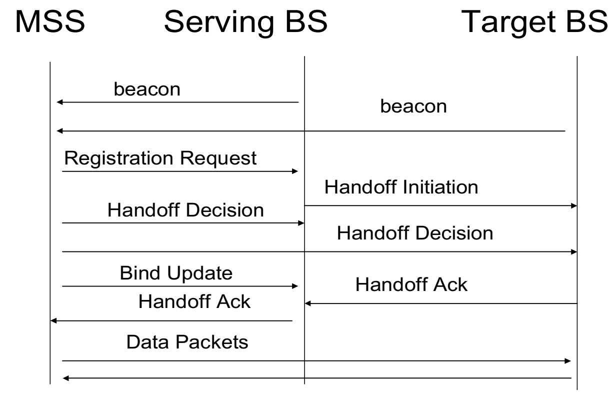

Figure 3. Handoff Procedure

The base stations will constantly broadcast their beacon advertisements to the MSSs. The MSS initiates a handoff by sending the Registration Request message to the serving BS. Upon receiving the message, the serving BS will send a Handoff Initiation message with routing and addressing data of the MSS to the target BS indicating its intention to handoff. There could be more than one candidate target BS at a time, in which case the serving BS will contact them one at a time. After the MSS decides which target BS to attach to, it will send the Handoff Decision message to the serving BS and the target BS to inform them his decision. It will also carry the pre-fix addresses for fast handoff. Subsequently, the MSS sends the serving BS the Bind Update as the last message before the handoff is executed. The target BS sends the Handoff Acknowledgement message to the serving BS when it is ready to take over. The serving BS will pass it to the MSS to complete the handoff procedure. The MSS starts exchanging messages with the target BS after receiving the Handoff Acknowledgement message.

5.3. Metropolitan medical network

Public health is identified as one of the four major applications of metropolitan networks.

For a trial, we are implementing the Metropolitan Medical Network (MMN) based on WiMAX. It is a network between health partners, hospitals, clinical laboratories and medical researchers. Its primary goal is to provide real time sharing of clinical and laboratory data amongst medical hospitals and other health entities. The network will be connected to the Indiana Network for Patient Care (INPC), which is one of the few operational community-wide public health reporting systems in the U.S. [10]. The system currently includes data from 11 hospitals in five health systems. The data received from all participating hospitals includes demographics, laboratory data, chief complaint, coded diagnoses, coded procedures from emergency department, and inpatient encounter data. These data are coded in the XML based HL7 V3 message standard. It also includes medical images from CT scan or MRI in DICOM format. This type of network is very advantageous for both patients and the health providers. A mobile patient can search for a nearby service in the area that accurately matches his need. The network is expected to be extended to cover ambulances and emergency vehicles upon the deployment of mobile units based on 802.16e. Emergency physicians can obtain in real time the patient data and medical images over the network when the patient is in transit on the ambulance. Figure 4 shows the environment setup for the trial.

6. Performance Analysis

Mobile-IP based mobility management system is one of the solutions proposed to IEEE 802.16e standard committee. Mobility mechanisms based on other technologies have also been proposed. For instance, the ones based on MPLS techniques have been discussed lately. The ones based on the WiBro technology have also been proposed. It is still in the early stage to discuss which of them will be selected in the final version of the standard. It is suffice to say that the final decision really depends on their performance under various traffic conditions. The unified mobility manager is an example of the cross layer management system. Its effectiveness verses the traditional link layer or network layer mobility systems are under study. We have been using the ns-2 simulator to study its performance. It is based on a fixed network topology and a variation on the radius of the signal. We have obtained preliminary results on effective handoff time during vertical handoff and horizontal handoff. Various flavors of the TCP protocol, like TCP Tahoe is examined for their impact on the handoff time. It is shown that overall handoff duration of 200 ms after the initiation from MMS is achievable. An overhead of 15% on packet loss due to sudden change in the access point is observed. It is worthwhile to study methods to reduce the overheads and improve the handoff duration and packet loss. The following is the simulation result.

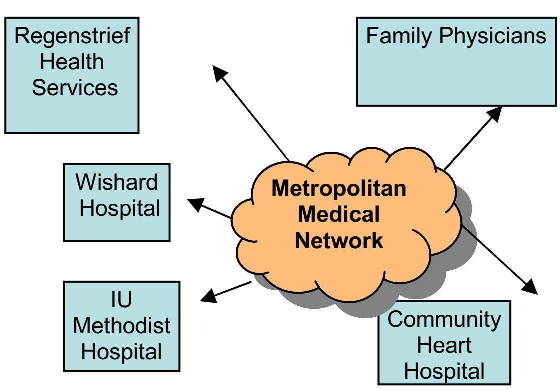

Figure 4. A Metropolitan Medical Network

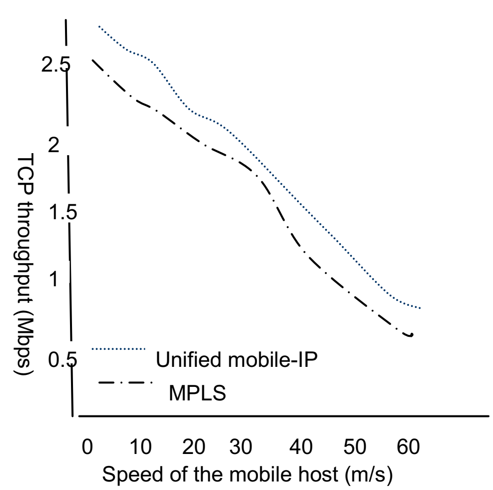

Figure 5. Mobile-IP vs. MPLS throughputs

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7. Conclusion

It presents as a challenge to introduce mobility into wireless metropolitan networks that demands low latency and fast handoff among heterogeneous technologies. Good mobility management scheme enables WiMAX to become the solution that fulfills the promises of ubiquitous broadband access. The proposed solution combines hierarchical micro-mobility with fast handoff and vertical handoff mechanisms to reduce the overheads associated with fast moving users. The effectiveness of WiMAX will be tested when the concept of wireless city becomes popular and the usage of broadband handheld devices becomes the mainstream of daily life.

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