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Media Independent Handover Platform with Context-Awareness Extension in Heterogeneous Wireless Networks

by

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CERTIFICATE OF ORIGINALITY

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Miao Xiong (Name of Student)

Abstract

In the past decade, we have witnessed the advance of technologies in wireless communication and mobile computing. Wireless access technologies including Wi-Fi, 3G, and Worldwide Interoperability for Microwave Access (WiMAX) enable mobile users to get wide access to the Internet. However, due to the limited coverage of wireless networks, the merits and shortcomings of different wireless technologies, mobile terminals are often equipped with more than one type of wireless access interfaces. Such a terminal is called multi-mode terminal. Multi-mode terminals and heterogeneous wireless networks pose new challenges to seamless communication, in particular, the handover management. The IEEE 802.21 is a standard that defines the Media Independent Handover (MIH) framework to support handover management in a heterogeneous wireless network environment. MIH consists of three services: MIH Event Service (MES), MIH Information Service (MIS), and MIH Command Service (MCS), which together serve to facilitate smart handover, providing functions for handover discovery, handover trigger and handover decision.

Most existing works on MIH make use of MIH as a tool to provide support to high level protocols such as Mobile IP (MIP), Session Initiation Protocol (SIP) or to assist handover management in the aspect of handover trigger or handover discovery. Some works introduce new parameters into the MIH functions to improve MIH services by providing additional information, such as the neighbour map. Since MIH framework provides services for mobile users, therefore, the quality of MIH services is finally evaluated by its users. In the wireless mobile environment, different mobile users have different mobility patterns, suffering different environmental interference, and have various requirements on the cost, efficiency or accuracy. This

kind of difference is distinct according to different users. User context represents the differences in the wireless mobile environment. However, unified MIH services are not aware of different user context, and thus cannot provide specified services to improve user experience. To address this shortcoming, we extend the MIH platform with context-awareness (MIHCA), and design context-aware applications for MIH services to show the improvement of service quality.

In the first part of this thesis, we present our MIH platform with context-awareness extension. Because the MIH framework involves several technology interfaces, having a large number of functions, and modifications are required both on the mobile terminals and remote networks. It is hard to carry out all the standard MIH functions in the short study time. So we name our MIH platform with basic functions as customized media independent handover framework (CMIH). We represent the work flow, service figures for CMIH services, and describe the context provider, context processor, and context-aware entity for the context-awareness module.

In the second part of this thesis, we provide a context-aware prediction for the "MIH link going down" event. It is a handover trigger in handover management. The "MIH link going down" event is defined in the MES. Unlike existing works, which focus on signal strength threshold, our proposed mechanism can guarantee user required handover preparation time. A timely handover trigger can be generated according to our test results.

In the third part of this thesis, we present a clustering based context-aware mechanism for predicting stability of wireless links in our framework. This context-aware prediction belongs to the MIS. Due to the limited coverage of a wireless

network, wireless interference, and user mobility, wireless links break down frequently. It causes service interruption, network overhead and latency. Therefore, a stable link is preferred by mobile users, and a criterion that can judge the link is needed. Unlike existing works, which require prior knowledge on network environment and user mobility pattern, our proposed mechanism can automatically be aware of environmental interference, user location, user handover policy, and user mobility. A K-mean clustering method is adopted to process the classification of user context, and then the link stability is predicted with conditional probability according to different classifications. Experimental results show that our proposed context-aware prediction on link stability can well guide the mobile user to obtain a stable wireless link.

Publications

Conference Papers

Miao Xiong, Jiannong Cao, and Jun Zhang, Context-Aware Mechanism for IEEE 802.21 Media Independent Handover, ICCCN 2011 Workshop on Wireless Mesh and Ad Hoc Networks.

Jiannong Cao, Chisheng Zhang, Jun Zhang, Yueming Deng, Xin Xiao, **Miao Xiong**, Jie Zhou, Yang Zou, Gang Yao, Wei Feng, Liang Yang and Yao Yu ,SHAWK: Platform for Secure Integration of Heterogeneous Advanced Wireless Networks, FINA-2012 .

Miao Xiong, Jiannong Cao, “A Clustering-based Context-Aware Mechanism for IEEE 802.21 Media Independent Handover”, Wireless Communications and Networking Conference (WCNC), 2013 IEEE

Patent

Miao Xiong, Jiannong Cao, Yonggang Tian, “Prediction on user handover preparation time in wireless networks”, submitted to HuaWei.

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List of Abbreviations

3GPP: 3rd Generation Partnership Project

AHP: Analytic Hierarchy Process

AP: Access Point

BS: Base Station

CMIH: Customize Media Independent Handover

HPE: Handover Preparation Time Estimation

IEEE: The Institute of Electrical and Electronics Engineers

LGD: Link Going Down

MCS: MIH Command Service

MES: MIH Event Service

MIH: Media Independent Handover

MIHCA: MIH with Context-Awareness

MIHF: MIH Function

MIHS: Media Independent Handover

MIS: MIH Information Service

MN: Mobile Node

QoS: Quality of Services

RSSI: Received Signal Strength Indicator

SAP: Service Access Point

WIMAX: Worldwide Interoperability for Microwave Access

Chapter 1. Introduction

The main objective of this study is to pursuing the high quality of Media Independent Handover (MIH) services. MIH is defined in the IEEE 802.21 standard [4]. With respect to the topic of context-awareness extension to MIH platform, we mainly discuss context-awareness extension and context-aware applications for MIH services. This chapter provides an introduction to our research, discussing the characteristics of heterogeneous wireless networks and issues in MIH framework. The discussion serves as the motivation of our works. We also summarize the contributions and outline the organization of the thesis.

1.1. Motivation

In the past decade, many wireless technologies are emerged for providing pervasive access to wireless networks, for instance, some well-known term Wi-Fi, 3G, WIMAX, Bluetooth, and so forth. The number of multi-media wireless access technologies enabled terminal increase sharply. It also poses new challenges in this kind of multi-media handovers in heterogeneous wireless networks. In the year 2009, when we began our study, the IEEE 802.21 standard [4] is just published. This standard concerns the challenges for multi-media technologies. It proposed a Media Independent Handover (MIH) framework to provide supports for handover discovery, handover trigger, and handover decision in the heterogeneous wireless networks.

Existing works on MIH mainly focus on two aspects. First, they take MIH as a tool to provide supports to high level services such as Mobile IP (MIP), Session Initiation Protocol (SIP) or assist handover management. Second, they add new MIH parameters into the MIH framework to meet their requirements, which is related to a specified application. As for the MIH services, little work has been done to improve its service quality. Since MIH framework works as services, so the quality of services can be finally evaluated by user experiences. However, unified MIH services are not aware of different user context, and thus cannot provide specified services to improve user experience. To overcome this shortcoming, we come to the idea of context-awareness.

Context-awareness has been widely applied in many areas such as mobile computing, pervasive computing, and smart environments. Researchers mainly focus on three aspects, including context application, context acquisition, and context modelling. It is not feasible to directly apply existing works in other areas to the MIH platform, due to the following issues. Primarily, different context-aware applications are designed with specific contexts, react behaviours, and system environment. So far, there is no context-aware application for MIH services. Second, works on context acquisition have their corresponding frameworks to support information exchange. In our case, it incurs a huge cost to add a new framework in heterogeneous wireless networks. Modifications are required in both the user terminals and networks. Heterogeneous wireless networks have multi networks with different technologies, which increase the cost. In our work, the MIH framework already exists as a standard, and it provides the information exchange mechanism in MIH Information Service (MIS). Besides, Extensible Mark-up Language (XML) is supported in MIH, which provide a method to describe and store data or context. Therefore, we propose the MIH platform with Context-awareness extension (MIHCA), and design context-aware applications for MIH services to show the improvement of service quality.

1.2. Contributions of the Thesis

The contributions of this thesis mainly lie on adding context-awareness module, and designing context-aware applications for MIH services. Our contributions mainly focus on two topics: 1) With respect to the MIH platform, there are few works make real implementation of MIH, that most existing works are based on simulation. Our work makes basic MIH services become reality. Moreover no work has been done for extending context awareness into MIH platform. Existing context awareness support in wireless heterogeneous networks is simply collect and process information into a specific context for a specific application layer application. It can hardly be extended to other applications. There are little studies on context-awareness for multi-media technologies. This work is the first work to design and implement a media independent handover platform with context-aware extension. 2) With respect to the MIH services, we design the context-aware prediction on the MIH link going down event for MIH Event Service (MES), which can guarantee user sufficient handover preparation time. Besides, we design a prediction on link stability for MIS. In this prediction, first, we investigate features with user collected Received Signal Strength Indicator (RSSI) histories, and provide insight results. Second, we cast the estimation problem of link stability as a classification-based conditional probability problem, which would lead to a more accurate result by identifying the mobile situation. Third, we evaluate our approach on a real-world 802.11 networks and 802.21 enabled test bed. Our results show that it really works for user to obtain a stable wireless link.

Moreover, the customize media independent handover (CMIH) part of our MIHCA is involved in ITF SHAWK project. This project is to provide security solutions to

HAWK project [5]. In the SHAWK project, there is a pre-authentication task, which provides a secure and fast authentication. Secure authentication requires very complex associations and computing, which cause latency. In the worst case, user will take 2 second long to execute the secure authentication, especially for those roaming authentication. The latency is unacceptable for those time sensitive applications. The pre-authentication is performed, when the user is already connect to a wireless network, and need to have access authentication to get the next wireless network. The secure authentication is executed with the next network before the mobile user lost the current wireless link. The challenges are how to locate the right next point to authenticate with the next network and when. Finally, our context-aware MES provides a timely handover trigger to serve this pre-authentication.

1.3. Outline of the Thesis

The outline of this thesis is shown in Figure 1.1. There are mainly three parts represented in our work. Chapter 1 is our introduction to this thesis. Chapter 2 briefly presents the literature review of relevant topics and provides some necessary background knowledge for this thesis. Finally, we conclude the thesis with discussions on directions of our future works in Chapter 6. The main body of this thesis is divided into three parts from Chapter 3 to Chapter 5. The details are presented as follows.

In the first part, we discuss the extension of context-awareness to our MIH platform in Chapter 3. A context-awareness module is proposed inside the MIH framework. It collects information from local user behavior and the dynamic changes in wireless network. In Chapter 4, we investigate the MIH event service. The challenging problem in event prediction should not only consider the network environment, but also concern the user behaviours. We predict the user required handover preparation time and link going down time to generate a timely MIH link going down event. It is the Part two shown in Figure 1.1. In Chapter 5, we investigate the MIH information service, and provide new MIH information named link stability to mobile users. Therefore, mobility management can make smart decisions by knowing the link stability. Part three in the Figure 1.1 shows the structure of Chapter 5.

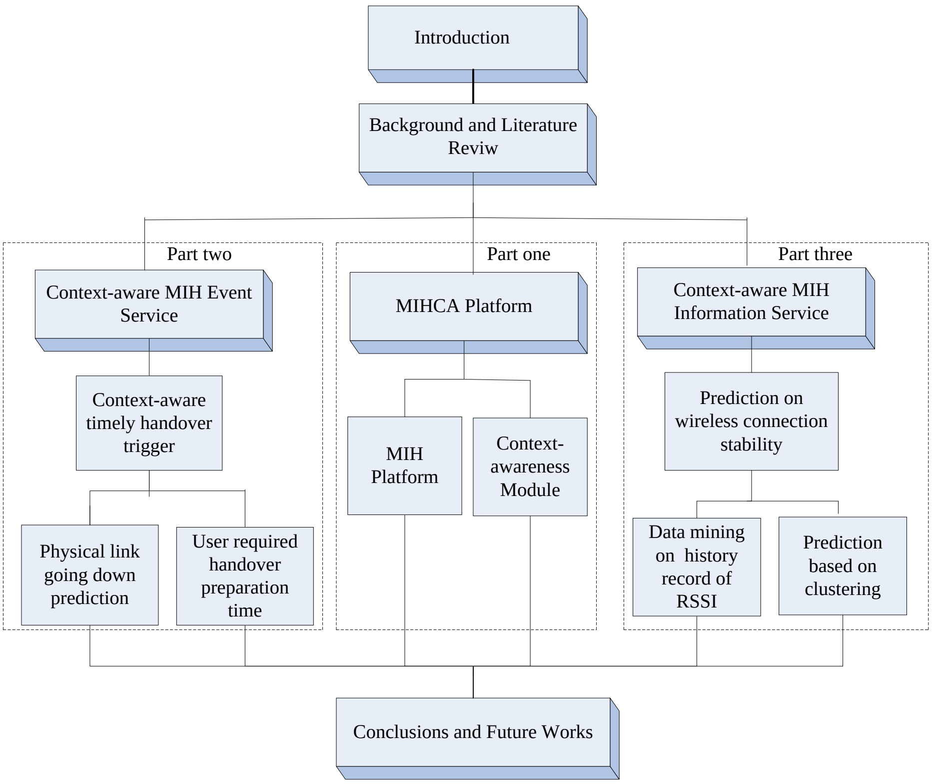


Figure 1. 1: An Outline of this Thesis

Chapter 2. Background and Literature Review

The demand of knowing environmental changes in wireless heterogeneous networks has been driven by the need for context awareness. A better user experience can be achieved with context awareness by utilizing sufficient network information and user context. In this work, we provide cross layer and cross media information to enable the ability of context awareness for mobile users, upper layer applications and our MIH platform in wireless heterogeneous networks.

2.1. Heterogeneous Wireless Networks

In the past decade, we have witnessed the importance and changes in wireless communication. Various wireless technologies exist around us, such as some well known term Wi-Fi, 3G, WIMAX, Bluetooth, and so forth. Those technologies emerged to meet certain condition, which comes from the human need, the environment request, or the demand for cost-effective. In short, every wireless technology has its own merit, which others cannot replace it, on the other side, every wireless technology has its own disadvantages. In that case, it inspires us to utilize the combination of some technologies, such that we can attain every merit of them and avoid some disadvantages by complementation. The combination of 3G and Wi-Fi is a good instance. We have the collective knowledge that the characteristic of 3G is the large coverage and small bandwidth, while the characteristic of Wi-Fi is the large bandwidth and small coverage. Therefore, we can see that the complementation of the two wireless technologies.

Wireless networks, which embrace the combination of more than one wireless technology also named heterogonous wireless networks. In this kind of network, mobile user always equipped with more than one type of wireless access technology media, here we call it multi-mode terminal.

2.2. Media Independent Handover

Media independent handover (MIH) is defined in the IEEE 802.21 standard [4]. It is a framework to facilitate a fast handover and provide cross layer information and cross media information in a standard way. There are three services: MES, MIH Command Service (MCS) and MIS. These services facilitate heterogeneous handovers. Firstly, MES provides standard event classification, event filtering and event reporting. Secondly, MCS enables MIH users to control link behaviour and manage cross layer and cross network information. Finally, MIS provides cross layer and cross media information.

The rapid increase number of multi-media equipped mobile terminal pose demand for different wireless media access technologies, meanwhile it also poses a challenge to vertical handover between different technologies. Our work MIHCA platform is pursuing for a better experience of mobile users by being aware of cross layer and cross media information in heterogeneous wireless networks. To explain it in a detailed way, we utilize MIH platform to collect and transmit useful information, and design context-aware services in the platform. MIH functions construct a freely communicate framework for context-aware mechanism. First we enable the MIH platform, and then we extend the context-aware services inside the MIH platform. In short, the purpose of this MIHCA is to adaptively react to environmental changes by utilizing cross layer information and cross media information. As we mentioned that MIH is defined in IEEE 802.21 standard [4], which is an approved standard in 2008 and completed published in 2009. At the time we start our work in 2009, there is no complete implementation in the real world. Most works concerns vertical handover in heterogeneous wireless networks focus on utilizing the advantage of MIH architecture. We classify those works into two types. One is purely utilizing MIH functions to pursuit for better performance of upper layer applications [6-11], and the other one is to get better performance by adding new MIH types [12-13]. Few works concern the performance of MIH and issues in MIH. To my best knowledge, only those works study the performance of MIH [14-15]. In [14], the authors focus on the MIH event service, and study the performance of a link going down trigger. In [15], they do very fundamental works to support the IEEE 802.21standard. In the standard, there is no ACK mechanism in MIH message transmission protocol, so the authors perform real world work to test the performance of transmission protocol with or without MIH ACK mechanism. The MIH ACK mechanism is just like the TCP ACK mechanism. It is responsible for making sure of successfully transmitted and received the MIH message. It is a NIST wireless research group, which working on the mobility in heterogeneous wireless networks. They developed a MIH model in NS2, which helps a lot for later researchers. However, their MIH model is not complete and real. Our goal of MIH platform can hardly be achieved by reusing their model. Real world information and context are required in our work.

On the other hand, there are many studies work on context awareness in wireless networks. We categorize them into four types, including Internet protocol [16-19], handoff management [20-22], sensing [23-24] and network implementation [25-27].There is an appealing phenomenon that we found few studies focus on context awareness in heterogeneous wireless network [28-29]. The challenge point is that to enable context awareness in heterogeneous wireless networks, there must be communication architecture across heterogeneous wireless networks, so that it can support collecting and updating cross media context. It is hard to achieve it, when the work includes the client side modification and cross media information. It is too expensive to modify the client side, all access points, and servers. The cross media information will involve more efforts for different media components in wireless networks. In a word, it is not practice to make such a big modification, so we come to the idea that we can utilize MIH platform to provide context transmission architecture, and MIH platform can be smarter with context-aware ability.

The work [29] is the first and the only work concerns both MIH and context awareness. However, it extends context awareness above MH platform, which means that it only provides service to upper layer applications. Our MIHCA provides context awareness to MIH platform, and can be extended to support upper layer applications.

2.2.1. Scenario of MIH Enabled Heterogeneous Wireless Networks

In this part, we show a scenario, which is widely seen in any heterogeneous wireless networks. This normal scenario happens every day in our daily life. It is a movement between home and office place. Though real life scenario is much complex than we represent, it can already present some interesting cases.

First, we briefly explain Figure 2.1. There are three people in this scenario. They both share the same situation, making movement and having mobile equipment. In other words, they are mobile users. In this movement, there are many access points (AP) provide service to them, but they can select only one to connect to. There are two base stations (BS) to cover the whole area, and all AP are connecting to routers with cable. How to select the next target is the problem that the mobile user wants to solve. We can see that handoff decision relates to environmental information. On the other hand, when to start a handover process is also depends on the environmental changes. There are two MIHCA servers, which provide cross layer and cross media information for mobile users.

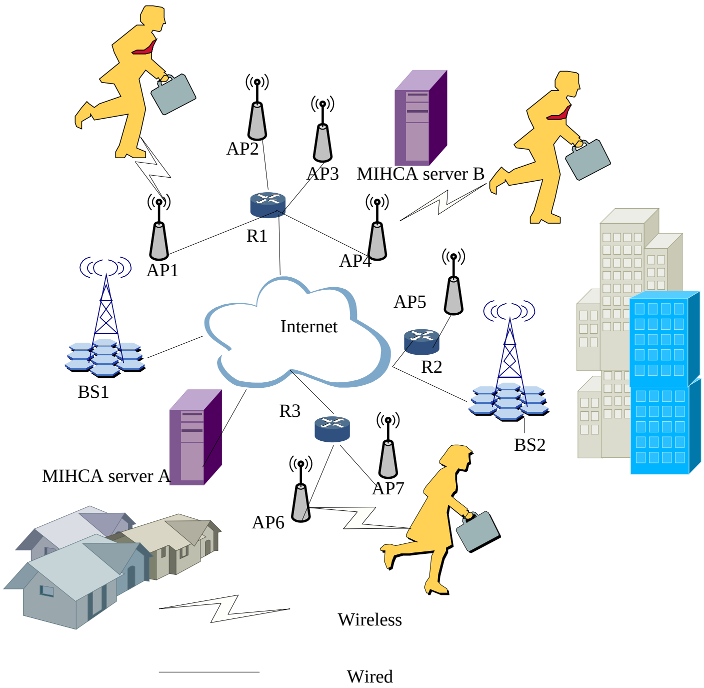


Figure 2. 1: Scenario of Mobile Users in MIHCA Enabled Wireless Networks

In this scenario, many interesting things can be involved. We expect the mobile users can have a better experience by utilizing MIHCA. Let's assume that the mobile device is always connected to the Internet by 3G technology, so that the mobile user can get information about Wi-Fi network by MIHCA server. This Wi-Fi network information can assist all the handovers, which happen during the walk from their home to the office. Information can be processed into useful context. With meaningful context, mobile users become context-aware mobile users, so that they can adaptively select networks and perform handovers. The best performance would be achieved by smart handovers, and the mobile users are not aware of the network service break during handoff.

2.2.2. Media Independent Handover Event Service

Most of previous works on MIH Link Going Down (LGD) event can be categorized into the following classes. The first class [36-38], [44], they focused on setting signal strength threshold, and the second class studied how to utilize MIH LGD to improve network performance [38-43], such as trigger of early preparation [38-41], [43] and session management in SIP [42]. All of them do not consider how to have accurate estimation on handover preparation time.

The paper [44] is the most related work to ours. It is considered the inherent purpose of MIH LGD event to provide sufficient handover preparation time. It proposed two estimation algorithms to generate a MIH LGD event. One is the signal strength estimation algorithm, which is calculated based on require handover preparation time and signal strength history. The other one is handover preparation time estimation. Nevertheless, its time estimation model is based on the assumption of knowing every detail of the handover process, and the estimation time is based on expert estimate time. This may not be practical, and does not work when handover procedures change. Moreover, it is not aware of the change of the wireless network environment.

In this thesis, we develop our context-aware handover preparation time estimation. There is no need for the assumption of knowing every detail of handover preparation procedure. In addition, the estimation method can be aware of the changes of user handover preparation procedure and network environment.

2.2.3. Media Independent Information Service

Many works study link stability, but they focus on the selection issue of routing path. In [49], the scheme on link stability was proposed based on the link related information. In [50]. it proposed a pattern matching scheme. Most prediction schemes of link stability in the literature [47]-[51] are based on low layer measurements, such as RSSI, while schemes purely based on link connectivity changes. In [45], [46], their algorithms are easily affected by different network environment. However, we deem link stability is not only a meaningful metric in routing, but can also be vital to handover decisions. For the handover management, mostly there is no historical link information between the mobile user terminal and the access point. Those methods works for predicting link stability in routing are not fit for mobile users. In our proposed method, we collect RSSI history and make classifications. The idea may have some similarities with fingerprint localization. However, there is no need to localize the mobile user in our problem. Even at the same point, the stability of wireless link various depends on the environmental interference, user mobility, and user handover policy. Moreover, unlike our mechanism, fingerprint technologies require large amount of manual work to put location labels. In another aspect, there are several works on the RSSI clustering [52], [53]. In [52], it adopts the K-mean clustering method to find the K nearest neighbours. The paper [53] takes density clustering technology to filter noise data, which leads to a more accurate localization. There is no feature analysis on RSSI history in their works, and no RSSI clustering for classify different mobile situations.

2.3. Context-awareness

There is no standard definition of context awareness. To know the specific definition of context awareness, we investigate how other researchers defined it in their work. Schilit and Theimer [1] first introduce this term "context-aware", the context here refers to location, identities of nearby people and objects, and changes to those objects. Then follows many similar definitions, however they any bind some specific elements to context. The definition of paper [2] defined that "context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves". Since the second definition is not restricted to specific elements, we will adopt this definition in our work.

The first definition of context-aware application is defined by Schilit and Themier [1], that "applications informed about the context and adapt them to the context". Later works related to context-aware also using those terms: adaptive, reactive, responsive, situated, and context-sensitive. Salber et al [3] defined that "context-aware to be the ability to provide maximum flexibility of a computational service based on real-time sensing of context". This definition from Salber shares the collective merit with context definition. There is no restriction to specific actions, so it is also adopted in our work.

Chapter 3. MIH Platform with Context-awareness Extension

In this chapter, we represent the proposed MIH platform with context-awareness extension (MIHCA). This chapter is organized as follows: Section 3.1 represents the architecture of MIHCA. Section 3.2 discusses the detailed components in MIHCA.

3.1. Architecture of MIHCA

To add context-aware ability to enhance the performance of MIH services, we provide a context-awareness module for MIH framework. We follow several guide rules to design MIHCA.

1) System complexity. The MIH framework exists both at the user terminal side and the remote network side. Moreover, network side may contain different media technologies. Therefore, system complexity should be minimized for practical.

2) Network overhead. Context-aware applications are designed for MIH services. Context exchange and process are required. Therefore, the context-awareness module is placed with MIH services locally, not though remote access.

3) System latency. Even if the MIH services access the context-awareness module locally, there is system latency induced by context exchange and process procedure. If the context-awareness module is placed outside the MIH framework, more MIH commands message and latency will be caused for extra indications. The work mechanism for the MIH command service is discussed detailed in next section.

To conclude all the guide rules, our target is to extend the context-awareness module inside the MIH framework. The architecture of the MIHCA is shown in Figure 3.1, as we can see that there are mainly two components in this framework. One is basic MIH services, and the other part is context-awareness module (CA). Those two components are below the interface of MIH_SAP, which provide MIHCA services to upper layer. The whole framework shows that the MIH_SAP faces to upper layers and other applications. The interface MIH_LINK_SAP connects to the physical layer with different wireless media access technologies. Finally, the interface MIH_Net_SAP is for the information transmission in layer three, which means those messages can be transmitted in a TCP or UDP method. Besides those interfaces, all media access technologies are listed in the physic layer. It is clear that MIHCA is 2.5 layer components in network reference model. It is located between layer two (link layer) and layer three (network layer), so that it can cover the difference from different wireless media access technologies, and provide a unique interface to upper layers.

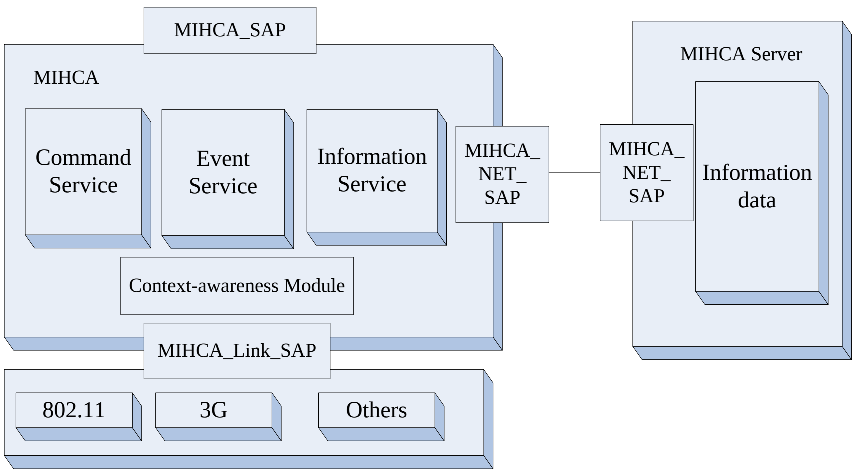


Figure 3. 1: MIH Platform with Context-awareness Extension

3.2. Main Components of MIHCA

There are two components in our MIHCA, which are MIH part and CA part. First, we discuss basic three MIH services including MIS, MIES and MCS. Then the detailed context-awareness module is represented including: context provider, context processor, and context-aware entity.

3.2.1. MIHCA Services

In our work, context-aware applications are designed for MIH services. Context-aware module mainly collect context, provide context and process context for MIH services. Therefore, the MIHCA services remain the same to MIH services. The only difference is the performance. As we mentioned before, the complete MIH service can hardly be carried out. We carry out the basic functions of media independent handover functions (MIHF), named Customized media independent handover functions ((CMIHF). In this section, we also represent the service figures and work flows for each CMIH service. It is in order to show more detailed CMIH services, because the context-aware applications we designed for MIH services in Chapter 4 and 5 require the detailed information.

In this MIHCA framework, we provide basic three services of MIH, which is event service, command service, information service, also a service management for subscribe and unsubscribe event service. Standard MES is to provide low layer link changes, also cross layer information on links to upper layers. We only provide low layer events like link up, link down, link going down for a subscription in CMIH. MCS is to provide service to upper layer applications, so that the upper layer applications can send command to get information and take actions. We provide local information and remote static information query command, scan network command, and make handoff action command in CMIH. MIS is to provide local and remote cross layer information, which can also provide cross media information for any media technology to query. We also provide local and remote cross layer information to upper layers. However, in the MIH standard, there are two ways of information transmissions. One is layer two information transmissions, and the other is layer three information transmissions. The difference between layer two and layer three information transmission is that layer two information transmission aims at peer to peer transmission, while layer three information transmission can be used for external transmission. In our work, we only carried out the layer three information transmission mechanisms, because the layer two information transmission leads to large amount of programming work on the MAC protocol, and modifications in the APs.

As figure 3.2 shows that we provide three services in CMIH. They are CMIH command service, CMIH event service, and CMIH information service, which comprises the CMIH service.

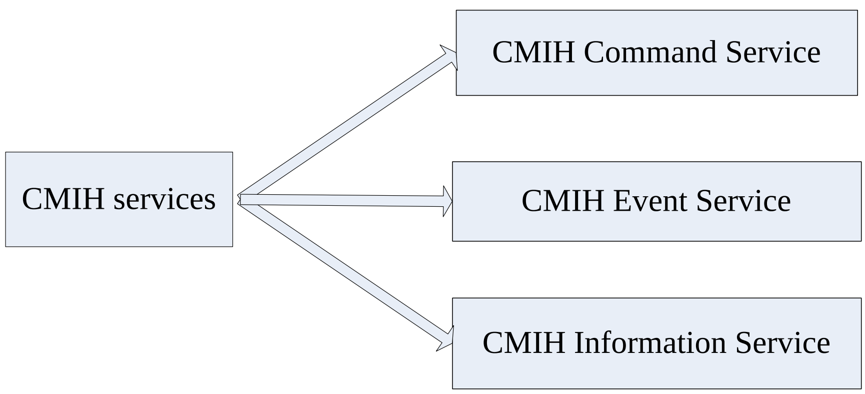


Figure 3. 2: CMIH Services

A. CMIH Command Services

The CMIH command service enables higher layers to control the physical layer (also known as "low layers"). The high layers control the reconfiguration or selection of an appropriate link through a set of command. When a CMIHF receives a command, it is always expected to execute the command.

In the case of local commands showed in Figure 3.3. Messages propagate from the CMIH user or upper layer applications (e.g., policy engine) to CMIHF, and then from CMIHF to lower layers. In the case of remote commands, message propagates from CMIH user via CMIHF in one protocol stack to CMIHF in CMIH protocol.

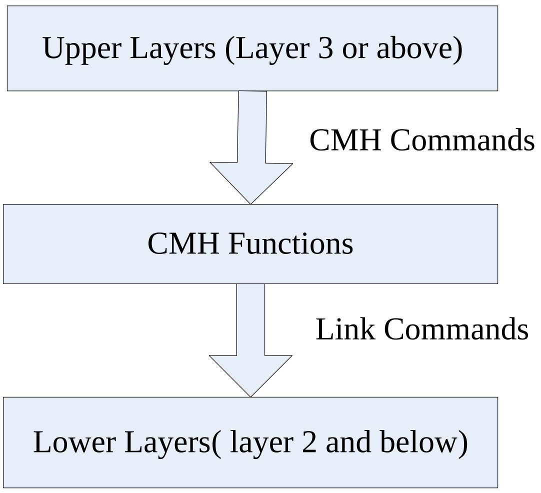


Figure 3. 3: CMIH Command Services

The command generally carries upper layer decisions to lower layers on the local device entity or to the remote entity. For example, the command service can be used by the upper layer handover policy engine to request an MIN to switch links (This command can be a local command or a remote command).

Therefore, CMIH facilitates both mobile-initiated and network-initiated handovers. Handovers are always initiated by changes in wireless environment. Event services collect and monitor network changes, so that handover management applications can make CMIH command to subscribe low layer events.

It also supports a set of media independent commands that help with network selection under different conditions. These commands allow mobile terminal side and the network to exchange network information such as: available networks, network secure method and network signal strength.

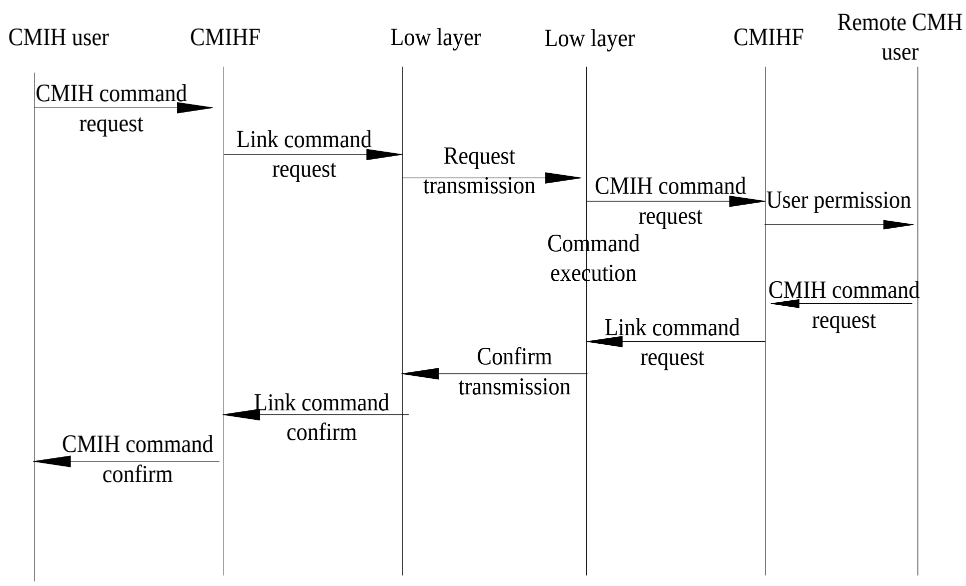


Figure 3. 4: CMIH Command Work Flow

Our CMIH command service can support two types of functions, one is to take upper layer command and return low layer information, the other is to take CMIH upper layer command and implement handover.

B. CMIH Event Services

MIH Events indicate changes in physical links, or predict state changes of these links. The event service can also used to indicate management actions, help user to get cross media information on physical link changes.

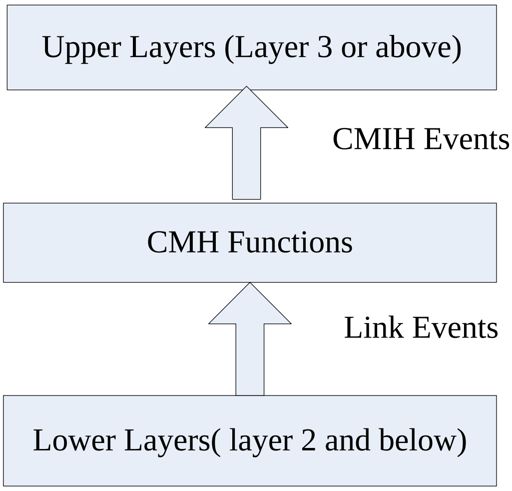


Figure 3. 5: MIH Event Service

In the case of local events shown in Figure 3.5, messages often propagate from the low layer (e.g. PHY, MAC) to the CMIHF and from CMIHF to an upper layer. In case of remote events, messages propagate from the CMIHF in one protocol stack to the CMIHF in the other peer protocol stack. The customized event service is broadly divided into two categories, Link events and CMIH events. Both Link and CMIH events traverse from a lower to a higher layer. Within the CMIHF, Link Event propagates further, with or without additional processing, to CMIH users that have subscribed.

Figure 3.6 shows the work flow of event service. CMIH user can subscribe specified low layer events, and unsubscribe the events that they have already subscribed. In our CMIH event function, we support link down, link up, link going down events.

The CMIH user can utilize command services to subscribe and unsubscribe those low layer events. Event subscription can be divided into two types: one is link events subscription, and the other is MIH events subscription. Link events subscription is performed by the CMIHF with the event source entities. MIH event subscription is performed by CMIH with its link events sources. It is possible for upper layer entities to subscribe for all existing events or notification that are provided by the event source entity.

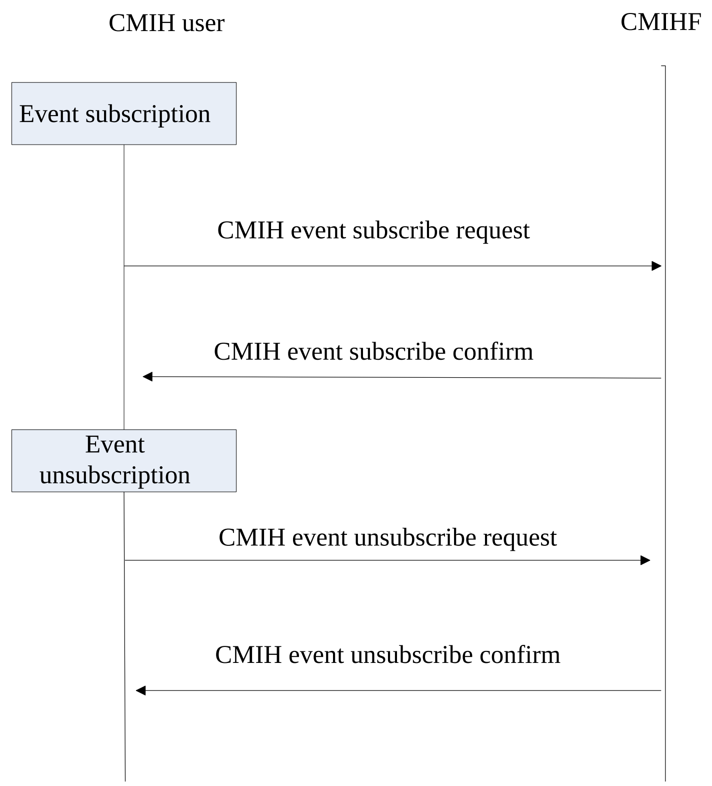


Figure 3. 6: The Work Flow of Event Service

Figure 3.7 shows the MES indications of a complete handover in an 802.11 homogenous environment. MIH LGD event should be generated before MIH link down happens to predict the loss of wireless links. It triggers a handover preparation process. The In IEEE 802.21 standard, there are two events for the predictable events in MES. One is link going down event, and the other one is MIH LGD event. The link layer LGD event is returned with link going down time, which indicates that the wireless link is going to lose time. The MIH LGD triggers user to perform handover preparations, which are generated whenever it receives a link layer LGD event. In this case, when to trigger a handover preparation only depends on the link layer link going down time. There is no way to guarantee mobile users to have sufficient handover preparation time, unless the user required handover preparation is known. However, it is a challenging task to estimate the user handover preparation time, especially when users' handover procedure and network environment change.

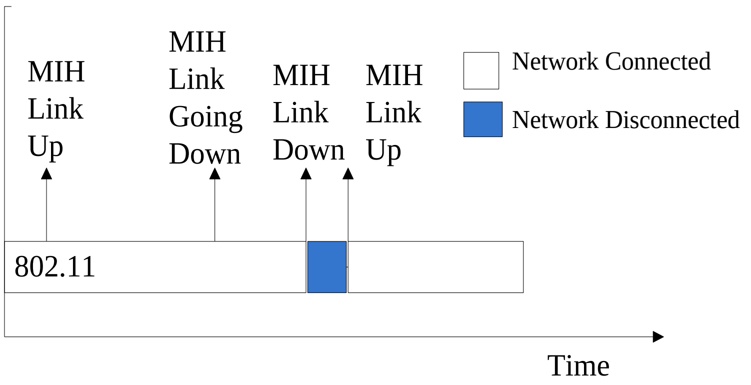


Figure 3. 7: MIH link going down event

C. CMIH Information Services

The customized media independent information service (CMIIS) provides a framework and corresponding mechanisms by which a CMIHF entity can discover and obtain network information existing within a geographical area to facilitate the handovers.

Neighbouring network information discovered and obtained by this framework and mechanisms can also be used in conjunction with user and network operator policies for optimum initial network selection and access, or network re-selection in idle mode.

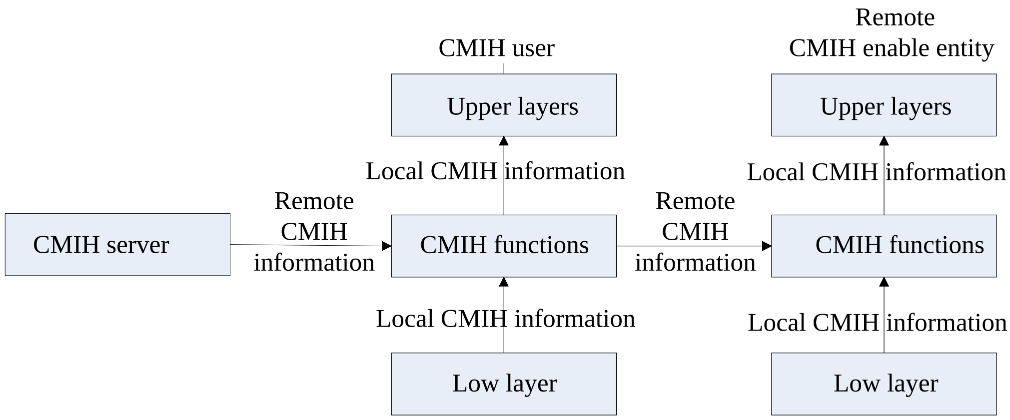


Figure 3. 8: CMIH Information Service

Figure 3.8 shows the CMIH information service. It can provide not only the local information, but also support the CMIH user to get remote information. Figure 3.9 describes an information service flow. The CMIIS within a CMIHF communicate with the remote CMIHF that resides with the access network. CMIH_Get_Information from the MN is carried over the appropriate transport and is delivered to the remote CMIHF. The remote CMIHF returns the necessary information to the MN

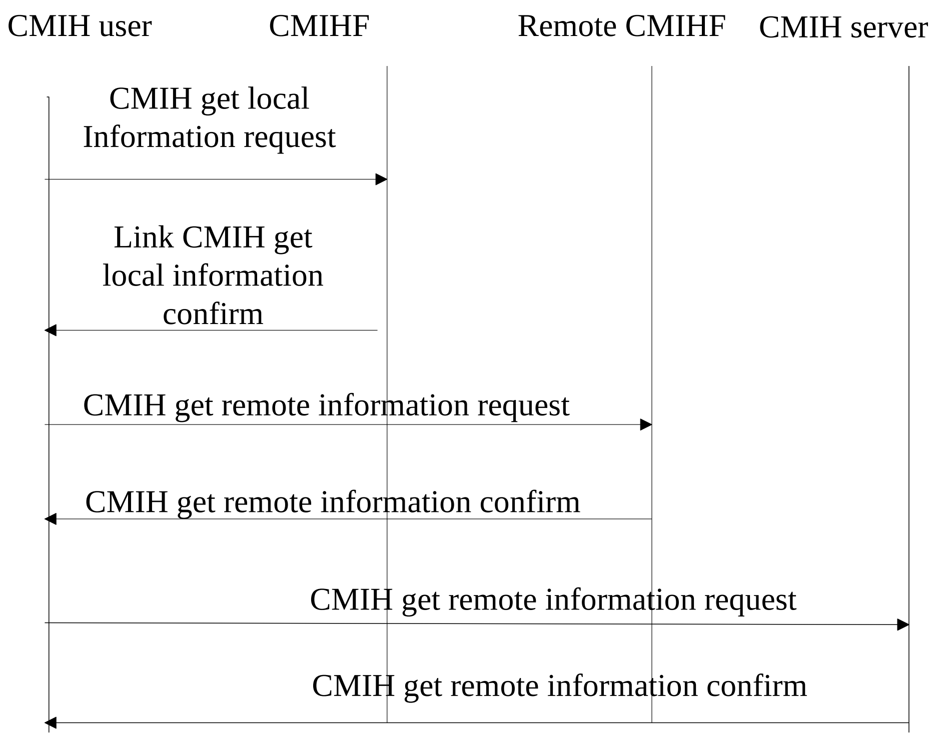


Figure 3. 9: CMIH Information Work Flow

Since the IEEE 802.21 standard is an extendable standard, we add two new primitives with parameters to make this link stability works in MIH protocol. The primitives are shown in Table 3.1. The MIH_Link _Stability_Requirements belongs to the MIH command service. Users send this command to trigger MIH information service with these MIH_Link _Stability primitives.

Table 3. 1 New Designed MIH Information Messages

Primitives	Service	Parameter
MIH_Link_Stability_Requrements	MICS	MIH_ID,Time
MIH_Link_Stability_Response	MICS	MIH_ID, Time, Link_Stability
MIH_N2N_LS_Query_Request	MIIS	MIH_ID, Time, Context

Primitives	Service	Parameter
MIH_N2N_LS_Query_Request	MIIS	MIH_ID, Time, Link_Stability

3.2.2. Context-aware Module

It is the extension component inside the CMIH framework, which collects the context, process context in heterogeneous wireless networks. With the help of context-aware service, mobile clients and upper layer applications can be benefit from that dynamic information, and be aware of environmental changes in heterogeneous wireless networks. The function required in our MIHCA is to collects required contexts, process those contexts, and finally react to those contexts, so there should be a context provider, context processor, and context entity.

A. Context-provider

As we mentioned in the related works that the context definition is not restrict to specific elements, however in real system and real world, we need to recognize different context recording to different requirements in heterogeneous wireless networks. Context provider plays the role of providing context source to our context-aware service.

In our platform, we have three context providers, including the mobile nodes, access points, and MIHCA servers. There are three tables showing the context providers and its context source. Table 3.2 shows the mobile node source. It is local context provider, which provides the local context and the user context. Table 3.3 shows the access point context source. It is a remote context provider. It provides the context information in access points. Table 3.4 shows the MIHCA server context source. It is also a remote context provider. It provides the context information in the MIHCA server.

Table 3. 2: Context Source in the Mobile Node

Mobile Node provider	Context
Media interface	Wi-Fi, 3G
Layer 2	Signal strength, noise, security
Layer 7	Real time application, QoS requirement
User information	Speed, location, user preference

Table 3. 3: Context Source in Access Points

MIH access point provider	Context
AP information	History of users' Link Lasting Time (LLT)

Table 3. 4: Context Source in MIHCA Server

MIHCA server provider	Context
Heterogeneous wireless network	Wi-Fi, 3G
Layer 3	IP configure method
Layer 4	MIP service
Layer 6	SIP service
Layer 7	Real time application, QoS

Other	Cost

B. Context-processor

Context-processor is responsible for context processing using logical reasoning and algorithm and manage collected context. For instance, we utilize the K-mean clustering algorithm to classify different mobile situations for predicting link stability for MIS. To manage the collected context and processed context, the context-processor needs to maintain the consistency of context and resolve context conflicts.

Context reasoning also belongs to context-processor, which has the functionality of providing deduced contexts based on direct context, detecting inconsistency and conflict in the context database. In our work, we adapt the Analytic Hierarchy Process (AHP) [32] as our reasoning rule for the context-aware prediction on link going down event.

To ensure freshness of contexts, the context provider requires updating its contexts. Different contexts require different update frequency. For example, static context may require updating every month or year, whereas dynamic context may need to be updated more frequently due to the dynamic nature. As for our designed context-aware applications for MES, all contexts we collect are dynamic ones. In the context-aware MIS, the clusters of user side changes slowly, so we set its update frequency for one week.

In our work, we adopt the MySQL database to store our context. Useful contexts are obtained after the processing, and then stored in the context database.

C. Context-aware entity

Context-aware entity indicates the entity, which has the ability of being aware of context changes. In another word, context-aware entities are all the entities subscribe the context changes and react to those changes. The purpose of MIH platform with context-aware extension is to provide context-aware ability to enhance the performance of MIH services and can be extended to support upper layer applications. Follow this purpose that we define two MIH context-aware entities inside MIH platform including MIH link going down event and MIH information.

In figure 3.10, not all MIH services have the ability of context-awareness. Since MIH functions itself is complex and has many sub functions. Considering the work load and time, in this phase, we only enable two sub MIH functions inside MIH services to be context-awareness. They are MIH Link going down event and link stability prediction. MIH Link going down is defined in MIH event service. Its purpose is monitoring the low layer links, whenever the current connecting link is becoming weaker than a threshold, and it generates a link going down event. The threshold is not easy to figure out. It may involve the signal quality, Quality of Service (QoS) requirements, user location, and user speed. If this function can be context-awareness, the link going down event can be generated smarter than a fixed threshold. The link stability is the information we added into the MIS, which help mobile users to select a stable wireless link. Several factors may cause wireless link breaks, including environment interference, user mobility, user location, handover policy. Link stability can be obtained, if the prediction algorithm can be aware of those factors.

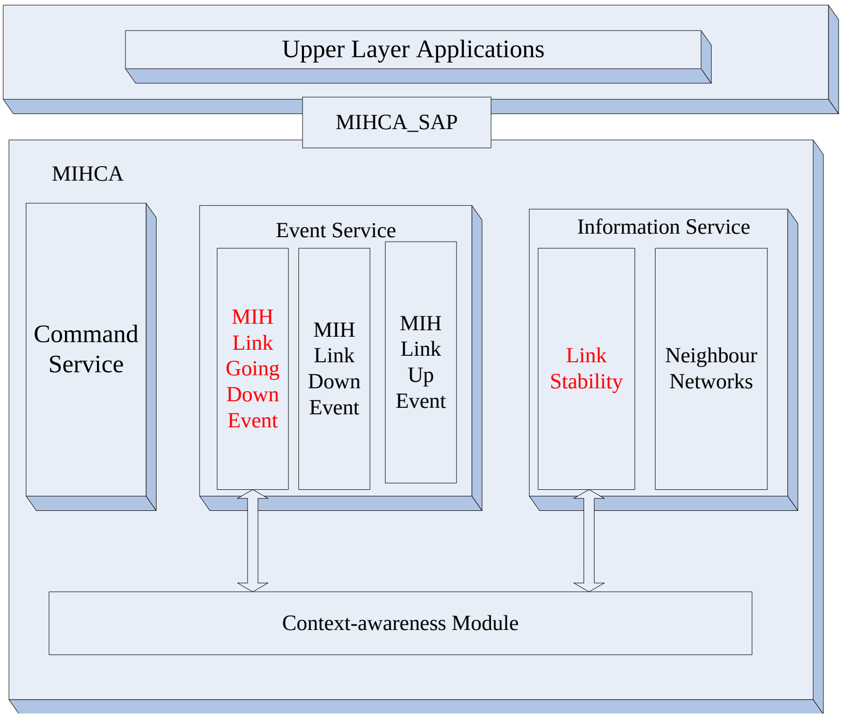


Figure 3. 10: Context-aware Entities

Chapter 4. Context-aware MIH Event Service

In this chapter, we introduce the proposed context-aware application for MIH event service. This chapter is organized as follows: Section 4.1 is the overview of this work. In Section 4.2, presents our context-aware handover preparation time estimation algorithm. Section 4.3 provides the performance evaluation of our solution. Finally, Section 4.4 concludes this chapter.

4.1. Overview

The IEEE 802.21 standard [4] defines three types of Media Independent Handover (MIH) services: MIH Event Service (MES), MIH Command Service (MCS), and MIH Information Service (MIS). These services provide cross layer information and cross media information in a standard way to facilitate a fast handover. However, the unified MIH services are not aware of different user context, and thus cannot provide specified services to improve user experience. To overcome this shortcoming, we proposed extending the MIH framework with context awareness.

We focus on MIH event service. MES helps to notify upper layer application being aware of low layer link's changes. MIH LGD event is the only prediction event, and the most challenging one to handle in MES. It aims at notifying the user to make preparation for the imminent handover. However, deciding when to generate a MIH LGD event is not a trivial task.

Most of previous works used signal strength as the only metric to trigger a handover preparation [36-37]. These methods set certain signal strength thresholds to trigger handover preparation. Whether the handover preparation time is sufficient or not is not of their concern. Paper [44] proposed a static model to estimate the handover preparation time based on the assumption of knowing all handover preparation procedure. However, it cannot fit dynamic changes in the network environment and handover preparation procedure.

We present a context-aware mechanism for generating MIH LGD event. It is based on the user required Handover Preparation Time Estimation (HPE) and the physical layer link going to break time estimation. When the handover preparation time of user required equals to the time of the link going to break, a MIH LDG event is generated. Unlike existing works, which focus on the link layer signal strength threshold, our proposed mechanism guarantee user required handover preparation time. We take two additional factors into consideration for the user required handover preparation time. One is the time needed for essential handover procedure, which depends on various handover managers. The other one is the data loss ratio, which has impact on latency of the layer 3 preparation message exchange. We collect users' history of handover preparation time inside MIH framework as one of our context. With the information of users' history, we can predict current handoff preparation time without the need of knowing the detail of handover procedures. On the other hand, by detecting current network data loss ratio, our context-aware module further dynamically amends estimation time. In short, the context-aware mechanism has two properties: (1) it collects packet loss ratio to adaptively adjust estimated handover preparation time; (2) it gathers users' handover preparation time history, which can be aware of the change of users' handover preparation procedure. As a result, the estimated handover preparation well matches the actual requirement by users.

4.2. Context-aware MIH Event Prediction

In this section, we discuss how to obtain the history context of handover preparation time and present the algorithm for HPE.

4.2.1. History Context of Handover Preparation Time

The historical context of handover preparation time includes two parts: 1) handover preparation time took by the user, and 2) the indication of the sufficiency of last handover preparation time. As shown in Figure 4.1, there are 5 situations of handover procedures, which are a) handover without MIH LGD, b) handover with late MIH LGD, c) handover with timely MIH LGD, and d) handover with type 1 early MIH LGD, and e) handover with type 2 early MIH LGD. It can be seen that timely LGD provides the just right time for handover preparation. Late LGD provides insufficient time, and the two types of early LGD provide too much handover preparation time. Type1 early LGD event causes unnecessary handover, because its handover management directly triggers the handover after receiving the MIH LGD event. On the other hand, type 2 early LGD triggers early preparation, as the information for the user is not timely, leading to triggering of frequent MIH events.

The handover preparation time defined as h, for different scenarios. As shown in Figure 4.1, the whole handover time includes: handover preparation time h, MAC scanning time t_s, handover execution time t_s. We assume that most preparation is network layer message transmissions, for instance, neighbour discovery. MIH scan can be processed before or after link down, depending on the current handover management. The reason to execute MIH scan before link down is that there is less procedure to do after link down, so the service interruption time can be reduced. However, starting MIH scan too early breaks current connection and still introduces more service interruption time. Therefore, we let MIH scan happen before link down within a very short time by adding a protective interval Δt.

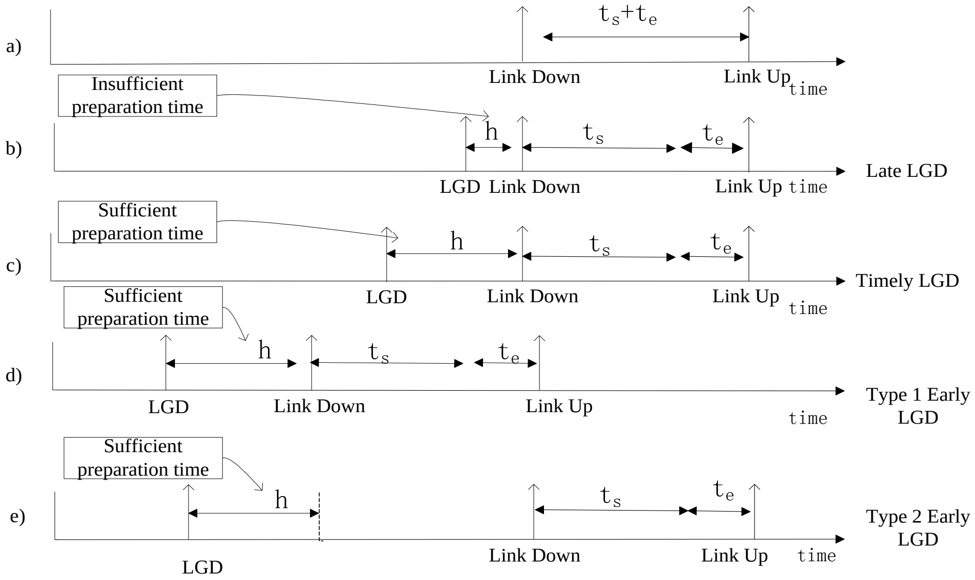


Figure 4. 1: Comparison of Different MIH Link Going Down Events

In our context-awareness module, we collect h_n and c_n as the user handover preparation time history. They are defined as follows:

$$h_n = t_{MIH\_scan} - t_{Link\_going\_down} \quad (1)$$

$$c_n = t_{Link\_down} - t_{MIH\_scan} \quad (2)$$

h_n denotes the real handover preparation time at round n, and c_n is the value to evaluate whether h_n is sufficient. t_{MIH_scan}, $t_{Link\_going\_down}$, t_{Link_down} are the system time when our context-awareness module receives these respective commands and events.

4.2.2. Estimation on Handover Preparation Time

We consider that the handover preparation time is affected by inherent handover preparation procedure and packet loss ratio. The handover preparation procedure determines the amount of messages needed to be transmitted. It is determined by the handover management, and remains the same for the same management system. It changes only when the management changes. On the other hand, packet loss ratio affects the packet transmission time, and it dynamically changes in wireless networks. There are two ways to transmit messages in the network, via TCP or UDP. The paper [15] investigated the relationship of message transmission with packet loss ratio via TCP or UDP. It shows that: 1) the relation between transmission time and packet loss ratio roughly follows linear regression for both TCP and UDP, when the packet loss ratio is smaller than 50%, 2) when packet loss ratio is larger than 50%, the latency increases dramatically as the packet loss ratio. For voice over IP service and video streaming service, more than 10%-20% packet loss ratio is not acceptable. Even for web service, the performance is not robust when the packet loss ratio is above 50%. Therefore, we assume that packet loss ratio is always fewer than 50%. Otherwise, a handover is triggered to select a more stable network.

Table 4. 1: Definition of parameters in our algorithm

Notation	Definitions
h_n	The actual user take handover preparation time

$h_n^{'}$	The preliminary estimation time of the nth handover
$\hat{h}_n$	The final estimation time of handover preparation time
T_n	The valid history to make estimation, it contains $\{c_n, h_n\}$
p_n	The data loss ratio of the nth handover
a,b	Calculation result for regressive equation
e_n	The error of between estimation time and real time
d_n	The bias to justify the output
l, m	The control parameter to adjust bias d_n

We first estimate handover preparation time based on linear regressive analysis on history of handover preparation time. Then we further adjust the handover preparation time by adding a correction coefficient d_n. All parameter used in our algorithm is defined in Table 4.1.

The preparation time estimation algorithm is shown in Figure 4.3. When there is no history record, the preparation time is set as a predefined value. If there is only one historical record, we can only carry out adaptation based on the last time history and c_n. If c_{n-1} is below zero, which means last time handover preparation time is insufficient, the historical context is not valid. In such a case, we empty this historical context, and increase m by one to enlarge estimation bias; otherwise, we use the last time's estimation time. If there are more than two valid records in history, we utilize the linear regression equation. In the Figure 4.2, equation 2 and equation 3 show the detailed calculation for the linear regression equation. We use c_{n-2} to check whether there are more than two valid histories. It is important to notice that in this situation, we use the combination of c_{n-1} and regression correlation value R to distinguish whether the handover preparation process has changed. R is Pearson's correlation coefficient, which is defined as follows:

$$R= \frac{n\sum x_n t_n - \sum x_n \sum t_n}{\sqrt{\left[n\sum (x_n)^2 - (\sum x_n)^2\right]\left[n\sum (t_n)^2 - (\sum t_n)^2\right]}} \qquad (3)$$

Its value lies between 0 and 1. When R equals to 1, it means the perfect correlation. When R equals to 0, it indicates there is no correlation. It is commonly accepted that when R is higher than 0.8, then there is high correlation. The idea behind the combination is to distinguish handover procedure changes and abnormal data collected with the same handover procedure. If the process has changed, then there is no need to use historical context, so we empty old history. Finally, $\overline{h_n}$ is returned as the result after time estimation and adaptation.

Figure 4.2 describe our update algorithm for parameter $h_n^{'}$,e_n,and d_n. We adopt linear regression function to analyze the handover preparation time and packet loss ratio, and make estimation for $h_n^{'}$. In order to approach to the real value of h, we calculate the error e_n between the result of preparation time in our regression equation and the real historical record in our context-awareness module.

Input: m , l , Δt , h'_{n-1}

$T = \{T_0 , T_1 , T_2 \ldots\ldots T_{n-1}\}$

Output: h'_n , d_n , e_{n-1}

1 $\hat{a} = \frac{\sum_{i=0}^{n}(p_i - \bar{p})(h_i - \bar{h})}{\sum_{i=0}^{n}(p_i - \bar{p})^2}$

2 $\hat{b} = \bar{h} - \hat{a} \times \bar{p}$

3 $h'_n = \hat{a} \times p_n + \hat{b}$

4 $e_{n-1} = h_{n-1} - h'_{n-1}$

5 $d_n = e_{n-1} \times p_n / p_{n-1} + \Delta t \times l^m$

Figure 4. 2: Algorithm for Updating

To adaptively make modifications and follow current situation, we implement adaption parameter d_n . It comprises two adaptation parts. The first part adaptation is based on the last time handover preparation error and latest two time packet loss ratio. The second part adaptation provides some extra time Δt to distinguish early and right MIH LGD event. In addition, if late MIH LGD event occurs, parameter l and m can add much larger extra time into this adaptation. It increases the adaptation speed to fit large user handover preparation time. In this updating algorithm both l and m is input data, but in the estimation algorithm, we can see that the m is initialized to zero and changes due to estimation errors. Parameter l is a default data. In our experiments we set l as 5. It is enough to cover the errors when process changes. However, if there is a big change for handover process change, we may need to set a larger value.

```
Input: l ,Δt, h'_{n-1}
T ={ T_0 , T_1 , T_2 ...... T_{n-1} }
Output:   p_n
K=the number of history item inside T
switch(K)
case 1:K=0 then ĥ_n = default time;
case 2: K=1
   if ( c_{n-1} <=0)
          m++; empty(T);
   end if
   default: update( e_{n-1}, d_n );  ĥ_n = h_{n-1} + d_n ;
 case 3: K>=2.
   if ( c_{n-1} <=0)
      if(R<0.8)
          m++; empty(T);
       end if
   default: update( e_{n-1}, d_n );   h_n = h_{n-1} + d_n ;
   else
       if( c_{n-2} <0)
          Update(( e_{n-1}, d_n );
          h_n = h_{n-1} + d_n ;
           Delete T_{n-2}
       else
          m=0;  update( h'_n, e_{n-1} , d_n );
          h_n = h'_n + d_n ;
        end if
    end if
  end switch
  save r_n in T;  return  h_n ;
```

Figure 4. 3: Algorithm for Estimating Handover Preparation Time

4.3. Performance Evaluation

The performance of context-aware HPE for MIH LGD event is evaluated in this section. We adopt signal strength prediction algorithm in [44] with our time estimation, and test its performance in real world handovers between homogeneous WLANs with three access points.

We developed MIH Information Server (MIS) in a Lenovo T61 notebook. In order to perform the complete handover process including preparation and execution we implemented basic services of MIH besides MIH event service. A prototype MIH platform with context awareness, extension has been developed in our test bed. This test bed currently supports the core features of the IEEE 802.21 standard.

4.3.1. Experiment Setting

We evaluate our context-aware time estimation in three situations. The first one has a fixed handover preparation procedure with changing the packet loss ratio. The second one has both changes in handover procedure and data loss rate. To show clearly the adaptation of our context-awareness, the handover procedure only changes once. The third one compares our context-aware time estimation with three predefined and static handover preparation time for a fixed handover preparation procedure. We test all handover procedures with an initiate handover preparation time estimation of 250ms, and set l as 5, and Δh as 50 ms.

We consider two types of handover procedures. As shown in Figure 4.4, the type 1 handover procedure calls the MIH_Get_Information_Reuqest to get neighbour information from the MIH server database, and calls MIH candidate query command to get more real-time and specific information; the type 2 handover procedure only calls MIH_Get_Information _Request. Type 2 handover procedure requires shorter handover preparation time than type 1.

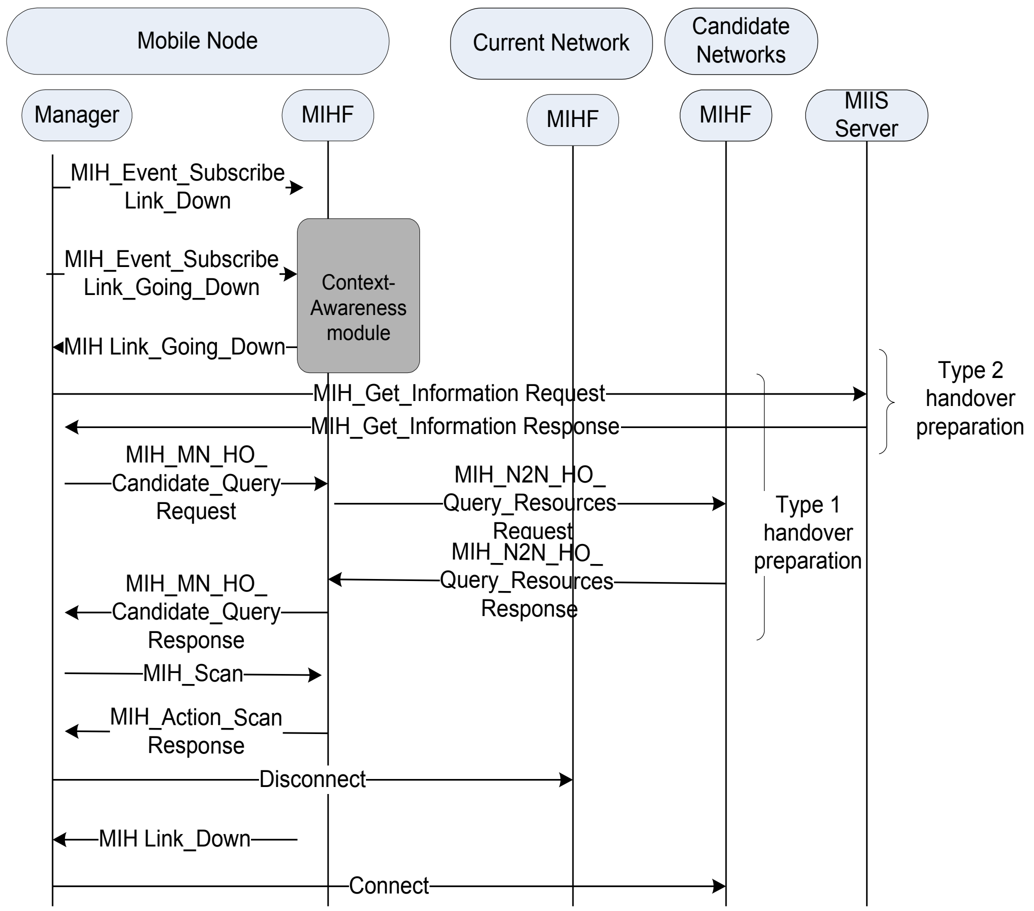


Figure 4. 4: Workflow of Handover Procedure

4.3.2. Testing Results

A comparison of type 1 and type 2 handover is represented in Figure 4.5. We compare the handover preparation time for type 1 and type 2 handover by estimation, actual time of handover preparation execution, and a benchmark for a fixed predefined handover preparation time. We can see that, if there is no adaptation, an early MIH link going down prediction for type 2 handover will be performed. Therefore, unnecessary handover is caused. The type 1 handover require more time than predefined time. If a mobile node adapts this type of handover, preparation time is smaller than the actual need. If there is no adaptation, late MIH link going down event will be generated, which leads to an uncompleted process of handover preparation.

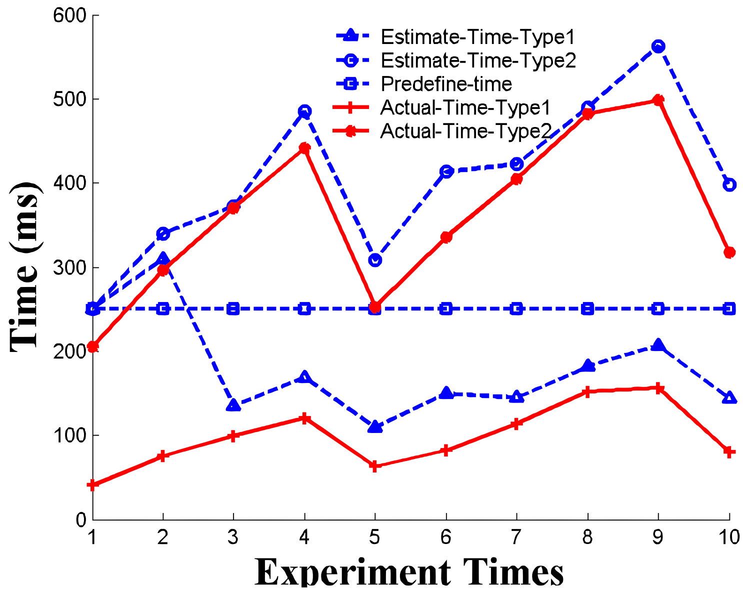


Figure 4. 5: Performance of Time Estimation for Handover Preparation

Figure 4.6 shows the different handover preparation time, by context-aware estimation, actual requirement, and the benchmark one with a predefined fixed value of 250 ms, in a scenario of hybrid type 1 and type2 handover procedures. We adopt the type1 handover process in the first four times experiments, then we change to type2 handover in the later five times. The first estimation is a default value 250ms without any user history. Single history can not trigger a linear regression calculation. Therefore, the first two times estimations are not well adapt to the actual situations. With two times user histories, our algorithm starts to estimate the correct handover preparation time for the mobile user. In the fourth experiment, there is a big raise from the last time, because the last time estimation is not sufficient. This change is to guarantee sufficient handover preparation time for mobile users, which is caused by Δt, l and m. After the handover process change in the fourth experiment, our algorithm quickly adapt to the new process and follows the actual handover preparation time. We can see that the time estimated by our approach closely follow the actual requirements. In contrast, the predefined method may give insufficient or too much handoff preparation time in different handover rounds. This shows that our approach is well adapted to changing network environment and handoff procedures. We can see that most estimated time is little higher than the actual needed time to provide user sufficient handover preparation time. This is because we add a protective factor Δt for handover preparation time to avoid the effect of estimation error.

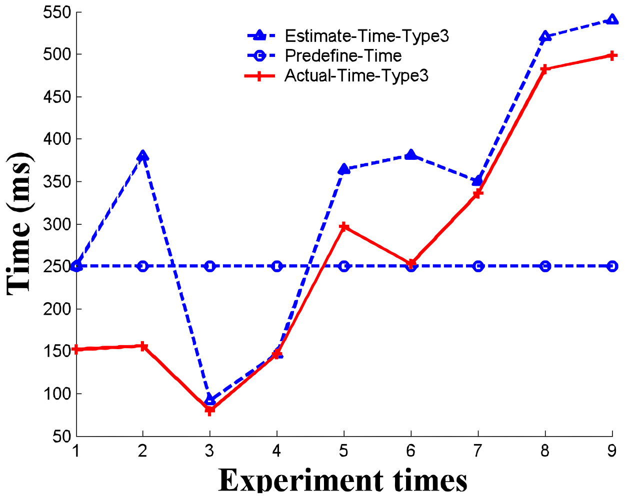


Figure 4. 6: Adaption of Time Estimation for Handover Process Changes

The handover preparation time is not the larger the better, because larger handover preparation time leads to more handovers. We collect the number of handovers within two hours for a user walking inside a building, when handover preparation time is static, or computed by our scheme. We find that the number of handovers increases as the increase in preparation time. Since the context-aware approach always calculates sufficient but not too large preparation time, it results in lower number of handovers, by avoiding unnecessary handovers.

Table 4. 2: Handover Preparation Time versus Number of Handovers

Handover preparation time	No. of handovers
Static time: 200 ms	20
Static time: 300 ms	22
Static time: 800 ms	36
Context-aware estimation time	18

4.4. Summary

The context-aware estimation on handover preparation time is well adapted to the change of the network environment and handover preparation procedure. It provides sufficient time to guarantee successful handover and avoids unnecessary ones. In this thesis, we focus on homogenous networks, which only contain WLANs. In the future, we will extend our investigation to heterogeneous networks composed by WLAN mesh networks and 3G cellular networks.

Chapter 5. Context-aware MIH Information Service

In this chapter, we introduce the proposed context-aware MIH information service. This chapter is organized as follows. Firstly, Section 5.1 is the overview of this work. Section 5.2 presents our context-aware prediction algorithm for link stability. Section 5.3 shows the methods we adopted and the analysis we made, which processes the history information of collected RSSI into the required context for our algorithm. Section 5.4 describes the performance evaluation of our solution. Finally, section 5.5 concludes this chapter.

5.1. Overview

Nowadays, large numbers of applications have been developed to provide convenient services for mobile users with low cost on money. For instance, the Skype [35] application can provide phone call service using free Wi-Fi technology. It costs mobile user much less money, but the performance of Skype phone service directly depends on the quality of wireless network. Intuitively, the Wi-Fi access point with strongest signal strength may have a large possibility to provide a high quality of wireless network service. However, the quality of wireless network service, which the mobile experienced, is not only dependent on current signal strength. A wireless network has a limited coverage area, when a user moves toward the boundary of the covered area, he or she will experience link breaks. Moreover, interference has big impact on the quality of network links. Loss of the current link leads to interruption of the user's application, and establishing a new link will add network overhead and latency. In the case of Skype, every disconnection from one wireless network will terminate an on-going call. Therefore, the user may prefer the networks that can provide long lasting wireless services.

In this paper, we predict the stability of the wireless links in our MIH framework with context-awareness extension. The wireless links are those links, which can be established between the mobile user and the candidate networks. Many factors have impact on the link lasting time (LLT). We divide it into three types. The first type is the inherent physic factor. Usually an AP is exposed to the environment. The damage of physical components leads to frequent link breaks. The second type is the dynamic ones: the user location, the user mobility and the environment interference. It is hard to obtain this type of information, because it changes timely and randomly. For the first two types, we name it together as the mobile situation. The third type is the preset factor: the user handover policy. Different handover policies lead to different practical link lasting time for different users, even the mobile situations are the same.

We represent a context-aware mechanism for predicting the stability of wireless links. We define the link stability as the probability for one wireless link to survive for a time t. In the traditional IEEE 802.11 networks, mobile users can obtain only common AP broadcasting information, before one wireless link is established, such as Service Set Identifier (SSID), Received Signal Strength Indicator (RSSI) and secure method. It is hard to predict the link stability based on that limited information. Intuitively, we assume that mobile situations have big impact on the link stability. Therefore, we need ways to gain mobile situation information before one wireless link is established. In this paper, we adopt the IEEE 802.21 MIH framework to obtain network information before one link is established. To gain user context and enhance user experience, we extend MIH framework with context-awareness module. Finally, we provide link stability as one information parameter of MIS. We assume the APs in our scenario are all static ones. Our basic idea is that different mobile situations corresponding to different link lasting time, however similar mobile situation may have a large probability to have a similar link lasting time. Thus, we first classify the mobile situation of a mobile user by K-mean clustering, and then we estimate the link stability with conditional probability, which based on the combination information of historical mobile situation and link lasting time.

5.2. Context-aware Prediction on Link Stability

In this section, we discuss the algorithm for predicting link stability, and the work process for prediction. In our work, we provide mobile users the choice that this t can be set manually, or taken a default one. We also represent the algorithm for deciding default t for every mobile user.

5.2.1. Algorithm for Predicting the Link stability

In our framework, there are two locations to store historical context of LLT: one is stored at the AP side, and the other is stored in the user terminal. The AP side information can only be general information for all mobile users. It cannot be aware of a specific mobile user movement or environmental changes, and it mainly indicates the physical condition of an access point. Therefore, we also collect information and store it in the user terminal. In this way, every user has a choice on whether to have a general information or specified prediction. We provide to types of link stability to mobile users. If a user only needs to know the general AP link stability, given the user command with time requirement t, the AP can calculate the link stability, and return it to the user. If a user specified link stability is required, we need to classify the user current situation with its RSSI historical context. Euclidean distance based k-mean clustering is adopted to cluster old RSSI history, and classify new RSSI context. Table 5.1 shows the contexts we used in all our prediction process. There are two levels of contexts. First level is the real data collected, and the second context is the information we calculated. The time context is easy to be understood, which can provide a historical probability for later prediction. As regards to the context of RSSI history, it helps to classify current user situation. Different situations may have large impact on the final LLT. On another aspect, it also helps to reduce unnecessary context of historical LLT, which leads to more accurate probability.

Table 5. 1: Context Used in Our Prediction

Primary Contexts	Processed Contexts
User Link lasting Time Stored in AP Side	Probability P_a for AP to provide link over time t
User Link lasting Time Stored in User Termianl	Probability P_u for User to get connected over time t
User Collected RSSI history for APs	Different mobile situation k_n

The final link stability is predicted with the mobile situation information k1, k2, and given time t, as shown in equation (4). The situation k1, and k2 is different, because they are calculated separately in AP side and User side. Since K-mean clustering is unsupervised clustering, different histories lead to different clusters. As to the details for the mobile situation kn, we will discuss it in section 5.3.

$$P_u a(t)=P_a(t,k1) \times P_u(t,k2) \qquad (4)$$

5.2.2. Algorithm for Deciding Default Time t

There are two locations to store history context of link lasting time in our framework: one is stored at the AP side; the other is stored in the user terminal. All the history data can be processed as statistics data. If a user only needs to know the general AP link stability, given the user command with time requirement t, the AP side MIS calculate the probability, and then return it to the user. If there are no user requirements on the time, a default time selection will be processed. In equation (5), tn indicates the history link lasting time collected by the user side under certain mobile situation k2 for APn. Among the entire time context, we select the average value T as the default request time. This k2 is calculated locally at the user terminal side.

$$T=\text{average}\ (t1, t2, t3\ldots\ldots tn, k2) \qquad (5)$$

5.2.3. The work Process for Prediction

As we mentioned, we discussed the algorithm for predicting link stability, and the algorithm for deciding the t for mobile user. A whole work process is shown in Figure 5.1.

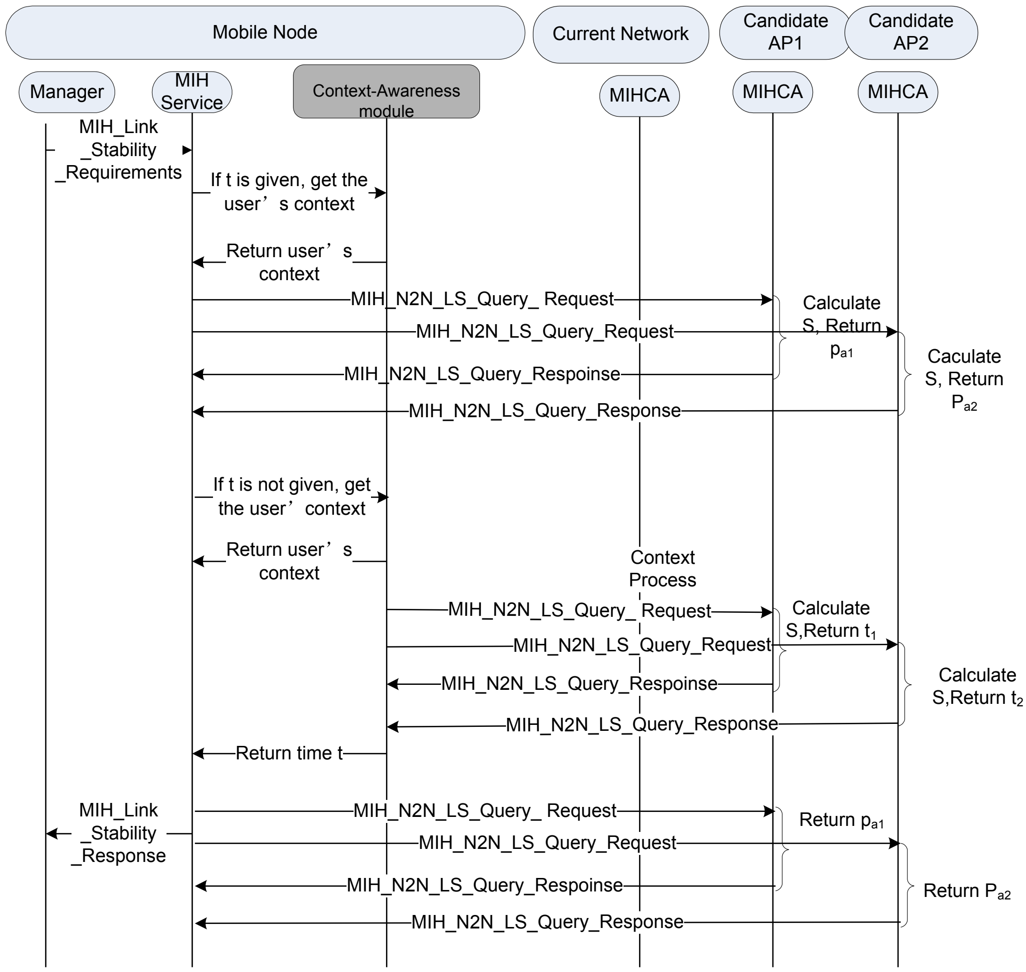
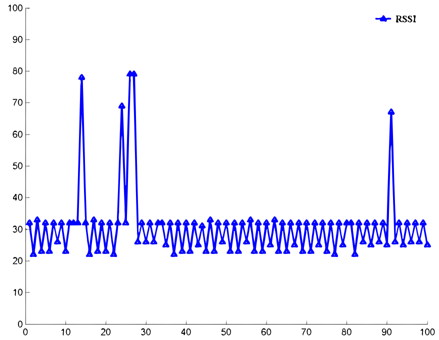


Figure 5. 1: Work Process of Prediction on Link Stability

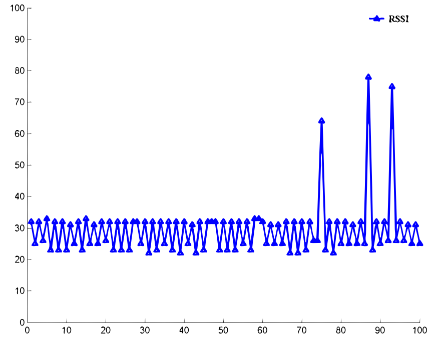
The manger in the mobile node side starts the process. It is usually a handover manager, but because the MIH interface is open, so other managers can also require this information. Therefore, we describe it as the managers not only the handover manager. When MIHCA service gets this request, it divides this request into two types. For the first type, if a require t is given by the manager, the MIH service will get the user context from the context-awareness module, and then send this context to the AP side. After got the user context, the AP side context-awareness module will calculate the user situation type k_n , and return the probability for this user situation k_n. If there is no t give by the manager's request, the MIHCA in the user side have to first gain a suggested t from all candidates AP. The algorithm for deciding the default algorithm is applied. After deciding a default t, repeat the first type work process.

5.3. Identify the Situation for a Mobile User

As we mentioned before, two contexts of wireless link lasting time from AP side and user side are collected. Without the mobile situation information, the AP side context only shows generally the probability of one link for to survive for a time t. This information is not sufficient to fit for a specific user. Users are different for their mobility, and their handover policy. More accurate links stability can be estimated with the mobile situation information for a specific mobile user. However, mobile situations do not contain the user handover policy, because handover policy generally belongs to the handover management, which is application level information. Even if our context-awareness module can get some information of this policy, it is hard to predict the impact on the link lasting time. To conquer this, we need the user side context of wireless link lasting time. User handover policy has directly impact on these contexts. Figure 5.2 represents the real RSSI collected by a mobile user. A and B is collected, when the mobile user does not move. C is collected, when the mobile user is moving towards an AP, and D is collected, when the mobile user moving away from an AP. Finally, E and F are collected, when the mobile user is moving around without a clear direction. Each curve contains a large amount of information, and much of them are unnecessary. Therefore, we try to make feature extraction, so that useful information can be remained, and useless information can be filtered.



A



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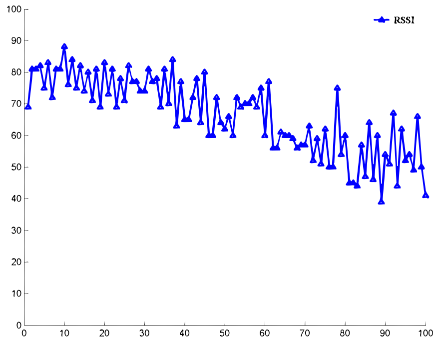

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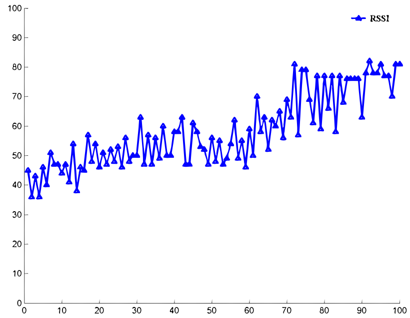
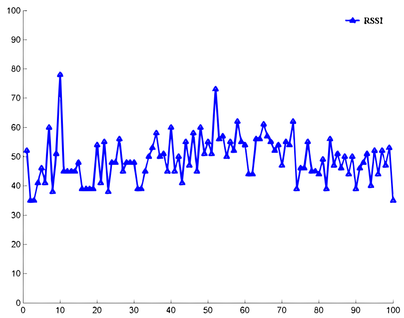
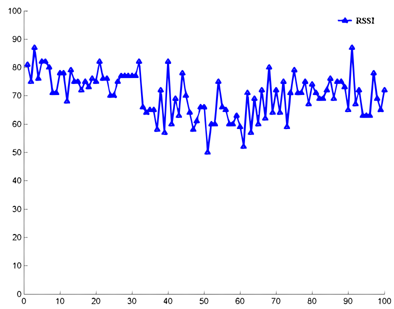


D



E



F

Figure 5. 2: RSSI History Collected by a Mobile User

5.3.1. Feature Analysis

To analysis the features exist in RSSI history, first we need to understand the physical meaning of the RSSI history. Generally speaking, there are several guiding rules. First, the closer a user is to one AP, and the higher the signal strength is. Second, if the environment has large interference, there will be more shake and summit points in a RSSI history. Third, if the user is moving fast, the RSSI may change rapidly. Finally, if the user moving towards to the AP, its signal becomes larger, otherwise it gets smaller. These rules may not 100% accurate when they are applied to real life. Grey area may exist. However, it will not affect our prediction, because grey area will also be classified into a specific cluster, and the LLS for this cluster have a large probability be similar. Take the first rule for instance. It utilizes the RSSI data to indicate the distance between the mobile user and the AP. Interference has a big impact on the RSSI data, but we don't need to calculate the accurate distance, instead we aim at identifying the user's mobile situation. Users at the same location suffering the same interference will be classified into one mobile situation; otherwise they will be classified into different mobile situations. To conclude all those properties, we deem that there are 27 mobile situations, which is decided by the degree (strong, weak, medium) of three features with physical meaning: location, Interference, mobility. Based on that ground, if the information of the three features can be obtained, we can determine a mobile situation. However, in the original RSSI history, information can not directly match to those three features. Therefore the feature extraction is needed to translate the discrete RSSI data into features.

The feature is useful, because most original data has too much information, and it is hard to summarize or compare with one another. The idea of extract features in a data set can help reduce the unnecessary data. The feature extraction is widely applied in face recognition, voice recognition, and heart diagnoses. Before the feature extraction, we should know what the features are inside the history data. Therefore, we perform some feature analysis. In the data mining and pattern recognition literal, there are most three ways to get information from a wave. They are frequency analysis, time serial analysis, and statistic analysis. Because there is no work has been done to get insightful information from the RSSI history, we investigate methods from the mentioned aspects.

A. Power Spectra Analysis

In the signal process and analysis area, there two types of signal. One is stationary signal, and the other is none-stationary signal. The spectra analysis is used for the stationary signal, and the power spectra analysis is used for non-stationary signal. In our work, the RSSI signal we collected is the none-stationary signal. It is random changed due to the environmental interference and the movement of mobile users. The advantage of power spectra analysis is that it turns the time serial data into spectra and power data. Therefore, various frequencies are easy to see, and their power distribution is clear. In the instance of voice word recognition, the wave is gained from the voice of the word. There is a guide line in the recognition of voice word. Various words have different power distribution, but the same word, which is pronounced by different people, may have large similarities. In our case, the wave is generated by the RSSI history. However, there is no concept of words in our work. We are pursuing to recognize different user situations. User situation is much harder than the words. Because the pronunciation has a standard, but there is no standard user situations. Moreover, even the same movement for one mobile user and it will generate different RSSI histories in different environment. Under this intuition, we analysis those history data represent in Figure 5.2, and try to find out that whether it is easy to distinguish those different user situations with the power spectra analysis. The analysis result is shown below in Figure5.3

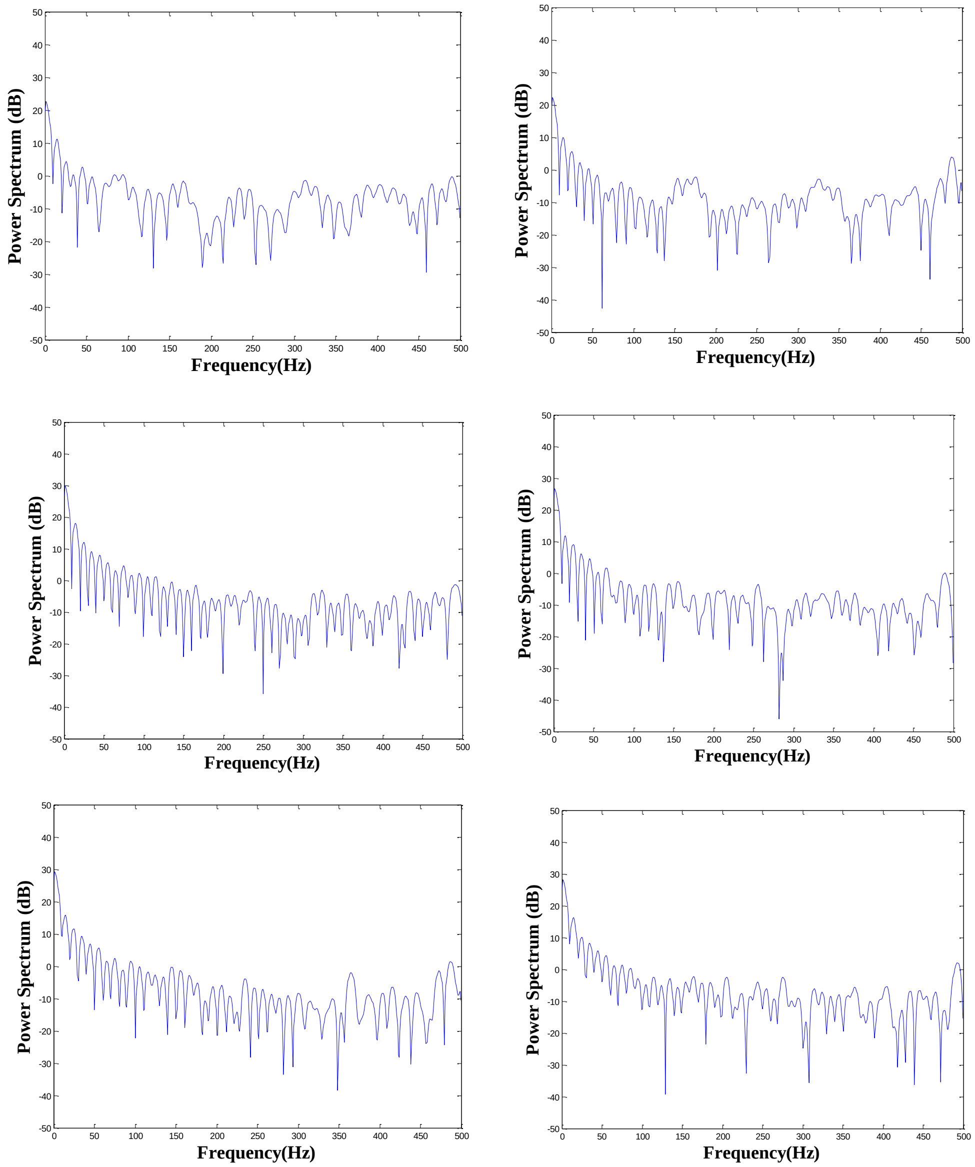


Figure 5. 3: Results of Power Spectra Analysis

From the analysis results, we can figure out that the results are obviously different. It is known that the Fast Fourier Transform (FFT) is the fundamental theory of spectra analysis, which turns the time related data to a frequency related data. However, there is no evidence has been proven that the different frequency can represent the interference. Moreover, there are also too much information inside this frequency figure.

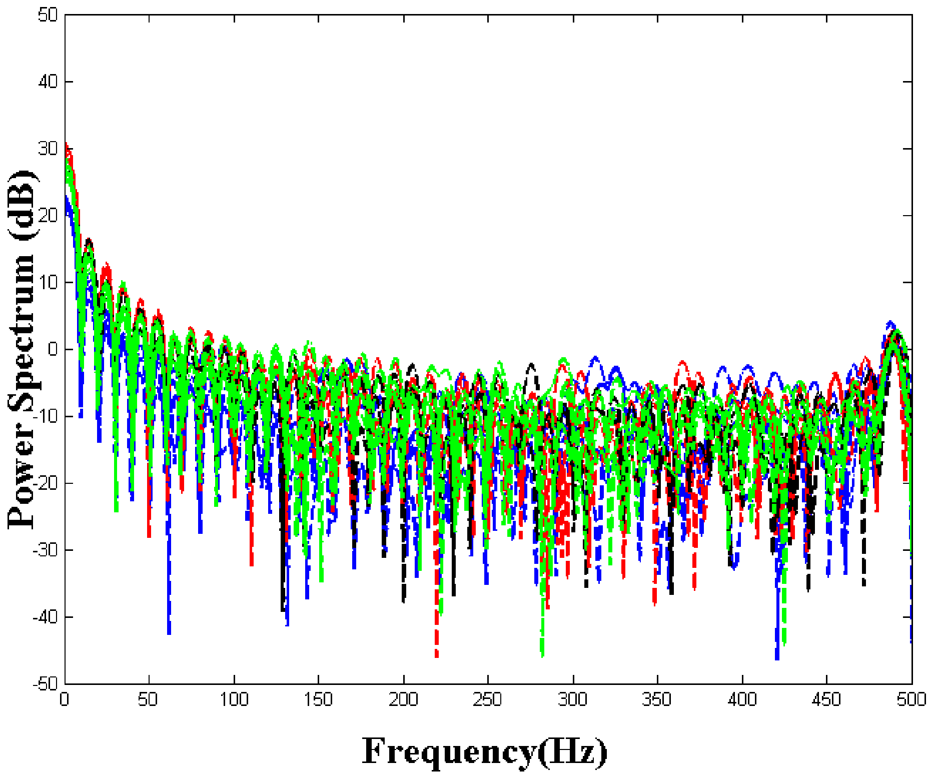


Figure 5. 4: Power Spectral Analysis for All Histories

The final results are shown in Figure 5.4. The blue line represents the results for the histories, which are collected for the static user. The red line represents the results for those histories, which are collected when the mobile user is moving towards an

AP. The black line represents the results for those histories, which are collected when the mobile user is moving away from the AP. The green line shows the results for those histories, which are collected when the mobile user is moving around without a direction. Most lines are in the same area, and there is also no distinguish difference. The results, we expect that every colour occupies one distinct area, does not show. Therefore, we stop mining more information for this category of analysis.

B. Time Serial Analysis

In the area of time serial analysis, it analyzes all the data with the timeline. By analyzing the relationship between the timeline and the data, we may find out that there are some rules, and some information can be predicted. For instance, for those commercial cases, the requirement on the air condition always reaches the summit of the year in the four season's timeline. It can also be predicted based on history of purchased number. However, in our case, there are no circles or rules to follow in the wireless network environment. It is hard to predict the network interference and user mobility based on past information. Therefore, we try to figure out that whether there is any relationship can be traced.

In the time serial analysis theory, all cases are divided into two types. One is stationary time serial, and the other is none-stationary time serial. The difference is there is no clue or rule for the none-stationary time serial. Our case belongs to the none-stationary one. To my best knowledge, there is no method, which can guarantee one hundred percent trend in time serial data. However, it would not be too difficult to analysis the data, if its trend were monotonous.

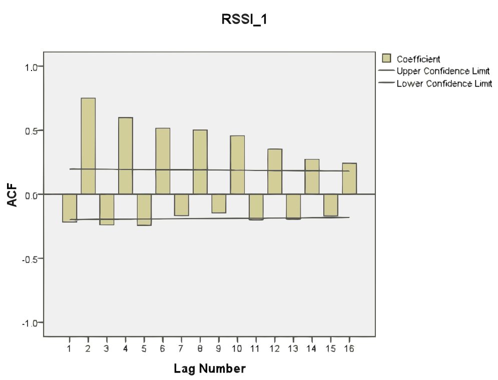
In our case, the monotonous cannot be guaranteed due to the unpredictable mobility of users. In practical, we may also pay no attention to the interim situation of one user. Therefore, we adopt the trend analysis technique to analysis the trend with the data collected in beginning period and in the end period. We take the moving mean value in the two periods, and compare them, there should be a trend. As table 5.2 shown, we take first twenty histories to calculate the beginning mean, and ending twenty histories to calculate the ending mean. A trend result is gained by using the ending mean minus beginning mean. Therefore, the larger absolute value result is the faster the user in moving, and also if the result is a positive number, then the user is moving away from the AP, otherwise, the user moving close to an AP. Moreover, the result matches the original trend as we can see in the Figure 5.2.

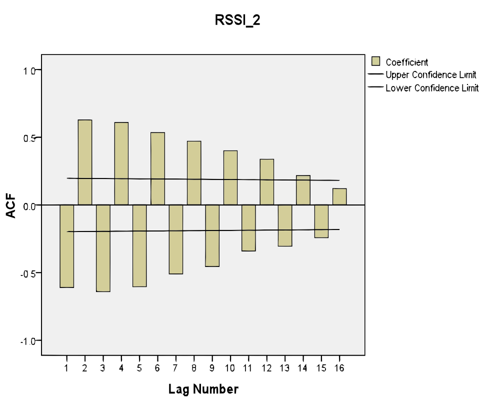
Table 5. 2: Moving Mean Analysis

Figure	Beginning Mean	Ending Mean	Trend
A	28.5	22	-6.5
B	29.2	28	-1.2
C	78.0	67	-11
D	73.7	51	-22.7
E	78.4	52	-26.4
F	45.5	74	28.5

Besides the trend analysis, we also do the auto correlation analysis, in order to find the similar patterns. In intuition, if the user is stationary, there may not be much interference cause by mobility, so the environment interference is the main factor leading the RSSI changes. In another aspect, because the auto correlation is done with the elder data among the data we analyzed, there are two thing we aim to discover, first, whether it has some periodically changes caused by the environment; second, whether the RSSI changes affect the final auto correlation results.

We do auto-correlation analysis on the history contexts belong to figure 5.2. The result is shown in Figure 5.5. Clearly, RSSI_1 and RSSI_2 are different than others. It has the positive result and the negative result. Because we have already known that RSSI 1 and 2 is collected by a stationary user. Therefore, we deem this information is really important. The physical meaning of the auto-correlation factor is to verify the relationship between elder history and new history with a periodic time. If there do exist a relationship, the result will finally come closely to zero. Besides this characteristic, we observed even for the positive result, different history is totally different. This may be caused by the interference, but the relation is not clear. There is no distinguishing difference among none- stationary users' results.





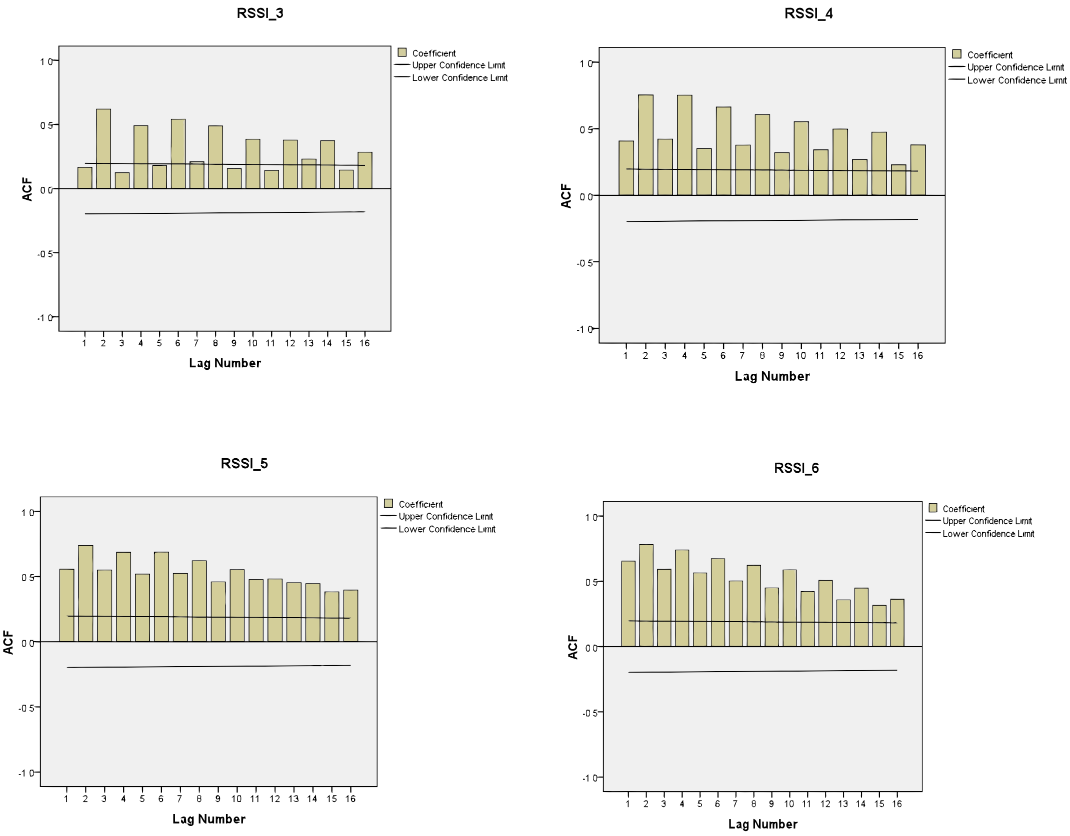


Figure 5. 5: Auto-Correlation Function Analysis Results

C. *Statistics Analysis*

In the area of statistics analysis, there are many statistics factor can be calculated from the original data. In table 5.3, we list the mean value, Standard deviation, Variance, Kurtosis and finally skewness. As we can see that mean value can indicate the distance between an AP and a mobile user. When the user is close to an AP and the mean value is low (because we gained the absolute value of RSSI). The lower value the higher signal strength is. The difference in one history context data on the aspect of the Std deviation, kurtosis, skewness is very small, and we cannot see the difference to highlight useful information. For instance, although Kurtosis value shows that only Figure B has a classic kurtosis distribution, then there is no more information to distinguish others, so is the skewness. The Std deviation values are all different from each other, but it is hard to match the data to a physical meaning.

Table 5. 3: Statistics Analysis Results

Figure	Mean Value	Std deviation	Variance	Kurtosis	Skewness
A	26.14	4.73	22.38	-1.69	0.49
B	27.98	5.8	34.58	12.48	2.2
C	75.50	8.26	68.36	-0.28	0.56
D	61.77	9.85	97.1	-0.92	0.19
E	66.41	1.19	141.60	-0.837	-0.328
F	58.18	1.23	152.876	-0.865	0.47

5.3.2. Feature Selection

We have already analyzed those features for the RSSI histories in three aspects include the frequency analysis, time serial analysis and statistics analysis. There are some guidelines to select meaningful features:

1) It is easy to distinguish the state of a mobile user, stationary or none-stationary.

2) It is clear to tell the location of a mobile user, near or far away from the AP. Third, It accurately indicates the interference effect.

3) The good features can distinguish different mobile situations. In one feature, the bigger difference between different situations the better.

With the three guidelines and the results of feature analysis, we find that the mean value can basically indicate the location of a mobile user, which follows the gudiline1. The std deviation, kurtosis, and skewness cannot meet guideline 1 and 2. The variance can indicate the changes, which may relate to the user movements. In the time serial analysis results, we also observed that the trend can indicate the user movement. In another aspect, the auto correlation shows the environmental interference. Therefore, we proposed mean, trend, variance, and auto correlation to reduce unnecessary information, and highlight a different situation characteristic. Since both the trend and variance mostly indicates the changes happened in RSSI history caused by movement of mobile user. Thus, we combine them as one by multiple the trends by the variance. Although feature selection is significant to our final clustering results, it is not the focus for this work. The selected features may not be the best, and each feature is not completely independent. However, due to the workload and time limit, we start our first attempt on this RSSI data mining. More deeper work can be done in the future.

5.3.3. K-Mean Clustering

In real world, one user can be in various mobile situations. However, it is hard for people to make rules to distinguish different situations. Therefore we adopt the K-

Mean Clustering [53]. The Euclidean distance is used to classifier new context. The equation for Euclidean distance is shown in equation (7), Calculating the new context with all cluster center point, select the minimum Euclidean distance one. Then this new context belongs to this clustering center. As mentioned before, we consider the user mobility, environmental interference, and distance as the factors that lead to different RSSI history, therefore, there should be 27 types of mobile situation, if we divide every factor into weak, medium, and strong. In the equation (6), it shows the classification. K equals to the minimal distance between a new join context and a centre point. There are three features, we compare, so there are three characters L, M, I. L indicates the location feature, M represents the mobility feature, and I represent the interference feature. Equation (7) shows the Euclidean distance calculation for the three dimension point. Moreover, K-mean clustering algorithm is an unsupervised method, so there is no need for manual changes or interruption in the process of clustering. The clusters are generated automatically, if the number of clusters 27 is set. Every mobile situation kn is corresponding to a Center_n in Equation (6). If a new context comes, Equation (7) will be performed for the new context from Center_1 to $\text{Center}_{k,}$ and then the minimal distance K between the new context and the Center_n will be calculated. This new context is belongs to the cluster Center_n. Because canters only show the physic meaning in clustering, we use kn to indicates the cluster and represents the corresponding mobile situation.

- $K=MIN(E(new(L,M,I),Center_k\ (l,m,i)))$ (6)
- $E(new(l,m,i),Center_k(L,M,I))=\sqrt{(L-l)^2+(M-m)^2+(I-i)^2}$ (7)

5.4. Performance Evaluation

The performance of context-aware prediction of link stability in MIH enabled wireless networks is evaluated in this section. We make a mobile user moving inside a WLAN with four access points. We build MIH Information Server (MIS) in a Lenovo T61 notebook. In order to perform the real user moving scenario and complete handover process, we implemented basic MIH services. A prototype MIH platform with context awareness extension has been developed in our test bed. This test bed currently supports the core features of IEEE 802.21 standard.

5.4.1. Experiment Setting

We evaluate our context-aware prediction of link stability in a typical scenario as Figure 5.6 represents. It is an indoor environment. The interference mainly comes from physic barriers, and human behaviour. AP 1, AP2, and AP3 are deployed in a corridor; AP 3 is placed inside one room. Two users are in different place with different mobility. User 1 is a static user, and the User 2 is a moving one. Especially, there are some physical damages in AP 2. Without link stability prediction, AP 2 may be the best candidate for user 2, and sometimes AP 4 may also be the best candidate for user 1, if the AP4 is close enough to user1. We will demonstrate how this prediction on link stability helps the user to make a smarter choice.

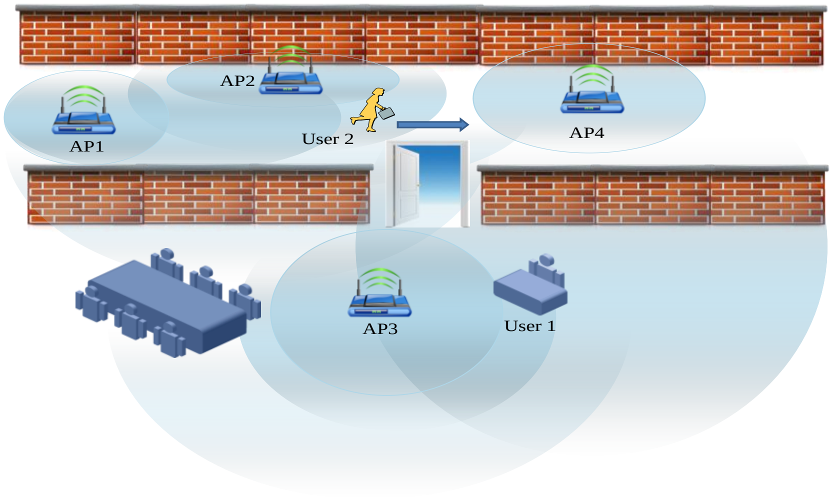


Figure 5. 6: Testing Scenario

5.4.2. Testing Result

We set the collection of RSSI period to 20ms one record. The shown AP order is the same in both Figure 5.7, and Figure 5.8. It represents AP2, AP3, and AP4. From these figures, we can see that the user 1 is almost none- moving, and user 2 is moving around AP 2, and AP3 towards AP4.

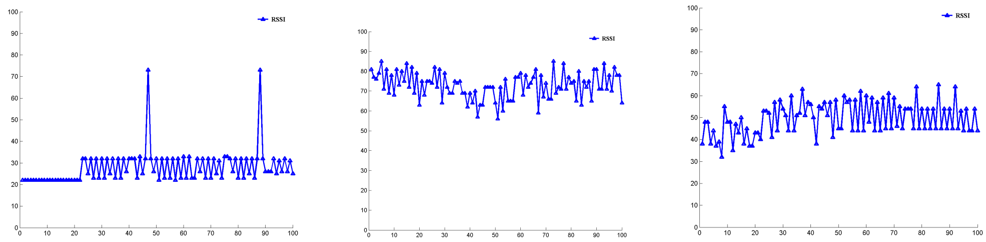


Figure 5. 7: RSSI Context of Different APs Collected by User1

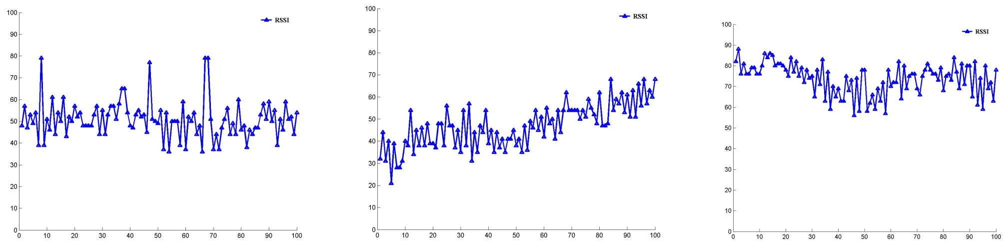


Figure 5. 8: RSSI Context of Different APs Collected by User2

Figure 5.9 shows the final results of AP1, AP2, AP3 for user 1 and user2. In this picture, we can see that AP3 should be the best choice for user1, and AP4 should be the best choice for user2.

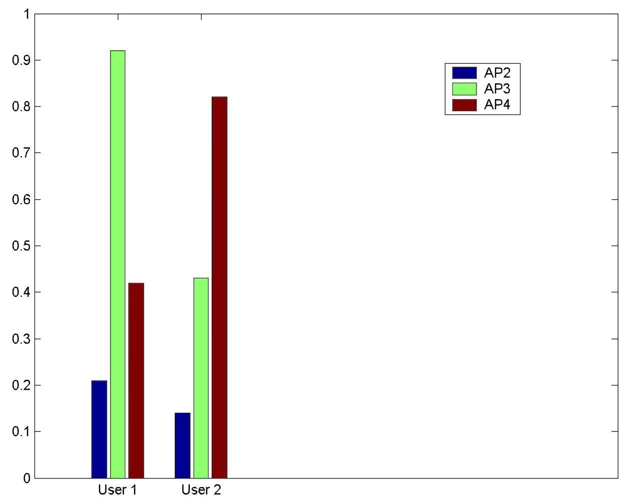


Figure 5. 9: Adaption of Time Estimation for Handover Process Changes

Since the probability cannot guarantee one hundred percentage accurate. We try to prove that the estimated probability result can guide a mobile user to select a wireless link, which is more stable than others. There are two users in our testing scenario for the link stability. However, the mobility and environment can hardly maintain exactly the same. Therefore, we select User 1, the static one, to perform anther experiments. Because User 1 is stationary, and the physical barrier interference in a room hardly change. We repeat to connect to AP2, AP3, and AP4 ten times, and record the largest link lasting time as one hour. Figure 5.10 shows the results, which indicate the link lasting time between the user 1 and AP2, AP3, AP4. The results almost match the predictions in Figure 5.9. AP 3 can provide user 1 a stable wireless link.

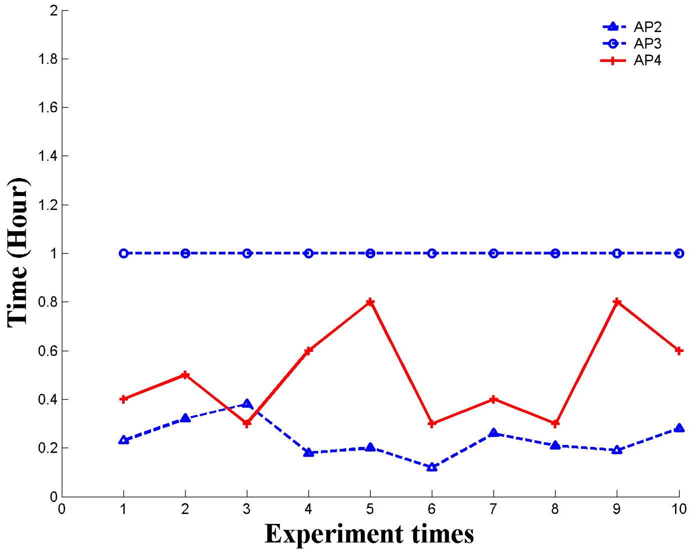


Figure 5. 10: Comparison of Link LastingTime

5.5. Summary

The context-aware prediction of link stability can help mobile user to select a stable wireless link, which can provide longer network services. In this prediction, there is no prior knowledge of network environment or mobility pattern. A Euclidean distance based K-mean clustering is adopted to classify mobile situations. Classification helps to delete unnecessary data, and to gain a more accurate probability for a specific user. Among all the process mentioned in this paper, the feature analysis and selection are the hardest parts. Because there is no specified situation that we can follow, the selection we have done is not completely. The analysis can cover more aspects, and the processing on the original data also can go deeper. We plan to do a further analysis with more features to have an insight view of this RSSI data.

Chapter 6. Conclusions and Future Works

In this chapter, we briefly summarize our works and outline the directions for future research.

6.1. Conclusions

The IEEE 802.21 framework is an evolutionary standard to assistant multi-media handover management. In this thesis, we represented our work of extending MIH platform with context-awareness. Two context-aware applications work as MIH service are proposed and evaluated in our test bed. The final testing results indicate that context-aware ability improves the performance of MIH services, and therefore optimizes the user experience in heterogeneous wireless networks.

In Chapter 3, we design the framework for our MIHCA. Because we build our MIHCA test bed, detailed functions and work flows are discussed for MIHCA services. As for the test bed, there are no real implementations at the time we begin our study. We had already implemented basic MIH event, command service and layer three MIH information services in heterogeneous networks between 802.11 and 3G.

In Chapter 4, we propose a context-aware prediction for handover trigger in the MES, named link going down event. This event is the most challenging one in the MES. Moreover, it has a large impact on user experience. If the handover trigger initiated late, it will lead to network services break down, otherwise, it will increase network overhead. We investigate the handover triggers, and figure out that a timely handover trigger should take user previous handover preparation time and physical link going to break into consideration. Finally, we compare the experiments for this handover trigger event with context-aware ability to those adopt static expert advised threshold in our test bed. Results show that our proposed mechanism can adaptively provide mobile users a timely handover trigger.

In Chapter 5, we proposed link stability as one primitive in MIS, and provide user the link stability for candidate wireless links. Many factors have impact on the wireless links including user mobility, user location, environment interference, handover policy. We deem that all the impacts come from those factors will finally show in the RSSI history. Therefore, we perform feature analysis and clustering on the RSSI history, and classify current mobile situations to calculate the corresponding conditional probability. Experiment results shows that this link stability information can well guide mobile users to select a stable wireless link.

6.2. Future Research Works

In Chapter 3, the context-awareness itself is a big topic. However, in our work, we mainly adopted it as a tool to optimize the MIH services. Therefore, if this work is carried on, it may require more focus on the context-awareness. More specifically, if mobile context can be formalized, then all entities in the heterogeneous wireless networks can communicate with this kind of context.

In Chapter 4, the context-aware prediction for MIH link going down only carried out in WLANs. In the future, we can extend our investigation to heterogeneous networks composed by WLANs, mesh networks and 3G cellular networks. Moreover, this handover trigger event can not only support local handover management, it also can provide triggers to a centre handover management. We may discover many issues in the central control handover management based on MES.

In Chapter 5, this part of work is initiated, because we deem that factors have impact on the wireless link stability, also have impacts on the RSSI history. This idea encourages us to discover their relationships. However, our work on digging the relationships is very limited. More features and further data processed can be tried. We believe that a large amount of information can be discover from the RSSI history, if we adopt proper data mining technologies to process the history.

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