Université de Montréal

Integrated Management of Interface Power (IMIP) Framework

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Mémoire présenté a la Faculté des arts et des sciences

en vue de l'obtention du grade de

Maîtrise ès sciences (M.Sc.)

en Informatique

Décembre, 2009

Université de Montréal
Faculté des arts et des sciences

Ce mémoire intitulé:

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Résumé

La présence importante de plusieurs réseaux sans-fils de différentes portées a encouragée le développement d'une nouvelle génération d'équipements portables sans-fils avec plusieurs interfaces radio. Ainsi, les utilisateurs peuvent bénéficier d'une large possibilité de connectivité aux réseaux sans-fils (e.g. Wi-Fi [1], WiMAX [2], 3G [3]) disponibles autour. Cependant, la batterie d'un nœud mobile à plusieurs interfaces sera rapidement épuisée et le temps d'utilisation de l'équipement sera réduit aussi. Pour prolonger l'utilisation du mobile les standards, des réseaux sans-fils, on définie (*individuellement*) plusieurs états (émission, réception, *sleep, idle,* etc.); quand une interface radio n'est pas en mode émission/réception il est en mode sleep/idle où la consommation est très faible, comparée aux modes émission/réception. Pourtant, en cas d'équipement portable à multi-interfaces radio, l'énergie totale consommée par les interfaces en mode idle est très importante. Autrement, un équipement portable équipé de plusieurs interfaces radio augmente sa capacité de connectivité mais réduit sa longévité d'utilisation.

Pour surpasser cet inconvénient on propose une plate-forme, qu'on appelle IMIP (Integrated Management of Interface Power), basée sur l'extension du standard MIH (Media Independent Handover) IEEE 802.21 [4]. IMIP permet une meilleure gestion d'énergie des interfaces radio, d'un équipement mobile à multi-radio, lorsque celles-ci entrent en mode idle.

Les expérimentations que nous avons exécutées montrent que l'utilisation de IMIP permet d'économiser jusqu'a 80% de l'énergie consommée en comparaison avec les standards existants. En effet, IMIP permet de prolonger la durée d'utilisation d'équipements à plusieurs interfaces grâce à sa gestion efficace de l'énergie.

Mots Clés: MIH (Media Independent Handover), Proxy, Proxied Interface, Energie Consommé, Mise-a-jour de localisation, mode Idle

Abstract

The large availability of wireless networks of different ranges, has contributed to the development of new generation of handheld devices with multi-radio interfaces. Thus, the end-users are able to achieve ubiquitous and seamless connectivity across heterogeneous wireless networks (e.g., Wi-Fi [1], WiMAX [2] and 3G_LTE [3]). However, a mobile node with multi-radio interfaces has its battery energy consumed rapidly, which reduces the operation/usage time of the device. To improve battery usage, wireless network standards have defined (*individually*) different interface states (transmit, receive, idle, sleep, etc.); when an interface is not transmitting or receiving, it goes to sleep/idle state where energy consumption is very low compared to transmit and receive states. However, in the case of multi-radio handheld devices, the total energy consumed by the interfaces in sleep/idle state is significant. Thus, equipping a mobile device with multiple interfaces increases its seamless connectivity but reduces its operation/usage longevity.

To overcome this inconvenient, we proposed a framework, called IMIP (Integrated Management of Interface Power) that consists of an extension of MIH (Media Independent Handover) IEEE 802.21 standard [4]. IMIP allows a better power management of radio interfaces of a multi-radio mobile node; indeed, it reduces considerably energy consumption. The basic idea behind IMIP is to shut down any interface in idle mode and use a proxy that emulates the interface; the proxy wakes up the interface when it receives a connection request directed to this interface. IMIP requires at least one interface in active mode. Experiments show that using IMIP enables a saving of up to 80% of power consumption compared with existing power management standards. Thus, IMIP allows longer usage of multiple interface devices thanks to its effective energy management.

Keywords: MIH (Media Independent Handover), Proxy, Proxied Interface, Energy Consumption, Location Update, Idle mode

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List of acronyms and abbreviations

Acronyme	Description
AP	Access Point
BS	Base Station
DHCP	Dynamic Host Configuration Protocol
DNS	Domain Name System
eNB	Evolved NodeB
GPS	Global Positioning System
IMIP	Integrated Management of Interface Power
IS	Information Server
LU	Location Update
LTE	Long Term Evolution
MICS	Media Independant Command Service
MIES	Media Independant Event Service
MIH	Media Independant Handover
MIIS	Media Independant Information Service
MME	Mobility Management Entity
NSE	Network Selection Entity
MN	Mobile Node
SIP	Session Initiation Protocol
PA	Paging Agent
PC	Paging Controller
PoA	Point of Attachement
PoS	Point of Service
UE	User Equipment

WLAN	Wireless Local Access Network
WMAN	Wireless Metropolitan Access Network
WWAN	Wireless Wide Access Network

Accord des coauteurs

Dedication

To my wife.

To my parents.

To my family.

To my family in law.

Remerciements

Je tiens tout d’abord à adresser mes remerciements et ma gratitude à mon directeur et mon codirecteur de recherche, les professeurs *Abdelhakim Hafid* et *Behcet Sarikaya* pour leur patience, leur disponibilité, leur aide et leur support tout au long de ce travail.

J’aimerais remercier ma femme ***Imane*** pour sa présence et son soutien permanent.

Enfin, que tous celles et ceux qui m’ont apportés leur appui trouvent ici l’expression de mes sincères remerciements

Chapter 1

Introduction

1.1 Multi-Radio Interface Device

Nowadays more multi-radio networks coexist with radios operating on adjacent and overlapping frequency bands. This coexistence has encouraged manufacturers to integrate multi-radio interfaces in one handheld device. This became possible thanks to integrated digital CMOS (Complementary Metal–Oxide–Semiconductor) processes and digital circuits. Fig. 1 shows an example of circuit card [21] containing two chips, ‘W2CBWG01’ and ‘W2CBWG03’, which are fully integrated 802.11b/g WLAN, Bluetooth and GPS solutions designed specifically for ultra-mobile portable electronics.

Figure 1: Circuit card with 3 fully integrated radio technologies [21]

The new generation of handheld devices, for example iPhone (apple), are now equipped with 3G, Wi-Fi, Bluetooth and GPS radio interfaces. The new generation of iPhone will be equipped also with WiMAX [2] interfaces too. This allows seamless connectivity to the iPhone user, as illustrated in Fig. 2. The user is then able to use the same device, his iPhone, to connect to the local network (WLAN) in his work place or home and establish an internet connection. When leaving his work place or home, he doesn’t need to *reestablish* the internet connection using WiMAX interface; he could seamlessly continue using his internet connection while moving his radio connection to WiMAX network. If the user moves from WiMAX radio area coverage, he could switch again seamlessly to 3G network and keep using the same internet connection. Obviously, this seamless handover procedure from one radio network to another is possible if the mobility over heterogeneous networks is supported by the network (see MIH IEEE 208.21 [4]).

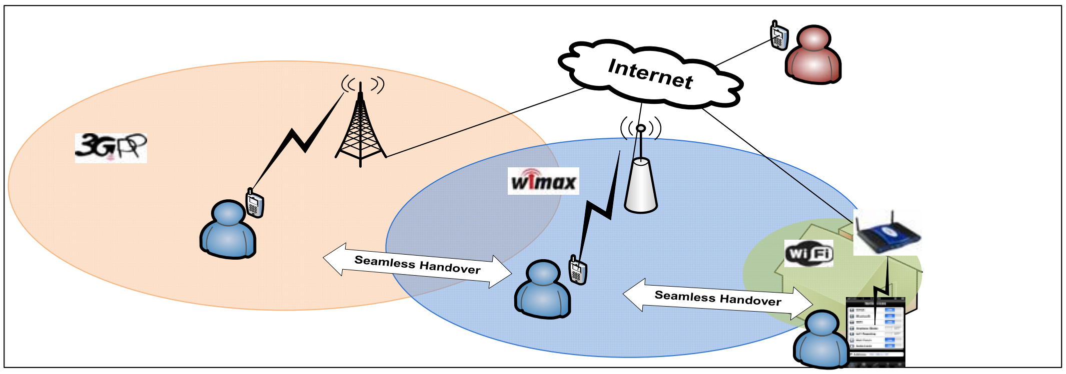

Figure 2: Example of inter-technology handover from Wi-Fi, WiMAX than 3GPP network.

1.2 Energy consumption issue

Multi-radio handheld devices have limited battery life time. According to [12] and [5] the radio interfaces in a PDA are the main source of energy consumption. A device equipped with multiple radio interfaces has its battery life decreasing rapidly. This is due to energy consumption of each radio interface even if they are not used for transmitting or receiving effective data. When an interface is transmitting, the energy consumption is the highest; lower when receiving and the lowest when in idle/sleep state. According to [12], [6] and [8], energy consumption of radio interfaces (Wi-Fi, WiMAX and 3G) in different states (transmitting, receiving and idle) is presented in Table 1.

Table 1: The power of radio interfaces for different modes.

Mode	Wi-Fi	WiMAX	3G
Tx(mW)	890	530	1100
Rx(mW)	690	510	555
Idle(mW)	256	80	19

The idle state is defined individually by each network standard. In general, it allows energy consumption reduction when the interface is not used (transmitting/receiving). However, when we put together the power consumption of the multi-radio interfaces in idle state, the consumed power energy is considerable. This is due to the fact that each interface in idle state is managed individually according to (or by) its defined standard.

1.3 Motivation

Energy consumption becomes a critical issue for devices with multi-radio interfaces. Power management has been already addressed by the different wireless network technologies/standards; however, it is considered from single radio interface point of view. We propose to use these solutions, however, from global point of view; indeed, we propose an integrated power management that proxy (and shut down) interfaces in idle mode and makes use of only one active interface. Our proposed approach enables considerable energy savings (see Chapters 3-4 [10, 11]) and it is based on MIH (IEEE 802.21) [4] which is a standard that allows seamless handover from one wireless network technology to another. This seamlessness is realized by a number of services (Command, Event and Information) and primitives defined in IEEE 802.21. It was easy choice for us to consider using IEEE 802.21 as a baseline to define our proposed approach. Indeed, most of service and primitives defined in IEEE 802.21 can be used to realize our approach; thus, we defined new primitives and extended functionalities, as an extension of MIH, called EMIH (Enhanced MIH) to implement our proposed integrated power management.

1.4 Contributions

In this project, we propose a solution for the energy consumption issue, called IMIP (Integrated Management of Interface Power). It consists of proxying idle radio interfaces, of a multi-radio device, when in idle mode. When proxied, the idle interfaces are turned off which allows considerable energy saving. Our contributions can be summarized as follows:

- In the first contribution [10], we proposed two sets of mechanisms that allow the management of idle radio interfaces. The first mechanism defines the procedures to be performed when an interface enters idle mode. The second mechanism defines the procedure to wake up an idle interface after being proxied. It is important to emphasize that during the idle/proxied period, the network believes that the interface is in idle mode; this way the assigned resources (to the corresponding mobile device), by the network, will stay maintained. When the proxied interface is powered-off, to ensure the communication between the MN (Mobile Node) and the network (of the proxied interface) we propose to use the active interface; we assume that a single radio interface is always active to maintain an IP session with the proxies(s) in the network(s). Thus, during the proxing period the communication between the mobile and the network is made through the active interface.
- In the second contribution [11], we propose another proxying mechanism "Proxying Location Update". The idle interface has to perform a location update to inform the network about its current location. The location procedure is performed either periodically or following location (paging/tracking area) change. This requires that the idle interface has to become available periodically to perform a location update and to check its current location; if it is in a new location it has to perform a location update. This situation is a source of energy consumption which could be saved/reduced if the proxy entity [10] (defined in the first contribution) performs the location update procedure instead of the idle interface. We identified two possible ways to proxy the location update: (1) the MN mobility is not considered and only

the periodic location update is proxied. In this case, the network believes that the mobile didn't change the location even if it does; and (2) the periodic location update procedure is proxied and the MN mobility is considered; the MN is able to determine its position (e.g., based GPS). In this case, the mobile checks periodically its geographic location and decides whether a location update should be performed or not

- If the response is yes, the proxied interface will be waken-up to perform a location update to inform the network about its new location.

This thesis is presented as 2 papers format. The first paper [10], "*A Framework for Power Management of Handheld Devices with Multiple Radios",* was published in IEEE WCNC 2009 and the second paper, *"Proxying Location Update for Idle Mode Interfaces"* was accepted in IWCMC 2010, [11].

1.5 Organization of thesis

The rest of this thesis is organized as follows. Chapter 2 presents related work. Chapter 3 consists of the paper "*A Framework for Power Management of Handheld Devices with Multiple Radios"* [10]. Chapter 4 consists of the paper *"Proxying Location Update for Idle Mode Interfaces"* [11]. Chapter 5 concludes the thesis and presents future work.

Chapter 2

Literature Review

In this chapter, we present an overview of wireless network standards and literature related to our research project. More specifically, we present idle mode and location update mechanisms, as defined in WiMAX/IEEE 802.16 [2] and 3G LTE (third Generation Long Term Evolution) [3] standards and the network entities directly concerned with these mechanisms. We also present the handover mechanism as defined in MIH standard [4] and the network entities supporting this mechanism. Then, we present the key contributions that aim to increase energy savings in wireless devices. We conclude by presenting a critical analysis of these contributions; this analysis gives the rationale behind our contributions in this thesis.

2.1. Network Standards

This section aims to provide an overview of idle mode as a mechanism to achieve a power saving and location update (in idle mode) as a mechanism for tracking the location of MNs. The network entities, PC/MME (Paging Controller/Mobility Management Entity) supporting these mechanisms in WiMAX/3G LTE systems, are briefly presented. This section also provides a brief description of paging/tracking areas used in the schemes that support both idle mode and location update mechanisms.

In this section, we also briefly introduce MIH standard, more specifically MIH services, IS server entities and a scenario describing a handover procedure,

2.1.1 WiMAX Technology

WiMAX is WMAN (Wireless Metropolitan Area Network) technology, also known as IEEE 802.16 [25], which provides up to 10 Mbps broadband wireless access within a range of up to 50/15 km for fixed/mobile nodes and designed to operate in 2-11 GHz frequency range. WiMAX technology, already, considered as a leading technology for next-generation mobile broadband, intends also to satisfy the requirements of 4G[1] standards.

Power saving is one of the key features supported by WiMAX standard; it helps reducing the power consumption of MNs (equipped with a WiMAX interface) not in active mode. To realize this feature, WiMAX defines; (1) Idle mode as a low power state; (2) location update as a procedure to update the system about the current location of the MN; and (3) paging area as a way of grouping base stations. WiMAX has also defined PC (Paging Controller) entity that manages the idle MNs located in paging area(s) that under its (PC) management. The idle MNs need to perform the location update procedure to update the PC about their new/current locations.

Before briefly describing the idle mode and location update in WiMAX networks, we define paging area and paging controller.

Paging Area

Base stations are divided (grouped) into logical groups called paging areas. They (paging areas) form a contiguous geographic coverage region where the MN does not need to transmit in the upper-link (communication from the user to the system), and can be paged in the downlink (communication from the system to the user) if there is traffic coming for it. The size of the paging areas should be designed large enough in such that the MN will remain within the same paging group most of the time, and small enough that the paging overhead is reasonable. Fig. 1 shows an example of a MN moving from one paging area to another.

[1] Refer to fourth generation of cellular wireless standards. Unlike earlier wireless standards (e.g. 2G, 3G), their successor, 4G technology is based on TCP/IP (core protocol of the Internet).

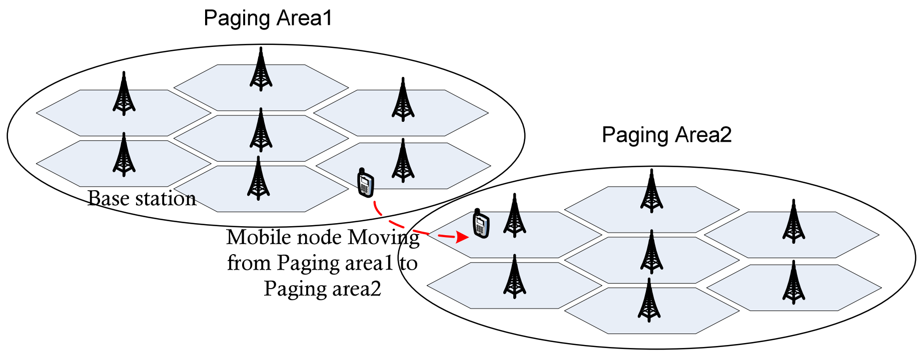

Figure 2: A mobile node moving from one paging area to another.

Paging Controller

PC (Paging Controller) is a functional entity that manages the activity of idle MNs in the network. The WiMAX standard [1] requires that each idle MN should be managed by a single PC (*anchor* PC). The latter manages and maintains the location information, of idle MNs located in the paging area(s) under its management, up to date. The location information maintained in the system is in fact, stored in an LR (Location Register) entity. WiMAX also defined *relays* PCs (non-anchor PCs) which participates in relaying paging and location management messages (from/to anchor PC). For different reasons (e.g. mobility) the idle MN could be assigned a new (different) anchor PC; this is referred to as PC relocation. The relocation happens mainly during the location update procedure.

Idle Mode

To reduce the power consumption of MNs and allow them to operate for a longer duration, WiMAX/IEEE 802.16 standards define two power-saving modes: (1) sleep mode; and (2) idle mode. When the MN has no traffic (not transmitting/receiving), it switches either to sleep mode or idle mode as the power consumption is lower in these modes. In both modes, the MN radio interface is powered off (in a controlled manner) and becomes occasionally available to receive calls from the network. Unlike in sleep mode, where the

MN has to keep registered with the serving base station and has to perform a handoff[2] procedure if necessary, in idle mode the MN has not. This allows it to achieve greater power saving [25].

However, even when not registered with any base station, the idle MN (with the interface in idle mode) still receives downlink broadcasted traffic. The MN exits idle mode (wakes-up) when it receives an indication of down link traffic from the system. To exit idle mode, the system sends a paging message (paging procedure [1]) to all base stations forming the paging area where the idle MN is believed to be currently located (last reported paging area).

Once the MN is paged and exits idle mode, it goes to active mode to handle the received call. Note that the MN (in idle mode) is also required to wake up periodically (for a listening period) to update its stored paging area identification and report it to the network if necessary (see location update mechanism below).

Location Update

When entering idle mode the MN is assigned a PC that manages the serving base station and the paging area it belongs to. The mobility management of idle MNs is based on the location update procedure. For the PC to track the location (paging area identification) of a managed idle MN, the MN should report its current location periodically and after each paging area change. The idle MN uses the location update procedure to report to its managing PC its current location. The PC could also initiate (request) a location-update procedure to update the maintained location information in the system. This location information helps the paging system to locate and page the idle MN efficiently (in terms of response time and deployed resources).

[2] Handoff procedure is the process of moving from one serving entity (i.e. base station) to another one.

2.1.2 LTE Technology

LTE (Long Term Evolution) is the next generation of mobile telecommunication networks and the last toward the 4G cellular networks. The LTE project is based on a set of enhancements to the existing UMTS (Universal Mobile Telecommunications System) technology and aims to comply with IMT-Advanced (International Mobile Telephony-Advanced) 4G [29] requirements. LTE is also considered as new generation of WWAN (Wireless Wide Area Network) technology; it is required (designed) to provide up to 100 Mbps for downlink and 50 Mbps for uplink with a radio latency of 10 ms. The LTE coverage range expected to go from 5 Km (full performance) to 100 Km (operational).

LTE specifications also addressed a set of power management requirements including idle mode [26] to reduce the power consumption of the MN when it is not active. In LTE systems, it is the MME (Mobility Management Entity) that manages the mobility of the MN in both modes: active and idle. The MME is also responsible for paging the idle MN when downlink traffic is received. The base stations, called eNB (evolved NodeB) in LTE system, are also grouped in what is called Tracking Areas. To page an idle MN, MME sends a paging message to the tracking area reported (by the MN) during the last tracking area update (procedure).

Before briefly describing the idle mode and location update in LTE networks, we define tracking area and mobility management entity.

Tracking Area (TA)

A tracking area model, in LTE system, is similar to paging area defined in WiMAX. A tracking area is a logical grouping of cells (eNBs) that helps to represent and manage the locations of MNs at higher level. It is important to note that LTE network management considers dynamic re-configuration of the TA(s) based on collected network statistics and monitored performance indicators. Note also that a MN could be assigned multiple tracking areas (in his TAL - Tracking Area List) to avoid unnecessary Tracking Area Updates

Mobility Management Entity (MME)

MME is the network entity that manages and stores MN contexts, generates temporary identities and allocates them to the MN. It is the key access-control network in LTE systems; it checks the authorization of MN to camp on the TA. It is also responsible for idle MN mobility management including tracking its location and performing paging procedure when needed.

Idle Mode

Unlike in active mode, where the MN is in full power mode and its location is determined at cell level, in idle mode, the MN is in power-conservation mode and does not inform the network of each cell change [25]. LTE system needs to track the location of idle MN to the granularity of a tracking area. In fact, idle MN maintains a list of tracking areas, sent by MME during idle mode entry, where the MN can traverse without updating the MME (by performing a tracking area update). To wake-up an idle MN, the MME pages it in the last reported tracking area list.

Tracking Area Update (TAU)

Unlike in WiMAX system, where the MN performs location update with the PC only in idle mode, in LTE systems, the MN may perform a TAU (Tracking Area Update) [30] with its managing MME, in both active and idle mode.

In LTE systems [4], a MN entering the network is assigned a TAL. The MN does not need to perform a TAU as long it is moving within these TAs. When the MN enters a new TA, not in the assigned list (TAL), it has to perform TAU with its MME. Note that if the new entered TA is managed by a different MME, the management of the MN is then relocated to the new MME; this is done during TAU with MME relocation. After performing a TAU, the TAL maintained in the system is updated with the one stored in the MN. The TAU is always initiated by the MN.

The TAU procedure could be also triggered when [30]; (1) a periodic TAU timer has expired; (2) a change of MN capabilities (e.g. radio, network, etc...); and (3) a change in the network configuration (e.g. caused by a load balancing of eNBs, dynamic reconfiguration of the network).

2.1.3 Media Independent Handover

MIH (Media Independent Handover) or IEEE 802.21 is a standard developed to enable mobile devices to seamlessly handover between different types of network technologies (e.g. moving from 802.11 network to 802.16). The handover procedure is composed of three steps:

1. *Initiation*: This step corresponds to the situation where the mobile device needs to move to another network (e.g. because the current radio link is going down or does not satisfy the application requirements). During this step all the available links in the mobile device neighborhood are discovered and pre-selected for handover.
2. *Preparation*: In this step, the resources in the future serving network are checked and reserved. The MN is then committed to handover to this network and sets up radio-link layer connection and IP connectivity with this one (called handover commit).
3. *Execution*: After link setup, with the new network, the mobile device starts handover signaling exchange, context transfer and finally data packet transfer and reception with the new network (also called handover compete).

To perform handover, the mobile device relies on network MIH functional entity called PoS (Point of Service) which could be collocated with AP (Access Point). Note that MIH standard scope mainly focuses on the first two presented steps. The third step, handover execution, is not considered within the scope of MIH. The next sections are brief presentations of the MIH services, IS (Information Server) and a case scenario illustrating a handover from one network technology to another one.

MIH Services

The communication between the MIH entities makes use of the MIHF (Media Independent Handover Function) layer located between layer 2 (wireless technology) and layer 3 (IP layer). The MIH messages are exchanged between different entities and different layers; they go through the MIHF layer. The exchanged MIH messages are of three types: event, command and information. MIHF layer is composed of three services that generate and handle these messages:

1- *MIES* (Media Independent Event Service): This service handles the event messages used to indicate the link or physical layer state changes in real time. The events may concern local or remote link/physical layer and are reported to the upper layer to be considered for any decision making. Event messages flow is always from lower layers to upper ones.
2- *MICS* (Media Independent Command Service): This service handles the command messages generated by higher layers (e.g. as reaction to a received event). The command message may convey a user decision to switch from one radio interface to another. They could concern local or remote decisions and their flow is always from upper layers to lower ones.
3- *MIIS* (Media Independent Information Service): This service handles the information messages that concerns mainly heterogeneous networks. This information, stored in MIH entity called IS (Information Server), concern mainly the resources of networks (candidates for a handover) in the mobile device neighborhood. This helps MN to achieve a seamless wireless handover. The flow of information messages is either from upper to lower layers or opposite.

Information Server (IS)

Information server is the MIH entity where the heterogeneous information concerning available neighboring networks is maintained; it could be requested by other MIH entities, particularly a MN detecting a handover condition. More specifically, the IS maintains, in its database, a list of available networks (e.g. 802.11/16, GSM, UMTS, LTE etc…), link layer information, higher layer services, operator costs or even vendor specific information. All this information could be requested and used for discovery and selection of networks during a handover.

Handover Scenario

In this case, we provide an overview of a handover in a heterogeneous environment, more specifically from Wi-Fi to WiMAX network, illustrating the MIH operations. Fig. 2 shows a user in communication with another one, using Wi-Fi network connection at home. When he starts leaving the house (getting away from Wi-Fi network), his Wi-Fi connection starts going down; thus, he switches to another available wireless network (WiMAX in this scenario). This network switching (handover) takes place without stopping or interrupting the user conversation (communication).

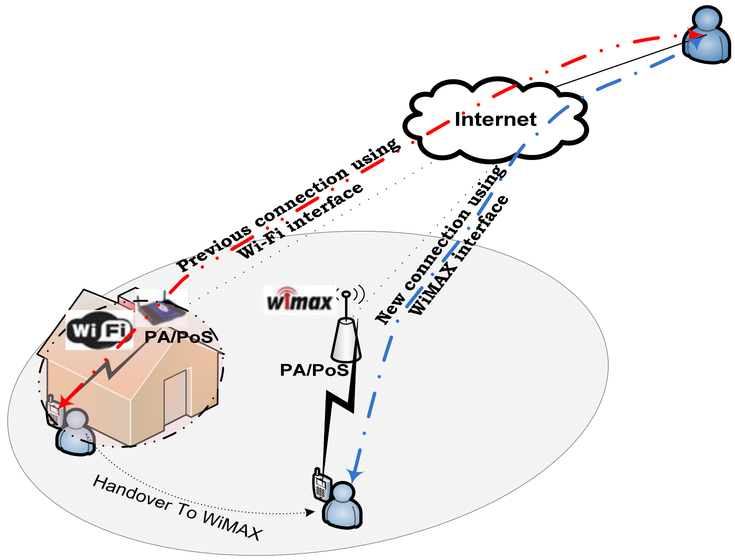

Figure 3: Case scenario of handover in a heterogenous envirement (from Wi-Fi to WiMAX network).

Fig. 3 describes the interactions between the MN and other MIH entities (PoS and IS) that took place in the scenario shown in Fig. 2. These interactions to initiate, prepare and execute the handover from WiFi network to WiMAX network, are as follows:

1- After leaving the house, the MN detects degradation in the radio signal strength received from Wi-Fi serving AP.

2- The MN then uses MIH Event Notification Service to inform the MIHF layer in the Wi-Fi/PoS about the link going down.

3- To prepare for a handover, the Wi-Fi/PoS sends a MIH Information message to the IS requesting the list of the APs (of different networks) in its location.

4- The IS processes and determines a list of candidate APs that are located near the requesting Wi-Fi/PoS.

5- The IS response contains the list of APs candidates for a handover.

6- The Wi-Fi/PoS sends a MIH Command message requesting it to scan the list of candidate APs.

7- The MN uses the received list of candidate PAs (Point of Attachments), performs a radio scan and makes a selection based on the results of the radios scan.

8- The selected PAs are sent back to the Wi-Fi/PoS as a response.

9- The Wi-Fi/PoS sends a Command request asking for the available resources in the selected networks (APs). Only the case of WiMAX is shown here.

10- After processing the response, the Wi-Fi/PoS selects the AP (in this case WiMAX/PoS network) with sufficient available resources.

11- After selecting WiMAX as the new network for the handover, the Wi-Fi/PoS sends a MIH Command, to commit to handover, to the WiMAX network.

12- The Wi-Fi/PoS informs and requests the MN to commit to handover with WiMAX/PoS entity.

13- The MN establishes radio link and IP connection with WiMAX network.

14- At this stage, the handover preparation is achieved, the handover execution is made. This includes MN context transfer to WiMAX network, higher layer handover and traffic flow re-establishment. This step also includes the release of the resources that were used by the MN in the old network (Wi-Fi).

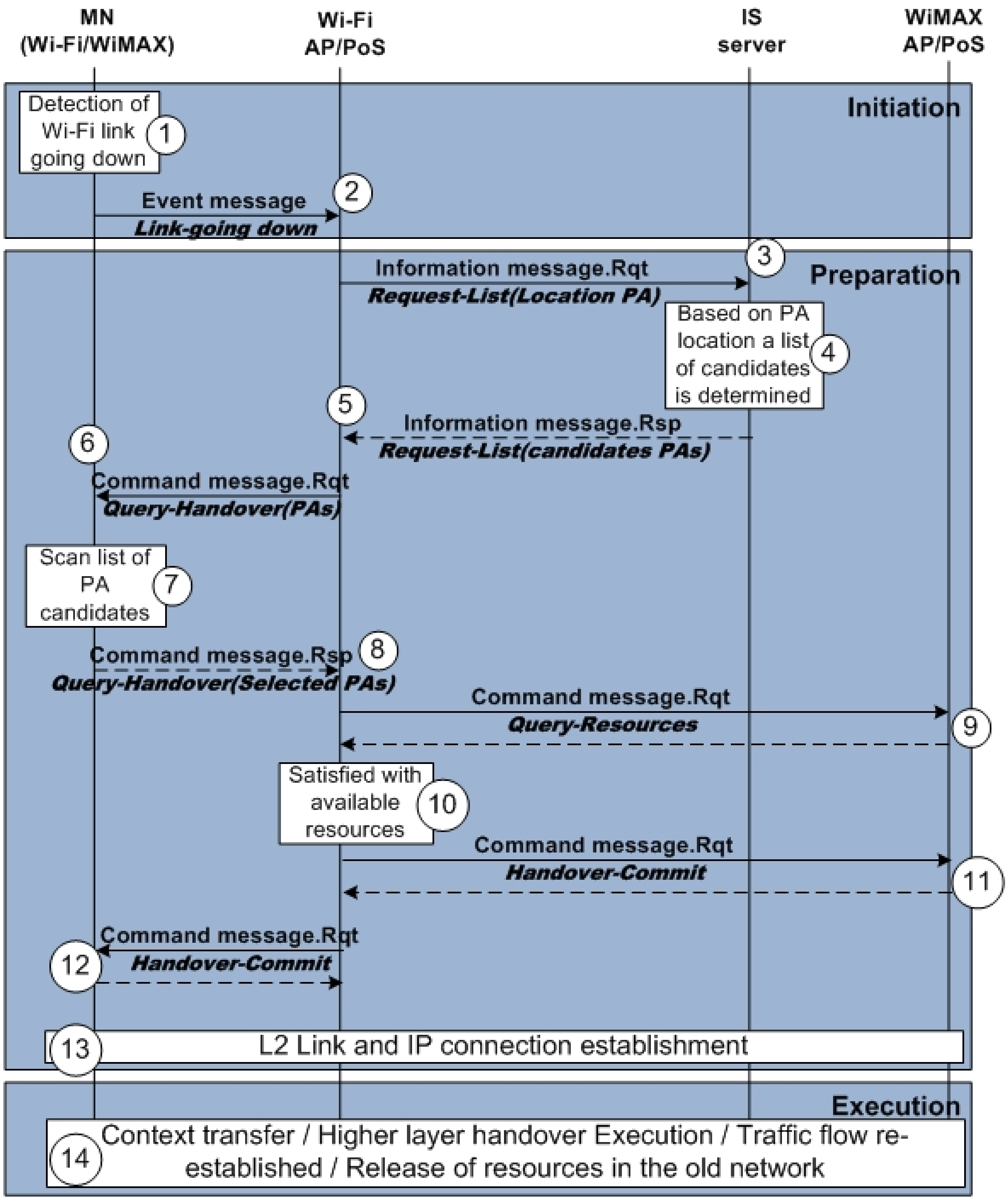

Figure 4: Simplified sequence diagram of case scenario of a handover from Wi-Fi to WiMAX network.

2.2 Key related Contributions

In this Section, we present briefly the most related contributions to our research in this thesis.

2.1.1. Hybrid location-Update Scheme

The hybrid location-update scheme [12] is an approach which combines two approaches (time-based and movement-based) that an MN uses to update the network concerning his location.

Time-based approach consists of updating periodically (every T time-unit) the system about the mobile location and movement-based approach consists of updating the system about the mobile location each time the mobile has crossed N cell-boundaries. The key issue with these approaches is that they may update the system too or less frequently than needed. This may cause either (1) waste of resources (including MN energy) when unnecessary location updates are processed; or (2) non-accuracy of the MN current location; this may introduce considerable delay to locate the MN upon receipt of a call directed to the MN.

With the objective to reduce energy consumption, the authors [12] propose a scheme to compute "optimal" values for T (time between two location-updates) and N (number of crossed cells).

First they define the total update period

$$T + \sum_{i=0}^{N-1} m_i \qquad (1)$$

where m_i is the i^{th} cell-residence time (i.e., the time spent by the MN inside cell i).

Figure 54 is a time diagram of the hybrid scheme. It shows the location updates taking place between two consecutive calls. Each location update process takes one cycle period time (as defined in equation (1)).

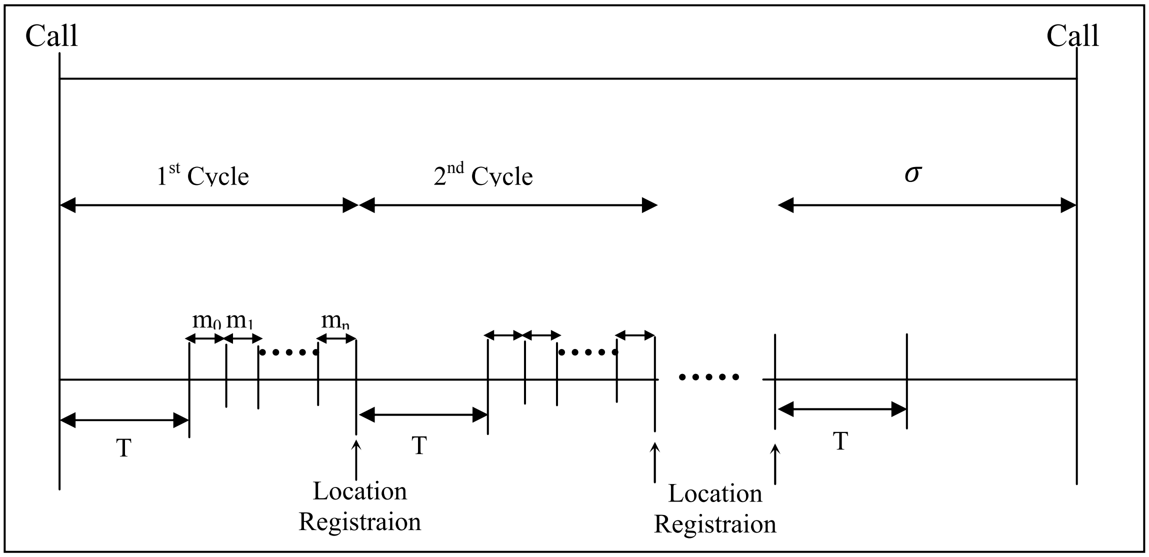

Figure 5: Frequency of location updates between two calls in hybrid scheme [12]

To estimate the total cost $C_T = C_u + C_v$ of location-management, the authors consider two costs: (a) C_u the cost of location update process; and (b) C_v the cost of paging a mobile after a call arrival. The network cells are considered arranged in rings model. This way, if a call arrives and the MN is not in the last reported cell, the system pages the MN (tries to locate it) in the first ring. If the system does not succeed locating the MN, then it will consider the second ring; the process continues until the MN is located.

The authors define the first cost as follows:

$$C_u = U \sum_{h=0}^{\infty} h q_h = U.g. \sum_{h=0}^{\infty} h(1-g)^h = U(\frac{1}{g} - 1)$$

where U is the cost for update message transmit, h is the number of location updates between two consecutive calls, $q_h = g\,(1-g)^h$ is the probability of a call arrival after h location updates and $g = P[c < T + m_0 + m_1 + \dots + m_{n-1}]$ is the probability of a call arrival after one location update. Notice that call arrivals are modeled as 'Poisson' process.

The second cost is defined as follows:

$$C_v = V \sum_{j=0}^{\infty} \pi_j w \omega_j$$

where V is the cost for page message transmit, j is the number of rings paged to locate the mobile, ω_j is the sum of cells in all the rings (from ring 0 to ring j) and π_j is the probability that a call arrives to the mobile located in the j^{th} ring (refer to [12] for more details about ω_j and π_j).

Based on their numerical results, the authors conclude that the movement-based approach works better when the coefficient of variation of cell residence time is relatively small. The hybrid approach outperforms the time and movement-based schemes when this coefficient is large.

2.1.2 Autonomic Group Location Update for Mobile Networks

The autonomic group location update (GLU) scheme [15] is used to report the location update, of a group of MTs (Mobile Terminals[3]) forming a mobile network, to the system. This scheme consists of electing a Leader Mobile Terminal (LMT) responsible of reporting the location update to the system on behalf of all MTs in the group. This scheme helps reducing energy and network bandwidth consumed by each MT when performing a location update. Since the communication range between MTs is shorter compared with the communication range between MTs and the system (Base Station - BS), minimizing the communication between MTs and the system helps definitely reducing energy consumption

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[3] The authors use MT (Mobile Terminal) to refer to MN Mobile Node.

of MTs. To realize GLU scheme, new group management procedures and architecture need to be implemented.

Fig. 5 shows the architecture in GLU where the base stations of the system network are grouped in Location Areas (LAs). As shown in Fig.5 a group of MTs that form a mobile network is moving from LA1 to LA2 which are delimited by LAB (LA Border).

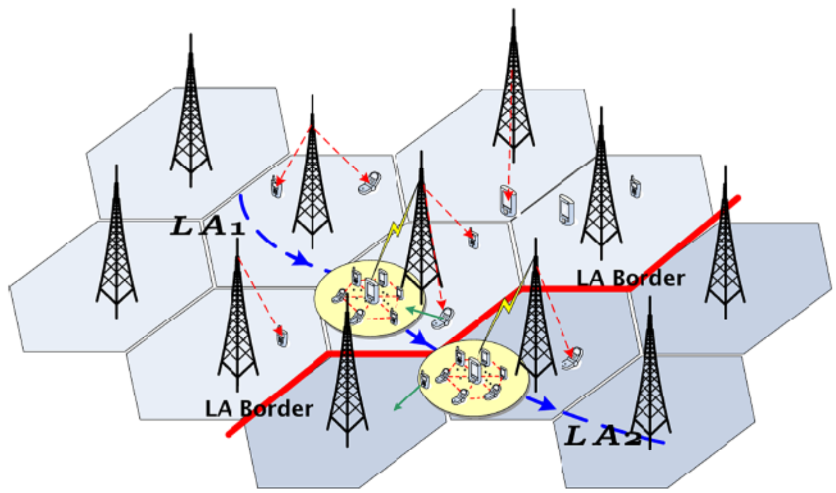

Figure 6: Typical scenario of group location update [15]

In summary, unlike in the classic Individual Location Update (ILU) scheme (where the MTs need to communicate directly with the base stations (*vertical communication*)), in GLU scheme the MTs communicate with the LMT (*horizontal communication*); the only one to communicate with the base stations. Obviously, the power cost for horizontal communication is much lower than vertical communication which GLU scheme is exploiting to save power energy of MTs' battery. The location update is then performed by the LMT on behalf of all registered members or GM (Group Members). The information concerning the location of the mobile network [15] is stored in Group Location Database (GLDB). This way, when a call to a MT (or GM) is attempted, the current location of the callee, more exactly the callee group, could be requested from the GLDB. The call can then be established between the caller and the callee of the mobile network. The GLU scheme realization is based on the implementation of the following operations/procedures: Group establishment, Group leader (re-)selection, join and quit the group, group and location update. More details on these operations can be found in [15]

2.1.3 CoolSpots: reducing the power consumption of wireless mobile devices with multiple radio interfaces

Pering et al. [17] propose a model called 'CoolSpots' that enables a wireless mobile device to automatically switch between multiple radio interfaces. They studied, mainly, the case of switching between short-range to very short-range radio-interfaces, such as between Wi-Fi and Bluetooth. Indeed, only the radio interface that fulfills the need of the MN (of the current running application) will be used and the other interface could be disabled; this will help increasing the battery lifetime of the multi-radio device.

According to Fig. 6, the energy consumption of the main components of a wireless device (in idle state) is dominated by the consumption of Wi-Fi interface; it consumes about 70% of the total energy. In general (according to Table1 page 32), Bluetooth interface is less expensive in term of power consumption than Wi-Fi interface.

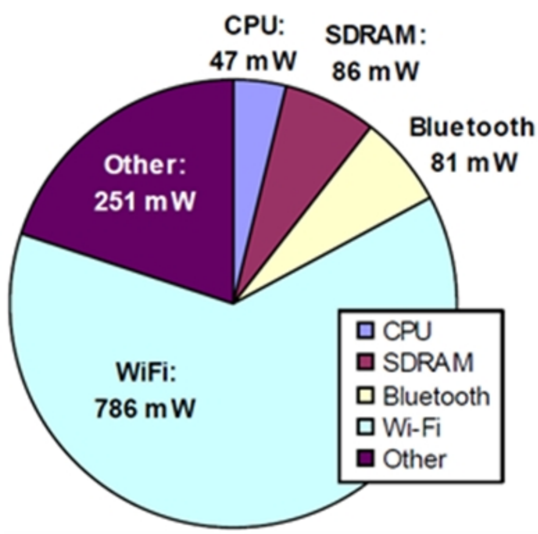

Figure 7: In idle state the Wi-Fi interface consumes approximately 70% of the total power [17]

Table 1: Comparing power consumption of Wi-Fi and Bluetooth radio interfaces in different states [17].

Interface	**Low-Power Idle**	**Active Tx**
WiFi Cards		
Cisco PCM-350	*390 mW*	*1600mW*
NetGear MA 701	*264 mW*	*990 mW*
*Linksys WCF12**	*256 mW*	
Bluetooth		
BlueCore3	*5.8 mW*	*81 mW*
*BlueCore3**	*25 mW*	*120 mW*

The authors propose a switching radio interface system (called CoolSpots) that considers power consumption and radio range of each radio interface to determine an optimal radio configuration. In summary, the basic idea behind CoolSpots switching system to determine the radio interface (WI-FI or Bluetooth) to be used (considering their radio states) is to select the one with lowest energy consumption that can satisfy the application requirements (e.g., in terms of bandwidth). As shown in Fig. 7, the interface not in use is switched to PSM (Power Saving Mode) in the case of WI-FI and Sniff[4] [28] in the case of Bluetooth; in these modes, the interface energy consumption is reduced.

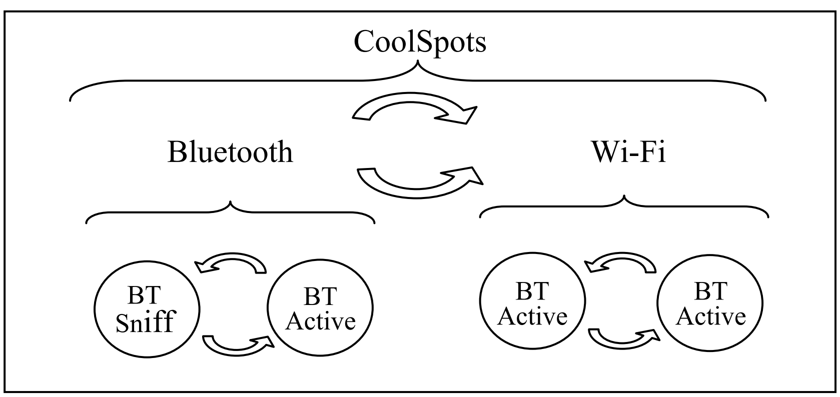

Figure 8: CoolSpots model consists of radio interface switching.

[4] Sniff mode is a low-power mode defined by Bluetooth specifications. The listening rate in this mode is reduced to conserve battery life.

Experiments [17] show that a substantial energy savings (more than 50% reduction in energy consumption of the MN could be achieved when using CoolSpots.

2.1.4 Wake-on-wireless: An event driven energy saving strategy for battery operated devices

Generally, PDAs (Personal Digital Assistants) use Wi-Fi to connect wireless LANs; this quickly drains PDA battery after only few hours being in non-active/idle state. Unlike Wi-Fi technology, cellular phones have up to several days for their idle lifetimes. Fig. 8 compares lifetime of a cell phone (GSM Motorola V60t) against a PDA (Compaq iPAQ H3650 equipped with a WiFi interface) both in standby mode. In the case of PDA, two modes are considered CAM (Continuously Awake Mode) and PSM (Power Save Mode) which allows more power saving. Fig. 8 shows that a cell phone has lifetime 3 times bigger than PDA using PSM and 10 times bigger with using CAM.

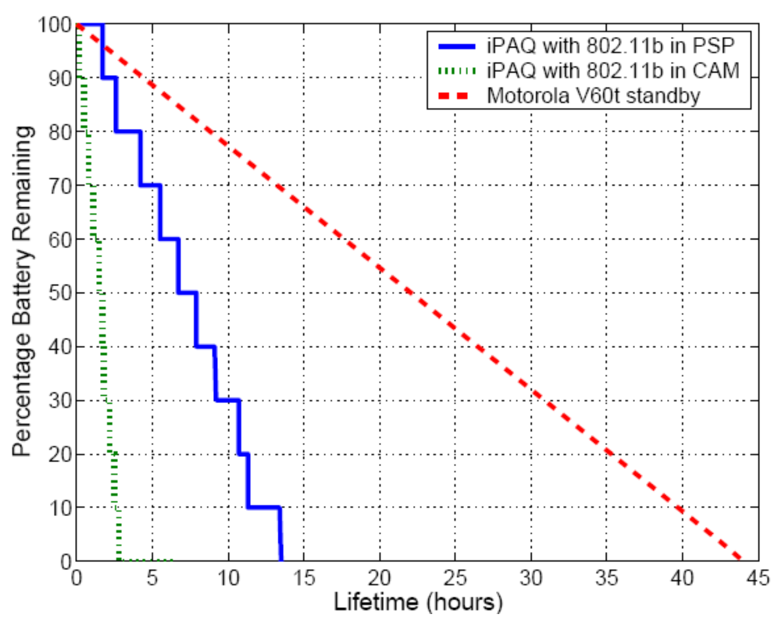

Figure 9: Comparing standby lifetime of a Motorola V60t (cell phone) with an IEEE 802.11b card in PS/CAM modes [18].

In wake-on-wireless [18], the authors introduce a technique that helps increase the battery lifetime of a PDA ideally make it comparable to the lifetime of a cell phone by reducing the power consumed when it is in '*idle'* state (as opposed to active state). To reduce this unused power energy, the authors propose to shut down the device and its wireless network card when the device is not in active communication. The device is then powered on only when an incoming call arrives and obviously when sending data.

To wake-up the device wake-on-wireless uses a secondary low-power radio interface (thus consuming far less energy than Wi-Fi and supporting low data rate); the secondary interface uses a frequency band that is different from the frequency band used by Wi-Fi. Thus, when the device is not actively in use, the high-power wireless card (Wi-Fi) is shutdown while low-power interface remains active to receive *wake-up* messages when an incoming call arrives. Once awake, the device accepts the call on its primary high rate and high power interface (Wi-Fi).

Analysis results show that wake-on-wireless can increase the battery lifetime of PDAs (using PSM) by up to 115%.

2.1.5 Cell2Notify: Wireless wakeups revisited: Energy management for VoIP over Wi-Fi smartphones

Agarwal et al. [16] propose a solution, called Cell2Notify, to reduce energy consumption of a MN equipped with two radio interfaces, namely Wi-Fi and 3G, used mainly for voice communication. The basic idea of Cell2Notify is to leverage the cellular radio interface (that consumes far less energy, when in idle mode, as shown in Fig. 12) to implement a wake-up mechanism of the Wi-Fi interface (that is powered off when in idle mode).

Fig. 9 [16] shows energy consumption, in different modes, of 2 cellular radio interfaces (VeriZon V620 and SE-GC83) and 1 Wi-Fi radio interface (Netgear WAG511). The power consumption of WiFi interface is smaller (75% less), compared to cellular interfaces, when in active mode. This is mainly due to the fact that the distance between the cellular device and the serving base station is usually very big (up to miles) which requires high transmit power energy from the device. This is not the case for the Wi-Fi interface which is usually close to the serving access point (a few 100s meters). Thus, 'Cell2Notify' (1) uses Wi-Fi interface, whenever possible, for voice communication; and (2) shuts down the Wi-Fi interface when it is not used (idle mode).

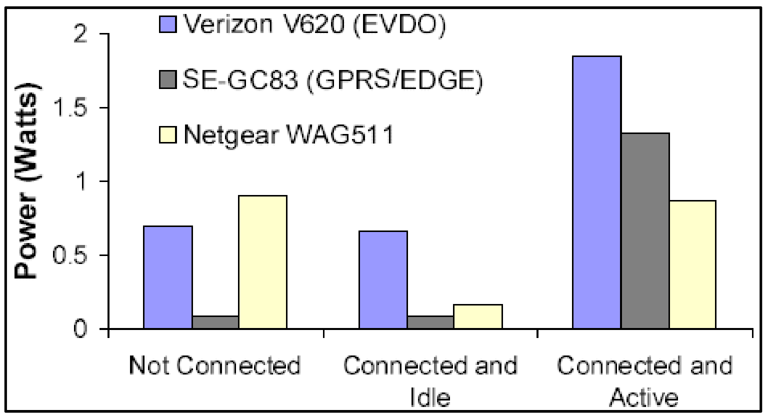

Figure 9: Comparing power consumption of three radio interfaces (2 Cellular and Wi-Fi) in three modes.

A typical setup, when using Cell2Notify, consists of MNs in enterprise environment with access to two networks: (1) WLAN which provides access to Internet; and (2) Cellular network which provides access to PSTN (Public Switched Telephone Network). A MN can be joined through either networks; using the Wi-Fi interface, a MN can use a SIP (Session Initiation Protocol) server in the LAN to establish a communication with MNs connected to PSTN. Cell2Notify architecture is based on classic server/client architecture where the MN ('Cell2Notify' client) has to register its Wi-Fi interface at the SIP server ('Cell2Notify' server) and then shuts it down. The SIP server maintains a list of registered MNs; it intercepts SIP incoming calls and sends a message through the cellular network (thus via the cellular interface) to wake-up the concerned Wi-Fi interface. Upon wake-up, the Wi-Fi interface re-establishes its wireless connection with the WLAN and gets ready to receive the call.

2.2. Analysis

In this chapter, different techniques, concerning saving battery energy of a handheld device equipped with multiple radio interfaces, were presented. In summary, to save energy in multi-radio devices, existing contributions either focus on a single wireless technology (e.g., Bluetooth or IEEE 802.11b), define switching policies between different radio interfaces (between Wi-Fi and Bluetooth), or extend the SIP server functionality to be able to intercept calls (at application level) coming to its registered client. All these contributions have a limited/restricted scope:

1. Hybrid location-Update Scheme [12] proposes an algorithm that predicts the optimum time and/or conditions (number of boundaries cells crossed) that trigger a location update procedure as a way to save energy. However, it does not address the issue of high energy consumption of a mobile using multiple radio interfaces especially when they are not active (situations where the power/energy consumption is important).
2. The autonomic group location update (GLU) [15] is limited to a mobile network, where one selected MN performs location update on behalf of all the other members. Although, this work does address the issue of consumed energy when the interface is idle and when location update is performed, it does not consider the case of multi-radio devices. In this case, the problem becomes much more important and this solution will be much more complicated to apply. Another limitation of this contribution concerns the location update; it is not clear when the location update should be triggered and when the MN should consider its location has changed.
3. CoolSpots [17] considers a MN with multiple interfaces (Wi-Fi and Bluetooth) of short range. The proposed solution considers switching to the interface that satisfies the currently used application requirements and drains less energy.

Even if this solution helps saving energy, it is still not efficient. Indeed, CoolSpots does not power off interfaces even in idle mode; this causes energy consumption withourt being used for effective communication; furthermore, CoolSpots applies only to WiFi and Bluetooth. .

4. The Wake-on-wireless [18], proposes to use an extra short range wireless interface (low power) to wake up the (powered off) interface used for data communication. Although this solution allows saving energy, it requires the usage of an extra short range wireless interface when the data interface is powered off. To satisfy this requirement, a large number of APs (to cater to the short range interface) is needed; this makes Wake-on-wireless very difficult, if not impossible, to use in general. Furthermore, the usage of Wake-on-wireless, as described in [18], is limited to SIP-based VoIP calls.

5. Cell2Notify [16] powers off the Wi-Fi interface when it is not active to save energy. The second interface (3G interface) is used to wake-up the Wi-Fi interface when an incoming VoIP call arrives. Cell2Notify solution is limited to SIB-based VoIP calls. Indeed, if WiFi is powered off and an incoming call (other than SIP-based VoIP calls) arrives, Cell2Notify will not be able to power on WiFi. Thus, to support different types of calls, Cell2Notify should not power off the WiFi interface; in this case, no energy saving can be provided.

Table 2: Metric-based comparison of representative energy management contributions

Approches	Considers multi-interface	Range of considered interfaces	Wake-up mechanism	LU mechanism	Complexity	Energy Saving	Integrated with a standard
Hybrid LU Scheme	No	All	No	No	Simple	Low	No
Autonomic GLU	No	Short	No	Yes	Complex	Medium	No
Cell2Notify	Yes	Short	Yes but limited to SIP apps	No	Complex	High	No
CoolSpots	Yes	Short	No	No	Simple	Low	No
Wake-on-wireless	Yes	Short	Yes but limited limited SIP apps	No	Complex	High	No
IMIP	Yes	All	Yes without limitation	Yes	Complex	Very High	Yes (MIH)

Table 2 shows that unlike some solutions in the literature, IMIP is not limited to a specific type of applications (e.g. VoIP) or upper layer protocols (e.g. SIP). IMIP is designed to provide the power management of wireless interfaces used to establish connections between any upper layer protocols and/or applications. It has no limitations on the types of interfaces that a mobile device can use; it also provides a solution to location update for powered-off interfaces. Furthermore, IMIP extends MIH standard; thus, it has the potential to be adopted in a newer version of MIH (amended MIH). The experimentations results (see the next 2 chapters) show that IMIP outperforms existing approaches in terms of energy savings.

Chapter 3

A Framework for Power Management of Handheld Devices with Multiple Radios

Context

The problem with idle radio interfaces (in idle mode) is that even when not active they still drain the battery. The problem is considerable for mobile devices equipped with multiple radio interfaces as they contribute to reduce the battery lifetime which directly impacts the utility of the mobile device.

It is true that a mobile device equipped with multiple radio interfaces provides the ability to the end-users to achieve ubiquitous and seamless connectivity anytime, anywhere across heterogeneous wireless networks (e.g., Wi-Fi, WiMAX, LTE); however, the existing power management solutions for idle interfaces, defined individually by wireless technologies, are not efficient which ends with considerable amount of battery energy lost.

In this chapter, we present our solution; a framework for integrated power management of handheld devices equipped with multiple radio interfaces. This framework, based on an extension of the MIH standard, allows considerable energy savings. The basic idea of our solution is to proxy idle interfaces using a proxy entity in the network and active interface in the MN. Unlike the existing power management solutions, our solution considers all the radio interfaces as elements of one system (the mobile device) rather than considering them isolated interfaces.

The results of this work are presented in the following paper entitled “A Framework for Power Management of Handheld Devices with Multiple Radios” published in the proceedings of IEEE WCNC2009 [10].

A Framework for Power Management of Handheld Devices with Multiple Radios

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Abstract

The new generation of handheld devices is equipped with multi-radio interfaces that enable radio link connections to a variety of wireless networks (i.e. Wi-Fi, WiMAX).This allows for seamless connectivity; however, this also raises a serious issue concerning the short longevity of the handheld usability due to the high power consumption of the wireless interfaces. In this paper, we present a framework that increases considerably the battery longevity of the handheld devices; it enables efficient power management from a global point of view (and not a single radio interface view) of multi-radio devices. The basic idea behind our proposal is to power off the idle interface but at the same time to keep it in virtual idle mode in the network by extending IEEE 802.21 on both sides (the mobile node side and the network side). On the network side, the 802.21 entity acts as a proxy of the powered-off interface to ensure the assigned resources for the interface are always maintained during the proxying period. In the context of the proposed framework, we present (details of) the mechanisms to proxy an idle interface (after powering it off) and to wake up a proxied interface respectively. The proposed solution is analytically evaluated to quantify the power savings compared with single-radio power management.

Keywords: Multi-Radio Power Management, Idle/Active mode, Proxy,Proxied interface, MIH services.

I. Introduction

Multi-radio devices provide end-users the ability to achieve ubiquitous and seamless connectivity anytime, anywhere across heterogeneous wireless networks (e.g., Wi-Fi, WiMAX); however, these radios consume large amounts of energy. The utility of the devices is directly impacted by the longevity of their operation before batteries need to be replaced or recharged. Thus, the challenge is to design multi-radio devices that use energy efficiently; the objective is to provide the benefits of using multiple radios with low energy consumption.

According to [3] and [4] the radio interfaces in a PDA are the main source of energy consumption. Equipping a device with multiple radio interfaces decreases the time of its operation/usage as its battery gets empty quickly. Energy consumption of each radio interface depends on its radio state. When transmitting data, the consumed energy is the highest; it is less when receiving and almost the lowest when in idle state. Usually, a multi-radio interface device is continuously consuming power because all its radio interfaces, when they are not transmitting or receiving, are in idle state where they continue using the battery power. Researchers, focusing on different wireless technologies, have addressed the energy consumption issue from their own scope and they ended with definitions of idle mode and/or sleep mode as a way to save the energy.

In [1], the authors propose a scheme to reduce energy consumption of a PDA-based phone by reducing its *idle power consumption*. The device and its wireless network interface (IEEE 802.11b) are shut down when it is not used; the device is powered only when an incoming call is received. This scheme uses a second low-power wireless radio connection; out-of-band control information is sent to maintain connectivity and wakeup the device when necessary. These types of radio typically have very small radio coverage; thus, to support the scheme in [1], a high density wireless infrastructure deployment is needed.

The authors in [2] propose a system that enables a multi-radio mobile device to automatically switch between multiple radio interfaces in order to increase battery lifetime.

More specifically, based on empirical measurements, the proposed system makes 2 decisions: when to "*switch-up*" to Wi-Fi to increase available bandwidth, and when to "*switchdown*" to Bluetooth and power-off Wi-Fi to conserve energy.

In order to save energy, the authors in [3] propose a solution that allows powering-off a Wi-Fi interface and waking it up, through a 3G connection (consumes less energy than a Wi-Fi connection), once a VoIP call arrives on the proxy SIP server where the Wi-Fi interface is registered. Although, the proposed solution helps saving energy, its applicability is limited; it is essentially based on the interception of a VoIP call at the application level (SIP server).

In summary, most existing schemes to save energy in multi-radio devices either focus on a single wireless technology (e.g., Bluetooth or IEEE 802.11b), define switching policies between different radio interfaces (between Wi-Fi and Bluetooth), have limited/restricted scope (e.g., intercept a call at application level using a SIP server).

In this paper, we make use of the MIH (Media Independent Handover) standard; and our contribution consists of reusing the predefined MIH messages and defining new ones service access points and the network entities (PoS). The idea is to extend the MIH services to include a new service (called MRPM: Multi-Radio Power Management) that supports integrated power management of multi-radio handheld devices. Because of lack of space, we present, in detail, only two mechanisms to illustrate the processes to (1) proxy an idle interface after powering it off; and (2) to wake up a powered off interface after a call arrival (i.e., connection request, such as VoIP call or data request). Location update, mobility and handover on active interface mechanisms will be described in future papers.

The primary contribution of this paper consists of the extension of MIH standard (called EMIH: Energy-aware MIH) to support efficient power management, from a global point of view (and not a single radio interface view), of multi-radio devices. More specifically, we define a new set of primitives and a new MIH service that supports integrated power management of multi-radio devices; we also present, in detail, the interactions including the exchanged primitives between the framework entities to (1) proxy an idle interface (after shutting it down); and (2) wake up an powered off interface (upon a call arrival). Our proposed solution can be used with any wireless networking technology; it can be easily augmented with "optimal" policies to switch between radio interfaces, and can be used with any MIH capable system.

The rest of this paper is organized as follows. Section II presents a description of the proposed framework. In Section III, we present the details of the interactions to proxy an idle interface after powering it off and to wake up a powered off interface (upon a call arrival). Section IV evaluates the performance of our proposal. Section V concludes the paper.

II. Energy Saving Framework

We propose a framework for an effective management of power of a multi-radio MN. The framework considers the power management of mobile devices from a global view contrary to the single radio power management proposed by each wireless standard. The best way to save energy is to power-off an interface when it is idle. Then, the problem becomes how to stay connected to the network of the powered-off interface; this connection is needed to process the calls, to the device, that arrive on that interface. In this case, the interface could be powered-on to exit the idle state and get ready to receive the calls.

In this paper, we propose a scheme to solve this issue; the basic idea behind the scheme is to keep a proxy network entity for each powered-off interface. The proxy acts on behalf of the powered-off interface. The proxied interface is considered, by the network, as an interface in idle state. Thus, the network maintains the resources allocated to the interface; if a call arrives, the proxy will be notified by the network and then it will send a wake-up message to the device, through the currently active interface, to wake up the powered off interface (we assume that there is at least one radio interface that is connected and not idle). After waking-up, the interface will handle the incoming call. In this paper the remainder of this Section is organized as follows. Section II.A briefly presents the elements of the MIH standard we will use in the proposed framework. Section II.B describes the idle mode as defined by WiMAX [6] and LTE (Long Term Evolution) [7]. In this paper, we consider the power management of the radio interfaces independently of any specific wireless technology as long as idle mode is defined. Wi-Fi technology is not considered, because it doesn't define idle mode (only sleep mode is defined). We consider proxying Wi-Fi interface a special case to be addressed in the future. Section II.C presents the details of the multi-radio node architecture. Section II.D describes the communication model among the entities of the proposed architecture.

A. MIH Services

IEEE 802.21 standard or Media Independent Handover (MIH) [5] defines a framework that enables service continuity while MN transitions between heterogeneous link-layer technologies also known as inter-technology handover. MIH is composed of three layers (see Fig. 1): (1) MIH user; (2) MIHF (Media Independent Handover Function); and (3) Radio media interface.

The MIH user receives the state changes of interfaces as events and consequently sends control signals to the lower layers as commands. MIH Function (MIHF) is the protocol standard which provides three services: 'Command' service (CS), 'Event' service (ES) and 'Information' service (IS). MN uses the specific media to establish the radio link with its corresponding network (CN).

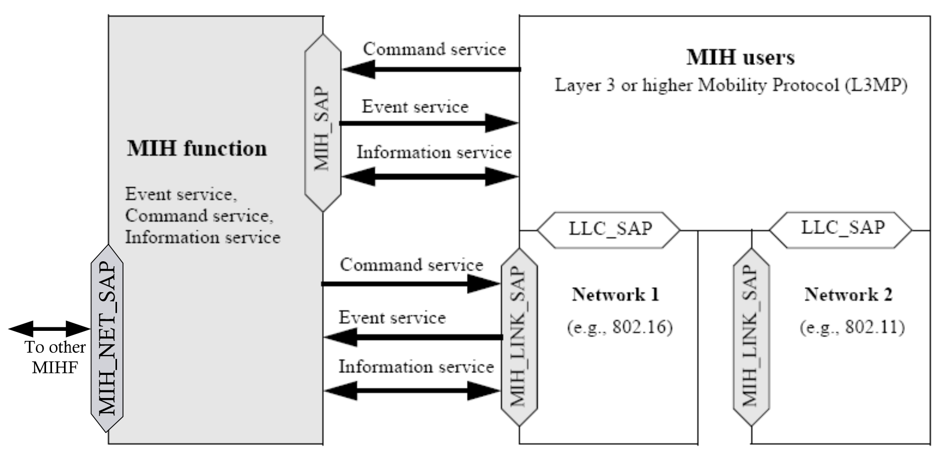

Figure 10. MIH layers, services and services access points (SAPs)

These layers communicate through service access points. MIH user and MIHF layers use MIH_SAP to communicate and MIHF and network interfaces use MIH_Link_SAP (or LinkLayerControl_SAP) to communicate the services primitives. Finally, the network and MN use the MIH_NET_SAP as a service access point to communicate remotely (see Fig. 1).

B. Idle Mode in WiMAX and LTE Networks

When IEEE 802.16e interface is not active, to save power, WiMAX standard [6] has defined the idle mode. In idle mode, the interface is managed by the Paging Controller (PC) and is not specifically connected to a particular base station (BS). The energy savings come mainly from the fact that the interface is not required to be all the time available. But, to be able to respond to the network requests it should periodically become available to check whether there is any call/data coming to it. When a call arrives on the network for the MN, the PC sends a paging message to the BSs that belong to the paging area where the MN is located (has been seen for the last time). The BSs, of that paging area, broadcast the paging message and the MN should now be available to receive the paging message and react accordingly.

In LTE system [7], the UE (User Equipment[5]) is managed and controlled, at the level of the control plane, by the MME (Mobility Management Entity) through NAS (Non-Access Stratum) protocol which runs in both sides. MME is a key control-node for the LTE access-network, among its functions for an active UE: network attachment, authentication, setting up of bearers, and mobility management. It is also responsible for tracking and paging procedure for an UE that is in idle mode. In idle state, the UE does not inform the network of each cell change; its location is only known, at the MME, at the granularity of a TA (Tracking Area) which consists of multiple eNBs (evolved Node Bs). So, when a call

[5] In LTE system the UE (User equipment) is used to refer to a MN (Mobile Node).

arrives for an UE (in idle state), for example, the MME sends a paging message to the TA where the UE lastly registered or is located.

C. Multi-radio mobile node architecture

Fig. 2 illustrates how the proposed framework ensures the communication and coordination between the MN and the proxies, on different networks, concerning the proxied/powered-off interfaces. The figure shows a heterogeneous network composed of 3 different networks (WiMAX, Wi-Fi and LTE) and a mobile node with 3 interfaces, two of them are in power-off state and the third one is in active state. The powered-off interfaces are proxied on their network by the corresponding Proxy entity/Point-of-Service (PPoS), the third one, in active state, is used to maintain the signaling session between PoS and Network Selection Entity (NSE).

Serving PoS is an MIH network entity that exchanges MIH messages with the MN, concerning the current/active interface, to prepare for an eventual handover to another one. The message exchange takes place between the MIHF layers of the MN and the serving PoS when preparing for a handover. To benefit from the PoS services, the MN has to

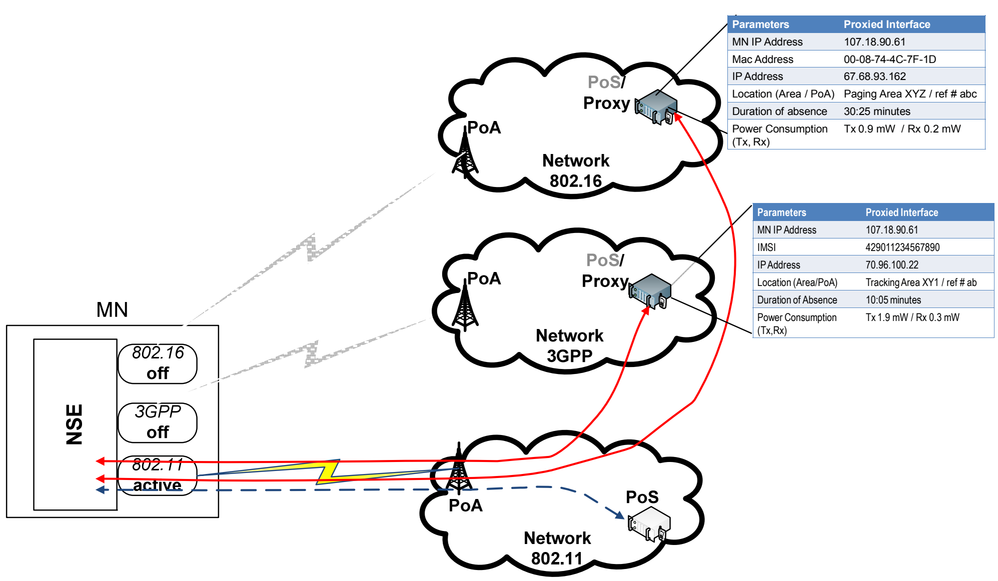

Figure 11. Multi-radio proxy architecture

subscribe to these services. Serving PoS is mainly responsible for the coordination with candidate/targeted PoSs, on other networks, where the MN may get hosted.

The proxy PoS is a network entity, like a serving PoS, with the difference that the former is proxying the powered-off interface, while the latter is serving the current/active interface. The proxy PoS is also communicating using new MIH messages (we define in Section III) with the MN/NSE concerning the proxied/powered-off interface. For example, when there is a call for the proxied interface, the proxy PoS sends a wake-up message to the NSE to power-on the interface and request it to perform an exit idle mode procedure.

NSE is the MN entity, on the EMIHF layer, that is responsible for the process by which a MN makes a decision to connect to a specific network based on a policy configured in the MN. The network selection decisions, made by NSE entity, could lead to a handover. The powered-off interfaces are proxied by the proxy PoS on the network side and their state change is managed locally by the NSE entity.

The active interface is a non-proxied interface and is actively connected to the network. It is used to maintain the NSE session which allows EMIH message exchanges between the NSE and proxy PoS entities.

D. Model of Communication

This section presents the communication model between different network entities. Local communication corresponds to the one between lower layers and higher layers and remote communication is the one between the same layers on the network and the MN.

NSE session

The NSE session corresponds to the remote communication session between the NSE entity and the proxy PoS. For each proxied interface the NSE entity maintains an IP session with the proxy which is called here a NSE session (see Fig. 2). It allows EMIH message exchanges between NSE and proxy PoS entities (see Fig. 3-4). These entities

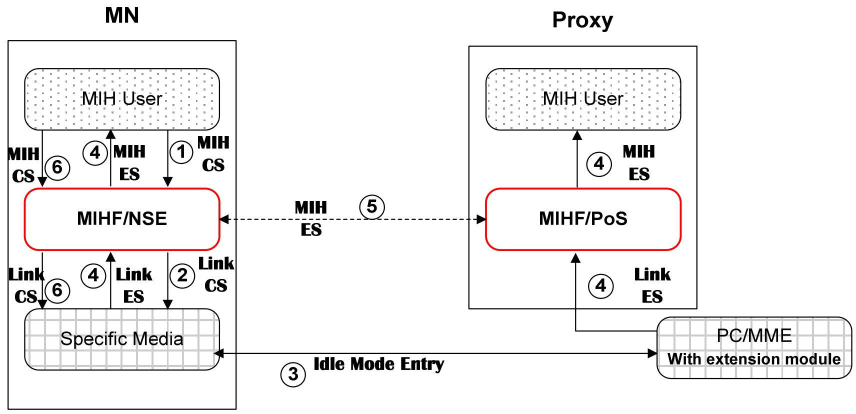

Figure 12. MN Initiated idle mode and proxied mode entry

coordinate to ensure that the functions that are supposed to be performed by the interface when in idle mode are performed when the interface is proxied.

The NSE session is established using the active interface, which is a requirement of this framework. At least, one interface should be in active/idle state (not proxied) to ensure the communication between the MN and the heterogeneous network entity (here the proxy PoS). NSE entity uses the L2 and L3 resources allocated to the active interface to establish its NSE sessions. The EMIH messages exchanged between the NSE and the proxy uses the same MIH_Net_SAP service access point as defined in [5].

Between NSE and Specific media

The NSE entity communicates with lower layer (media-specific protocol stacks) using the proposed command and event primitives (see Tables I-II) through the MIH_Link_SAP as defined in [5].

Between PPoS and PC/MME

The communication between the proxy entity and PC/MME is defined from a high layer (proxy) to a lower layer (PC/MME). The event on the network level (i.e. MN terminated call, idle mode entry or exit) are reported to the higher entity (proxy PoS) by a PC/MME extension module. The commands are sent by the proxy to the PC/MME (through the extended module).

Table I. Command Service primitives' extension

Name	Type	Role
MIH_Link_ProxiedMode_Entry	MIH CS	See sec. III.B/step1
MIH_Link_Go_Idle	MIH CS	See sec. III.B/step4
MIH_MN_Start_NSE_Session	MIH CS	See sec. III.B/step5
MIH_MN_End_NSE_Session	MIH CS	See sec. III.C/step7
MIH_Link_PowerOff_State	MIH CS	See sec. III.B/step6
MIH_Link_PowerOn_WakeUp	MIH CS	See sec. III.C/step4
Link_ProxiedMode_Entry	Link CS	See sec. III.B/step2
Link_PowerOff_State	Link CS	See sec. III.B/step6
Link_PowerOn_WakeUp	Link CS	See sec. III.C/step4

Table II. Event Service primitives' extension

Name	Type	Role
MIH_Link_Go_Idle	MIH ES	See sec. III.B/step4
MIH_Net_Call_WakeUp	MIH ES	See sec. III.C/step5
MIH_Link_Call_WakeUp	MIH ES	See sec. III.C/step5
Link_Call_WakeUp	Link ES	See sec. III.C step1
Link_Go_Idle	Link ES	See sec. III.B/step4

III. Mechanisms

In this Section, we present the new commands and event primitives we defined for EMIH; we also present two mechanisms that illustrate how commands/events are used to support the proposed power management. The first mechanism shows the case of an interface that goes to idle mode, get proxied and then is powered-off. The second mechanism shows the case of a proxied interface that gets powered on after receiving a call.

A. MIH Extensions

This section presents a set of command and event service primitives, in Tables I-II. We propose these primitives as an extension of MIH service primitives. Sample usages of these primitives are illustrated in the mechanisms described in the following sub-sections.

B. Idle mode entry mechanism

We assume that (1) there is an interface in active state; and (2) the serving PoS, responsible for handover functionality in the network, is known to the MN. It is worth noting that this serving PoS will be used by the MN as a proxy PoS of the proxied interface, after going to idle/power-off state. In the following, we describe the steps, in a chronological order, of the first mechanism (see Fig. 3).

- Step1: The MIH user sends a CS command (MIH command: **MIH_Link_ProxiedMode_Entry**) to MIHF/NSE requesting it to put the media interface in idle mode/power-off state.
- Step2: The MIHF/NSE processes the CS command (consult the local policy) and sends a CS command (Link command: **Link_ProxiedMode_Entry**) to the media asking it to enter the idle mode (to perform idle mode entry with the network).
- Step3: The media performs idle mode entry with PC/MME through the current PoA (Point of Attachment). When the PC/MME (the network entity responsible of the management of idle MNs) confirms to the MN the acceptance the idle mode entry request; the confirmation message is intercepted by the PC/MME extended module which maintains a table of associations between PoAs and the corresponding PoSs.
- Step4: After idle mode entry, (1) on the MN side, the media informs the MIHF/NSE about the MN state change in the network by issuing an ES (**Link_Go_Idle**). Then, the MIHF/NSE sends an ES (**MIH_Link_Go_Idle**) or confirmation to the MIH user. (2) On the network side, the PC/MME extension module, after intercepting the idle mode entry confirmation message, sends also an ES (**Link_Go_Idle**) to PoS at this point PoS starts acting as proxy for this MN.
- Step5: The MIHF/NSE sends a CS command (**MIH_MN_Start_NSE_Session**) to the PoS to start NSE session and to register for the events that occur in the network (i.e. call arrival). Thus, the PoS will be informed about the MN interface state change. The PoS should inform the MIH user (network) about this change. At this

level the PoS should start proxying the interface. Concerning the event registration (for a call arrival) the CS command (**Link_Event_Subscribe)** [5] could be used. Call arrival event is a new event (to MIH) we define for EMIH; we propose to use bit number 8 (bits 0-7 are already used by MIH) of the parameter RequestedLinkEventList of Link_Event_Subscribe to code the new event.

In the case of PC, the PoS sends a CS command to the PC asking to be considered as the proxy for the referred interface. This should take place in the case where the PC doesn't have the PoS reference available (for the first MN). To save more energy, Step 5 could be skipped; indeed, when the idle mode entry is successfully completed, if the PoS knows about it (from the PC/MME), then it can start immediately proxying the MN interface.

- Step6**:** The MIH user sends a CS command (**MIH_Link_PowerOff_State**) to the MIHF in order to power-off the interface. Upon receipt of this command, the MIHF sends the corresponding CS link command (**Link_PowerOff_State**) to the media SAP (MIH_Link_SAP). At this stage, and before powering off the interface, each of the sub-layers (i.e. MAC layer) of the interface has its own configuration state. All the information concerning the configuration of those media sub-layers should be stored and managed by the NSE. The configuration information should be retrieved and handed to the media sub-layers during the wake-up.

C. Waking-up mechanism

In this scenario, we assume that (1) the MN has an NSE session with the PoS that is proxying the powered-off interface; (2) the MN has at least one active interface that is used to maintain this NSE session; and (3) the MN has used the resources of the proxied interface, before it is powered-off, to register on an application server (i.e. SIP server). In the following, we describe the steps, in a chronological order, of the second mechanism (see Fig. 4).

- Step 1: Upon receipt of a notification about a call to the proxied interface MN, the PC/MME sends a layer2 paging message to the paging/tracking area (PoAs). The message is intercepted by the extended module of PC/MME which sends an ES event (**Link_Call_WakeUp**) to the PoS to inform it about the call arrival.

- Step 2: The PoS sends an ES event to MIH user to update the state of the interface (**MIH_Link_Call_WakeUp**). It sends an ES event (**MIH_Net_Call_WakeUp**) also to NSE entity concerning the proxied interface to inform the MN that the system has a call to the powered-off interface and the NSE should wake-up the interface.

- Step 3: Once the NSE entity receives the ES message, sent by PoS to wake-Up the interface, it forwards the message to the MIH user layer which should update the interface state. ES: **MIH_Net_Call_WakeUp**.

- Step 4: MIH user processes the received ES message concerning the proxied interface and sends a CS command (**MIH_Link_PowerOn_WakeUp**) to NSE to wake up the powered-off interface. Then, the NSE sends a CS message (**Link_PowerOn_WakeUp**) to the media (MIH_Link_SAP) to power on the interface and to get ready to accept the call.

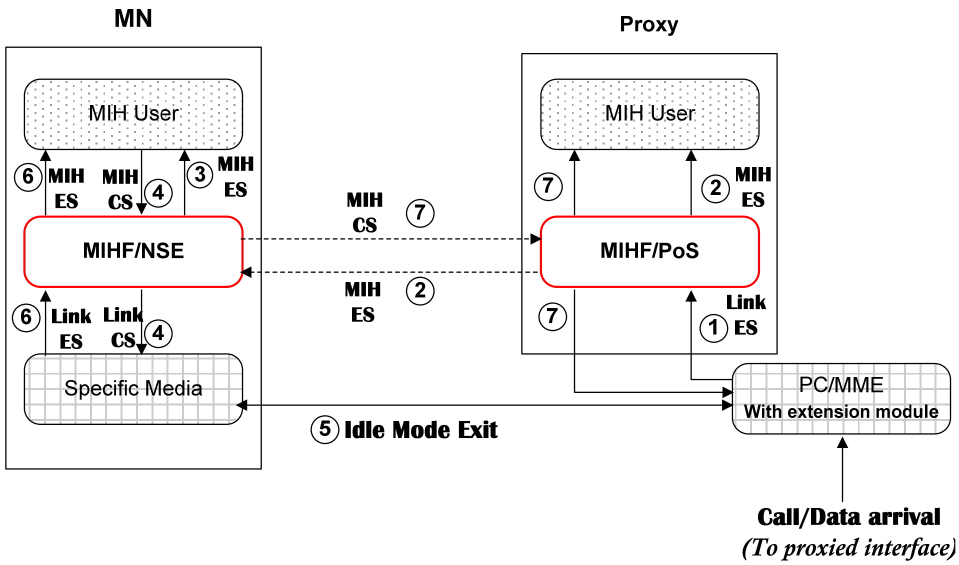

Figure 13. Waking-Up a proxied interface

- Step 5: Upon receipt of the CS message, the media layer powers on the interface, retrieves the configuration information concerning each sub-layer (i.e. MAC layer) and configures them accordingly. The sub-layers should now have the same configuration they had just before being powered off (i.e., idle mode). Now the interface is ready to start an idle mode exit procedure with its network.

- Step 6: After a successful idle mode exit procedure the interface sends an ES (Link event) to the NSE informing it that the interface is no longer in idle state but it is now in active state. Then, the NSE sends an ES message to the MIH user to update the state of the interface. Those events already exist. **Link_Up / MIH_ Link_Up.**

- Step7**:** The NSE sends a CS message (**MIH_MN_End_NSE_Session**) to the PoS to end the NSE session. Upon receipt of this message, the PoS stops proxying the powered-off interface and sends a CS command (**Link_Event_Unsubscribe**) to the extended module of PC/MME and notifies the MIH user about the interface state change.

IV. Analysis

For the evaluation of the proposed solution, we consider two handheld device user profiles: (1) low-usage user (user1): the average network usage is assumed to be about T_1=30 minutes a day (T =24 hours); and (2) moderate-usage user (user2): the average network usage is assumed to be about T_2=2 hours a day. The device is equipped with two radio interfaces; WLAN and 3G interfaces. The only interface to be proxied, in this analysis, is the 3G interface; WLAN will be active/idle all the time (proxying the WLAN interface is for future work as explained above). Power consumption, from [3] and [8], of each interface is listed in Table III.

Table III. POWER CONSUMPTION OF WLAN AND 3G INTERFACES

Mode	Power	Probability of usage (active mode)
Transmit (WLAN)	P_{WTx}890 mW	$P_{Tx1} = 0.25$
Receive/awake (WLAN)	P_{WRx} 690 mW	$P_{Rx1} = 0.25$
Idle/sleep (WLAN)	P_{WI} 256mW	---
Transmit (3G)	P_{3GTx} 1100 mW	$P_{Tx2} = 0.25$
Receive (3G)	P_{3GRx} 555 mW	$P_{Rx2} = 0.25$
Idle (3G)	P_{3GI} 18 mW	---

In this analysis, we assume that the interfaces have been used equally for all the user communications and for each interface the total receiving and transmitting time is equal. This is true for both users on both interfaces. Thus, $P_{Tx1} = P_{Tx2} = P_{Rx1} = P_{Rx2} = P_{mode} = 0.25$ (chance of using WLAN/3G or transmit/receive, see Table III).

First, let us consider the case, called SRPM (Single Radio Power Management), where each radio is managed independently; thus, when an interface is not active it is in idle mode. The total consumed energy during a day, for each user is expressed as follows.

$$E_{1SRPM} = T_1 P_{mode} (P_{WTx} + P_{WRx} + P_{3GTx} + P_{3GRx}) + (T - T_1/2)\ (P_{3GI} + P_{WI}) \quad (1)$$

$$E_{2SRPM} = T_2 P_{mode} (P_{WTx} + P_{WRx} + P_{3GTx} + P_{3GRx}) + (T - T_2/2)\ (P_{3GI} + P_{WI}) \quad (2)$$

The radio consumption, using our proposed solution (MRPM) is expressed in the equations below. At any given time, only one radio is in idle state, the other interface is proxied/powered-off.

$$E_{1MRPM} = T_1 P_{mode} (P_{WTx} + P_{WRx} + P_{3GTx} + P_{3GRx}) + (T - T_1/2) P_{3GI} + (T_1/2) P_{WI} \quad (3)$$

$$E_{2MRPM} = T_2 . P_{mode} (P_{WTx} + P_{WRx} + P_{3GTx} + P_{3GRx}) + (T - T_2/2) P_{3GI} + (T_2/2) P_{WI} \quad (4)$$

Fig. 5 shows that using MRPM, for both users, provides considerable energy saving compared with using SRPM. For user1, the energy consumption is about 3.4 times less with MRPM than SRPM, for user2 it is around 3. The gain is more important for low-usage users; this can be explained by the fact that most of the time the interface is in idle mode for user1.

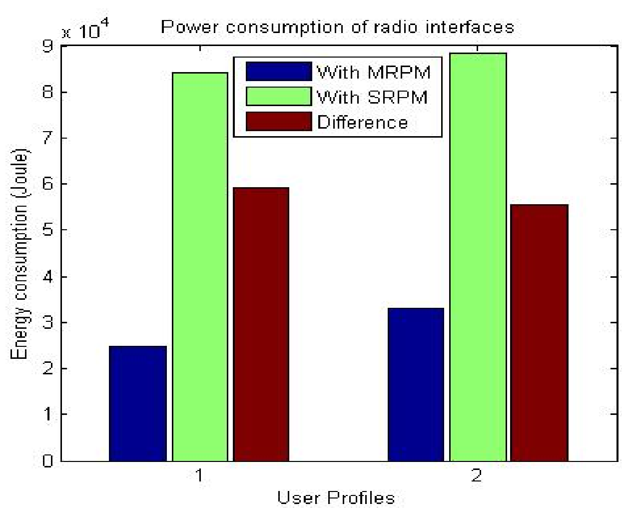

Figure 14. Power consumption saving with MRPM framework

V. Conclusion

We introduced a new mechanism to manage the interface power of multi-radio mobile handhelds. The mechanism is based on extending 802.21 services with new commands and events. Idle mode radios are powered off and their presence is proxied. When a call is received the cellular network generates paging message which is intercepted and the interface is waken up using the active interface. We presented an evaluation of our mechanism for two types of users and have shown that our mechanism leads to power savings compared with single-radio power management. Other functions that concern the power management of the radio interfaces (e.g. location update) are left for future work.

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Chapter 4

Proxying Location Update for Idle Mode Interfaces

Context

In the previous chapter we presented our framework for an integrated power management of mobile devices equipped with multi-radio interfaces. This framework, based on proxing idle interface by using a proxy entity in the network and the active interface in MN, allows important energy saving as the results in chapter 3 had shown. However, the idle interface (powered-off) has to wake-up either on periodic basis or after a location change to perform location update procedure to update its network about its current location. The idle MN has to wake-up, periodically, to receive this information broadcasted by the neighboring base stations. Recall that the paging procedure is based on the last reported MN location information.

In our framework, the idle interface is powered-off to save energy, thus, it is not able to receive from the network its location information and consequently will not perform a location update. Moreover, it has to wake-up periodically for the periodic location update.

In this chapter, we present our solution "proxying location update", to overcome the inconvenient of location update requirements. Two algorithms are proposed for this problem; (1) Proxying LU (Location Update) procedure without considering the MN mobility (periodic LU only); and (2) Proxying LU procedure considering the MN mobility (and periodic LU). We also describe the extensions needed for the framework, in chapter 3, to support the proxying location update solution for both algorithms. The results of this work are presented in the following paper entitled "Proxying Location Update for Idle Mode Interfaces" submitted to proceedings in IEEE WCNC 2010 [11].

Proxying Location Update for Idle Mode Interfaces

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Abstract

In cellular networks it is the mobile node's responsibility to update the network about its location change, especially when this one enters idle mode. We developed a new framework [8] where the idle interface is powered-off to save energy and thus could neither detect its location change nor perform a location update. This framework uses a proxy entity at the network and at the mobile node the active radio interface for proxying the idle interface. In this paper, we present an approach that relies on the proxy entity and the active interface for proxying the location update procedure of the proxied interfaces. More specifically, we propose two algorithms. The first algorithm considers proxying periodic location update of idle interface without considering its mobility if there is any. The second algorithm is based on sending the location to the Information Server which determines the list of paging/tracking areas that serves the current location. We present the design of our architecture for 4G systems, namely WiMAX and LTE. The algorithms are analytically evaluated to evaluate the power savings compared with single-radio power management.

Keywords-component*; Location-Update; Proxied Multi-Radio Interface; Idle/Active mode; Proxy entity; Proxied interface; MIH services.*

I. Introduction

Multi-radio devices provide end-users the ability to achieve ubiquitous and seamless connectivity anytime, anywhere across heterogeneous wireless networks (e.g., Wi-Fi, WiMAX, LTE); however, these radios consume large amounts of energy. The utility of the devices is directly impacted by the longevity of their operation before batteries need to be replaced or recharged. Thus, the challenge is to design multi-radio devices that use energy efficiently; the objective is to provide the benefits of using multiple radios with low energy consumption.

In existing systems, the power management of each radio interface of a multi-radio device (the mobile node) is managed individually by its corresponding network technology. For example, each idle radio interface of the mobile node (MN) has to perform a location update individually with its corresponding network entity. In fact, each idle interface of the MN has to be available for a certain amount of time (this depends on the network policy) to be able to receive data from its network and react accordingly. This is how a network informs the idle interface (through paging procedure) about a pending call/data if there is any. The concerned interface (by this call/data) has to switch to active mode to be able to receive the call/data.

Actually, it is the location update procedure, performed by the idle interfaces with their corresponding network entities (e.g. PC (Paging Controller) in WiMAX [3]) that allows the network to be updated about the location of the managed interfaces at paging/tracking area granularity. To page an idle MN, the network broadcasts a paging message in paging/tracking area(s) where the network believes the MN is currently located. In [8], we proposed the IMIP (Integrated Management of Interface Power consumption) framework [8] which is built as an extension of the IEEE 802.21 Media Independent Handover (MIH) standard [6]; the proposed extension concerns mainly the MIH services, their primitives and a new functional network entity called proxy (co-located with the Point of service (PoS) [8]).

In this paper, we propose an extension of IMIP to support a new function namely the location update (or proxied location update). The rest of this paper is organized as follows. Section II briefly presents the IMIP framework and then the location update procedure in WiMAX and 3GPP LTE systems. Section III describes the proposed proxying location update mechanism in IMIP. Section IV presents the implementation details used for the communication between the proxy and the PC/MME. Section V evaluates the performance of proxying idle radio interfaces (WiMAX and 3GPP) and location update procedure. Finally, section VI concludes the paper.

II. IMIP Framework for Location Update

In this section, we briefly introduce IMIP framework (see [8] for more details); in this paper, we propose an extension of IMIP that concerns location update in 4G networks; thus, an overview of location update mechanisms in WiMAX [3, 6] and 3GPP LTE [4, 7] systems is presented.

A. IMIP Framework

In [8], we proposed a framework, called IMIP, for an effective power management of a multi-radio MN. The framework considers the power management of mobile devices from a global view; this is in opposition to existing single radio power management provided by each wireless standard. The best way to save energy is to power-off an interface when it is idle and to use a proxy network entity (in its corresponding network) for each powered-off interface.

Fig. 1 shows a heterogeneous network composed of 3 different networks (WiMAX, Wi-Fi and 3GPP LTE) and a mobile node with 3 interfaces. Two of these interfaces (WiMAX and 3GPP LTE) are in power-off state and the third one is in active state (Wi-Fi). Each powered-off interface is proxied on its network by the corresponding proxy entity; the active interface is used to maintain the signaling sessions between proxies and Network Selection Entity (NSE) on the MN [8]. For each proxied interface, the NSE entity (on the MN) maintains an IP session, called NSE session (Fig. 1-2), with the proxy. It allows EMIH (Enhanced MIH) [8] message exchanges between NSE and proxy entities. This is how the proxy sends and receives requests (commands, events information) to/from the MN concerning the proxied interface. Thus, when an idle interface is proxied, it is the proxy that becomes responsible for the functions (i.e., performs the functions) intended for the interface.

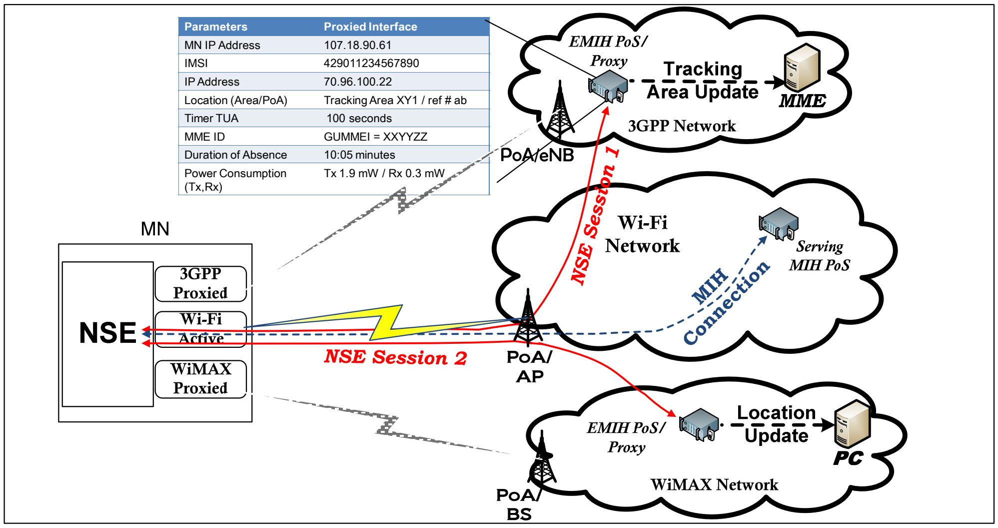

Figure 15. Architecture for proxing interfaces of multi-radio interfaces

B. Location update in WiMAX

With location update procedure, to save battery power on the handset device (MN), the WiMAX radio interface goes into idle mode when it is not involved in an active session. To alert the mobile, in this case, about an incoming message, WiMAX network makes use of its paging system. The WiMAX paging reference model decomposes the paging function into three separate functional entities: PC (Paging Controller), PA (Paging Agent) and Location Register [3].

The PC is a functional entity that manages the activity of idle interface in the network. The PC is identified by PC_ID and may be co-located with the base station. WiMAX system requires that each idle interface to be managed by a single PC which is referred to as *anchor* PC. The latter manages and maintains the location information of more than one idle interface and could manage more than one paging area. For different reasons (e.g. user mobility) the idle interface could be assigned a new anchor PC which becomes its managing entity. This is referred to as PC *relocation*; it happens mainly during a location update procedure.

The PA is a BS functional entity that handles the interaction between the PC and the BS paging-related functions. A set of PAs/BSs form a PG (*paging group or paging area)*.

According to [10], there are four location update conditions which trigger the MS (Mobile Station) in idle mode to perform a LU (Location Update). Among these conditions; (1) 'Paging Group Update': this is when the mobile detects a change in the paging area; and (2) 'Timer Update': where the MS shall periodically perform Location Update prior to the expiration of the 'Idle Mode Timer'. The latter defines time interval between two LUs.

C. Tracking area update in LTE

In 3GPP LTE system [4], when a radio interface is in idle mode, the location of the mobile is known by the MME and only at the granularity of a Tracking Area (TA) which consists of multiple eNBs (evolved NodeBs). The MME manages one or more TAs, and keeps the list (of TAs) sent to each mobile where no TAU (Tracking Area Update) is required as long as the mobiles are located in these TAs. If the mobile gets in a TA which is not in the TAL (Tracking Area List) sent by the MME, it has to perform a TAU (Tracking Area Update) with the MME informing it about its new location. For different reasons (e.g. user mobility, MME load balancing) the mobile could change the serving MME to become managed by a different MME [11]. This is referred to as MME change or relocation. To locate the mobile to a cell granularity, paging is necessary.

The tracking area update procedure performs two types of tracking update [5]: (1) normal tracking area update and its objective is to update the registration of the actual tracking area of the mobile in the network; and (2) periodic tracking area update which is controlled by timer T3412 [4], this used by the mobile to notify periodically the network about his availability (or presence).

In summary, for both systems (WiMAX, 3GPP LTE) presented here, there are mainly two situations where a LU is performed: (1) periodically where the MN maintains 'LU timer' and after its expiration it should perform a LU. Otherwise, the mobile may get considered out of the network and the allocated resources in the system will be released; and (2) when the MN changes the tracking/paging (location) area.

III. Proxying Location Update

The following section presents the proxying LU mechanism according to IMIP framework; more specifically, we are concerned with WiMAX and 3GPP LTE systems.

A. Proxying radio interface

The proxy entity is an extension of PoS [8] functionality which concerns the proxied interface. The extended functionality corresponds mainly to the tasks that the proxied interface is required to perform while in idle mode. Thus, the interface can get powered-off, which allows a maximum of energy saving and thus longer MN lifespan and this without losing the connectivity state with the network.When a call arrives, the proxy sends a CS (Command Service) message (**MIH-Wake-Up**) [8] to the MN to wake-up the concerned proxied interface which then performs an idle mode exit.

In this paper, we present a new proxied functionality performed by the proxy on behalf of the MN. The proxied functionality is location update (a MN is required to perform while in idle/proxied mode). Fig. 1 presents a MN with multiple radio interfaces (Wi-Fi, WiMAX and 3GPP LTE) where one (Wi-Fi) is in active state and the others are proxied. It illustrates how the MN maintains NSE sessions with the proxies for the proxied interfaces (WiMAX and 3GPP LTE) through the active interface. It also shows the proxies exchanging messages, concerning the LU procedure for the proxied interfaces, with PC/MME.

B. Techniques for proxying LU

Recall that for networks supporting idle mode management, the idle MNs have to perform a LU/TAU procedure periodically (periodic LU). This procedure is used by the network entities (e.g. PC and MME) to maintain the managed MNs present in the network (or connected). The inconvenient of this requirement is that the idle interface has to wake-up periodically in order to perform periodic LU. Thus, the MN energy is consumed for non useful usage. Our solution to overcome this inconvenient is that the proxied interface stays powered-off and it is the proxy entity that performs the periodic LU on its behalf. For example, Fig. 1-2 illustrate the case of two proxied interfaces (e.g. WiMAX and 3GPP) for which their corresponding proxies are performing periodic LU for them.

Fig. 2 shows how the proxy exchanges LU/TAU messages with the PC/MME concerning the LU procedure for the proxied interface. These technology specific messages correspond, in IEEE 802.21 standard, to a new proposed command service link primitive (**Link_Location_Update**) to be used by the proxy for the LU procedure with PC/MME entity. The Figure also illustrates, the PC/MME asking in their response (TAU Accept/LU_Rsp) the MN to update some of its parameters (e.g. GUTI (Globally Unique Temporary ID), TAI (*Tracking Area* Identity) or PC relocation indication). Upon receipt of the response (from PC/MME), the proxy updates locally the maintained parameters for the proxied interface. Then, it sends back to the MN a command service message **Net_MIH_Location_Update**, using NSE session (through the active interface). The MN could use these new received values to update the maintained parameters for the proxied interface and stays synchronized with its network.

In proxied multi-radio framework, proxied interfaces are not able to receive the PG/TA (Paging Group/Tracking Area) ID broadcasted by their respective PoAs (Point of Attachment); this means that the location update (triggered by user mobility/location change) will never take place. However, the MN is required to perform a LU, to inform the network each time it gets aware that it has moved to a new area (or if the current TA not in the TAL). The LU procedure allows the system to maintain and update the information concerning the location of the MN; this helps paging the MN with reduced resources (using only PoAs that belong to paging/tracking area where the MN is currently located) and within an acceptable delay. To satisfy this requirement, the MN should be able to detect that it has changed the paging/tracking area without using the broadcasted information (e.g. Paging_ID) by the PoAs.

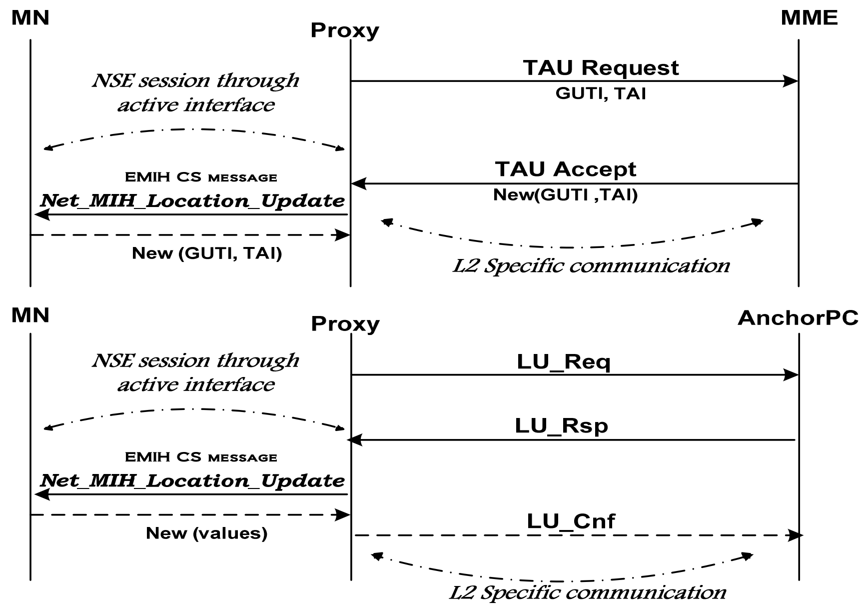

Figure 16. LU procedure performed by the Proxy with PC/MME

We propose two solutions for this problem; (1) Proxying LU procedure without considering the MN mobility (periodic LU only) and (2) Proxying LU procedure considering the MN mobility (and periodic LU).

1. **Proxying LU without considering MN mobility**

When the MN enters idle mode and gets proxied (powered-off) by the proxy entity, the latter starts performing the required periodic LU procedure on the MN's behalf. During the proxying period, the MN is considered to be located on the same paging/tracking area where the MN has performed the idle mode entry (and get proxied). In this solution, the MN is considered to be located in the same location even if it has really moved to a new location/area not under the management of its PC/MME. The MN could move freely without the obligation to be aware of its 'real' location and to report the changes to the proxy (then to the PC/MME). Thus, during the proxying period the system believes that the MN has not changed the location. The only requirement that should be respected here is that the system should be always able to wake-up the MN when a call arrives.

In [8] we explained how the MN maintains a NSE session with the proxy during the proxying period. The session is used to exchange the extended MIH messages (extended CS (Command Service), ES (Event Service) and IS (Information Service) messages). To wake-up a proxied interface, the proxy sends a wake-up message to the MN instead of using the paging system which relies on the location information of the MN. This way the location information is not very critical to be maintained and updated in the system.

2. Proxying LU considering MN mobility

In this section, we present a solution that the MN can use to detect that it has changed the paging/tracking area. This solution uses two types of information; (1) the geo-location of the MN and (2) the geo-location of the paging/tracking areas maintained by the IS (Information Server) (refer to [2] for details about the IS server). The event that triggers the proxied interface to initiate a LU procedure is the geographic position/location change.

Fig. 3 shows how a location update is performed considering the MN mobility. The figure focuses mainly on the interaction between the MN and the IS server and the trigged functions on each entity. After idle interface enters idle mode and get proxied, here are the steps to be performed to realise a LU:

a) MN periodically checks its new geolocation and compares it with the previous one. If the difference is significant (≈200 meters), then the MN has possibly changed the paging/tracking areas (of some or all proxied interfaces). The value for the periodicity check, of the mobility of the MN, and the value of the distance (triggering the MN to send a request to the IS server) depedend on the radio coverage of the network of the proxied interface.

b) The MN then sends an IS (Information Service) request (MIH_Get_Information) to the IS server indicating; (a) its current geographic location and (b) the list of networks the MN needs to know if there is a location change.

c) The IS server uses the geolocation of the MN to determine the paging/tracking areas (among the requested networks) that are serving this region, then, it sends the response to the MN.

d) Upon receipt of the response, the MN (MIH user layer) compares the received list with the paging/tracking areas maintened by the MN. If there is a difference, this means the MN has moved to a new location (new one in the received list) and a LU should be performed.

e) As the MN has changed the location, the proxied interface should be waked-up to perfrom a LU. This is initiated by the MIH user which sends a CS message (MIH_Wake-Up) to MIHF layer; to be sent to the proxied interface(s) (concerned by the location change). The CS message indicates that the proxied interface has to perform a LU procedure (with its corresponding PC/MME).

f) If the new location is managed by the same serving PC/MME entity, then the location update is performed between the MN (concerned interface(s)) and that PC/MME entity; without involving the proxy. The case where the new location is managed by a different PC/MME is presented later (see PC/MME relocation section).

g) After performing the location update, the interface goes back to idle/proxied mode.

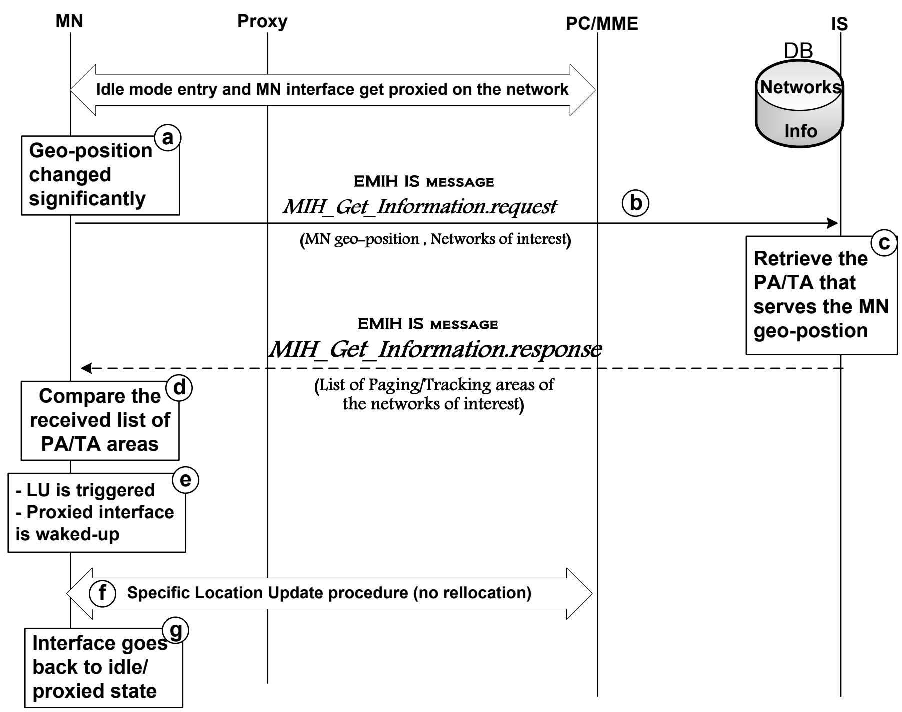

Figure 17. Geo-position based LU without PC/MME relocation

PC/MME Relocation

If the MN has moved to a new location that is managed by a different PC/MME entity, then the MN management should be relocated to different managing PC/MME entity; the relocation procedure is then performed as defined by the corresponding network [3,4]. Since the proxy is co-located with the PC/MME entity, it should be relocated too, this results in; (1) ending the NSE session with the old proxy; (2) establishing a new NSE session with a new proxy co-located with the new PC/MME entity and (3) the new proxy starts EMIH message exchanges with the new managing PC/MME (see section IV for more details). Once the LU is performed successfuly, the interface could go back to idle/proxied mode without having to switch to active state.

The proposed solution here requires; (a) to extend the usage of the IS message (*MIH_Get_Information*.request/response) to be used as request/response between the MN and IS. The extension, of this existing IS message concerns, mainly, adding the possibility to exchange paging/tracking areas information, of the MN's proxied interfaces, specifically, the areas where the MN could be current located; (b) to wake-up the proxied interface after the reception of the *MIH_Wake-Up* and (c) the relocation (if needed) of the serving PC/MME and the proxy that might be trigged by the MN mobility.

IV. DESIGN of IMIP FRAMEWORK FOR LU

The requirements we consider in the proposed design are: the proxy must be collocated with PC/MME and no change or minimum modification to the existing PC/MME software. Thus, we propose to add a light-weight entity, called Wrapper, to PC/MME; this entity receives/intercepts messages from the lower layers (e.g. link layer or base station) and sends a copy to the proxy entity which communicates with NSE over the active interface. Proxy and Wrapper entities communicate using inter-process communication (IPC).

A. Wrapper Entity on MME

In LTE systems, the MME entity exchanges control messages with its managed eNodeBs through the S1-MME interface between the S1-AP (S1-Application Protocol) layers on both sides [7].

As illustrated in Fig. 4, we propose a new wrapper entity (in S1-AP layer) that will be used for communication between the MME and the proxy. The role of this entity is described in the following. To communicate with the MME, the proxy (extended MIHF layer) sends it messages to the wrapper entity which receives them and processes them like coming from the access network entities (e.g. eNobeB). Then the wrapper entity sends them to the MME upper layer. This way the extended MIHF layer (on the proxy side) generates link_CS (Link Command Service) messages to be sent to the MME through the IPC channel. When the proxy has to send a link_CS message (to the MME), which trigged either locally (MIH user) or by the proxied MN, it is the extended MIHF layer, on the proxy, that formats the Link_CS message. The formatting is made in a way to be S1-MME compatible and could be interpreted correctly at the S1-AP layer.

Similarly, messages sent by MME, to the managed eNodeB(s), are intercepted by the wrapper entity and forwarded to the proxy. The extended MIHF layer (on proxy) receives S1-AP messages, from the MME as ES (Event Service) messages, processes them and sends them up to the MIH user and/or to the MN using the NSE session. This is how the paging message (the 3GPP LTE [S1-AP] paging message [5]) sent by the MME is intercepted as an ES message (**Link_Call_WakeUp**) and used by the proxy to wake-up the proxied MN interface.

B. Wrapper Entity on PC

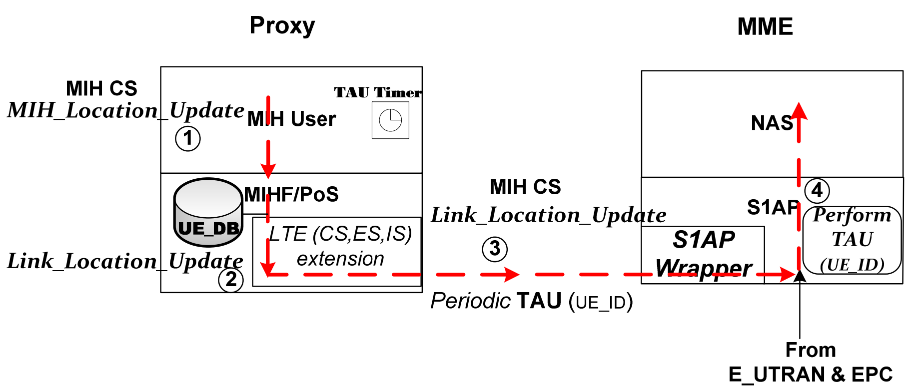

Figure 18. Proxy Design on MME

The proxy is co-located with the anchor PC on the same ASN-GW (for the three profiles A, B &C [4]); it is extended with a wrapper entity that supports IPC message (MIH CS, ES & IS primitives) exchanges with the proxy. As shown in Fig. 5, when the MS enters idle mode and gets proxied, the proxy starts performing the periodic location update with the anchor PC. A CS message (***MIH_Location_Update***) is sent from upper layer (MIH user) to lower layer (MIHF layer) which triggers Link_CS message (***Link_Location_Update***) to be sent to anchor PC. This CS message is equivalent, in WiMAX technology, to ***LU_Req*** message.

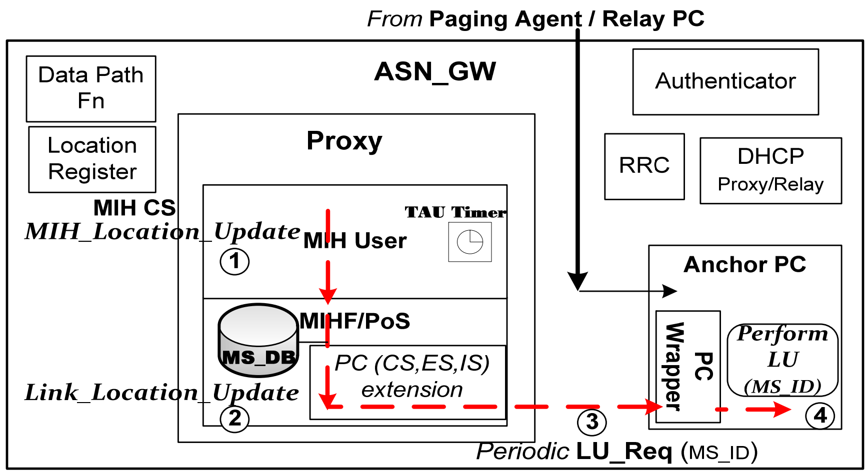

Figure 19. Proxy Design on Anchor PC

As illustrated in Fig. 4-5 the MIH user maintains a timer for each proxied interface. When the timer expires, the MIH user sends a CS message (***MIH_Location_Update***) to the MIHF layer. The latter processes the message and generates the corresponding specific Link_CS message (***Link_Location_Update***). This message corresponds to ***TAU_Request*** message in 3GPP LTE and to ***LU_Req*** message in WiMAX. The new generated specific Link_CS message (***Link_Location_Update***) is sent to the PC/MME using the IPC communication channel. Once the PC/MME receives the CS message through the S1-AP/PC wrapper layer (it is perceived as received directly from the idle interface), the location update procedure is performed and the PC/MME updates the MN state.

C. IS and CS primitives extension

For proxying the LU procedure, new MIH CS primitives are proposed and one existing IS primitive definition is extended. The two first CS primitives (see Table 1) are used mainly for periodic LU. They can be used also in the case where the MN initiates a LU procedure by sending the third CS message shown in Table 1.

Table 3. Proposed MIH CS and IS primitives for proxying LU procedure

Name	Type	Role
MIH_ Location_Update	MIH CS	To perform a LU (WiMAX & LTE)
MIH_Link_Location_Update	Link CS	LU-Req (WiMAX) & TAU (LTE)
Net_MIH _Location_Update	MIH CS	MN initiate a LU procedure
MIH_Get_Information	MIH IS	List of T/P areas for the MN location

The last IS information primitive, in Table 1, is already defined in [7] (***MIH_Get_Information.request/response***) is used by MNs to request information and to receive response from the IS server. In order to support our proposed approach, we need to extend the parameter ''INFO_ELEMENT'' (in the response) with a new IE (Information Element) called ''IE_Paging_Tracking_Area_ID''. This IE will be used to carry the identification of a paging/tracking area. Upon receipt of MN request (***MIH_Get_Information.request***), the IS server specifies in the ***response*** the list of *all* paging/tracking areas that cover the current MN location. Obviously, both the MN and the IS server should be capable of generating and interpreting the request and the response primitives correctly.

D. Extension of IS database

For the IS to respond properly to the extended ***MIH_Get_Information.request***, we propose the extension of its database with geographic information of its managed paging/tracking areas.

To populate the database with the geographic coverage of each paging/tracking area, the IS server could use the existing information related to the PoAs. The concerned information consists on, the geographic position of PoAs and their radio coverage area (radius). The information that has to be added in the IS server (database) are the paging/tracking areas identification of the managed networks. A table could be used to identify which paging/tracking areas each PoA belongs to. Thus, given the geo-position of the MN, the IS server could determine the list of paging/tracking areas serving the MN.

So, when the IS receives the request message (***MIH_Get_Information.request***) indicating the geographic position of the MN, it just identifies the paging/tracking areas that are covering this position and then sends them in a list to the requesting MN.

V. Analysis

A. Energy consumption

To evaluate the energy saving during one day of usage (T_U = 24 hours), we consider 3 types of users [10]: low, moderate and heavy usage user. The total active time for each user (1, 2 and 3) is respectively T_1 = 30, T_2= 140 and T_3 = 300 minutes.

In this section, we compute the total energy consumed by the radio interfaces of a multi-radio interface MN in 3 scenarios: (1) When the radio interfaces, namely WiMAX and 3G, of the MN are not proxied; in this case, power management of each radio interface is performed individually as in existing solutions; (2) The MN interfaces are proxied but location updates, triggered by MN mobility, are not considered; and (3) The MN interfaces are proxied and location updates, triggered by MN mobility, are considered. Wi-Fi interface is not proxied in all 3 cases since the idle mode and location update for Wi-Fi are not defined in 802.11.

For each scenario, we consider that the MN is equipped with two radio interfaces: Wi-Fi and WiMAX/3G. In the three scenarios and during all the usage period T_U, the active time of the two radio interfaces is equally shared between them, this is also true, for the time of transmit and receive of the data. Half of the active period, of an interface, is used to transmit data and the other half is used to receive data it.

The parameters considered in this evaluation are; (1) $\mathbf{t_{LU}}$ which corresponds to the time interval between two consecutive location updates; (2) $\mathbf{t_{LC}}$ which corresponds to the frequency of location (paging/tracking area) change that triggers a LU procedure; (3) $\mathbf{T_D}$ is the duration of a location update procedure and (4) $\mathbf{T_{TR}}$ is the transition switching (on/off) time. The values of these parameters are shown in Table2.

Table 2. Values of the parameters used in the evaluation

Parameter	Values
t_{LU}	$25 \leq t_{LU} \leq 4095$ seconds
t_{LC}	$200 \leq t_{LC} \leq 14400$ seconds
T_D	~ 50 milliseconds
T_{TR}	~100 milliseconds

According to [9, 10, 11], the power consumptions for each radio interface in transmit mode (P_{TX}), receive mode (P_{RX}) and idle mode (P_{Idle}) are shown in Table 3.

The total time of using the IS service is $T_{IS} = ½* T_{LC}$ (with $T_{LC}= T_U/ t_{LC} * T_D$). The total time of using the location system is $T_{GPS} = T_{LU}$ (with $T_{LU} = T_U/ t_{LU} * T_D$). The power consumed by GPS chip is P_{GPS}= 45mW [12].

Table 3. Power consumption values of wireless interfaces in different modes

Mode	Wi-Fi	WiMAX	3G
Tx(mW)	P_{TX1} = 890	P_{TX2} = 530	P_{TX3} = 1100
Rx(mW)	P_{RX1} = 690	P_{RX2} = 510	P_{RX3} = 555
Idle(mW)	P_{idle1}= 256	P_{idle2} = 80	P_{idle3} = 19

The evaluation, of energy saving achieved with each the two proposed approaches, consists of comparing the energy consumed with the single radio power management (existing one) and our two approaches. The comparison consists simply on computing the consumed energy using three approaches. Recall that the second and the third approaches are respectively proxying interface without considering MN mobility and proxying interface considering MN mobility. To evaluate the performance of our proposed approaches (approaches 2 and 3) we consider three user profiles (Low, Moderate and High) as presented above. The evaluation is made individually for both radio interfaces (WiMAX and 3G).

To quantify the energy savings using our two approaches; we compute the difference of the consumed energy using (1) approach 1 (single radio approach) versus approach 2 (proxying radio interface without considering MN mobility); and (2) approach 1 versus approach 3 (proxing radio interface considering MN mobility) respectively. This computation is performed for the three user profiles and the two radio interfaces (WiMAX and 3G). Notice that the x-axis (of Fig. 6) corresponds to the time interval (t_{LC}) between two consecutive (periodic) location updates required by the network system ($200 \leq t_{LC} \leq 14400$ seconds; see Table 2).

Fig. 6 shows the energy savings when the interfaces are proxied without considering MN mobility; the maximum of energy saving is achieved when (1) proxying WiMAX interface; it is around 7000J, which is more than 80% of the total energy consumed when this interface is not proxied, as shown in Fig. 6(a); and (2) proxying 3G interface; it is around 1500J, which is more than 45% of the total energy consumed when this interface is not proxied, as shown in Fig. 6(b). This difference in energy saving (between the two interfaces) is due to the fact that the power consumption in idle mode for WiMAX interface is much more important than for 3G interface. For both interfaces the energy saving decreases (relatively) when we move from a low usage to a higher usage.

The same trend (not shown because of lack of space) shown in Fig. 6 is observed for approach 3 with less energy saving (10 to 20 % less than approach 2) ; the difference is due to the fact that MN (using approach 3) uses a GPS system to detect its position, checks with the IS whether it has changed the location (paging/tracking area) and reports to the PC/MME its new location. The gains in energy savings, using approach 2, come at a price: longer delays (not shown because of lack of space), compared to approach 3, to wake-up the proxied interface.

In both approaches, the time interval of location update doesn't seem to influence the energy saving when it is more than 250s. This means that the consumed energy (in 1 day) due to the periodic location update is significant when t_{LC} is between 25-250s (very frequent), and less important (less frequent) beyond 250s. The ratio of energy saving for both interfaces (and for both approaches) is much important for lower usage users.

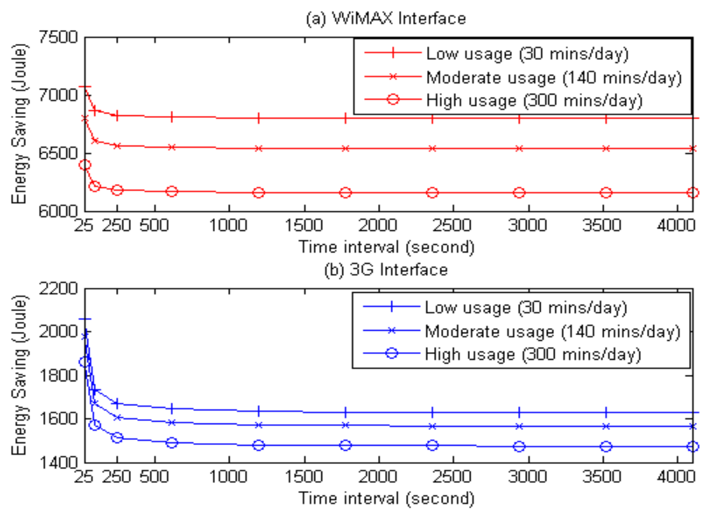

Figure 20. Energy saving when proxying (a) WiMAX, (b) 3G idle interface without considering MN mobility

VI. Conclusion

In this paper, we proposed new proxying mechanisms, for the location updates, and the extension needed on IMIP framework and 802.21 services (primitives) for its realization. Proxying location update procedure, definitely reduces (or may eliminate) the necessity to power-on the proxied interfaces to perform a location update; this allows for considerable MN energy saving. The evaluation of the power savings, using the proposed LU proxying mechanisms based on daily usage of a multi-radio MN for three types of users, has shown that the proposed proxying mechanisms improved considerably the power savings, compared with existing schemes (single-radio power management).

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Chapter 5

Conclusion and perspectives

5.1. Conclusion

In this thesis, we propose a framework for power management in mobile devices equipped with multi-radio interfaces; the objective is to reduce energy consumption by the radio interfaces. More specifically, we propose (1) a solution, called IMIP, to counter energy consumption when one or more radio interfaces are in idle mode (not used for communication); and (2) a solution, in the context of IMIP, to implement location update that radio interfaces are required to perform (periodically or after a location change) to report their location to the network. The basic idea behind our solutions is to power off and proxy idle interfaces and proxy location update procedure.

After proxying idle interface, the MN can completely switch off its idle radio interface. The proxy acts on behalf of proxied interface making the system/network believe that interface is powered on. Thus, the proxied interface can stay powered off (before an incoming call arrives) which provides considerable MN energy saving. However, an idle interface is required to perform a location update, either periodically or after a location change, to stay "connected" (upon arrival of an incoming call) to the network; a powered-off/proxied interface is not able to track its location changes. A solution to location updates for powered off interfaces is then needed. We propose to proxy location update procedure/operation; thus, there is no needed to have a powered interface to report location updates

To realize IMIP, we extend MIH [4] with new primitives/messages; we also propose extending MIH IS (Information Server) database with new data, concerning the areas (paging/tracking areas) that are under IS management, in addition to new functionalities to process this data. For example, a request coming from a MN (e.g., including its location update) is processed by the managing IS which has to determine the serving paging/tracking areas and then forwards this information, as a response, back to the MN.

To make use of IMIP, radio technologies (e.g., WiMAX and 3G-LTE) need to implement some changes; these include the implementation of a new network entity ‘proxy’ which is used to proxy idle interfaces. We propose to collocate the proxy with the MIH PoS (Point of Service) entity and enable communication between the proxy and PC/MME entity; this is implemented by a new wrapper entity in both WiMAX and 3G_LTE.

Experiments show that using IMIP allows for considerable energy savings for devices with multiple radio interfaces.

5.2. Perspectives

Our contributions rely on MIH which is not well supported (accepted) by the 3G standards; it is worth noting that it is not the case for other technologies, such as WiMAX and Wi-Fi. Thus, it will be interesting to investigate the adaptation/application of the proposed solution (proxying idle interfaces and location updates) in the context of other standards than MIH. More specifically, one can investigate the proposed solution in the context of OMA (Open Mobile Alliance) [22] since the 3G community is interested in adopting OMA standards. OMA groups that should be targeted to adapt the proposed solution include interoperability, Location, Messaging and Presence & Availability groups.

Another promising future work concerns the re-design of IS (defined in the context of MIH) which stores information concerning the resources available in a heterogeneous network. The stored information concerning a specific network technology, is available to be accessed by a user/entity network that belongs (connected) to a different network technology; IS could be actually seen as any other server (e.g., DNS and DHCP) that provides information concerning services, resources etc… available in this (heterogeneous)-network. Thus, IS could be redesigned with a view that considers providing information services in heterogeneous-network in general, rather than being designed to provide information services in the context of MIH only.

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