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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 insure 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 Maangement, Idle/Active mode, Proxy, 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 amount 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

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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 details, 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 details, the interactions (i.e., mechanisms) 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 in active state). 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

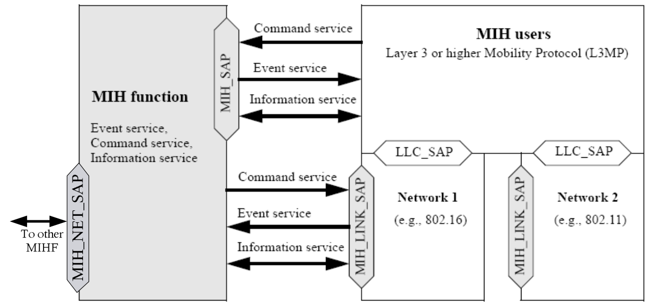

Figure 1. MIH layers, services and services access points (SAPs)

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 a (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).

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 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 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 insures 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 a 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 subscribe to these services. Serving PoS is mainly responsible for the

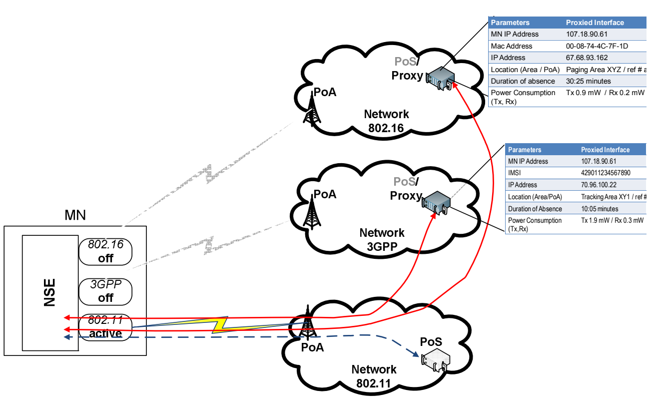

Figure 2. Multi-radio proxy architecture

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.

1) 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 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 insure 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].

2) 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].

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3) 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).

III. MECHANISMS

In this Section, we present the new commands and events 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).

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

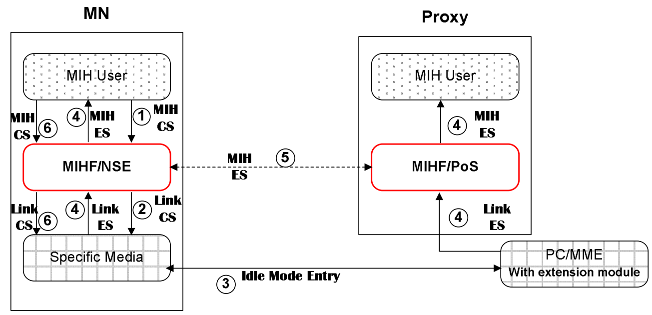

Figure 3. MN Initiated idle mode and proxied mode entry

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

- 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.

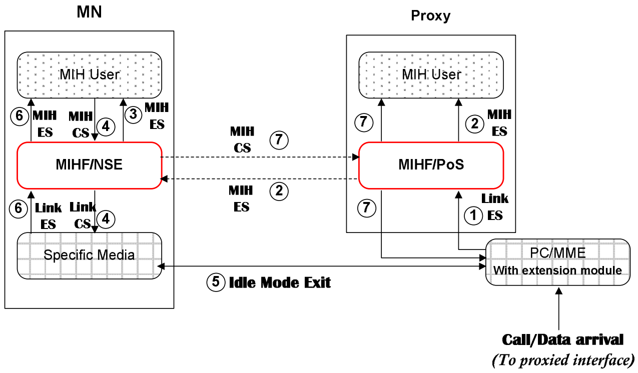

Figure 4. Waking-Up a proxied interface

- 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.

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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).

- Step1: 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.

- Step2: The PoS sends an ES event to MIH user to update the state of the interface (**MIH_Link_Call_WakeUp**). PoS sends also an ES event (**MIH_Net_Call_WakeUp**) 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.

- Step3: 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**.

- Step4: 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.

- Step5: 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.

- Step6: 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.

In this simulation, 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.

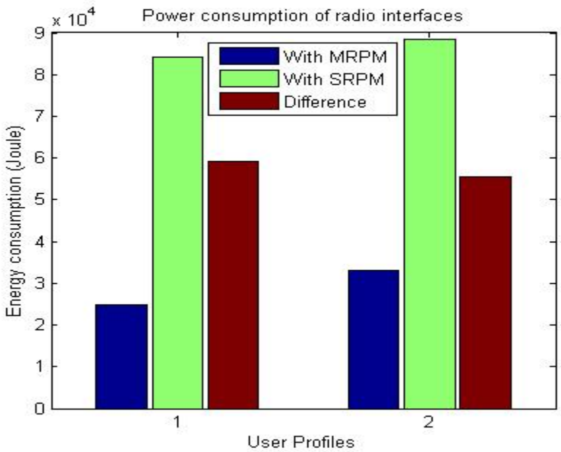

Fig.5. Simulated power consumption saving with MRPM framework

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	---

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

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

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.

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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