

WINA: A Framework to Conserve Energy in Mobile Wireless Communications

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Abstract—Mobile phones nowadays are equipped with multi-radio interfaces which allow radio link connections to an array of wireless networks. The presence of these interfaces however, introduces serious concerns. These interfaces consume huge amounts of energy thus can quickly drain their batteries and reduce the length of usage of the mobile phones. In this paper, a new activation service is proposed to reduce the energy consumption in mobile phones. The basic idea behind this proposal is to introduce an auxiliary receiver that is able to receive a special signal from the access point and activate the wireless interfaces on the mobile phone. During idle times, the wireless interfaces are switched off to reduce its idle power – the energy a device consumes in ‘standby’ state. When call or data arrives, the auxiliary receiver will receive notification from an access point and activate the relevant wireless interface on the mobile phone to receive the data or call. Through this activation service, we believe that power consumption can be reduced thus increase the longevity of mobile phone usage.

Index Terms— energy saving, low-power radio, wireless communications

I. INTRODUCTION

Modern mobile phones are fitted with multi-radio interfaces to allow end-users to be connected ubiquitously and seamlessly to an array of wireless networks. For example, it is commonplace for a typical mobile phone to be equipped with 3G, Wi-Fi and Bluetooth wireless interfaces. However, these radio interfaces consume a significant amount of energy and quickly drain the battery on mobile phones even if they are not in active use. Therefore, an interesting and relevant question that arises is the following: *How can energy consumption by wireless interfaces in standby state be reduced?*

Several researchers have attempted to answer the question above. These attempts fall into two broad categories: Eun-Sun and Nitin [1] tackled the issue focussing only on the Wi-Fi interface, while others [2-4] approached it by studying the use of out-of-band signal to regulate the duty cycle of wireless interfaces to reduce energy consumption. The basic principle behind the out-of-band approach is to switch off wireless interfaces that are in standby state, and activate them whenever a call or data arrives. While the latter approach

promises to significantly prolong battery usage, they are either directed to a specific interface or support limited applications.

Existing research has shown that regulating the duty-cycle of wireless interfaces conserves energy in mobile phones. However, we argue that a better design that incurs minimal latency and supports a wider range of interfaces and applications is needed for mobile phone users today. This is due to two reasons. Firstly, today’s mobile phones support more than just 3G and Wi-Fi interface. Some mobile phones support WiMAX, which provides full mobile Internet access. In a few years time, it is expected that Long Term Evolution (LTE) - a 4G wireless broadband technology – will also be available in many mobile phones. The presence of multiple interfaces poses serious concerns on energy consumption and a common solution to address this issue is therefore needed.

Secondly, some mobile phones support VoIP, Instant Messaging (IM), and the push email technology that allows users to receive messages effortlessly as messages are automatically pushed to their devices. These applications require always-on capabilities, which require that the wireless interfaces are turned on at all times. However, these applications are not always actively involved in data transfers. Shye et al [5, 6] reported that on average, mobile phones are in the idle state 89% of the time. Taking into account the amount of time a phone is in its idle state, we cannot ignore the fact that a mobile phone consumes a significant amount of energy at idle times, even though during the active time the interfaces consume much more energy per unit of time compared with the power consumption during the idle time.

Within this context the following question is asked: *Is there an activation system that universally regulates the duty-cycle of multiple wireless interfaces to conserve energy in mobile phones?* To date, researchers such as Wake on Wireless [2] have focussed primarily on the Wi-Fi interface, while Cell2Notify [3] and PIANO [4] studied the activation of Wi-Fi interface via the cellular network.

In this paper, a new service is proposed to activate wireless interfaces on mobile phones. We call this service WINA (Wireless Interface Notification and Activation). The basic idea behind this proposal is an auxiliary receiver, which listens for incoming notifications from the access points and activates the relevant wireless interfaces on the mobile phone. During idle times, the existing wireless interfaces on the

mobile phone are switched off to reduce power consumption. When a call or data arrives in an access point for a wireless interface on a mobile phone, the auxiliary transmitter on the access point would send a special signal to the auxiliary receiver on the mobile phone. This auxiliary receiver will then activate the relevant wireless interface on the mobile phone for it to receive the data or call. With this service, the wireless interfaces on mobile phones remain switched-off when they are not in active use, thus eliminating the idle power consumption by the wireless interfaces on the mobile phones.

The remainder of this paper is organised as follows: Section 2 describes the energy consumption in mobile phones, and our motivation. Section 3 then discusses existing energy-saving strategies. The design of WINA is presented in Section 4. Subsequently, Section 5 discusses WINA procedure and the interactions between the auxiliary receiver on the mobile phone and the auxiliary transmitter on the Points of Access (PoA) in different connectivity scenarios. The issues and challenges are presented in Section 6. Section 7 concludes the paper.

II. ENERGY CONSUMPTION IN MOBILE PHONES

Mobile devices derive the energy required for their operation from batteries. In the case of mobile phones, lithium-ion batteries are used. Most batteries supply charges between 780 and 1,200 milliamp hours (mAh), which is sufficient for several days of standby operation or a few hours of phone calls [7]. Yuvraj et al [3] measured the power consumed by the Cingular 2125 smartphone's Wi-Fi interface in the scanning, sending and receiving, and idle scenarios. Perrucci et.al [8] measured the power consumption for a Nokia N95 in different scenarios for voice services. The power consumed by the WiMAX interface is measured by Wong et al [9]. Pering et al [10] reported the power consumption of the BlueCore3 Bluetooth interface. The power consumed by each interface measured in various scenarios by these authors is summarized in Table I.

As we see from this table, a mobile phone expends a huge amount of its battery power when the wireless interfaces, especially the Wi-Fi and 3G interfaces, are switched on to transfer data. These interfaces continue to consume energy even when they are in idle state. The Wi-Fi interface consumed up to 422 mW of power which was almost half of the amount needed to transfer data. It is worth mentioning that the Wi-Fi interface used the IEEE 802.11 Power Saving Mode, was intended to reduce energy consumption in mobile devices. According to study by Shye et al [5, 6], on average, mobile phones are active only 11% of time and remain in idle state 89% of time. The amount of energy consumed during this period constitutes to 49.3% of the overall system power of a mobile phone when averaging across different users [5]. Taking this into account, while the wireless interface consumes more energy per unit of time during active transmission, mobile phones are usually in idle state and the amount of idle power consumed during this period is significant and thus cannot be ignored. Therefore, it is

TABLE I POWER CONSUMPTION OF WI-FI, 3G, WiMAX AND BLUETOOTH INTERFACES		
Interfaces	Scenario	Power Consumption (mW)
Wi-Fi	Scanning	1042
	Idle	442
	Transfer	1132
3G	Scanning	N.A
	Idle	25.3
	Sending	1265.7
	Receiving	1224.3
WiMAX	Scanning	120
	Idle	25
	Transfer	280
Bluetooth	Scanning	120
	Idle	10
	Transfer	81

imperative to implement a strategy to stop energy wastages by wireless interfaces during idle times.

The above result serves as a motivation for our investigation into wireless interface activation. Wireless interfaces should be switched off when there is no active use. An auxiliary receiver on the mobile phone will monitor for special notification signals sent by the auxiliary transmitters fitted on the access points. The receiver then activates the relevant interface only when a call or data arrives to conserve energy. Existing projects have only targeted a specific interface (e.g. Wi-Fi). In WINA, we propose a common activation system for these multiple interfaces. The mobile phone, via its auxiliary receiver will continuously monitor for these notification signals while the inactive wireless interfaces remain switched-off.

III. RELATED WORK

Several previous projects have investigated techniques to reduce energy consumption of wireless interfaces in mobile devices. These techniques include protocol optimizations at various layers of the networking stack for single-radio systems, to the use of custom radio as a wake-up channel for the main radio.

The idea of using a secondary radio to activate the high-powered interfaces was proposed in Wake-on-Wireless [2]. Wake-on-Wireless explores the use of a second special-purpose radio as a wake-up channel for the Wi-Fi interface. In this approach, users are connected to each other via a server and proxy. The server keeps track of users' locations and authenticates a caller's identity when there is an incoming call. The proxy forwards the client's registrations to the server, and sends the activation command to the client's device. Through this technique, the battery life is increased by up to 115%. However, Wake-on-Wireless requires users to register to its proxy and servers to be able to use its services. Furthermore, Wake-on-Wireless requires presence servers which introduce large start-up latencies and incur huge deployment costs. In our scheme, the use of presence servers and proxies is eliminated. Any user can use the notification and activation system as long as the user is subscribed to the

service provider and the mobile phone supports the wireless service.

Cell2Notify [3] used a secondary radio to activate the Wi-Fi interface. In this approach, the Wi-Fi interface is powered off when there is no VoIP call. The Wi-Fi interface is activated when there is an incoming call via the GSM interface. Using Cell2Notify, Yuvraj et al, reported that a user with heavy usage pattern experiences up to 70% increase in mobile phone usage time, while a light user can experience up to 540% increase in mobile phone usage time. However, Cell2Notify has been specifically designed for enabling VoIP in Wi-Fi-based smartphones and its implementation requires calls to be routed via the cellular network which introduces delay and raises cellular operators concerns for the use of their infrastructure.

PIANO [4] is another approach which explored the use of cellular interface to activate the Wi-Fi interface when there is an incoming VoIP call. In this approach, the Wi-Fi interface of a dual-mode phone is turned off, while the cellular interface monitors for paging messages. When the cellular interface receives a paging message indicating a VoIP call, the Wi-Fi interface is switched on to respond to the incoming SIP message. PIANO reduces the energy consumption in a smartphone by 65%. The implementation of PIANO introduces significant delays. When the SIP server does not receive a response to its *SIP INVITE* message, it triggers the exponential backoff for retransmission. The Wi-Fi interface has to wait for the message to be resent. Another setback for these projects is requiring the cellular interface to remain in the active state while the Wi-Fi interface is switched off. While the Wi-Fi interface is switched off to conserve energy, the cellular interface continues to consume power.

IV. WIRELESS INTERFACE ACTIVATION AND NOTIFICATION

In this section, the architecture of WINA is described. The central goal behind WINA is to reduce the energy consumed by the idle wireless interfaces on a mobile phone. WINA introduces an auxiliary receiver on the mobile phone, and an auxiliary transmitter on access points. While other wireless interfaces on the mobile phone are switched off, this auxiliary receiver continuously monitors the air interface for special notification signals sent out by auxiliary transmitters on access points. When a call or data arrives at the access point, a notification signal is sent to the receiver. The receiver then activates the relevant interface to receive the call or data.

A. System Architecture and Components

WINA is an activation service that operates in the infrastructure mode, where mobile phones are connected to Points of Access (PoA) through an infrastructure network. Figure 1 illustrates WINA's architecture. The design of WINA is based on two principles: (1) Universality - WINA caters for multiple wireless interfaces and applications; and (2) Ease of integration - WINA should not alter the standard protocols used in telephony and IP-based services, and must

not require a complete modification to network infrastructure it relies on.

Each main wireless service, such as 3G, Wi-Fi, is augmented with a special transmitter on its access point that sends out special signals to the relevant mobile phones. Each mobile phone is augmented with a special receiver that can receive the signals from those transmitters from various access points in the area. The functions of the transmitter and the receiver are described below:

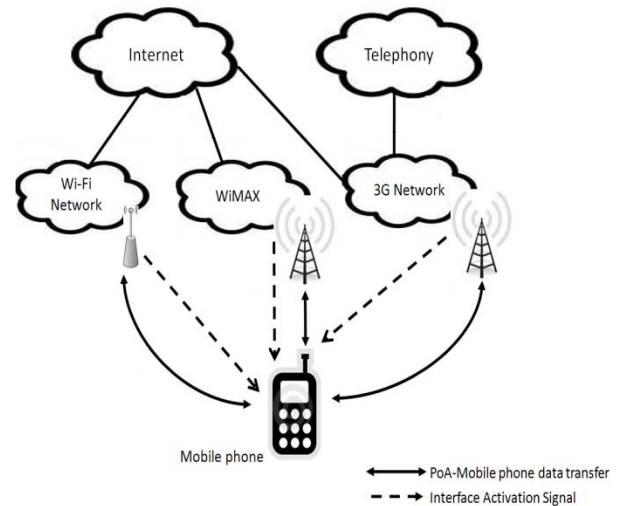


Figure1. WINA Architecture

WINA Transmitter: The WINA Transmitter is an auxiliary transmitter mounted on a PoA. This transmitter is responsible to periodically broadcast the presence of a wireless service in an area, and to notify a mobile phone when there is an incoming call or data to a mobile phone. The WINA Transmitter workflow is illustrated in Figure 2.

When a PoA is powered up, it needs to inform the auxiliary transmitter of its ID and the service which it provides. The WINA Transmitter will then broadcast this information to announce the presence of the PoA to mobile phones. Figure 3(a) shows the radio packet format used by the WINA Transmitter to broadcast the presence of a PoA.

In the radio packet format, the PoA_ID field contains the identity of the PoA. The PROTOCOL field specifies the service provided by the PoA (e.g. 3G or Wi-Fi). The remaining fields in the packet format are left blank in the broadcast signal.

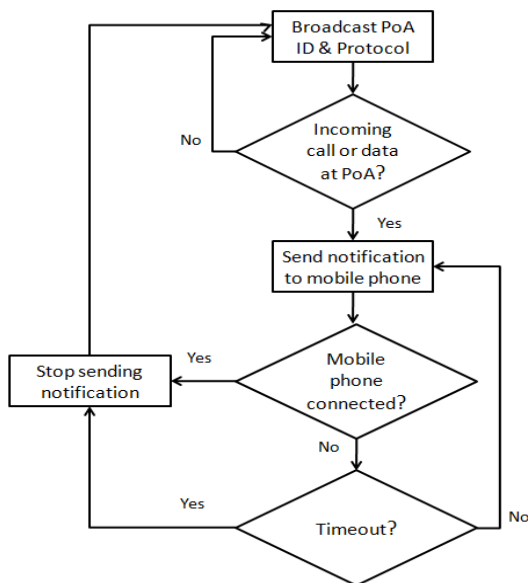


Figure 2. WINA Transmitter Workflow

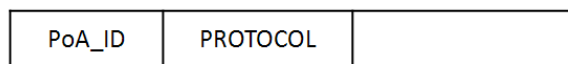


Figure 3(a). Packet Format – Broadcast Presence

The WINA Transmitter is also responsible to notify the mobile phone when there is an incoming call or data. When a call or data arrives at the PoA, the PoA informs its auxiliary transmitter that a call or data has arrived for an intended recipient. The WINA transmitter then beams out a special signal to notify the mobile phone of the incoming call. Figure 3(b) shows the radio packet format of the special notification signal.

In this packet, the MS_ID field contains the identity of the mobile phone. Based on the PROTOCOL field, the mobile phone is able to activate the relevant interface.

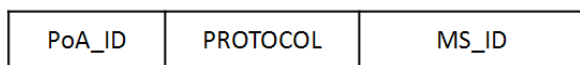


Figure 3(b). Packet Format – Notification Signal

We consider two scenarios when the notification signal is sent out to the mobile phone. First, a notification signal is sent out and received by the mobile phone. The relevant interface on the mobile phone is then switched on to accept the call or data. When the mobile phone is connected with the PoA to transfer data, the PoA needs to inform the WINA Transmitter to stop sending the notification signal. The format to inform the transmitter to stop sending the notification signal is shown in Figure 3(c). In this packet format, the MS_ID field indicates

the mobile device's identity. The CONN field indicates that the mobile phone is connected to the PoA and the WINA transmitter should stop sending out the notifications. In the second scenario, the mobile phone does not respond to the notification signal. After an interval, the transmitter will stop sending the notification signal.



Figure 3(c). Packet Format – Device Connected

WINA Receiver: The WINA Receiver is an auxiliary receiver on a mobile phone. This receiver performs two primary functions – monitors the air interface for broadcast signals which indicates the presence of wireless services, and activate the relevant interface when there is an incoming call.

When a main wireless interface, such as 3G and Wi-Fi, is not in active use, it is switched off to conserve energy. The WINA Receiver will scan the air interface for broadcast signals sent by the WINA Transmitters on various PoA announcing the presence of wireless services. It also scans the air interface for special notification signals sent by the PoA. If the receiver detects the presence of a service, or receives notification of an incoming data or call, it informs the operating system to activate the relevant interfaces to establish a connection and receive the call or data. The receiver's workflow is shown in Figure 4.

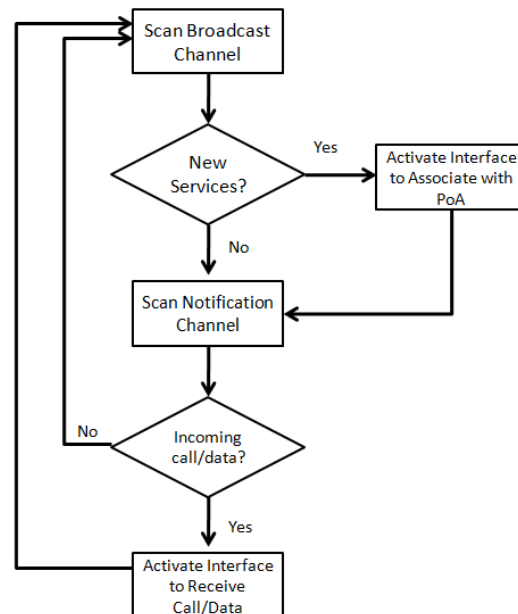


Figure 4. WINA Receiver Workflow

V. WINA PROCEDURE

In this section, the WINA's procedure and its operation under different connectivity scenario are discussed.

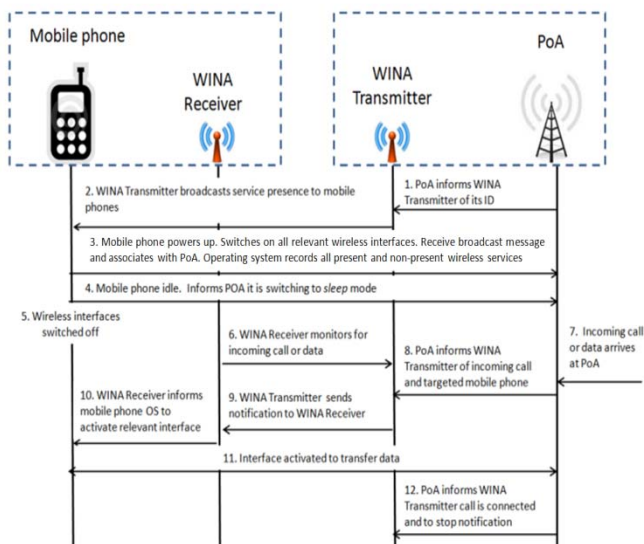


Figure 5. WINA Operating Procedure

A. Mobile phone power up

The main steps of WINA are illustrated in Figure 5. First, the PoA needs to inform the auxiliary transmitter of its ID. This is essential to enable the auxiliary transmitter to broadcast the presence of the PoA and the wireless service the PoA provides.

When a mobile device is first turned on, the wireless interfaces will be switched on. These interfaces will detect the presence of wireless services and will associate with relevant PoAs if it is subscribed to their services. At this point, the mobile phone's operating systems will record the available services and the PoA IDs.

The 3G cellular interfaces differ from and Wi-Fi interfaces in how they associate with their respective PoAs.

For 3G communication, the phone first listens to the air interface for a System Identification Code (SID) which is a unique 5-digit number assigned to a carrier. The SID is then compared to a SID programmed in the phone to establish its identity and determine if the phone is in its home system. If the SID does not match, it is said to be roaming. If the phone does not receive a SID, it is out of range.

The process above also informs the Mobile Telephony Switching Office (MTSO) of the mobile phone's current location. This allows the MTSO to forward incoming calls to the cell in which the phone is located.

For Wi-Fi, the Wi-Fi interface-PoA association begins with the Wi-Fi interface acquiring synchronization information from the PoA. This is achieved via passive scanning or active scanning. In passive scanning, the Wi-Fi interface waits for the beacon frame sent by the PoA. For active scanning, the Wi-Fi interface transmits a Probe Request Frame and waits for the Probe Response from the PoA. Afterwards, both the PoA and the Wi-Fi interface go through an authentication process where they exchange knowledge of a given password. This is simply the first step in a handshake process for network attachment that is not mutual, meaning only the PoA

authenticates the mobile station and not vice versa. Once this has completed, the mobile station can associate with the PoA (router) to gain full access to the network. Association allows the PoA to record each mobile device so that frames may be properly delivered.

At this stage, the WINA service via the mobile phone's operating system registers the presence of the 3G, Wi-Fi and other available wireless services it detected. In a register, the operating system makes distinction of the services that the mobile phone is accessible and subscribed to, services that are accessible but not subscribed to, and services which are not accessible. The time of which presence is detected is also recorded.

The wireless interfaces on the phone can now be either in *active* state where it actively exchanges data or in *idle* state where they waiting for incoming call or data.

B. Switching off wireless interfaces

In this scenario, it is assumed that an interface has remained in *idle* state for a time interval and it will be switched off to conserve energy. The interface was not switched off immediately simply because the energy consumed in one initial start-up is equivalent to sustaining the IEEE 802.11 Power Saving Mode for 10 minutes, as reported by Shih et al [2]. Therefore, in WINA, we propose that the interface uses the longest listening interval granted by the PoA before switching off to save energy.

Before the interface is switched off, it has to inform the PoA that it will be switching to *sleep* state. When the PoA is notified that an interface will be switched off, it registers the mobile phone's ID. This is performed so that when there is an incoming call or data, the PoA can perform a lookup and inform the auxiliary transmitter to inform the intended mobile phone.

C. Wireless interface activation

The wireless interface activation corresponds to the notification signals sent by the PoA auxiliary transmitter to the auxiliary receivers on the mobile phones. During idle times, other wireless interfaces on the mobile phone are switched off while the WINA Receiver continuously scan the air interface to see if there is a notification addressed to the mobile phone.

When an incoming call or data arrives at the PoA, the PoA will inform its auxiliary transmitter to notify the auxiliary receiver on the mobile phone. The special notification signal is sent to the receiver on the mobile phone. If the receiver detects there is a notification of an incoming call or data, it checks the packet sent by the PoA. The signal carries information about the sender's ID and the interface to be activated. The information is then forwarded to the operating system which will activate the relevant interface to receive the incoming call or data. If the signal is sent by a non-recognized sender, it is ignored.

In the event of call or data arrival at the PoA while the WINA Receiver is scanning other frequencies, the

notification signal may not be received by the intended WINA receiver. The PoA will repeatedly send the notification signal until it receives a message from the PoA that the intended wireless interface on the mobile phone has been activated. Once the mobile phone is connected to the PoA, the PoA needs to inform its auxiliary transmitter to stop sending the notification signal to the mobile phone.

In WINA, we also consider the scenario that a mobile phone does not respond to the notification signals. After the maximum number of attempts have been made or after a predefined timeout T_{Timeout} , the PoA assumes that the mobile phone is either power off or is out of range. The buffered messages will then be dropped. In WINA, the T_{Timeout} value is set to be long enough to ensure that the mobile phone is not falsely assumed to be out of range. After T_{Timeout} , the register in the PoA is updated to indicate that the mobile phone is now out of range.

Similarly, if a mobile phone detects that it has not received any signals from a PoA after a given time, it powers up the relevant interface to scan for the PoA's presence. If a PoA's presence is not detected, the mobile phone switches off the wireless interface and assumes that it has moved out of the PoA's range. The phone will also update its register.

D. New service discovery

Apart from continuously scanning for notification signals and activating the relevant interfaces in the event of an incoming call or data, the WINA Receiver is responsible to sense for new services. This is particularly important when a mobile phone has just moved into an area which is within the coverage of a wireless service.

The PoAs are network entities that continuously broadcast signals via its auxiliary transmitters to announce their presence and services to mobile phones. To be able to discover new services, the WINA Receiver periodically scans for the broadcast signals. When the receiver detects a broadcast signal which indicates the presence of a wireless service, it informs the operating system to activate the relevant interface. The operating system will also register the PoA ID and the time.

VI. ISSUES AND CHALLENGES

In this section, we discuss the issues and challenges in the design of WINA.

A. Signaling & Interference

An important issue to be deliberated in the deployment of WINA is the use of the radio spectrum for WINA Broadcasting and Notification Channels. Radio spectrum is a scarce resource and a careful plan for the spectrum usage is needed. In WINA, the use of appropriate signalling frequency, the modulation mechanism as well as ways to mitigate interference will be addressed separately.

VII. CONCLUSION & FUTURE WORK

Energy consumption of battery-powered mobile phones is a critical issue that calls for major attention. In this paper, a

service which focuses primarily on reducing *idle* power by using a secondary low-powered receiver to activate other wireless interfaces is proposed. It is argued that allowing idle interfaces to switch to *sleep* state reduces the energy wasted in *idle* state thus conserving energy in mobile phones. While other schemes proposed in the past were developed along this line, they have focussed on a specific interface or application, and require the presence of intermediary network entities which incur delays and costs.

This proposed service uses a low-powered receiver to scan the air interface for notification signals sent by the auxiliary transmitters mounted on the access points, and activate the relevant wireless interfaces on a mobile phone. It is expected that this approach will significantly extend the mobile phone usage time. This study also suggests several questions that are in need of further investigation, including the signalling mechanism for the proposed service, link layer issues and effects on latency.

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