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# Analysis of Context-Aware Network Selection Schemes for Power Savings

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## Abstract

*Socio-technical developments in computing have resulted in the emergence of innovative mobile systems which exploit the information available on the Internet to optimize the performance of hosted applications and services. One of the challenges in the real-time critical mobile applications such as remote patient monitoring is to ensure optimal power usage. We consider herewith a case, where context-aware middleware hosted on the mobile device uses wireless networks availability data obtained from the remote QoS Information Service to selectively turn on the network interface and handover to the wireless access network which results in the optimal power consumption on the mobile device. We evaluate the power savings potential of the proposed concept using close-to-real life simulations and compare the results with the network selection mechanism which uses only information locally available on the mobile device. The results obtained from the simulations encourage applying the proposed concept in real operational remote patient monitoring systems.*

## 1. Introduction

Due to the recent technological advances, a wide range of multi-homed mobile devices capable of connecting to the Internet using multiple *Network Interfaces* (NI) such as WLAN and GPRS is available in the market. Such devices, combined with auxiliary sensors (e.g. GPS receiver), smart software (e.g. *remote patient monitoring service* [1]) and increasing user willingness to share the information available on and around mobile device (e.g. location, network information) to the fixed network, are capable of generating a vast amount of valuable information which can be further exploited, for example to predict the

timely and geographic patterns about the *Quality of Service* (QoS) characteristics (throughput and delay) and *wireless networks availability* along the user trip path [1].

Our application for the work reported herewith is in the *mobile (M)-Health* domain for *remote patient monitoring* [2] where a patient's mobile device acquires the vital signs data from sensors attached to the patient's body, (pre-) processes the data locally at the mobile device, and sends the data to the *back-end system* using wireless connectivity to the fixed network. The results of our previous work [3] based on the principles of *context aware computing*, show that using the QoS predictions made available by the *remote QoS Information Service* (hosted somewhere in the Internet; hereafter referred as *QoS Context Source*) for the handover decision on the handheld mobile devices increases the availability, reliability and data resiliency of the remote patient monitoring service [3].

In line with the commercially available handheld mobile devices, we consider that a mobile device is equipped with one *Wireless Wide Area Network* (WWAN) interface (e.g. GPRS and/or UMTS) and one *Wireless Local Area Network* interface (e.g. WiFi). From the data transfer perspective, at any given time, the NIs of the mobile devices could be in one of the following states:

- *OFF*: No IP connectivity.
- *POWERING-ON*: This is an intermediate state to switch on the NI.
- *ON-IDLE*: an *IP-idle* state, where the NI has IP connectivity to the Internet. However it does not send/receive any IP packets carrying application-data.
- *ON-ACTIVE*: an *IP-active* state, where the mobile device is sending or receiving application level IP packets through this NI.

In [4], we observed that a significant amount of energy is consumed by the NIs for real-time data transfer, which results in the reduced lifetime (as low as 90 minutes!) of the remote patient monitoring service till the device runs out of the battery power. Usually, it is required to keep all the NIs on the mobile device switched on all the time to search for the mobile networks available in the vicinity. We argue that if the network availability in terms of the predictions provided by the *QoS Context Source* (QoSCS) is a priori known, then it suffices to switch on the required interface at a particular location and time, and keep it off when not used, which could result in the power savings on the mobile device. To prove this argument, we extended our work reported in [3] to include the following:

1) *Power context source* to provide context information such as the remaining battery power, NI power requirements and user's power saving preferences; 2) Extension of the *Context Reasoner* (CR) component to take into account information provided by Power CS; and 3) Comparison of the following four network selection schemes for their energy utilization over the simulation run:

- a). **BASIC**: This scheme is based on our experiments in [5] in which the information available only on the mobile device is used to select the network with the highest theoretical throughput; i.e. it does not use QoS predictions. If the state of WLAN (WWAN) NI is ON-ACTIVE then the state of WWAN (WLAN) NI is ON-IDLE.
- b). **ADVANCED**: This scheme relies on the QoS predictions and uses the *Analytic Hierarchy Process* (AHP) based network selection mechanism which in addition To Whom It May Concern: AHP functionality reported in [3] considers power context information and energy spent by the NI combination [WWAN ON-ACTIVE, WLAN ON-IDLE] in case of evaluating the WWAN network and [WWAN ON-IDLE, WLAN ON-ACTIVE] in case of the WLAN network.
- c). **ADVANCED<sub>WLAN-OFF</sub>**: This strategy is similar to ADVANCED strategy, except that the AHP selection mechanism considers energy spent by the NI state combination [WWAN ON-ACTIVE, WLAN OFF] ([WWAN ON-IDLE, WLAN ON-ACTIVE]) in case of evaluating the WWAN (WLAN) network. This strategy is motivated from the fact that WWAN connectivity is ubiquitous, hence in case where WLAN suddenly becomes unavailable or the WWAN is not available, it is easy to switch to WWAN immediately without wasting time for NI activation. If the WWAN network is selected for

the handover, then the WLAN NI is switched off. If the WLAN network is selected for the handover, the WLAN NI is switched on if it is in the *OFF* state.

- d). **ADVANCED<sub>WLAN-OFF,WWAN-OFF</sub>**: This strategy is an extension of ADVANCED<sub>WLAN-OFF</sub> strategy, where the AHP selection mechanism considers energy spent by the NI combination [WWAN ON-ACTIVE, WLAN OFF] in case of evaluating the WWAN network and [WWAN-OFF, WLAN ON-ACTIVE] in case of the WLAN network. This strategy is introduced to study the effect of switching off WWAN interface on the power savings. If the WWAN (WLAN) network is selected for the handover, then WLAN (WWAN) NI is switched off.

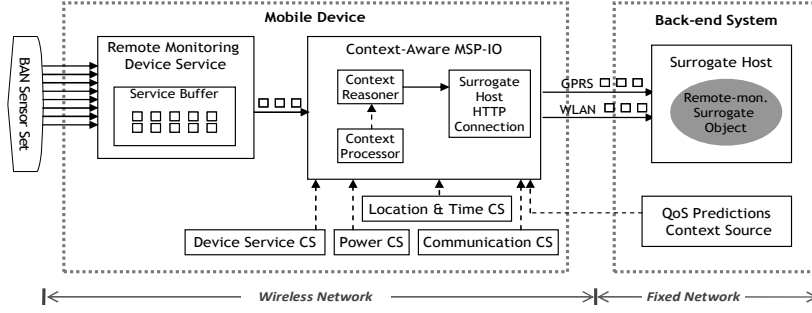
In addition to these, for achieving results close to a real operational system, the simulation methodology uses the geographical topology data available in the Internet (from *Google maps server*) as well as other simulation parameters such as NI power consumption values of two mobile devices (QTEK 9090 and IPAQ PDAs) available from the experiments conducted previously for the real-time data transfer.

The remainder of this paper is organized as follows: Section 2 of the paper describes related work. Section 3 briefly introduces the components of remote patient monitoring system. Section 4 is on the performance comparison metrics for the simulation exercise. Section 5 describes the simulation environment, methodology and parameters. Section 6 presents the results of the simulation run. Section 7 concludes the paper.

## 2. Related Work

There exists a wide variety of research work to achieve power savings on the mobile device by selectively turning off the unused NIs. Chen et al. [6] propose to use information such as coverage area, bandwidth and delay of available wireless networks information provided by the *Location Service Server* (LSS) to selectively turn off the WLAN NI. QoSCS is similar to LSS. However, herewith we also take into account user power preferences and compare performance of four network selection schemes. Rahmati et.al. [7] also propose to use historic WLAN data to switch on WLAN NI only when required. However, the results reported in [7] consider burst mode data transfer (at regular intervals) while we consider real-time data transfer.

In this work, we have used the NI state combination power consumption data measured for real-time data transfer using QTEK 9090 and IPAQ PDAs by Bargh et. al. [8] and for the QTEK 9090 PDA by Wac. et. al.



**Figure 1: Elements of Remote Patient Monitoring System**

[4]. The measurement results in [4] and [8] report the power consumption on the mobile device for a particular NI state combination strategy; however they do not use any information such as QoS predictions to achieve power savings. For the detailed related work on NI activation strategies, we refer to [4].

Compared to the related work, the distinguishing aspects of the work reported herewith are the following: 1) Network selection decision based on the remaining battery power, NI power requirements and user's power saving preferences; 2) Comparing three network selection schemes which use QoS predictions available from the QoSCS against the network selection scheme which uses information available only on the mobile device; 3) Use of close-to-real life simulators and data collected from the real operational system for the simulation purposes.

### 3. Remote Patient Monitoring System

*Nomadic Mobile Service* (NMS) [6] is a service hosted on a mobile host such as a handheld device, mobile phone or any type of embedded device capable of connecting to the Internet using wireless network and it participates in the service discovery network in the Internet to offer its service. *Mobile Service Platform* (MSP) [9] is a middleware for the development, deployment and lifecycle management of NMS. The design of MSP is based on the *Jini Surrogate Architecture Specification* [10]. MSP consists of an *HTTPInterconnect* protocol to meet the specifications of the Jini Surrogate Architecture. The NMS, realized using MSP, is composed of two components: 1) A service running on the mobile device (*Device Service DS*); and 2) Representation of DS in the fixed network (*Surrogate Service SS*) which registers with the *Jini Lookup Service* and is hosted by the *Surrogate Host*. MSP implementation consists of three modules: *Messages*, *Input-Output* (IO) and *Interconnect*. The *Messages* module defines the structure of messages exchanged between the DS and

the surrogate host. The *IO* module resides on the mobile device and is responsible for the lifecycle of the DS and communication with the surrogate host using *Surrogate Host HTTP Connection*. The *Interconnect* module resides at the surrogate host and is responsible for the SS management.

Figure 1 shows one of the applications of NMS, namely remote patient monitoring system; which also roughly corresponds with the simulation setup in this paper (for differences see Section 4). The following components contribute to this system:

**Body Area Network (BAN) Sensor set:** A BAN sensor set processes vital signs measured by the sensors attached to the patient's body, and outputs multiple channels of the patient vital signs data.

**Remote Monitoring Service:** The remote monitoring service consists of two components: 1) *Remote Monitoring Device Service* on the mobile device; and 2) *Remote Monitoring Surrogate* in the fixed network. The monitoring device service consists of a service buffer which maintains the number of packets waiting to be processed by the MSP-IO. This number is mapped to the *fill level* (0-100) of this buffer.

**Context-Aware MSP:** The IO module of *Context-Aware MSP* (CA-MSP) uses the context information obtained from a number of context sources (explained in the following) and subsequent context changes for the dynamic selection of and (NMS unobtrusive) handover to the optimal wireless network which satisfies following objectives: 1) *maximize NMS bandwidth requirements*; 2) *minimize NMS delay requirements*; and 3) *minimize power consumption of the mobile device* (introduced in this work). For this purpose, MSP-IO interacts with the *Context Sources* (CS) described in the Table 1.

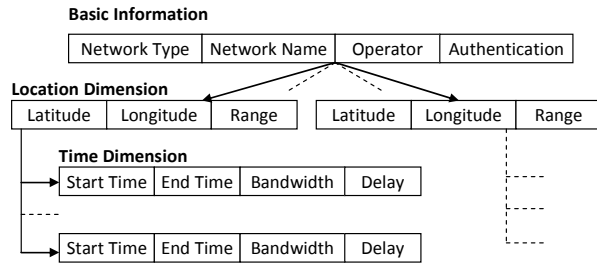
We assume that the user provides the power preferences only once during the installation of the software on the mobile device (However, it is possible to update the power preferences in the later stage). The value of power preference corresponds to the importance of energy saving to the user. We consider that the user assigns the power preference in a range of 1-5 (from least important to most important), which is later mapped from 0 to 100 on % scale.

The QoS-prediction information provided by the QoS Predictions CS (QoSCS) for a particular wireless network typically contains one element providing *basic* information (e.g. WiFi, Guest WLAN, University

of Geneva, and Open), multiple elements providing *location-dimension* information (e.g. 46.179956, 6.13896, 55m) and for each such element, multiple elements providing *time-dimension* information (e.g. 24 APR 2008 13:55:30, 24 APR 2008 14:20:33, 15149 bps, 650 ms) as shown in the Figure 2. For the motivation of this hierarchical structure, we refer to [3].

**Table 1: Description of Context Sources**

| CS Name   | Context Information   |
|---|---|
| <i>Location And Time Context Source</i>                             | Coordinates of the device's current geographic location (longitude, latitude) and time (Date, HH:MM:SS) as obtained from the GPS receiver.  |
| <i>Communication Context Source</i> (for details see [11])          | A list of mobile networks along with provider names, technologies, theoretical uplink throughput and delay (Network Cross Layer Info. in XML) in the surroundings of a mobile device at a given time and location, current state of the NIs on the mobile device. |
| <i>Device Service Context Source</i>                                | Required bandwidth and delay of every running device service.   |
| <i>Power Context Source</i> (introduced in this work)               | Maximum battery capacity stored and current energy level of the battery of mobile device, energy consumption in Joules/Sec by a combination of network interface states, user's power preferences.  |
| <i>QoS-Predictions Context Source (QoSCS)</i> (for details see [1]) | All the available mobile networks as specified by provider names, network names and technologies along with their coverage ranges and availability at a given location/time and predicted QoS information (bandwidth and delay).                                  |



**Figure 2. Structure of QoS Information**

The role of the *Context Processor* (CP) component is to get/subscribe context information from the context sources and provide a necessary aggregated context information to the *Context Reasoner* (CR) to be able to make a network selection decision at a given location and time. Upon the activation of the first DS on a given mobile device, CP obtains the current location and time from the location and time CS and provides this information to the QoSCS to obtain QoS-predictions. After conducting a set of experiments in [3], in the current setting, QoSCS sends QoS predictions for a

pre-defined number of networks (e.g. 30 networks) closest to the current location of the mobile device. Along with the QoS-predictions, the QoSCS specifies the distance between the farthest network from the current location of mobile device (*predictions range*) and the time for which the QoS-predictions are valid (*predictions time*).

CP takes care of requesting fresh predictions when the user is on the boundary (within certain distance) of the predictions range or the predictions time is about to expire. The QoS predictions useful at a given location and time (i.e. the wireless networks to which a mobile device can connect) combined with the QoS requirements of NMS and context information obtained from the power CS together form the *current context snapshot* which is later sent to CR for further processing. Based on the subsequent context changes (e.g. *location change*, *time change*, *NMS QoS requirements change*, *network unavailable*) CP takes an appropriate action such as *create current context snapshot*, *update QoS requirements* or *request (new) QoS-predictions*.

Based on the information received from the current context snapshot, and given one of the ADVANCED network selection scheme (pl. refer to the Section 1), CR applies *Analytic Hierarchy Process* (AHP) [12] based algorithm to optimize the objectives of:

- 1) Maximizing NMS bandwidth requirements;
- 2) Minimizing NMS delay requirements; and
- 3) Minimizing power consumption.

As described in [12], AHP is about dividing a problem into several sub-problems and later aggregating the solutions of these sub-problems into a conclusion. For the first two objectives, AHP algorithm is described in [3]. AHP method applied to satisfy minimizing power consumption objectives consists of the following three steps:

**Step 1:** *Decide the weights of the bandwidth and delay optimization objectives based on the value of user's power preference:* The combined sum of the objective weights is always 1. This is a two sub-step process:

- a)  $VALUE_{Bandwidth} = VALUE_{Delay} = 100 - VALUE_{Power}$
- b)  $WEIGHT_{Bandwidth \text{ OR } Delay \text{ Or } Power} = \frac{VALUE_{Bandwidth \text{ OR } Delay \text{ Or } Power}}{(VALUE_{Bandwidth} + VALUE_{Delay} + VALUE_{Power})}$

Following this calculation, if the user power preference value is 75%, then the objective weights are 0.2, 0.2 and 0.6 respectively.

**Step 2:** *Compute relative weight of each available network by considering the NI states' combined power consumption:* Depending on the type of network selection scheme (e.g. either of ADVANCED, ADVANCED<sub>WLAN-OFF</sub>, or ADVANCED<sub>WLAN-OFF,GPRS-OFF</sub>), this step considers the power consumption by the NI state combination (refer to Section 1) for calculating

the relative weight of each available network according to the AHP calculation in [12].

**Step 3:** Calculate the overall score for each network and select the network having the highest score: The overall network score is the sum of relative network weights multiplied by the objective weight. The most optimal network is the network with the highest overall score.

#### 4. Performance Metrics for Comparison

To substantiate our claim that the power savings could be achieved on the mobile device by selectively turning off the network interfaces if the network availability is known a priori in terms of the QoS predictions and to verify that AHP based network selection algorithm provides a fair treatment to all the three optimization objectives, the following performance metrics are evaluated:

*Remaining energy:* This is the amount of energy remaining in the mobile device battery at the end of simulation. Given the available energy before the simulation start (*initial energy level*), we also calculate the expected *lifetime* of a mobile device till its battery drains completely.

*Average data sent:* This is the amount of data sent from the mobile device using a particular handover scheme.

*Average buffer fill level:* This is the average amount of data accumulated in the NMS service buffer waiting for its transmission by MSP-IO.

*Average data loss:* The average amount of data lost over the simulation period. The data loss occurs only when the service buffer is full and can not accommodate more data.

*Average delay:* the average of delay experienced by the service by using the selected network over the simulation period.

The choice of the above metrics is motivated from the real operational system experiments carried in [13].

*Disconnection time:* the time for which there is no network connectivity available to the mobile device. Note that disconnection occurs in the following cases: 1) Mobile devices moves out of the coverage area of WLAN network; 2) NI to be used is powering on; and 3) During the handover start and handover complete process [13].

#### 5. Simulation Environment

There are two main problems in evaluating the network selection schemes using a real operational system. Firstly, it is not possible to execute all of the network selection schemes simultaneously on the mobile device because in the worst case it may result in

the selection of four different networks resulting in the network usage conflicts. Secondly, the QoSCS is still in the development phase [1]. Hence to get a better understanding of how the system, with interactions between CA-MSP and QoSCS, could be viable in practice to achieve power savings on the mobile device, we performed a series of simulations. For this purpose, we developed and used *QoSCS simulator* and *user trip simulator*.

In contrast to the traditional simulation topology (e.g. square plane areas with uniformly placed WLAN base stations [14]) for vertical handover mechanisms, the QoSCS simulator takes a close-to-real life approach. Nowadays most of the businesses and institutes are covered by WLAN and we observe that there is an increasing trend in the urban environments to deploy high capacity WLANs covering large geographic areas (e.g. city centre). Moreover, the accurate location listings of businesses and institutes are available on the Internet (in our case, *Google maps server*). Based on these two facts, the QoSCS simulator takes a novel approach of using the locations of the businesses and institutes to assign WLAN base stations.

Similar to the approach used by the QoSCS simulator, the user trip simulator also uses the route information available on the Internet (in our case, *Google maps server*) to model user movements between a source and destination locations. For details on these simulators we refer to [3].

The simulation environment considers two types of wireless networks namely WiFi (WLAN) and GPRS (WWAN). The QoSCS simulator obtains the list of around 2000 businesses from the Google maps server approximately covering area of radius 70 km around *Geneva (Switzerland)* city centre and WiFi base stations are assigned to these locations. For the user trip simulator, the trip originates at *Carouge* and ends at *Vernier* (both are municipalities in the *Canton of Geneva*) via *Geneva city centre* covering a distance of 8.470 km at the speed of 40 kmph and consisting of 107 sub-steps (transition from one step to another roughly corresponds to the direction change).

The bandwidth and delay requirements of the remote patient monitoring device service are 25580 bps and 500 msec respectively [13]. We consider two handheld mobile devices namely QTEK 9090 and IPAQ PDAs. The values of the energy consumed (in Joules/Sec) for the NI state combinations of these devices are listed in the Table 2. These values are derived from the experiments conducted in [4] and [8] for streaming data. We performed 20 simulation exercises for every device with 5 user power preference

% values (0, 25, 50, 75, 100) and 4 initial energy % levels (25, 50, 75, 100). We derived that the fully charged battery of mobile device stores 19847 Joules energy, based on the specifications of PH26B battery model (3.7V, 1490 mAh, a commonly used battery in QTEK 9090 PDA).

**Table 2: NI States Power Consumption Values**

| NI State Combination |             | Power Consumed (Joules/Sec) |          |
|----------------------|-------------|-----------------------------|----------|
| WLAN                 | GPRS        | QTEK                        | IPAQ     |
| OFF                  | OFF         | 0.304317                    | 0.304317 |
| Powering ON          | OFF         | 1.466861                    | 1.466861 |
| ON-IDLE              | OFF         | 0.386954                    | 1.163138 |
| ON-ACTIVE            | OFF         | 1.813634                    | 1.665883 |
| OFF                  | Powering ON | 1.466861                    | 1.466861 |
| Powering ON          | Powering ON | 2.933722                    | 2.933722 |
| ON-IDLE              | Powering ON | 1.853815                    | 2.629999 |
| ON-ACTIVE            | Powering ON | 3.280495                    | 3.132744 |
| OFF                  | ON-IDLE     | 0.359697                    | 0.333305 |
| Powering ON          | ON-IDLE     | 1.826558                    | 1.800166 |
| ON-IDLE              | ON-IDLE     | 0.445363                    | 1.187583 |
| ON-ACTIVE            | ON-IDLE     | 1.865985                    | 1.719099 |
| OFF                  | ON-ACTIVE   | 1.959870                    | 1.440037 |
| Powering ON          | ON-ACTIVE   | 3.426731                    | 2.906898 |
| ON-IDLE              | ON-ACTIVE   | 2.042509                    | 2.298857 |

Please note that the QTEK 9090 and IPAQ devices have very different characteristics for the NI power consumption. E.g., for QTEK 9090, GPRS NI consumes more power than WLAN NI in the ON-ACTIVE state, which is opposite to the case for the IPAQ. We do not consider the power consumption values for the NI state combination [ON-ACTIVE, ON-ACTIVE], because in the existing implementation of MSP, it is not possible to use two NIs simultaneously for the data transfer.

## 6. Simulation results

Since we are interested to investigate the effect of using QoS information on the possible power savings, we compare the performance of the ADVANCED schemes against the BASIC scheme; the latter of which uses information available only on the mobile device for the network selection. Moreover, we report two sets of results, one for QTEK 9090 PDA and another for IPAQ PDA; because they have different NI power consumption characteristics. For brevity, the results shown in the graphs in this section are averaged over the simulations conducted for 4 initial % energy levels (25, 50, 75, and 100). Also, all the graphs display the *improvement* in the performance metric of the corresponding ADVANCED scheme against the BASIC scheme. This means that while understanding the graphs, negative value of a metric means the

corresponding ADVANCED scheme does not perform better than the BASIC scheme.

Considering NI states power consumption values for the QTEK (IPAQ) device, the graphs in the Figure 3 (Figure 6) and Figure 4 (Figure 7) respectively show the average performance improvement for the ADVANCED schemes as compared to the BASIC scheme; when the value of user power preference is 0 [ $WEIGHT_{Power} = 0$ ,  $WEIGHT_{Bandwidth} = 0.5$ ,  $WEIGHT_{Delay} = 0.5$ ] and 100 [ $WEIGHT_{Power} = 1$ ,  $WEIGHT_{Bandwidth} = 0$ ,  $WEIGHT_{Delay} = 0$ ]. Figure 5 (Figure 8) shows the average performance improvement over the average of user power preferences (0, 25, 50, 75, 100) for the QTEK (IPAQ) device.

As can be observed from the graphs in the Figure 3, Figure 4 and Figure 5, the ADVANCED schemes do not result in any power savings on the QTEK device.  $ADVANCED_{WLAN-OFF}$  scheme results in the higher energy consumption as compared to the other schemes. Except the *disconnection time*, for every other performance metrics, ADVANCED scheme performs better than the  $ADVANCED_{WLAN-OFF}$  and  $ADVANCED_{WLAN-OFF,GPRS-OFF}$  schemes. The reasons for not achieving any power savings on the QTEK device are the following: 1) GPRS NI consumes higher energy in the ON-ACTIVE state as compared to the WLAN NI and the GPRS offers ubiquitous coverage as compared to the WLAN; and 2) The ratio of energy consumption for WLAN NI in the POWERING-ON state and IDLE state is large. Hence the effect of energy savings achieved by switching off the WLAN NI is negligible as compared to the energy spent in switching on the WLAN NI.

However, though there is no energy savings for the QTEK device, there is significant improvement in the other performance metrics irrespective of the user power preference value because of the higher QoS characteristics of the WLAN network. However, this improvement is higher (lesser) for the user preference value 0 (100) as shown in the Figure 3 (Figure 4).

As seen from the graphs in the Figure 6, Figure 7 and Figure 8, the  $ADVANCED_{WLAN-OFF}$  and  $ADVANCED_{WLAN-OFF,GPRS-OFF}$  schemes result in significant power savings on the IPAQ device (as much as 35% average increase in the lifetime when the value of user power preference is 100). This is because of the following reasons: 1) For the IPAQ device, in the ON-ACTIVE state, GPRS NI has lower power consumption as compared to WLAN NI; and 2) Compared to QTEK 9090 device, there is less difference in the power consumption of WLAN NI in the ON-IDLE state and POWERING-ON state. In contrast, ADVANCED scheme results in a negligible amount of power savings. For the performance metrics other than the

disconnection time, the ADVANCED scheme performs better than the  $ADVANCED_{WLAN-OFF}$  and  $ADVANCED_{WLAN-OFF,GPRS-OFF}$  schemes, mainly because it prefers WLAN network over GPRS network due to lower power consumption by [WLAN ON-ACTIVE, GPRS ON-IDLE] NI state combination as compared to the [WLAN ON-IDLE, GPRS ON-ACTIVE] NI state combination.

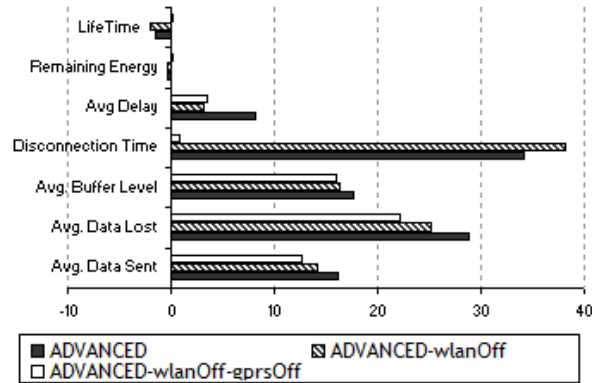


Figure 3. Improvement for User Pref. 0 (QTEK)

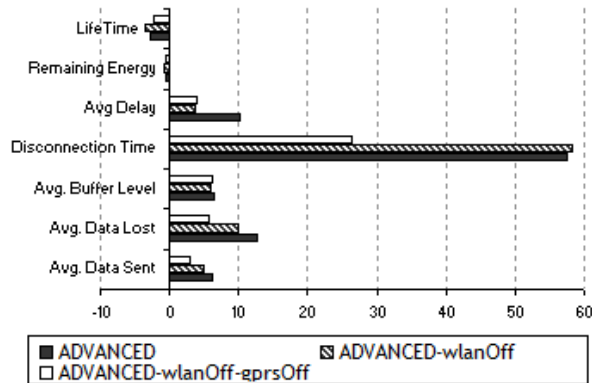


Figure 4. Improvement for User Pref. 100 (QTEK)

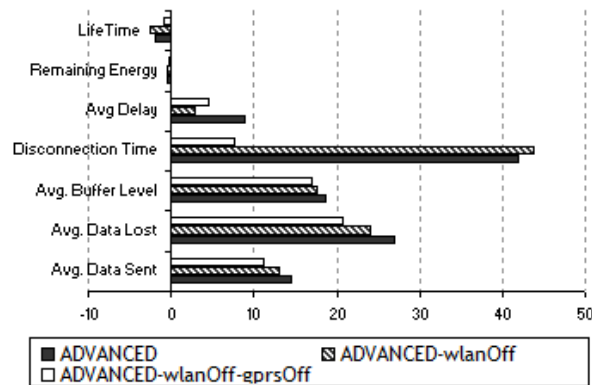


Figure 5. Improvement over averaged user power preferences (QTEK)

For both devices, in comparison to the  $ADVANCED_{WLAN-OFF}$  scheme,  $ADVANCED_{WLAN-OFF,GPRS-OFF}$  scheme results in higher disconnection time, because in the former, it is possible to handover to GPRS network immediately when no WLAN network available, while in the latter, it takes some time for GPRS NI to make a transition from OFF to ON state.

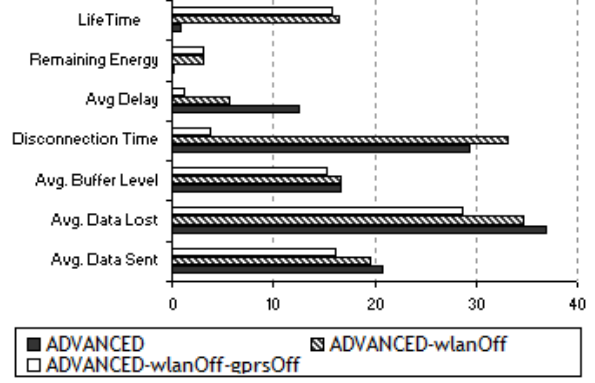


Figure 6. Improvement for User Pref. 0 (IPAQ)

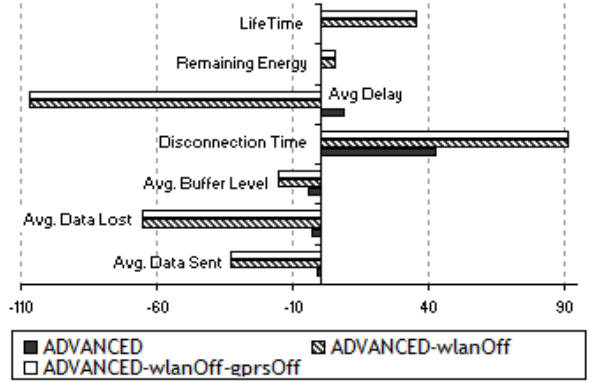


Figure 7. Improvement for User Pref. 100 (IPAQ)

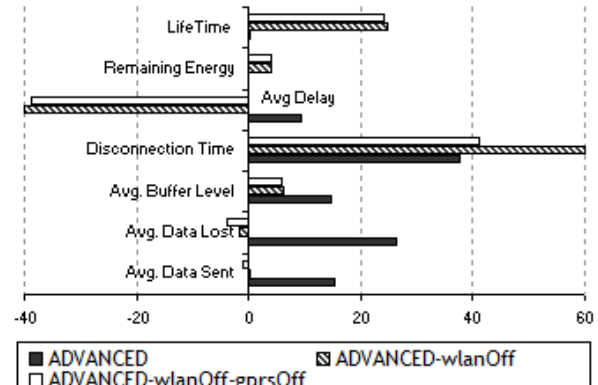


Figure 8. Improvement over averaged user power preferences (IPAQ)



By analyzing the results of the conducted simulation, the following trends are observed: Given that the network availability is known a priori in terms of the QoS predictions, power savings can be achieved by selectively turning off the unused NIs on the mobile device where WLAN NI consumes higher power compared to WWAN NI. When the mobile device has *opposite* characteristics, the proposed AHP based algorithm provides an improved QoS experience to a nomadic mobile service without compromising energy consumption of the mobile device NIs.

## 7. Conclusion

One of the challenges in nomadic mobile service provisioning such as remote patient monitoring, is to ensure optimal power usage on the mobile device. If the wireless network availability is a priori known to the mobile device in terms of the QoS predictions, it is possible that the unused *Network Interfaces* (NIs) can be selectively turned off to achieve power savings. We evaluated the power savings potential of this concept using close-to-real life simulations and compare the results with the NI selection mechanism which uses information available locally available on the mobile device. We observed the following trends: Given that the network availability is known a priori in terms of the QoS predictions, power savings could be achieved by selectively turning off the unused NIs on the mobile device where WLAN NI consumes higher power compared to WWAN NI. When the mobile device has opposite characteristics, the proposed *Analytic Hierarchy Process* based optimization algorithm provides a much improved QoS experience to a nomadic mobile service without compromising the energy consumption of the mobile device NIs. The results obtained from the simulations encourage us to apply the proposed concept in real operational remote patient monitoring systems.

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