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Application-Level Energy Consumption In Communication Models For Handhelds

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Introduction

The need for energy management grows along with the increasing computing and storage capacities of mobile computers such as handhelds (Personal Digital Assistants - PDAs), while the energy capacity of batteries lags behind [1]. Since faster Central Processing Units (CPUs) and larger memories tend to require more power to operate, techniques to reduce and manage energy consumption are necessary. Energy management is being performed at multiple layers of the systems: the physical layer, the operating system (OS) layer, and the application layer. Though there has been many techniques proposed for saving energy at the physical layer (e.g., dynamic frequency or voltage scaling of CPU), there is still much space for energy improvement at the application level, too. For example, the energy-efficient software algorithms can be developed [2] or the energy-efficient graphical user interface of an application can be designed. On the other hand, applications may have specific characteristics, such as computation, user interaction or communication-oriented, which allow focusing on energy issues using slightly different approaches.

In this paper, we focus on the investigation of energy awareness in wireless communication for communication-intensive applications. The aim is to present an infrastructure of the experimental modelling, energy evaluation and measurement strategy, and methodology. The basic result is the identification of an impact of various factors, such as switching on/off various modes of using PDA (e.g., playing music, playing movie, etc.) during the communication session, on energy consumption. However, our experiments show that the most influential factor is the state of the wireless network.

Wireless Local Area Networks (LANs) are becoming widely popular due their cost effectiveness and easy installation. Nevertheless, the limited battery power characteristic of handhelds limits the utilization time of wireless device and entire network. From the technical perspective, there are several possibilities to communicate with remote data sources via wireless communication such as using Wi-Fi, Bluetooth and GSM (Fig. 1).

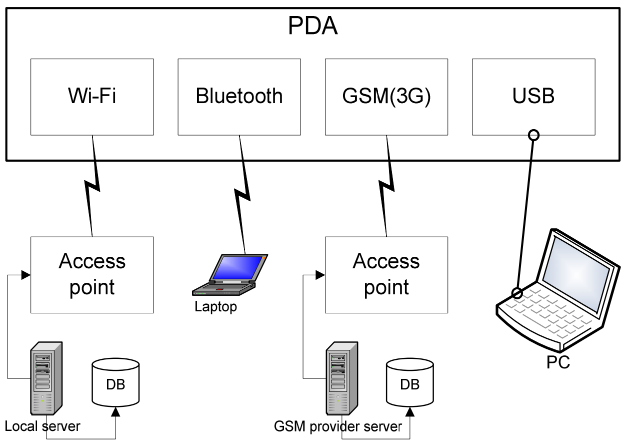

Fig. 1. Available communication modes

Currently, Wi-Fi is the most mature technology for wireless Internet access. The IEEE 802.11 standard that governs the Wi-Fi technology is widely deployed in commercial products, and has become the *de facto* wireless technology for LANs. Despite the wide spread of Wi-Fi access points, the energy limitations of mobile devices still hinder the effective use of this technology. Wi-Fi was not originally designed for the energy-constrained handhelds. As a result, the working time of a PDA with Wi-Fi interface is low. The communication activities can consume up to 50% of total energy spent by a handheld [3]. Checking for Wi-Fi availability and establishing an internet connection consume considerable energy, too. This large energy overhead makes Wi-Fi inefficient for small data transfers.

Using power-saving mode is a simple solution to reduce power consumption. Power management in IEEE

802.11 defines two types of states of wireless communication interface [4]: the awake state and the sleep (doze) state (see Fig. 2). In the awake state, a station can transmit a packet, receive a packet or stay idle (listening), consuming 1.65W, 1.4W and 1.15W [5] respectively. In the sleep state, a station is not able to transmit or receive a packet, but it consumes only 0.045W. The transition from doze to awake and vice versa also consumes a small amount of energy. The energy consumption in the awake operation states is very high compared to the sleep state. Therefore, the most effective approach to reduce energy consumption should minimize the time spent in the awake states and maximize the time spent in the sleep state, or to switch off the Wi-Fi and then re-establish the connection when necessary.

The other approach to energy consumption minimization deals with modification and tuning of Media Access Control (MAC) protocol, which is not considered in this paper.

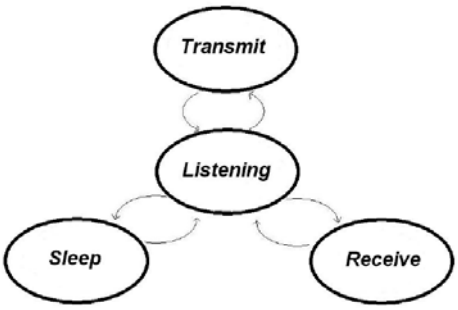

Fig. 2. States of wireless communication interface

Methodology

Fig. 3 presents a general framework of the proposed methodology for evaluating resources needed by operating applications using PDAs. The methodology is described using a feature diagram [6, 7]. A feature is an externally visible characteristic of the system (application). A feature diagram is a tree-like graph, where nodes (boxes) represent features (e.g., mandatory features are shown with black circles above boxes and optional/alternative features have white circles) and branches represent various kinds of relationships among features. The relationships are of two kinds: the parent-child relationships on the tree and the relationships among the terminal nodes (doted lines, see Fig. 3). Other notations used in Fig. 3 are as follows: HIC – human intensive communication; white arc means that only one feature can be selected; black filled arc means that any feature can be selected.

The identification of various dependencies among the energy consumption features, Wi-Fi mode features and network factors is the task of the experiments. Fig. 4 outlines an algorithm that enables to perform measurements of energy consumption and obtain the desired relationships. We apply the OS-based measuring scheme [2], where the amount of the consumed energy over time is periodically written to the file during the data download session.

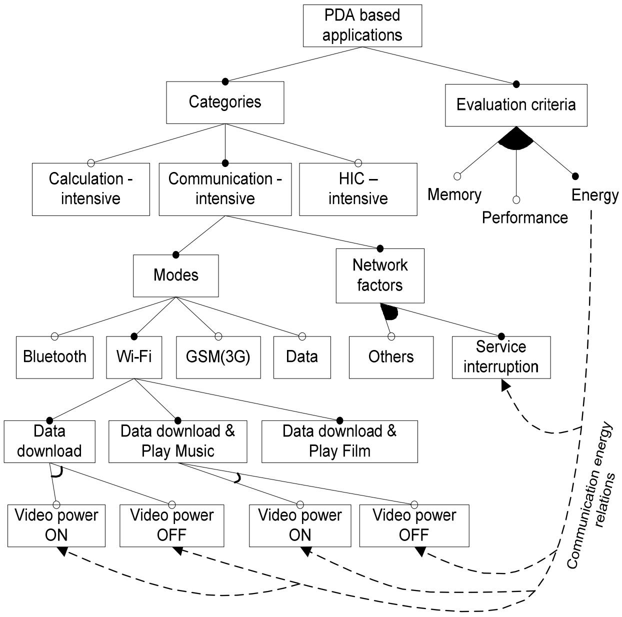

Fig. 3. Application-level feature model to represent energy consumption relationships

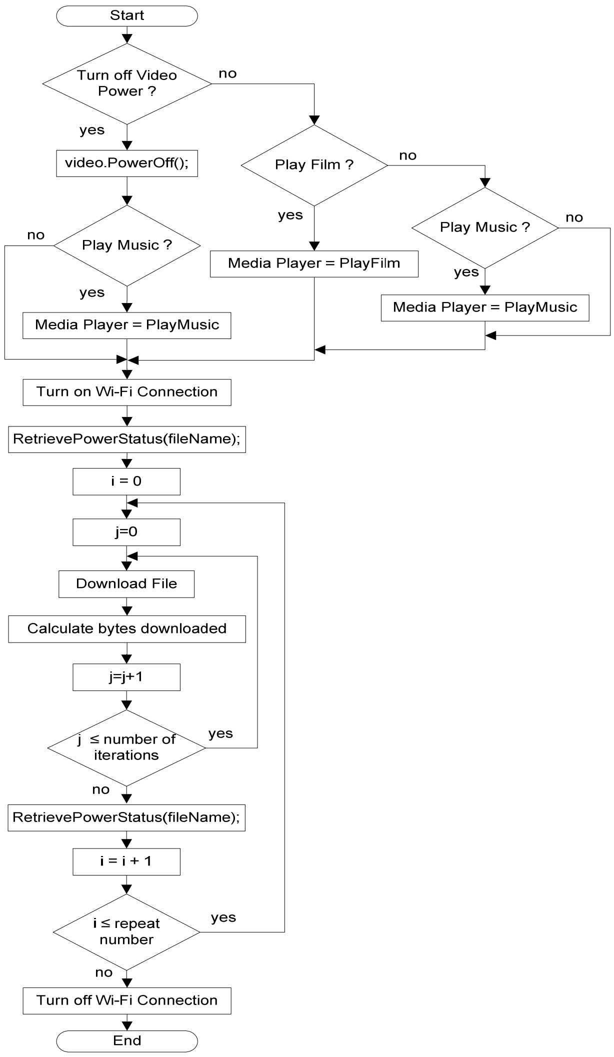

Fig. 4. Energy measurement algorithm during Wi-Fi communication

Experiments

The experiments were performed on the PDA of the model ASUS P750 (Pocket PC platform, Intel PXA270 520 MHz CPU, 64 MB RAM, Windows Mobile © 6 Professional CE OS 5.2).

Conditions of the experiments: the location of PDA, its position on the table and physical orientation with respect to the access point are the same in each session, as well as the network server and the database.

During one measurement session 82.080 MB were downloaded. The download was performed in 60 iterations (the number was identified empirically in order to get noticeable/measurable energy consumption results), using a 1.368 MB file. The size of the downloaded file is limited by the size of random-access memory (RAM) in PDA. The buffer size was 4K. The experiment was performed during 2 weeks at different days and different hours within a day (1 experimental session per day). The results are presented in Table 1.

Table 1. Summary of experimental results (sorted by energy)

No	Feature variants (Fig. 3)	Time duration, hh:mm:ss	Energy consumed, %	Down-loaded data, GB	Notes
1	Video Power ON	01:14:34	53%	1.6416	
6	Video Power OFF and Play Music	01:38:05	57%	1.6416	3rd trial
3	Video Power ON and Play Music	01:23:06	60%	1.6416	
5	Video Power OFF and Play Music	01:54:25	67%	1.6416	2nd trial
2	Video Power OFF	02:19:34	72%	1.6416	
7	Video Power ON and Play Film	01:40:50	73%	1.6416	
4	Video Power OFF and Play Music	03:04:27	100%	1.3133	1st trial

First compare the results No. 1 and No. 2 (see Table 1). While the experimental conditions were equal in both cases (except different days and different day-time) we received the result, which was quite contrary to our expectations. Next compare the results No. 4, 5 and 6. Again, the results are unexpected; however there is no mistake because we repeated the experiments three times (again at different days and different day-time). Here energy consumption is evidentially different and the difference is very large (about 50%). The experiment No. 4 has the worst execution time, so that even the task wasn't executed to the end in terms of the amount of data that had to be downloaded (see Table 1).

What is the explanation of the achieved results? The answer is that the state of the *ad hoc* networking plays an extremely important role to the Wi-Fi communication [8], which is much larger than the PDA usage modes (see also Fig. 3 and the 2-nd column in Table 1). As a result, quality of service (expressed in terms of the task execution time) and energy consumption highly depends upon the state of wireless network [9, 10].

As the communication problem using Wi-Fi was identified, we propose the solution to solve it. At the application level, a user should control the stream of downloaded bytes in the buffer over time in order to avoid wasting communication cycles when information is not loaded into the buffer due to random interruption of wireless network communication.

Power-aware communication improvement

Fig. 5 presents the improved communication algorithm enabling to identify the time slots when the waste communication state takes place. The response to the state is to turn off the Wi-Fi connection and postpone the task execution. The wait time should be identified according to the requirements to the quality of service. User should decide what is more important: either to save energy (with a great risk to diminish the quality of service) or to try to execute the task with higher quality, but at the great risk of large energy losses (and also with some possibility to not finish the task at all).

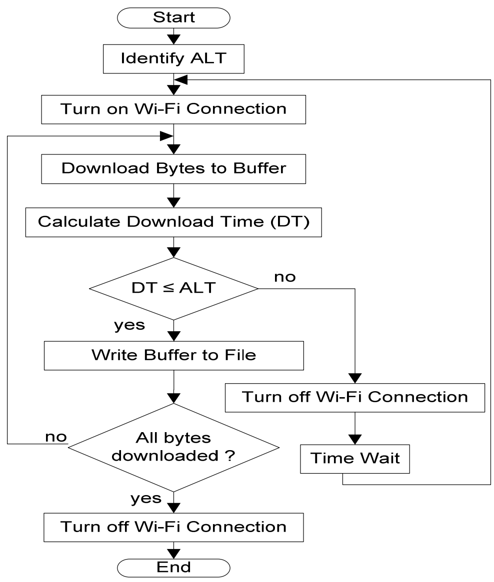

Fig. 5. Fragment of improved Wi-Fi communication algorithm

The proposed algorithm has two stages. The first stage is the identification of the Allowed Limit of Time (ALT) for the filling of full buffer. The second is the interval size for Time Wait. As both values depend on multiple factors that are random (e.g., user requirements for service quality, current level of battery charge, application type used, and of course, the unpredictable state of networking), it is impossible to precisely identify these values. As a result, the algorithm has to suggest some alternatives for the user. For example, the algorithm may implement several choices for the selection of Time Wait and ALT values. This selection can be pre-programmed (not shown in Fig. 5) enabling the user to act on the fly, when an application is executed. Such a solution allows to adjust the impact of different contradicting factors (e.g., energy consumption and quality of service), bringing some trade-offs in using resources and achieving the goal of the task.

Conclusions

Reducing energy consumption at all levels of battery-powered devices such as PDAs is still a major challenge. Energy-awareness, when Wi-Fi protocol is used for communication-intensive applications, is the challenge too, because a wireless network consumes a significant portion of overall energy. Our experiments show that the communication-related energy consumption has greater influence over total energy consumption of a mobile device than the application-specific energy management factors (video on/off, music on/off switching). The problem is due to the unpredictability of wireless connection states. We have not only suggested a methodology for modelling energy-awareness for the application, but also presented an improved algorithm for evaluating instability of wireless connection to reduce the energy consumption. Future work will be done to investigate the improved algorithm experimentally.

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Reducing energy consumption for handhelds (PDAs) is still a major challenge. In this paper, we investigate the application-level models for energy-efficient Wi-Fi communication, using IEEE 802.11b. The basic idea is to conserve energy by modelling energy awareness depending on the device usage modes. We describe an infrastructure for the modelling of energy awareness, the energy evaluation and measurement strategy and the methodology, which is supported by the experimental results we carried out. The application-aware strategies can reduce the energy consumption in communication when downloading large files to PDAs, however, the largest portion of energy consumption falls on the unpredictable state of wireless communication. We suggest the algorithm to deal with the problem. Ill. 5, bibl. 10 (in English; abstracts in English, Russian and Lithuanian).

Е. Толдинас, В. Штуйкис, Р. Дамашевичюс, Г. Зиберкас. Потребление энергии прикладного уровня в моделях коммуникации для карманных компьютеров // Электроника и электротехника. – Каунас: Технология, 2009. – № 6(94). – C. 73–76.

Проблема уменьшения потребления энергии мобильными устройствами, такими как карманные компьютеры, особенно актуальна. В статье исследуются модели прикладного уровня, применение которы оказывают влияние на потребление энергии при безпроводной связи Wi-Fi (IEEE 802.11b). Основная идея энергосбережения основана на построении моделей, с помощью которых можно установить влияние существующих факторов (например, режимы работы карманного компьютера, нестабильность работы сетей) на потребление энергии. Приводятся инфраструктура моделирования и методика с результатами эксперимента. Несмотря на то, что прогнозирование потребления энергии на прикладном уровне может уменьшить расход энергии, наибольшая часть расходуемой энергии приходится на непредсказуемое состояние безпроводной связи. Предложен алгоритм управления данной проблемой. Ил. 5, библ. 10 (на английском языке; рефераты на английском, русском и литовском яз.).

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Mobiliųjų įtaisų, tokių kaip kišeniniai kompiuteriai, energijos naudojimas kelia daug problemų. Straipsnyje nagrinėjami taikomojo lygmens modeliai, kurie turi įtakos energijos naudojimui bevieliam ryšiui Wi-Fi (IEEE 802.11b). Pagrindinė energijos taupymo idėja remiasi siekiu sukurti modelius, kuriais naudojantis būtų galima nustatyti esamų veiksnių (pvz., kišeninio kompiuterio naudojimo režimų, tinklo nestabilumo veiksnių) įtaką energijos sąnaudoms. Straipsnyje pateikiama tokio modeliavimo infrastruktūra ir metodika, o kartu ir eksperimentų rezultatai. Nors išmanant energijos naudojimo strategiją galima sumažinti energijos sąnaudas, didžiausia energijos dalis sunaudojama nenuspėjamai bevielio ryšio būsenai. Pasiūlytas būdas jai suvaldyti. Il. 5, bibl. 10 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).