Achieving collaborative service provisioning for mobile network users: the CollDown example

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This paper proposes a distributed model of service provisioning process for mobile network users who share a common interest in a service content offered in the network. The model is based on an idea that such users could individually acquire disjunctive parts of service content from a remote server (via a wide area mobile network), and then subsequently exchange them among themselves in an ad hoc local network in a peer-to-peer fashion, thus allowing each user to reassemble the entire content for her/his own use. The benefits of this approach include lowering the load on the "expensive" link to the telco's network and saving the energy for wide-area communication on users' mobile devices. The key questions to solve include recognizing the "common interest" of users and achieving their collaboration as described above. As an example, we show a service in which mobile users form an implicit social network and collaborate while downloading a selected multimedia content from the server under the control of the telco. A proof-of-concept implementation, named Collaborative Downloading (CollDown for short), is evaluated by using real mobile phones in a real network.

1. Introduction

Simultaneous development of mobile devices and telco infrastructure resulted in the network ability to provide more complex mobile services [1]. In this paper we study a particular type of mobile services, namely, *collaborative services* for *mobile users*. A mobile user is defined as a person who uses a mobile device (e.g., a mobile phone) which has the ability to attach both to a public land mobile network and an ad hoc or other local wireless network (e.g., Bluetooth, IEEE 802.11) operating in the unlicensed spectrum. A collaborative service [2,3] is defined as a service in which a set of users, sharing a common goal (e.g., downloading the same video clip from a service server), work together as a group in order to achieve that goal. The main idea behind the collaborative service is that the network operator can build an implicit social network of mobile users based on information provided by the users at the time of subscription. The social network is built with respect to user interests, their mobile devices' characteristics and the context in which they find themselves while requesting a service. The implicit social network of mobile users is built autonomously, without the interference of users themselves and in order to provide useful information for telcos [4].

This paper presents an extended version of our previous work [5], in which our main contribution was an implementation of an agent-based [6] middleware for group-oriented mobile service provisioning, while this paper focuses on an evaluation of the collaborative service called *Collaborative Downloading* (CollDown for short). The evaluation, focusing on overall download time and energy consumption, is done by using a real world network environment and Sony Ericsson mobile phones. The rest of this paper is organized as follows. Section 2 describes the idea of a three-layered architecture for enabling collaborative services. Section 3 elaborates upon a proof-of-concept collaborative service called *CollDown*. Section 4 concludes the paper and proposes some directions for future work.

2. Architecture for enabling collaborative services

The proposed model for enabling the collaborative service provisioning has a three-layered architecture, based on three views on the mobile users [7]. These layers are the *physical layer,* the *ontology layer* and the *social layer,* as shown in *Fig. 1*.

The **Physical layer** observes mobile users as persons physically situated in a mobile network environment and using mobile devices. Mobile users are connected to a telco's network via physical links and communicating with the telco's *base stations* via *wireless links*. Mobile users' devices are also equipped with Bluetooth and/or Wi-Fi technology which enable ad hoc connections among mobile devices. The base stations are interconnected using *wired links* in the telco's core network.

The **Ontology layer** observes mobile users through their semantic profiles, which all refer to an ontology representing domain knowledge. We use the World Wide Web Consortium (W3C) Composite Capabilities/Preferences Profile (CC/PP), an RDF-based specification which

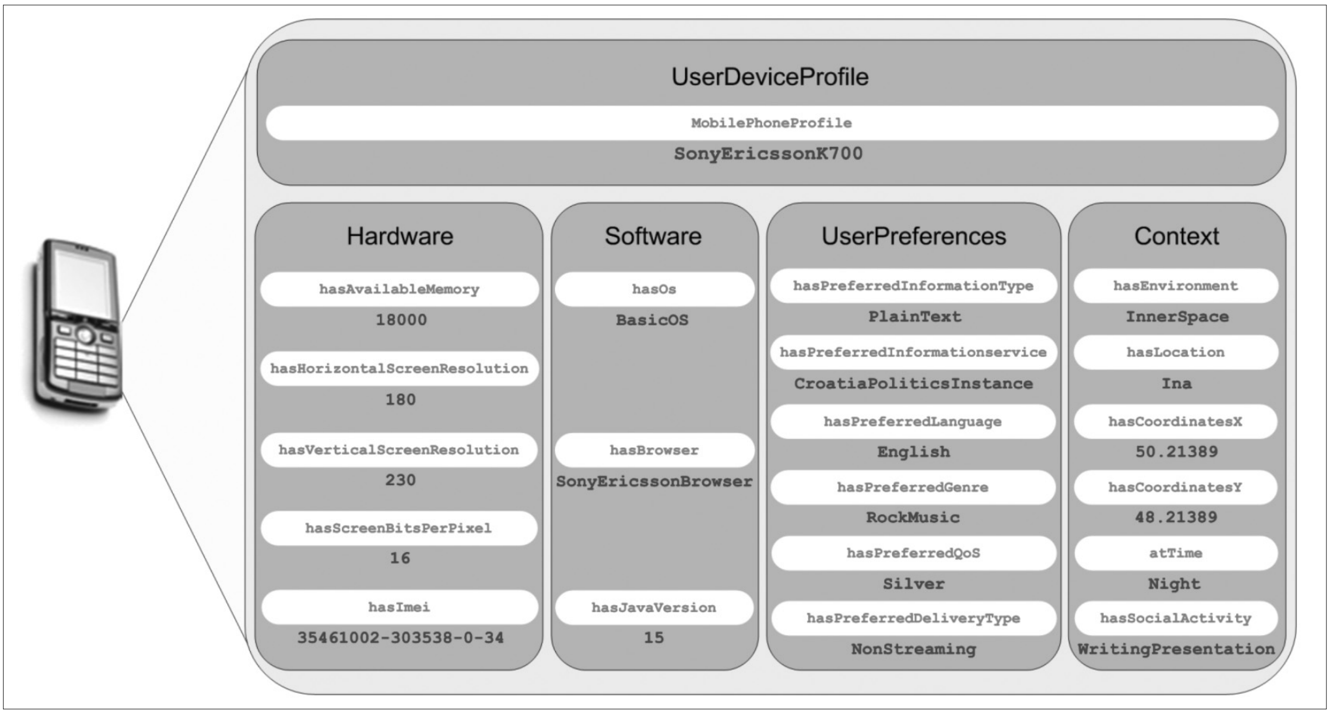
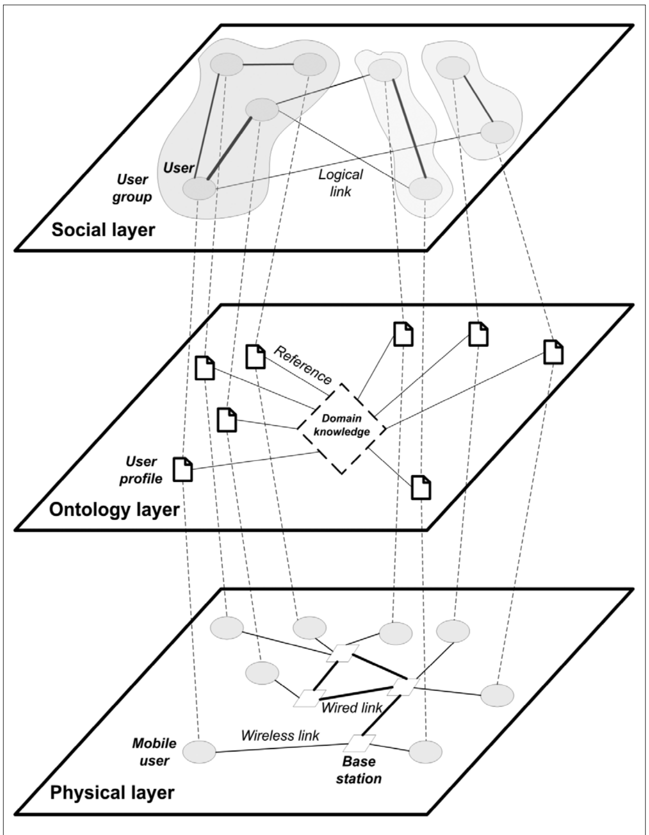


Figure 2. User profile

describes device capabilities and user preferences, and apply it for adapting the content to the user's mobile device. Such an approach maps each user with a mobile device (from the physical layer) to a user profile (within the ontology layer).

Figure 1.
Three-layered architecture for enabling collaborative service provisioning



The user profile (see *Fig. 2*) consists of five parts:

- *UserDeviceProfile,* describing the type of user mobile device (e.g., a mobile phone);
- *Hardware,* describing the configuration of user mobile device (e.g., screen vertical resolution of 230 pixels);
- *Software,* describing the software installed on user mobile device (e.g., an operating system);
- *UserPreferences,* describing the preferences and the interests of a mobile user (e.g., English as the preferred language);
- *Context,* describing the mobile user's context (e.g., the "time of day" is "night").

The **Social layer** observes mobile users through an implicit social network. Mobile users' profiles are initially filtered according to a certain criterion (e.g., location). Profiles of filtered users are then compared by semantic matchmaking between all pairs of those mobile users. Specifically, the context part of user profiles enables telcos to calculate the physical distance between users. Both the semantic similarity and the physical distance can be useful in order to determine the potential target set of users for a specific telecom service. Thus, we can create a social network and identify its subnets with respect to the combination of the user physical location and the semantic similarity among the user profiles.

Semantic matchmaking is the process of comparing two objects represented through semantic profiles, resulting with a number within a certain interval (i.e., a number between *0* and *1*, where the larger number reflects a higher level of similarity between profiles). A detailed description of semantic matchmaking of user profiles (structured according to Fig. 2), as well as building an implicit social network of mobile users, is given in [4], while the procedure for grouping users who form a social network into clusters is described in [8].

One of the practical issues that need to be addressed when considering the proposed model implementation is how the privacy of mobile users' profiles is handled. For the purposes of this work, we consider the role of a telco as being both a network provider and a service provider. As such, it provides a content of interest (e.g., video clips) to mobile users who subscribe to a related service. We are currently considering only the collaboration among subscribers having the same operator, but the model could be extended to have more than one telco. From the technical point of view, introducing more than one telco would be fairly straightforward, while from business point of view it would require collaboration not just among users, but among their respective telcos as well.

We also considered an approach with a third party service provider, with which a telco would have a service agreement in place, but decided to exclude it for the time being due to unsolved privacy issues (sharing user profiles with third party entities as something that users have not agreed on). In the described approach, telcos do not share user profiles with third parties, but directly provide services to their own subscribers (based on the information that the users have willingly provided upon subscription).

3. Proof-of-concept service: CollDown

A collaborative proof-of-concept service we developed is called *Collaborative Downloading* (CollDown for short). CollDown aims to make the mobile service provisioning process more efficient for both mobile users and telcos. It lowers battery consumption for mobile users' devices which is of great importance because limited energy supply is one of the main obstacles for using advanced mobile services. It also has several benefits for telcos: their mobile network resources are less loaded, and the overall CPU load and memory consumption on their service (content) servers are lower, meaning that the servers consume less energy and are thus more environmentally friendly.

The proposed approach moves a step further from the "traditional" content download service model we have today. Namely, when a mobile user wants to download a certain multimedia content to her/his mobile device, s/he is not aware of other mobile users interested in the same content. Consequently, each user communicates only with the service (content) server and downloads the complete desired content via a mobile network (e.g., General Packet Radio Service; GPRS, or Universal Mobile Telecommunications System; UMTS). We refer to this standard approach to mobile service provisioning as *individual approach*.

The basic idea of CollDown is that mobile users, who are physically located at a relatively small distance from each other (e.g., 10 meters – the Bluetooth range), and who are interested in the same content, collaborate and download the desired content together. Two typical examples of such situations are rock concerts and sport events, where users may want to view close-up views of performers or in-game action replays during the event. To allow collaborative download, the media content on the server is divided into a number of disjunctive parts and each part can be downloaded independently from the server via a mobile network and afterwards exchanged with other mobile users via an ad hoc network (e.g., Bluetooth or Wi-Fi). Exchange of content parts is performed as an "auction" where mobile users compete on the "market" to determine which parts of a requested content to download directly from the service server and which to exchange with other users.

Further details about the procedure how mobile users from a targeted group accept or decline to participate in a particular CollDown scenario are given in [5], while the auction, which manages the exchange of content parts, is presented in [10]. In this article, we refer to such a new mobile service provisioning approach as a *collaborative approach*.

Mobile users who collaborate can form either *flexible groups* (in which mobile users can leave a collaborating group before the service provisioning is completed) or *fixed groups* (in which mobile users cannot leave a collaborating group before the service provisioning is completed). In the present application, we assume fixed groups, in which users may move or change their individual location only as long as they remain "within range" for *ad hoc* communication. This assumption may be considered realistic for the case where the content download takes less time than the usual time period for one (or more) users to leave the group. However, in future work we may consider different flexibility models which would allow users to leave their groups before the service provisioning is completed.

3.1 The system for CollDown service provisioning process

The system model for CollDown service is illustrated in *Fig. 3.* Let $\mathbf{I}=\{i_1, ..., i_N\}$ denote the set of N mobile users who are subscribers of a certain service offered by a telco and let $\mathbf{J}=\{j_1, ..., j_M\}$ denote a subset of mobile users who form a mobile ad hoc network. Set $\mathbf{J}$ is always a rather small subset of set $\mathbf{I}$ ($\mathbf{J}\subset\mathbf{I}$), while $M=|\mathbf{J}|$. The calculation of subset $\mathbf{J}$ from set $\mathbf{I}$ is based on a three-layered architecture for enabling collaborative service provisioning (presented in previous section), namely on grouping of mobile users who form a social network into clusters. The content on the service server is divided into smaller disjunctive parts. Let $\mathbf{K}=\{k_1, ..., k_p\}$ denote the set of content parts on the server, which the users may download individually and reassemble by sharing them through an ad hoc network.

In the system shown in Fig. 3, there are two modes in which mobile devices may communicate:

a) the wide-area mobile network, shown as GPRS; and

b) ad hoc communication, shown as Bluetooth.

Networks	Send (*µJoule/bit*)	Receive (*µJoule/bit*)
Bluetooth	0.064	0.064
GPRS	15.647	1.422
IEEE 802.11a	0.028	0.022

Table 1.
Energy consumption in GPRS, Bluetooth and Wi-Fi networks [11]

Mobile phones communicate over GPRS with the service server by using Session Initiation Protocol (SIP) as the control protocol and Hypertext Transfer Protocol (HTTP) for the content download. The direct communication among mobile phones takes place in a mobile ad hoc network and uses Bluetooth-based communication.

The energy consumption while sending and receiving data within GPRS, Bluetooth and Wi-Fi networks is compared in *Table 1* [11].

It may be noticed that Bluetooth-based communication consumes much less energy than GPRS-based communication. For the purpose of comparison, we also cite the energy consumption for a wireless LAN (IEEE 802.11a), which is even lower than Bluetooth.

3.2 The CollDown performance measurements

The CollDown service was evaluated in a real network environment, by using a prototype service server developed in Java, and SonyEricsson W910i mobile phones as mobile users' devices. (The CollDown server was accessible through a real GPRS network of a mobile operator.) SonyEricsson W910i phones support Java platform 8 (JP8), as well as different Application Programming Interfaces (APIs) required for CollDown service execution on mobile devices: JSR180 (SIP API), JSR82 (Bluetooth API) and JSR256 (Mobile Sensor API). The CollDown service is developed for mobile devices supporting Connected Limited Device Configuration (CLDC) 1.0 and Mobile Information Device Profile (MIDP) 2.0.

We have compared our *collaborative approach* based on CollDown with the *individual approach* for a video clip downloading in mobile networks. We measured the time and the energy consumption in both cases. *Fig. 4* presents the comparison of time required for a system composed of one, two, three and four mobile users/phones to download the whole video clip by using the individual approach and by using the collaborative approach. *Fig. 5* shows the respective energy consumption.

As shown in Fig. 4, the low data rate on Bluetooth links presents a serious limitation in this particular implementation of the collaborative approach. The time duration for the four-mobile-users scenario in the individual approach is 74.31 s, while in collaborative approach it takes 187.25 s. For practical purposes, a faster and more efficient ad hoc or (if available) a local area network (Wi-Fi) should be used.

Results in Fig. 5 show energy consumption in the system. In our system the overall energy consumption is calculated as a size of chunk multiplied by mobile devices' characteristic energy consumption per bit shown in Table 1. Chunk is the information unit which includes only data packets for individual approach and both data packets and gossip messages for collaborative approach. Gossip messages are used to propagate content availability information between users in an ad hoc network. While the gossip messages clearly introduce a certain overhead, the presented collaborative approach

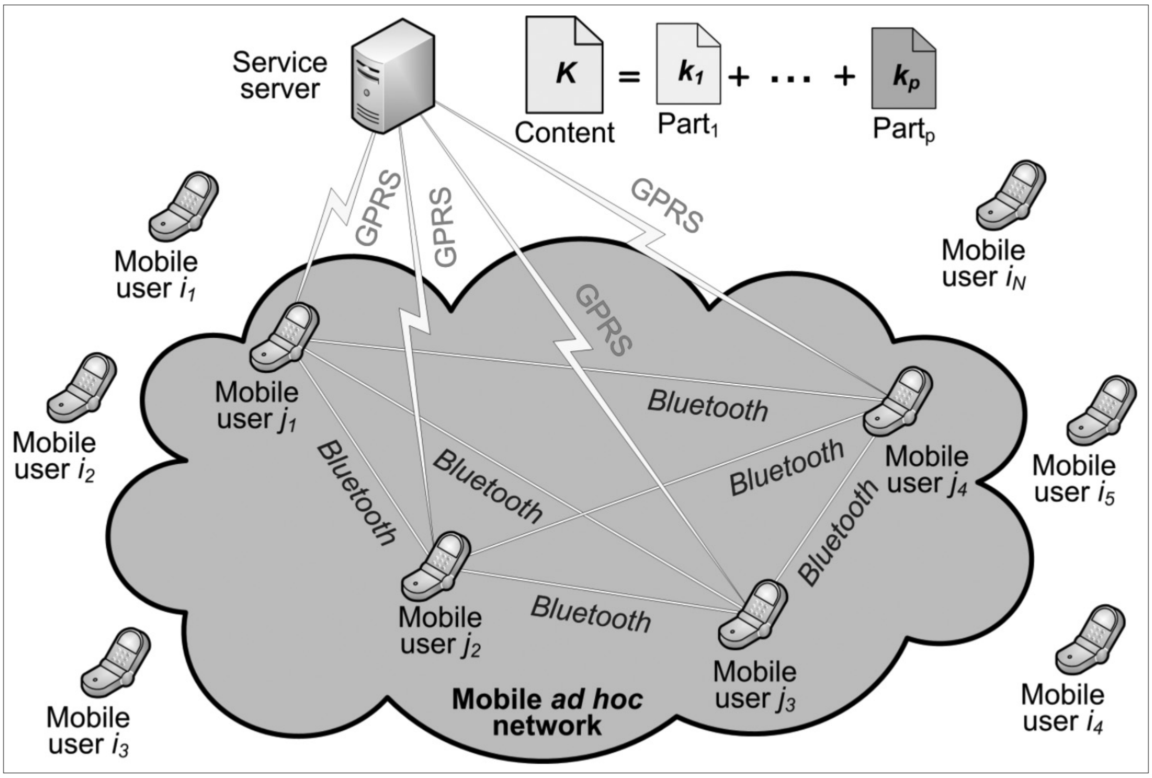


Figure 3.
System model for CollDown

consumes only 0.61 J, and the same four-mobile-users scenario for individual approach consumes 1.91 J of mobile users' phone battery energy.

3.3 The CollDown performance evaluation

Using collaborative download has many benefits, but also some drawbacks. The main advantage for mobile users is saving the mobile device battery energy, since the GPRS-based communication consumes more energy than the Bluetooth-based communication (see Table 1). Consequently, if some parts of content are exchanged with other mobile users via Bluetooth instead of being downloaded using GPRS, a significant amount of energy may be saved.

Additionally, redirecting some of the network traffic from GPRS to Bluetooth can free up some of the scarce access network resources and allow telcos to make more profit by offering these resources to other users and/or using them for other services. Collaborative downloading also reduces the total load on telcos' service servers since (ideally) each content part would only be downloaded once and service servers would have to process fewer users' queries. The servers' CPU and memory consumption would be lower, meaning that they would consume less energy and be more environmentally friendly.

Last but not least (when considering replacing Bluetooth with Wi-Fi where available), Wi-Fi technologies

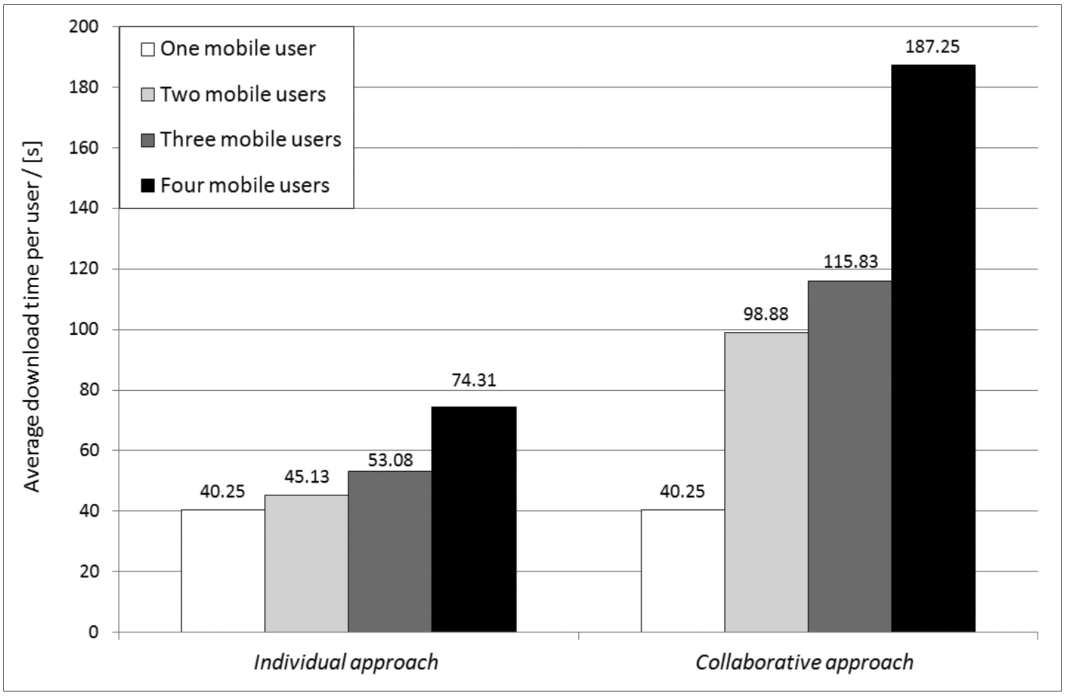


Figure 4. Comparison of time for the individual and the collaborative approach

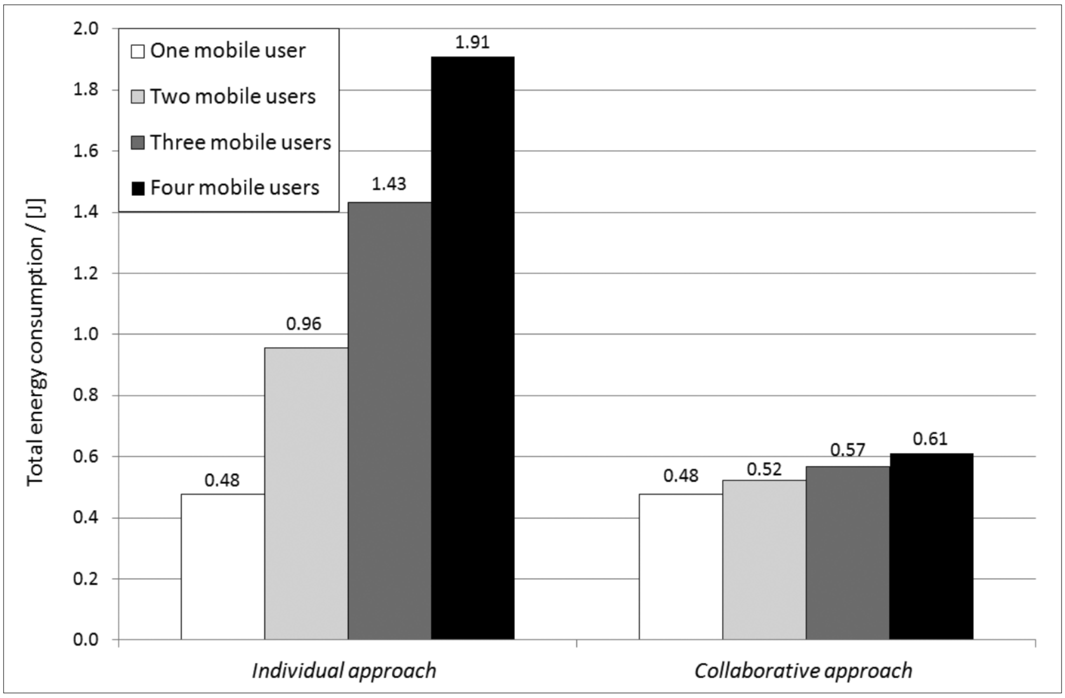


Figure 5. Comparison of energy consumption for the individual and the collaborative approach

are considered a non-risk for human health. The official stance of the Health Protection Agency is that *"there is no consistent evidence to date that Wi-Fi and WLANs adversely affect the health of the general population"* [12].

The main disadvantage of our approach is that the service response time for collaborative approach can be longer than for individual approach. Currently, Bluetooth-based communication consumes more time than GPRS-based communication. Although according to the specifications the declared speed for Bluetooth is higher, the test results reported in [13], as well as those we obtained, show data rates of only 10-11 KB/s. In future, Bluetooth v3.0 should be able to deliver up to 3 MB/s of data throughput [14].

Additionally, Bluetooth communication could be substituted with Wi-Fi communication, in which case the transmission speed would be higher, and energy consumption still lower than in GPRS network (see Table 1). Beside the transmission speed, the processes of semantic matchmaking and group formation, required for enabling user collaboration, introduce an additional delay in the service provisioning process.

4. Conclusion and future work

Mobile users are becoming more and more involved in the process of telecom service provisioning – they are evolving from individual users towards collaborative users. The collaborative users want to gain added value from the mobile service provisioning by collaborating during the provisioning process with other mobile users who share a common goal.

In this paper we described and evaluated *Collaborative Downloading* (CollDown), an energy-efficient Bluetooth-based collaborative service. The simulation results show a significant decrease of energy consumption of mobile users for the *collaborative approach* based on CollDown compared to the *individual approach* based on individual downloading via a mobile network. This is of prime importance since limited battery energy is one of the greatest challenges faced by both mobile users and telcos.

For future work we plan to implement CollDown service using Wi-Fi technology with the aim of improving our service's time efficiency. Moreover, we intend to extend our model with group flexibility to see how our approach can be used if a user leaves her/his group during the collaboration process.

Finally, we will use the three-layered architecture for enabling collaborative service provisioning to model other innovative examples of collaborative services, such as collaborative mobile learning and collaborative recommenders. The former service enables electronic learning experience for mobile users based on peer collaboration, while the latter provides recommendations from users with similar interests and preferences.

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