Towards a Smart Campus with Mobile Social Networking

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***Abstract*—With the development of wireless communication, the popularity of smart phones, the increasing of social networking services, mobile social networking has become a hot research topic. The characteristics of mobile devices and requirements of services in social environments raise a challenge on building a platform for mobile social services. In this paper, we elaborate a flexible system architecture based on the service-oriented specification to support social interactions in campus-wide environments. In the client side, we designed a mobile middleware to collect social contexts such as the proximity, the cell phone log etc. The server backend, on the other hand, aggregates such contexts, analyses social connections among users and provides social services to facilitate social interactions. A prototype of mobile social networking system is deployed on campus, and several applications are implemented based on the proposed architecture to demonstrate the effectiveness of the architecture.**

Keywords-Mobile Social Networking; Smart Campus; Social Interaction

I. INTRODUCTION

With the development of wireless communication and pervasive computing technology, smart campuses are built to benefit the faculty and students, manage the available resources and enhance user experience with proactive services. A smart campus ranges from a smart classroom, which benefits the teaching process within a classroom, to an intelligent campus that provides lots of proactive services in a campus-wide environment. Although, many contexts such as location, activity and user profiles are adopted to provide proactive services, social contexts (e.g., the proximity and the communication history) are not taken into account. Campus is a social environment where college students have lots of social interactions with their friends. However, little research has been conducted on social aspects, e.g., supporting social interactions.

Nowadays, Social Networking Sits (SNS) such as Facebook, MySpace and Twitter are very popular for college students. Tens of millions of college students spend numerous hours logging on such sites, communicating with their friends, and sharing media in their community. With the development of wireless communication and smart phones, social networking sits are going mobile which promotes the emergence of mobile social networking. Different from the Web-based social networks, Mobile Social Network (MSN) is capable of continuous, seamless sensing, which allows us to obtain contexts from the physical world. Lots of contexts can be extracted from sensors embedded in mobile phones. The mobility of MSN endows data with spatiotemporal information, which benefits the understanding of contexts where the user situates. Furthermore, MSN makes it possible to provide ego-centric services for users anywhere, anytime to enhance user experience. The MSN outperforms the Web-based social networks with the support to social interactions in the real world. It makes full use of the smart phones for extracting social contexts by analyzing sensing data and provides social services. Thus we introduce MSN into the built of smart campuses to support social interactions among faculty and students.

In this paper, we propose a flexible mobile social networking system architecture from the service-oriented perspective (with a centric server and clients) in a campus to support social interactions. In the client side, a mobile middleware is introduced to collect social contexts such as proximity, communication history, etc. The server aggregates those contexts, analyses social connections among users and provides social services to facilitate social interactions. Based on the proposed architecture, several applications are implemented to demonstrate the feasibility of the architecture.

The rest of this paper is organized as follows. In Section 2, the state of art of the research on the smart campus and the mobile social networking are described. Section 3 elaborates

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the system architecture and details of the server backend and client. Three applications based on the proposed architecture are described in Section 4. We conclude the paper in Section 5.

II. Related work

A number of studies have been conducted in the construction of smart campus. Context-awareness has been introduced to provide proactive services for faculty and students on campus. A campus is essentially a social environment, where the human communication plays an important role in daily life. The emergence of the mobile social networking makes it is possible to support social interactions in a campus.

A. Smart Campus

The smart classroom takes a key step in the development of smart campuses. As teaching is one of the most important activities in colleges and universities, more attentions were paid to smart classrooms [1-6]. In literature [1], a smart classroom prototype was designed to provide seamless tele-education. The prototype integrates voice recognition, computer vision, and other technologies and turns a physical classroom into a natural user interface to provide a tele-education experience like in a real classroom. An architecture based on the web service technology was proposed in [2] to overcome the weakness in extensibility and scalability. Stephen et al. [3] presented a reconfigurable context-sensitive middleware to achieve the collaborative learning. In the prototype, everyone is equipped with a PDA to recognize situation and the system provides different services to users based on their current situations to enhance the collaboration among students and teachers.

With the evolvement of pervasive computing, a few smart campus prototypes [7-9] were developed to offer assistive services for users situated in a smart space. Talal et al. [7] proposed a solution to efficiently integrate services in a campus with the smart card. With the embedding of these services on a single card, smart cards facilitate users to access various services in a campus. Michael et al. [8] presented the ETHOC system, which focuses on the integration of virtual and physical elements in the campus environment. The system supports to interact with virtual counterparts of printed document using a variety of devices, such as mobile phones or PDAs. Dong et al. [9] designed a location based service system to support the interaction between the 3D virtual world and the real world. A prototype system was deployed on a campus to make user experience the school life in the virtual world.

Although lots of context-aware applications on the campus were implemented, most of them focus on the interactions between users and services by providing proactive services according to user status. The previous works mainly aim to support the individual users with ego-centric services. However, a campus is essentially a social environment, where social interactions are very important. The social contexts should be introduced to promote the social connections among users.

B. Mobile Social Networking Systems

The advent of mobile social networking breaks out with the popularity of smart phones and the maturity of wireless communication. The mobile social networking has been a hot topic in the recent years, and many applications have been designed in this field. Some typical applications are as follows.

Numerous researchers [10-12] dedicated to inferring friendship network structure by using mobile phone data. The social contexts, such as call logs, text message, location, proximity and time etc. are taken into account. The location-base services (LBS) are triggered when users enter or leave the range. The crucial part of the LBS is to detect locations of users. Currently, many positioning technologies such as the GPS and the locating in ad-hoc network are available. PeopleTones [13] detects the buddy proximity and notifies the user with mobile phone.

There have been already numerous kinds of applications deployed on the campus. However, how to manage lots of applications in an open environment is still a challenge. Eunhee et al. [14] developed a Smart Campus test bed based on the extensible service orientated architecture (SOA), which run a suit of applications that link “People-to-People-to-Place”, called P3-System. The P3-system includes several social applications such as *CampusWiki*, providing editable pages about information of the campus, and *CampusMesh*, a location-aware social reminding.

The CenceMe System [15-16] transparently gathers contexts from sensors embedded in mobile phones, and adopts reasoning techniques to extract high-level contexts for mobile social applications. Although the CenceMe fills the gap left between manual status updates by automatically updating activity and location presence information, the semantic reasoning is time-consuming which may lead to poor user experience due to the delay of response. Furthermore, the reasoning process is performed on the smart phone which leads to the sharp increase of power consumption.

It is obvious that the research on mobile social networking is still at its early stage. The features of the resource-limited devices such as PDAs or mobile phones are not fully taken into consideration when designing the architecture. Furthermore, the architecture should provide a mechanism to maintain system performance in heterogeneous networks.

We aim to support social interactions among students and the faulty on campus with the mobile social networking technology. Social contexts are extracted from mobile devices apart from social networking sits. A lightweight architecture is presented to support mobile social networking applications.

III. Mobile Social Networking Infrastructure

A. System Requirements

There are many mobile devices, services, and users in mobile social networking. The architecture should manage the entities and provide a mechanism to access the services in the mobile environment. In the mobile social networking, some basic modules, such as the semantic extraction, pattern mining, ubiquitous search and location management, etc. are very important for the implementation of applications. The modules provide useful information for the high-level services or applications.

Semantic Extraction There are lots of data sources such as sensors from mobile phones, call logs and interaction records from social networking sits etc. The diversity of data sources makes it necessary to introduce the semantic extraction component to extract and manage the large amount of contexts. Semantic extraction aggregates the contexts collected from users themselves and users' environment and represents them in a machine understandable way, which not only facilitates the integration of contexts from heterogeneous networks, but also benefits the representation of relationships among different entities. The semantic extraction also infers high-level contexts based on the semantic representation of basic contexts.

Pattern Mining With both of the low-level and high-level contexts semantically extracted, pattern mining can be used to discover higher level knowledge about users. For example, the tri-axial accelerometer can be used to measure the acceleration of the movement (low-level context) as well as to recognize user activities (high-level context). Based on these contexts, higher level knowledge, such as the energy expenditure in daily life, and the traffic modes can be mined. These new knowledge is significantly important for the construction of proactive services and the design of the recommendation services.

Ubiquitous Search Ubiquitous search serves as the interface between human being and entities in the mobile social networking systems. Different from the traditional search engine, the ubiquitous search provides more complex retrieve of interesting information. It supports the tempo-spatial query of entities in the real world, such as interesting events, user activities etc. Furthermore, the ubiquitous search utilizes relationships among objects to explore the related information. For example, *"Who called me while I was jogging in the park?", "Where his classmates are when he is on the play yard?"*.

Location Management Location is one of the most important contexts, which not only drives the development of location-based services with the perfection of positioning technology, but also reveals the situation. The location management, on one hand, tracks the positions of users in the environment; on the other hand, it stores the trajectory of users and provides the data inputs for pattern mining. Furthermore, the location management should support both indoor positioning and outdoor positioning. The GPS offers the outdoor positioning and the WiFi access points (AP) contribute to indoor positioning.

Besides the three functional requirements depicted above, we also identify the following three requirements from the system perspective.

Scalability There are many mobile devices, services and applications in the mobile environment. The handheld mobile devices are different from each other in terms of their capabilities. Thus, the architecture should be scalable to support heterogeneous mobile devices and the deployment of the increasing number of applications. The scalability is important for the system due to the mobility and dynamics of the objects in the social environment.

Lightweight Mobile devices not only collect social contexts such as call logs, text messages, sensory data, but also take charge of communications between peers and the server. Due to the diversity of contexts, a middleware is required to aggregate those social contexts. However, the mobile devices are limited in terms of battery and CPU speed. Considering the multiple functions and the constraint resource of a mobile device, the middleware deployed on the mobile should be lightweight, which means less power consumption.

Connectivity Currently, many communication services are available such as Wi-Fi, Bluetooth, GSM, and 3G. Services are situated in such a heterogeneous network. Those services should be capable of communicating with each other in this heterogeneous environment. Thus, the architecture should provide a mechanism to guarantee the connectivity among different communication services. For example, when the Wi-Fi is not available, the public communication services such as the GSM can be used to accomplish the delivery of information. On the other hand, when the public network is destroyed in an emergency, the personal range network is still available, which gives an opportunity to share information based on the opportunistic network. The connectivity of networks depends on the support of system architecture.

B. System Overview

The main target of a smart campus system is to collect and analyze data from the public to enhance human social experience in a campus. From a system's view, its basic functions consist of semantic extraction, pattern mining, ubiquitous search, location management, etc. To develop a scalable, weightless and robust architecture, the first challenge for the system design is to support reliable and scalable communication in heterogeneous network. Since the data is produced by users' devices, and collected through access points or the Internet, multiple network protocols are necessitated to guarantee the robustness of the system.

The system architecture is illustrated in Fig. 1. It consists of two main entities, Server and Mobile Client. The servers are Ethernet-connected, which are equipped with rich storage and computational power. A mobile client is a smart phone (linking to its custodian), which are equipped with various sensors, such as accelerometer, thermometer, GPS, etc. Mobile clients support sensing via lots of built-in sensors. The mobile clients get original sensing data and submit to the server through wireless network. The server extracts the social contexts from the sensory data and returns relevant results to the appropriate client. Separating the tasks of sensing and processing can enhance the system scalability.

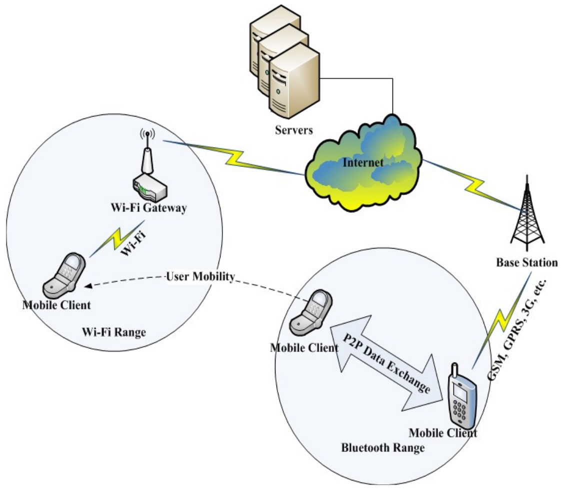


Figure 1. System Architecture Overview

The system mainly works in the infrastructure mode. The mobile devices access to the Internet via the wireless AP in order to interact with servers. As the infrastructure network might be not available in some situations, the system also supports the ad-hoc mode when the devices come within the range of each other using opportunistic network. This guarantees the robustness of the system, and makes services available in most cases.

C. Server

The sever backend consists of several modules ranging from context aggregation, social network analysis, context storage, knowledge mining to peer communication and admission control. The hierarchical architecture of the server is depicted in Fig. 2. The server consists of three layers: Network Layer, Service Layer, and Application Layer.

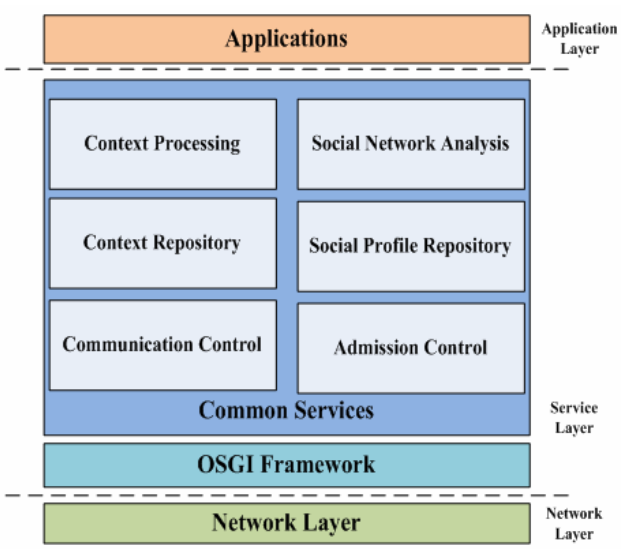


Figure 2. Server Architecture

The Network Layer provides the communication mechanism for connecting server and clients. Due to the heterogeneity of network, the Network Layer supports multiple network connections including wired and wireless, and supports multiple network protocols such as GSM, 3G, Wi-Fi, and Bluetooth. All the mechanisms aim to guarantee the robustness of the architecture in heterogeneous network environments.

The Service Layer is the core of the server, which includes two main parts: OSGi (Open Services Gateway Initiative) framework [17] and Common Services. The OSGi, a service oriented framework, provides a public platform to manage services registered in the server. The Common Services is a set of public services, which are implemented based on the OSGi specification. These services compose the central functionalities of the server and provide high-level contexts to the Application Layer.

To achieve the scalability and lightweight, the OSGi framework is adopted in the server. OSGi is a service oriented framework, which supports the module management and benefits the loose coupling of modules [18]. Furthermore, it supports hot plug, that is the services could be installed or stopped without restarting the server. Advantages of this framework make it suitable for managing the mobile social applications. Furthermore, OSGi is a lightweight framework for delivering and executing service-oriented applications. It offers benefits including platform independence, multiple service support, security, service collaboration, and multiple network support.

The Common Services include various public services. The functions of the services are described as follows. Communication control is responsible for the reliable and secure communication, and supports multiple networks. It hides the details of the underlying network layer, and provides seamless and transparent communication with mobile clients. The system only allows legal users to register, and admission control service is introduced to manage users and provides a mechanism for efficient user validation. Context repository stores context instances such as location, time, activity etc. These contexts are collected from mobile clients and submitted to context repository, while the context processing infers high-level contexts based on low-level contexts, resolves context conflicts, and reduces context uncertainty. Social profile repository deals with user's social profile data storage, which includes personal details, social relations, preferences, etc. Social network analysis focuses on analyzing relationships among users, and determining the role and impact of individuals in a particular community.

D. Client

Client, together with the mobile device, on one hand, serves as the sensing node of social contexts. It sends the sensory data to the server through different networks, such as GSM and Wi-Fi. On the other hand, it serves as the terminal for users, and plays a role of interactive interfaces. Users could send and retrieve information from the server. As there are many sensors and functions deployed on the mobile phone, managing the sensors is quite important. We designed a middleware to collect social contexts and communicate with the server. The client architecture consists of three layers: Hardware Layer, Middleware Layer, and Application Layer (see Fig. 3).

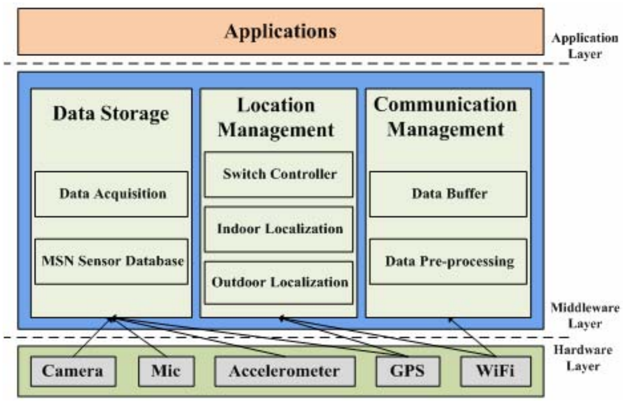


Figure 3. The Architecture of Client Side on Smartphone

The Hardware Layer is composed of several sensors, GPS module and Wi-Fi module which are integrated on mobile devices or connect to the mobile devices via Bluetooth.

The Middleware Layer consists of three function modules: Data Storage, Location Management, and Communication Management. The Data Storage consists of two parts. One is Data Acquisition part which offers interfaces for applications to access the sensory data stored in the mobile devices automatically. The other is MSN Sensor Database which is used to store the sensor data, the user's moving trajectory and the user's contact history. As GPS works well in outdoor environment while Wi-Fi localization is suitable in indoor environment, Location Management module is used to combine them. Its main function is to switch between the indoor localization mode and the outdoor localization mode. The switching operation is controlled by the Switch Controller. The third module of the Middleware Layer is the Communication Management module. The client communicates with the server through the nearby access point (AP). The Data Buffer part is used to cache data which is sent to the server or from the server. The Data Pre-processing part is used to perform certain initial data processing before sending or upon receiving data. For the data to be sent, it will be enveloped with packet header which contains the data type, user ID, and other useful information. For the data received, the Data Pre-processing will check the user related information contained in the packet header to see whether it matches the local user's information and if so, more useful information will be read from the packet header for further processing, otherwise the data received will be dropped.

On top of the Middleware Layer is the Application Layer. We have implemented several applications to help user enjoy the mobile social network and to make the campus life more convenient and interesting. The details of applications will be presented in the next section.

Mobile devices have limited memory and energy, thus memory-saving and energy-saving are important for the system. To achieve memory-saving, the basic strategy for this system is to reduce redundant data. When the Middleware Layer receives a new sensor reading, it will first compare the reading with the previous value to check whether there is an update. If they are the same, the new data will not be stored in the database. Another energy-consuming process is data transmission from a client to the server. For energy-saving, one strategy is to minimize the time of data transmission [19]. We have set that only when it is the first time a mobile device connects to the server everyday in the morning, the client sends all the data in database to the server and cleans out the database and starts a new data-collecting process.

IV. APPLICATIONS

Generally speaking, the campus life consists of study, communication and entertainment. It would be helpful for people to learn about the usage of the facilities before planning. For example, *whether the study lounge is available? Which classroom does my classmate sit in? Whether the tennis-court is crowded?* Three applications were implemented and deployed based on the proposed architecture, which are closely related to the daily campus life and aim to enhance the social interactions among college students.

The three applications are named *Where2Study, I-Sensing, BlueShare* respectively. The two applications, *Where2Study* and *I-Sensing*, are developed on the Android 2.1 platform; the *BlueShare* is designed on the Symbian S60 system. In addition, a variety of mobile devices are deployed in the system, such as Samsung i909, Nokia X6, MeiZu M9, etc. The client software are installed on the mobile phones for data sensing and context gathering. The Wi-Fi network with complete coverage of the campus is available. The server is implemented based on the OSGi specification, which provides a service oriented architecture to manage the service registered on the server.

A. Where2Study

Scenario 1: *A student named John is going to look for a study lounge to prepare for the coming final exam, he wonders which classroom is available (i.e., having free seats). To solve John's problem, a retrieve request is sent to the server and information about all classrooms is presented on his cell phone. Later, he encounters a question in his study and wants to discuss it with his friends. Thus, he needs to know where his friends are (i.e., in which classroom).*

A prototype system, namely Where2Study has been developed for this usage scenario. The main purpose of Where2Study is to make campus life more convenient, which focuses on helping users find a suitable place to study and locate his/her friends (see Fig. 4). To achieve this goal, the Wi-Fi positioning technology is adopted to calculate the region of classroom where the user is situated in. Every Where2Study client connects to the nearest three Wi-Fi APs, and calculates its own position by RSSI (Received Signal Strength Indicator) information using triangle centroid location algorithm. Their location is collected and processed by the server. Thus, the system could determine whether a classroom has empty seats for individual study.

Where2Study not only presents the navigation map of a building to help students find classrooms (Fig. 4a), but also shows the status of all classrooms as Fig. 4b, such as which classroom is full and which one has empty seats. To check the detailed information of a particular room, a user can click a button in Fig. 4b and then the status of the seats in the room is displayed, as shown in Fig. 4c. Furthermore, the application supports to query the location and activity of user friends, as shown in Fig. 4d.

Figure 4. Where2Study User Interface

A key feature of this application is the capability to browse the status (e.g., name, location, activity) of close friends. This allows users to reach out and be aware of their social network established by friendship, which will facilitate each other to study (e.g., all my friends are studying at the moment). In addition, when a user encounters a problem during study, he or she could turn to their friends for discussion according to their location shown on the mobile phone.

B. *I-Sensing*

Scenario2: *On Sunday, James wants to play basketball with his friends but he doesn't know whether the basketball court is available. So he edits a sensing task (e.g., is the court crowded?) with the I-Sensing client and sends it to the server. On receiving the task, the server transmits it to the users nearby the basketball court. When a user receives the task, he can choose different ways to accomplish the task, for example, writing a text, taking a photo and so on. Once receiving the replies, the server transmits them to James and James will know the information of the basketball court and then make a decision.*

People are often interested in the information about a place while they are not there. There is no doubt that the people who are there can offer you the most accurate in-situ information. Therefore here comes the question that how to locate the mobile devices that are within the range of your interesting place. Analyzing the above mentioned scenario in detail, we can find that it has many things in common with an emerging sensing system called *Participatory Sensing*, where the mobile devices can form an interactive, participatory sensor network that enables users to gather, analyze and share local knowledge [20]. I-Sensing is a campus information sharing system based on participatory sensing, which is deployed on mobile devices to gather information of place of interest. We developed real-name registration mechanism and reliability mechanism to intensify the data quality and introduce a friend-ranking mechanism to encourage user participation. We have implemented it on Android platform.

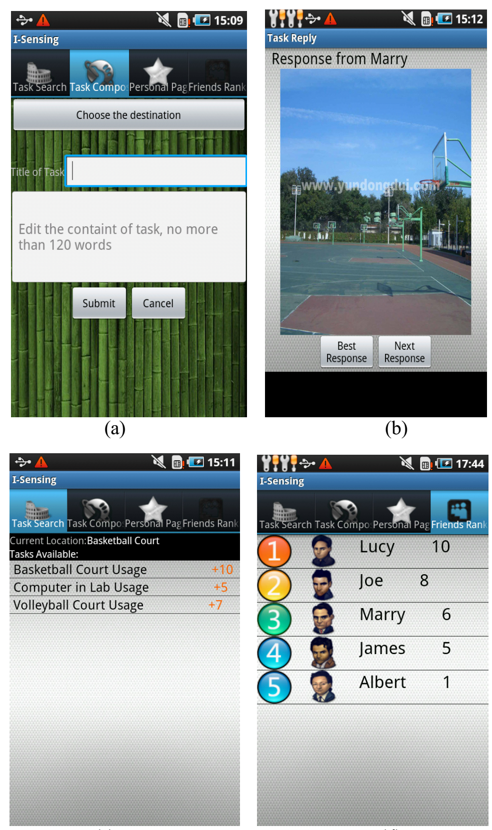


Figure 5. I-Sensing User Interface

There are four parts in the application: Task Composing, Task Search, Personal Page, and Friends Ranking. As shown in Fig. 5a, a user on campus can use the application to propose a sensing task which indicates what the user wants to know and the prize that someone may get after completing the task. The user may get several replies from different sensing sources. He can choose the type of reply that he wants to read, for example, a reply with pictures, which is shown in Fig. 5b. At Task Search part, a user can see the sensing tasks which are launched by other users and transmitted by the server according to their location information as Fig. 5c shows. At last, a user can browse his or her points and ranking among his or her friends (see Fig. 5d).

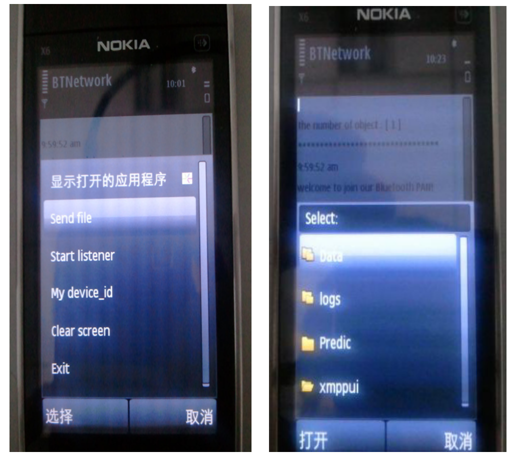
C. *BlueShare*

Scenario 3: *A teacher named Jim found copying courseware is time consuming during the break time. When he wants to send some references or slides to his students, the students have to take turns to copy those files from his computer. To relieve Jim and his students' workload, an application uses Bluetooth protocol to deliver those assignments or courseware. Specifically, the nearby devices receive data directly from Jim's computer, and then forward the received data to their neighbors. Only a few minutes, all the students carrying Bluetooth devices receive the data.*

We have implemented a prototype system named BlueShare on the Symbian S60 platform that runs on a variety of mobile phones. BlueShare is a media sharing application among Bluetooth devices based on the opportunistic network. The interesting media is sent to all users nearby the Bluetooth devices.

The mainstream of computing paradigms like Internet have many constraints on network communication and the connectivity is exceedingly required, which is not feasible for applications in certain situations under which emergencies might occur and the communication facilities are not always available. BlueShare is a resource-sharing system based on opportunistic network, which mainly use Bluetooth to transfer data. Opportunistic networks use the communication opportunities to forward data when any two nodes encounter. This new network mode is different from the traditional network communication mode, in which connectivity is not essential in opportunistic forwarding, and few infrastructures are needed.

With BlueShare, users share files with other participants in a *store-and-forward* mode. In opportunistic forwarding, we adopt a hybrid of redundancy-based and utilize-based algorithm. The scheme ensures a high success rate of opportunistic forwarding, and takes into account the network performance as well.



(a) (b)

Figure 6. BlueShare User Interface

Two working modes are provided with the application, i.e., positive mode and negative mode. In the positive mode, the devices actively send files to proximate Bluetooth devices; On the other hand, negative mode indicates that the devices are passive and ready to response to the connection request from positive nodes. As shown in Fig. 6a, the mode of devices can be configured. The operations on the positive nodes are presented in Fig. 6b.

The aforementioned three applications are typical ones in the campus life, which aim to enhance social interactions among college students in their daily life including study, communication and entertainment. The applications make full use of the social connections and mobile phones to promote the development of a smart campus.

V. CONCLUSIONS

Campus is essentially a social environment where lots of social interactions occur. To bring more convenience to campus life and enhance social interactions, we propose to build a smart campus based on mobile social networking. To efficiently manage the services in the system, we propose a scalable system architecture based on the OSGi specification. Three applications were developed on top of the infrastructure, which demonstrate the feasibility of the system.

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