# Improved Bluetooth Connectivity with RFID

Nisha
*Jagannath University, Jaipur, Rajasthan, India*

Soniya Goyal
*Poornima Group of Colleges, Jaipur, Rajasthan, India*

Neeraj Manglani
*Jagannath University, Jaipur, Rajasthan, India*

**Abstract-One of the challenges in pervasive computing is communication between a mobile user's terminal and the continuously changing local environment. Bluetooth is one potential option for providing connectivity, but its usage is hindered by the time consuming device discovery and service discovery processes. We propose using RFID technology to enhance the Bluetooth connection establishment procedure. We present quantitative evaluation and qualitative user evaluation of our system compared to the standard Bluetooth mechanism. Measurements show that our approach dramatically increases the performance when establishing a Bluetooth connection between two devices. Also users prefer our approach because it is faster to use, there is no need for menu selections, and it is considered easier and more pleasant to use than the standard approach.**

## I. INTRODUCTION

Pervasive computing environments comprise a number of devices that a mobile user can interact with using his or her terminal device. To enable interaction with the user's mobile terminal and the environment, a proper communication mechanism is required. As the services are, in most cases, physically located nearby the user, some personal area networking (PAN) technology would be ideal to be used in such scenarios.

Bluetooth [1] is an emerging standard for Wireless Personal Area Networking (WPAN). It is an excellent low-cost technology for providing connectivity between terminals that are limited in size, processing capabilities and battery life. Thus, Bluetooth could be utilized as an integrating communication technology between the user's terminal and pervasive computing environments. However, a limiting factor of the Bluetooth technology especially in human-centered pervasive computing scenarios is its time-consuming device discovery process, which can take even tens of seconds until the device to be connected is found. Also the scalability of Bluetooth's discovery process is not sufficient in practice if many devices are present [2] [3], which is a typical situation in pervasive environments. If the user desires to use a service offered by some Bluetooth enabled device, service discovery is also required to resolve the services that the other party offers and the mechanisms how they are accessed. This additional procedure increases the time required to open a communication channel to the service.

From the usability point of view, the discovery procedures are unnecessary, because in most cases, when connection initialization to some service is started, the user already knows what device he or she wants to connect to and what service he or she desires to use. Thus, navigating through these mandatory and time-consuming steps may be frustrating especially in pervasive computing environments where interacting parties change frequently. As also addressed by Scott et al [4], the described scenario lacks context awareness, since the user has a certain task with strict objectives but there is no way to tell that to the system. If we had such a mechanism, the described process could be improved from the usability point of view.

In this paper, we suggest the RFID system to be used to initiate a Bluetooth communication channel between the user's terminal and the services in the environment. We have developed a prototype for comparing the performance of our approach to the standard Bluetooth connection establishment method. To initiate a connection, the user simply touches an RFID tag with his or her mobile terminal that is equipped with an RFID reader. We have built a test environment and evaluated our system both quantitatively and qualitatively.

## II. BLUETOOTH

Technology standard operating in the 2.4 GHz ISM (Industrial, Science and Medical) band. The Bluetooth standard defines a uniform structure for a wide range of devices to communicate with each other, with minimal user effort. [1]

A connection between two Bluetooth devices is established in a two-step procedure. At first, all devices in the neighborhood are discovered in a procedure called Device Discovery. The purpose of device discovery is to obtain, for instance, the class of the device and the device name, which is a text- formed, human-readable name assigned to a particular Bluetooth device. In the second phase, Service Discovery is performed to resolve the available services and their characteristics. Device discovery starts with a phase called Inquiry.

During the Inquiry, the discovering device learns the Bluetooth Device Addresses (BD_ADDRs) of its neighbors by broadcasting inquiry packages to which the nearby devices reply. BD_ADDR is a 48 bit address that identifies a communication endpoint and is unique to each Bluetooth device. In an optimal, error-free environment, the inquiry takes 10.24 seconds in order to discover all devices within the range [1]. In practice, however, a number of other appliances that share the same radio band can dramatically lengthen the inquiry process [2] [3]. After the inquiry phase has been completed, the device discovery proceeds by Paging procedure where the device names of discovered devices are resolved. Bluetooth Service Discovery Protocol (SDP) enables applications to discover the Bluetooth services that are provided by remote hosts and to determine the characteristics of those services. The services that the Bluetooth device advertises via SDP are characterized by attributes, which include Service Class IDs, Service ID, Protocol Descriptor List, and Service Name. Service Class IDs are used to categorize Bluetooth services. Each Service Class is identified by a 128-bit Universally Unique Identifier (UUID), which is also used in service search patterns when service records are matched by SDP. The Service ID is a UUID that identifies a service instance. Protocol Descriptor List (PDL) defines the protocols and protocol-specific parameters such as the port number for incoming connections. Thus, PLD describes how the service can be accessed by the client. Finally, Service Name is a human-readable name for the service.

The protocols can be used in a pervasive environment as such. First, the user starts device discovery, and then, after receiving a list of available Bluetooth devices, selects the desired one. This stage requires over ten seconds in an error-free environment to complete, in addition to the time required for name discovery.

After the user has selected a device, service discovery is performed and the user is asked to select a service that he or she desires to use. Of course, if the device offers only one service, or if the desired service class is already known, the service selection can be done automatically, but otherwise user input is required again. Thus, in the worst case scenario, the user has to go through two lists; first to select a device and secondly to select a service. Services in a pervasive environment are, in most cases, physically located in the user's environment, and in the described scenarios the user also already knows what service he or she desires to use. Thus, it is probably frustrating for the user to go through these mandatory steps before the service can be used and, from the usability point of view, the described connection establishment procedure is highly gratuitous.

## III. RFID-ENHANCED BLUETOOTH CONNECTIVITY

Radio Frequency Identification(RFID) is a low- power wireless communication technology that uses radio waves to transfer information. An RFID system consists of RFID tags and an RFID reader. When a reader is placed near a tag, the data stored in the tag is read. Reading a tag is an instantaneous operation which requires only some tens of milliseconds.

The approach which we have taken enhances Bluetooth connectivity by reading the information required to establish a Bluetooth connection from an RFID tag. Skipping the device and service discovery phases decreases the time that is needed to start interaction with the service. The idea is to label the pervasive environment's devices (printers, projectors, displays, DVD, music players, etc) with RFID tags. The user can navigate in this service space by simply touching the desired devices with an RFID enabled mobile terminal. However, if some device offers more than one service, these services need to be differentiated to the user. For example, a device can provide services for printing, sending faxes and photocopying documents. We suggest labeling each service that a device provides with an individual RFID tag. Furthermore, we suggest that the visual appearance of a tag represents the service that can be activated by touching the tag [5]. Examples of the tags that we use are illustrated in Figure 1.

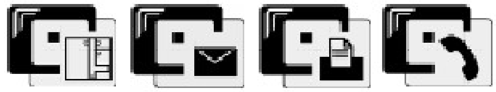

Figure 1. Examples of RFID tags

The RFID tags act as a two-fold interface between the system and the user. Data stored in the tag represents the service to the system whilst the visual outfit represents the service to the user. We store the device's BD_ADDR and the attributes of the provided service in RFID tags. In addition, it can be reasonable to store the names of the device and the service as well as a short description of the service.

## IV. TEST ENVIRONMENT AND SCENARIOS

The prototype architecture is presented in Figure 2. The hardware that we utilize in our system is composed of Symbian OS based Nokia 7610 mobile phone, several RFID tags, and Bluetooth-enabled network servers running Windows XP. The mobile phone is a prototype with an integrated RFID reader in the back cover. The applications in our test environment are running on the mobile phone and developed in native C++ language using Symbian Series 60 SDK v2.1. The RFID reader software is implemented as a Symbian server module and it is a general resource for all applications. It acts as a proxy between applications and the reader module; when a tag is read, the reader software forwards the data read from the RFID tag to its clients, that is, to the applications.

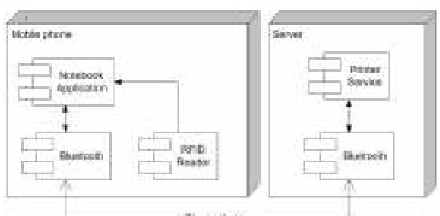


Figure 2. Prototype architecture

We have implemented a simple notebook application to demonstrate the RFID-enhanced Bluetooth connectivity. The application is able to utilize services running on network servers, such as printer service, which offers printing capabilities to its clients. The printer service accepts text documents as input and prints out the document using the local printer. All server side components are implemented in Java. The service is available over RFCOMM (Serial port) protocol of Bluetooth.

The RFID tags utilized in our system can carry 48 bytes of data. We store 39 bytes in a tag: 48-bit BD_ADDR of the device to be connected, 128-bit Service Class UUID, 128-bit Protocol UUID, and 8-bit number identifying the channel or port where the service is available.

In the tests, we compared our RFID-based service selection and the standard Bluetooth discovery method, which includes device discovery and service discovery. For testing the concept, we used the notebook application and the printer service. The application offers two mechanisms for accessing the printer service: (1) by using standard Bluetooth device discovery and service discovery and (2) by touching the corresponding RFID tag attached to the printer.

The tests were carried out in two phases. At first \the user was asked to print a memo shown on a notebook application using the standard method. For this, the user had to select menu command "Print doc (norm)" which started Bluetooth device discovery. The device discovery was implemented using the standard discovery dialog provided by Symbian OS that people are already familiar with. The standard dialog also has a special feature that attempts to reduce the discovery latency experienced by the user. It performs inquiry and name discovery simultaneously; the name discovery resolves the device names whilst other Bluetooth devices are still being discovered. Thus, the list of discovered devices shown to the user is updated dynamically as new devices are found. The user can interrupt the discovery as soon as the desired device is shown, so there is no need to wait until every Bluetooth device in the neighborhood is discovered.

After selecting the device, service discovery was performed and the user was shown a list of the services that the device offers. In addition to the printer service, the device offered four other services. When the printer service was selected, the notebook application connected to it utilizing discovered service attributes (protocol and channel). As soon as a connection was established, the service was used to print out the open note. Dialogs shown to the user are illustrated in Figure 3.

Figure 3. User prints a note with Bluetooth only (left) and RFID-enhanced Bluetooth (right)

In the second phase, the user was asked to print the document using the RFID-enhanced model. The user printed the document by touching a tag on the printer when the notebook application was running (Figure 3). In addition, to log the time when the experiment started, the user was required to select “Print doc (RFID)” command from the menu before touching the printer. In real life, however, this selection would be unnecessary. As soon as the application received an RFID event about the requested service, it used the service attributes, delivered within the event, to connect the printer service. When the connection was established, the service was used to print out the note.

## V. Evaluation

We measured the time from the first menu selection until a Bluetooth connection to the service was established and the document started to print. To accurately simulate a pervasive environment where described scenarios would be probable, the test environment included four discoverable Bluetooth devices in addition to the printer. Moreover, the test environment was equipped with IEEE 802.11b wireless network and several 802.11b-enabled laptops were actively used in the office during the tests.

### *5.1 Performance evaluation*

Tests were carried out with 15 test users, each of whom repeated the scenarios three times. Thus, we had a total of 45 measurements for both methods. Before the experiment was started, the users were shown how the mobile phone was used in both scenarios, which eliminated variation in test data caused by learning. Because standard device discovery dialog was noticed to cache and show the Bluetooth devices found in a previous discovery, we performed hard reset to the mobile phone before each test run. This ensured that the experiment was executed in line with the scenario where the environment is new to the user. All actions that the user made were logged to the file system of the mobile phone with a timestamp.

The distribution of times required to establish a connection with both methods are illustrated in Figure 4. In the “Bluetooth only” scenario, a connection to the service was established in 18.03 seconds on average with a standard deviation of 5.6 seconds. In the RFID- enhanced scenario the corresponding result was 3.42 seconds with a standard deviation of 0.80s.

In addition to overall time, we measured for the “Bluetooth only” method the time required from the user to: (1) select the printer device from the list after print command was given (device discovery + user’s selection), (2) select the printing service from the list after the device was selected (service discovery + user’s selection), and (3) the time required to connect to the service. For the RFID-enhanced method we measured: (1) the time required from the user to select the printer service after print command was given, (corresponds to tasks 1 and 2 in the “Bluetooth only”), and (2) the time required to connect to the service.

The results of the measurements are collected in Figure 5. As expected, most of the time required to establish a connection using only Bluetooth was consumed in device discovery process and in selecting the printer device. Furthermore, the average time required from the user to first select the device and then the printing service was 17.14 seconds, which is over 14 times more than using RFID (1.21 seconds).

The most surprising result was the difference between the two methods when establishing a RFCOMM connection after the service was selected. The time required for the RFID-enhanced model was significantly (3.3 times) longer than in the “Bluetooth only” method. The reason for this finding is unclear, but it is probably caused by the fact that in the "Bluetooth –only" method a connection to the service was established after the device and service discovery processes. Thus, the Bluetooth radio was already turned on and synchronized with the device to be connected. However, this does not correspond to the results reported by Scott et al [4] in an equivalent experiment, in which the difference between corresponding methods was only nominal.

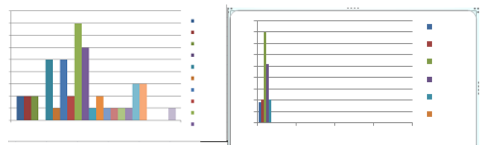

Figure 4. Distribution of total times

### *5.2 User evaluation*

To qualitatively evaluate the RFID-enhanced Bluetooth connectivity against the standard model, a questionnaire was made for the test users. The test users were fellow researchers and other university employees. Out of the 15 test users, 14 were male and 1 female. A majority (10) of the users were 23-25 years old and the rest (5) between 28 and 36. The average age of the users was 26 years. 14 test users had used RFID-based systems (electrical keys, bus cards, etc.) before and 11 had used Bluetooth-based devices (headsets etc.). Thus, the majority of the test users were already familiar with both technologies.

The users were asked the method with which they preferred to use the printer service and why. Fourteen (14) test users preferred the RFID-enhanced method because one or more of three main reasons (number of users shown in parenthesis):

1. It was faster to use (10).
2. There was no need for menu selections (8).
3. It was easier or more pleasant to use (7).

One user preferred the RFID-enhanced method because it was "less technical". Even though the RFID-based method was superior, it was reported to have some weaknesses as well. Two users considered it somehow unreliable or untrustworthy. Three users were afraid that it is possible that the user does not understand the visual tags, because the visual tags are open to the user's interpretations. Also the fact that the user has to be physically near the printer service to use it caused dissatisfaction among five test users. However, this can be seen as general criticism towards Bluetooth, which has a maximum operation range of approximately ten meters and, thus, the used service did not support printing from a distance (the way a shared printer is normally used in office environment).

Finally, the user experiences with both methods were evaluated. The users' were asked about how easy it was to use the RFID-based and the "Bluetooth – only" method. As shown in Figure 6, all users considered the RFID-based method to be very easy. Out of fifteen users, two users did not find a difference to the RFID-enhanced method. Ten users considered the "Bluetooth –only" method to be easy to use and three answered that is was difficult.

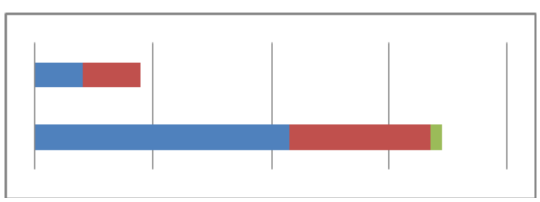

Figure 5. Task time breakdown

Users were also asked how fast they experienced the methods to be. The test users were asked how they agree with the given claim on a scale of 1 (totally agree) to 4 (totally disagree). The results are shown in Figure 6. Twelve users totally agreed by (1) that using the service with the RFID-enhanced model was fast and the rest agreed by answering (2). Seven, that is the majority of the users, disagreed by (3) that using the service by the "Bluetooth only" method was fast. The variation of results, however, was big compared to the RFID-based model. Three users totally agreed by (1) and also three totally disagreed by (4) with the statement. The rest of the users agreed by (2).

## VI. RELATED WORK

The time-consuming connection establishment procedure of the Bluetooth protocol has been addressed by many researchers and several suggestions exist to increase its performance. Also technologies, such as Near Field Communication (NFC) [6], are proposed as a method for quickly establishing other types of wireless communication between devices.

Woodings et al [7] accelerated Bluetooth device discovery by utilizing IrDA. In their system, the communicating parties first established an IrDA connection that was used to transmit BD_ADDR of a remote device. The BD_ADDR was used to initiate the Bluetooth connection between devices, thus eliminating the need for device discovery. However, their system did not provide a method for service selection. Using IrDA is otherwise beneficial since it is a highly widespread technology and already integrated in a great set of different devices. The drawback of IrDA is, however, that it requires line of sight between the devices to be connected. Also the scalability of IrDA may become a considerable challenge, if a number of services exists nearby each other.

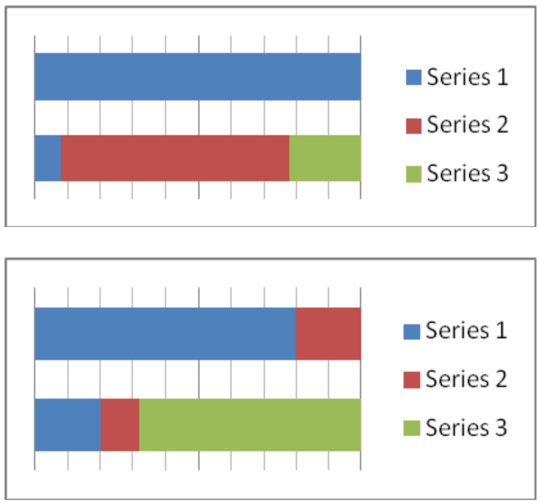


Figure 6. User experiments about using the printer service with both methods

Scott et al [4] utilized barcode-like visual tags to bypass Bluetooth device discovery. They used visual tags to store the BD_ADDR of a remote device. The data was read by dedicated software that was running on a mobile phone equipped with a built-in camera. Visual tags presented application-specific data that was used for selecting content from the service being used. However, it is unclear how the system can be utilized if several services, or content providers, are offered by a single Bluetooth device. Also, the user does not know the type of the content before using the service if the barcode-like tag is not provided with a specifying text or descriptive symbol. Similarly to IrDA, the advantage in their system is that, due to the wide adaptation of built-in camera technology, deployment of the system is easy.

Hall et al [8] propose using RFID infrastructure to eliminate the power and inquiry costs of Bluetooth device discovery. In their system, RFID tags were used to "wake up" a sleeping Bluetooth radio module and transmit a device's BD_ADDR to the connecting party. A similar approach was taken by Siegemund et al [2]. They utilized passive RFID tags attached to the user's mobile phone. The user's phone number and Bluetooth address was stored in the tag. This information was used to initiate interaction between the human users and smart objects in the environment. These systems, like any of the previously discussed, do not provide a mechanism for service selection.

## VII. DISCUSSION AND CONCLUSIONS

We introduced a method for RFID-enhanced Bluetooth connectivity, where the connection to Bluetooth-enabled pervasive services is initiated by RFID technology, overrunning the need for Bluetooth device and service discovery. We measured the performance of our system compared to the traditional method. Measurements showed that our approach is dramatically faster than the standard Bluetooth connection establishment method. User evaluation provided evidence supporting more favorable user acceptance on our method, although three users found no difference between the two methods. In user evaluation, our model was found to have several other benefits as well. However, because only one type of service was used to evaluate the two methods and because usage models depend heavily on the utilized service, a much more extensive user study is required to provide real assessment on the topic.

There are several issues to be considered in our RFID-based system in order to utilize it in real life applications. First of all, RFID technology is not yet widespread. However, it is gaining ground in consumer device industry and at least one RFID- enabled mobile phone is already on the market.

Services utilizing our approach cannot be dynamic in a way that e.g. service attributes would often change. This can be a considerable constraint if it is necessary, for example, to update service availability information as the service is in use. Another challenge related to our approach is how the visual symbols can be designed in a way that everybody can understand them regardless of technical or cultural background. On the other hand, this challenge must be solved when designing any general user interface.

One more challenge in using RFID technology as we proposed is placement of the RFID tags. If the user desires to use, let us say, a projector, the tag cannot be attached to the projector device, which is most probably installed up to the ceiling. In this situation, the standard Bluetooth mechanism would be more practical. Thus, with the described approach, we are not aiming to replace the Bluetooth device and service discovery. The aim is to provide a complementary solution and a rapid mechanism for the user to interact with the nearby services in a pervasive environment.

## REFERENCES


[1] BluetoothSpecificationversion1.1.http://www.bluetooth.com/.

[2] Siegemund, R. and Rohs, M. Rendezvous layer protocols for Bluetooth-enabled smart devices. Personal and Ubiquitous Computing Journal, pp. 91-101, October 2003. Springer-Verlag.

[3] Aalto, L., Göthlin, N., Korhonen, J. and Ojala, T. Mobile applications: Bluetooth and WAP push based location-aware mobile advertising system. Proceedings of the 2nd international conference on Mobile systems, applications, and services (MobiSys '04), pp. 49-58, 2004

[4] Scott, D., Sharp, R., Madhavapeddy, A and Upton E. Using visual tags to bypass Bluetooth device discovery. ACM SIGMOBILE Mobile Computing and Communications Review, vol 9, issue 1, pp. 41-53, January 2005. ACM Press.

[5] Riekki, J., Salminen, T. and Alakärppä, I. Requesting Pervasive Services by Touching RFID Tags. IEEE Pervasive Computing, vol 5, issue 1, 2006.

[6] NFC white paper. ECMA International. Available from http://www.nfc-forum.org/

[7] Woodings, R., Joos, D., Clifton, T. and Knutson C. D. Rapid heterogeneous connection establishment: accelerating Bluetooth inquiry using IrDA. Proceedings of the Wireless Communications and Networking Conference (WCNC2002), pp. 342-349, 2002.

[8] Hall, E., Vawdrey, D. and Knutson C. RF Rendez-Blue: Reducing Power and Inquiry Costs in Bluetooth-Enabled Mobile Systems. Proceedings of 11th International Conference on Computer Communications and Networks, pp. 640-645, 2002.