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Wireless Networks - Telecommunications' New Age

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On the Use of Mobile Ad Hoc Networks for the Support of Ubiquitous Computing

Juan-Carlos Cano-Escrivá, Carlos-Miguel Tavares-Calafate, Manuel-José Pérez-Malumbres, and Pietro Manzoni

Ubiquitous computing aims to create environments in which devices with communication and processing capacity (cellular phones, Personal Digital Assistants -PDAs-, sensors, electrical appliances, electronic books, etc.) can cooperate in an intelligent and context-aware while being transparent to the user. Communication plays a fundamental role in this field and Mobile Ad Hoc Networks (MANETs) in particular can provide the flexibility of access it requires. We present a 'proof of concept' experiment on the use of the Bluetooth and IEEE 802.11 wireless technology to build a MANET which provides network support to a context-aware application.

Keywords: Bluetooth, IEEE 802.11, Mobile Ad Hoc Networks, UbiqMuseum, Ubiquitous Computing.

1 Introduction

The term *ubiquitous computing* refers to making many computing devices available throughout the physical environment, while rendering them effectively invisible to the user [1].Thanks to the advances made in devices' processing power, miniaturization and battery life, and the proliferation of mobile computing devices, the goal of ubiquitous computing is becoming ever more realistic. Closely related to ubiquitous computing is context-aware computing. In context-aware computing, applications change or adapt their functions, information and user interface depending on the context (by inferring or sensing it), the client, and possibly the moment in time [2]. Communication plays a fundamental role in this field and Mobile Ad Hoc Networks (MANETs) in particular can provide flexible access.

MANETs are wireless networks with no fixed infrastructure. Nodes belonging to a MANET can either be end-points of a data interchange or can act as routers when the two end-points are not directly within their radio range. Such a network may operate in a stand-alone fashion or be connected to the larger Internet. Ad hoc architecture has many benefits, such as self-reconfiguration and adaptability to highly variable characteristics such as power and transmission conditions, traffic distribution variations, and load balancing.

However, such benefits come with many challenges. New algorithms, protocols, and middleware have to be designed and developed to create a truly flexible and decentralized network. Protocols should be adaptable; that is they should learn and anticipate the behaviour of the network, using parameters such as level of congestion, error rate, and variation of routes. Resources and the services have to be located and used automatically, without the need for manual configuration. Access and authentication issues should also be considered to ensure security and user privacy. Finally, Quality of Service (QoS) technologies and techniques should be introduced to provide

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guarantees on the ability of the network to deliver predictable results.

Many groups, research centres and industries are actively working on the issues of context-aware applications or more generally on ubiquitous computing [3]. Research into smart spaces and intelligent environments is becoming increasingly popular at many universities and corporate research centres (see [4][5][6]).

Context-aware applications necessarily require some kind of mobile wireless communication technology. This mobile wireless technology will interconnect computing devices together with various sensing technologies such as motion sensors or electronic tags, setting up a new kind of intelligent environment in which context-aware applications can search for and use services in a transparent way without user intervention.

Many possible wireless networking technologies are available, ranging from 3rd generation wireless networks to Wireless Local Area Network (WLAN) or Personal Area Network (PANs) [7]. We base our proposal on Bluetooth [8], which is a versatile and flexible short-range wireless network technology with low power consumption [9]. Bluetooth is designed to be small enough and inexpensive enough to be incorporated into practically any device.

We describe an experimental context-aware application called *UbiqMuseum* that provides context dependent information to the visitors of a museum. The system gives visitors precise information about what they are viewing, adjusted to their level of knowledge, and in their preferred language. It also provides a Graphical User Interface (GUI) adapted to their devices, whether they be mobile phones, PDAs (Personal Digital Assistants), or laptops. The application will also help museum curators to reduce the cost of guiding the visitors around the museum, and to keep track of what visitors' favourite exhibits are, and so on.

The rest of this paper is organized as follows: Section 2 outlines the state of the art in ad hoc networking. Section 3 gives a brief overview of Bluetooth technology. Section 4 describes the final application and the overall system architecture. Section 5 presents some details of the implementation prototype. Future extensions are given in Section 6 followed by conclusions in Section 7.

2 Ad Hoc Networking

The history of wireless networks dates from the late '70s and interest has been growing ever since. Towards the end of the last decade, interest reached a peak mainly due to the fast growth of the Internet. Recent developments are centred around infrastructure-less wireless networks, more commonly known as 'ad hoc networks'. The term 'ad hoc', despite sometimes having negative overtones and being equated with 'improvised' or 'not organized', in this context is used with the sense of having a higher level of flexibility. All nodes within an ad hoc network provide a "peer-level multi-hopping routing" service, to allow out-of-range nodes to be connected.

Unlike a wired network, nodes in an ad hoc network can move, thus giving rise to a variable topology which often makes introducing changes unpredictable. This fact gives rise to many challenging research issues since the way routing should occur is often unclear because of the many different parameters to be taken into consideration, such as bandwidth and battery power, and because of demands such as low latency or QoS.

The routing protocols used in ordinary wired networks are not well suited for this kind of dynamic environment. They are usually built on periodic updates of the routes, creating a large overhead in a relatively empty network, causing a slow convergence of changes in the topology. Recently, given the interest aroused by ad hoc networks, the Internet Engineering Task Force (IETF), created a new dedicated workgroup called the Mobile Ad Hoc Networking group (MANET) [10], whose main objective is to stimulate research in this area.

Whereas until just a couple of years ago there were close to 60 proposals for routing protocols being evaluated, now a mere four proposals, respectively the Ad hoc On Demand Distance Vector (AODV) [11], the Dynamic Source Routing for Protocol Mobile Ad hoc Networks (DSR) [12], the Optimized Link State Routing Protocol (OLSR) [13], and the Topology Broadcast based on Reverse-Path Forwarding (TBRPF) [14], have been able to withstand the competition. Of these AODV and OLSR have reached the "Request For Comment" (RFC) level. AODV and DSR offer routing on demand; that is, the routes for a specific destination are only calculated when they are requested. On demand routing algorithms try to reduce the overload by reducing the number of periodic update packets sent over the network by determining routes only when they are needed. The main drawback to these algorithms is the initial delay they introduce, which is a limiting factor for interactive applications requiring a specific level of quality of service (e.g., audio and interactive video). OLSR and TBRPF offer proactive routing; that is, all routes to all possible destinations are calculated a priori and are updated using periodic messages. These protocols create a fixed overload level but they allow routes to be supplied almost instantaneously.

Even if the aforementioned protocols solve the problem of routing at the data link layer, a great deal of work still has to be done to optimise their operation so they can be used efficiently for ubiquitous computing. We believe that automatic configuration is probably the most important issue that still remains to be solved in order to enable the user to take full advantage of ubiquitous computing.

3 Bluetooth Technology for Ad Hoc Networking

Recently, Bluetooth technology has appeared as a promising platform for ad hoc networking. Bluetooth's core protocol specifications and architecture are defined in [8]. The Bluetooth standard is a short range, low cost wireless radio system, aimed at connecting portable devices like PDAs, mobile laptops and phones, and eliminating the need for additional wiring between these devices. It operates in the 2.4 GHz ISM (IP Multimedia Subsystem) band and is the baseline approach for the IEEE 802.15.1 Wireless Personal Area Network (WPAN).

Bluetooth is based on a connection-oriented protocol which uses a polling scheme whereby a single master coordinates the access to the medium of up to 7 active slaves, i.e., a piconet.

The Bluetooth specification defines two different types of links, namely Synchronous Connection-Oriented (SCO) and Asynchronous Connection-Less (ACL). The former handles real time traffic, such as voice, while the latter is commonly used for data transmission.

Ad hoc networking over Bluetooth can lead to many useful ubiquitous applications especially due to its ability to locate nearby devices and discover the type of services they offer. Nodes that are nearby can find their neighbours by using the inquiry procedure. After discovering nearby devices, a node can decide to page to them and to connect to them. A dedicated protocol called Service Discovery Protocol (SDP) is then used to interchange information about all the available services at each node.

In a previous work [15] we designed and implemented a prototype for the OLSR routing protocol that allowed us to integrate multiple operating systems, device types, and radio technologies in a single network. Using a specifically designed API, called PICA (Protocol Implementation Specific API) [16], we analysed the development process required to obtain a multi-platform implementation of the protocol. Support for heterogeneous radio technologies was introduced with an extension of OLSR in order to support Bluetooth nodes. We showed how well this strategy performed in terms of applicability and preserving the scarce bandwidth available in Bluetooth links. The basic strategy was to produce an implementation in which no OLSR packets were required to flow through Bluetooth channels.

The proposal integrated Bluetooth devices in a MANET using a star topology in which the star core was a device with high availability of resources and connectivity. The 'Bluetooth only' nodes were kept unaware that they belonged to a MANET. The node to which they're connected to, the star core, must have both an IEEE 802.11b as well as a Bluetooth card.

In the UbiqMuseum design we extended the concept of a Bluetooth node of that previous work, replacing it with a scatternet. We introduced a scatternet formation protocol, see Section 5, to extend the potential and flexibility of the topology formation.

4 The UbiqMuseum System Architecture

In the UbiqMuseum, the overall network architecture is based on the cooperation of an *edge* wireless network and a core wireless/wired network. The edge side is based solely on Bluetooth technology. The core network is based on the integration of a fixed Ethernet local area network and a wireless IEEE 802.11b WLAN. The OLSR modified version described in [15] is used as the routing "glue" for the overall network.

The system considers three types of nodes: the Museum Information Clients (MICs), the Museum Information Points (MIPs), and the Central Data Server (CDS). A visitor provided with a Bluetooth enabled PDA is the typical example of an MIC. There is an MIP associated to one or more exhibits. Finally, the MIPs are connected to the CDS with an 'adequate' combination of Bluetooth, Ethernet or IEEE 802.11b devices. The adequacy of the configuration depends on the physical structure of the facilities. Figure 1 shows a pictorial representation of a possible configuration.

A client, while wandering around the museum, will continuously search for new MIPs through the Bluetooth inquiry process. When an MIP is found, it is checked to see whether it can offer any new information of interest by using the service discovery protocol.

If the user wants to see the new information he has to send his profile entered in the initial configuration process. The information point will process the request by combining the user profile with an identifier of the object the user is viewing and sending it to the central server. There, the request is logged and processed, and a reply is returned to the information point which relays it to the client. The search for an MIP can take place automatically, which is the default option, or on user-demand. The user can change his profile at any time, for example if he considers the obtained information is too advanced or too basic. This allows future access to be more in line with user expectation.

UbiqMuseum is build around the following properties:

- *Java based implementation:* We used the Java APIs for Bluetooth wireless technology proposed by the Java Expert Group JSR-82 [17]. JSR-82 provides a non-proprietary open application development standard for creating Bluetooth applications. More then 20 leading companies have adopted it in their devices.
- *SQL Database support:* All the information related to the exhibits is stored in an SQL database. This solution gives flexibility, ease of use, and a higher level of security and more efficient storage support and maintenance.
- *Flexibility:* UbiqMuseum can deliver a dynamic and variable amount of images and text to describe an exhibit. The

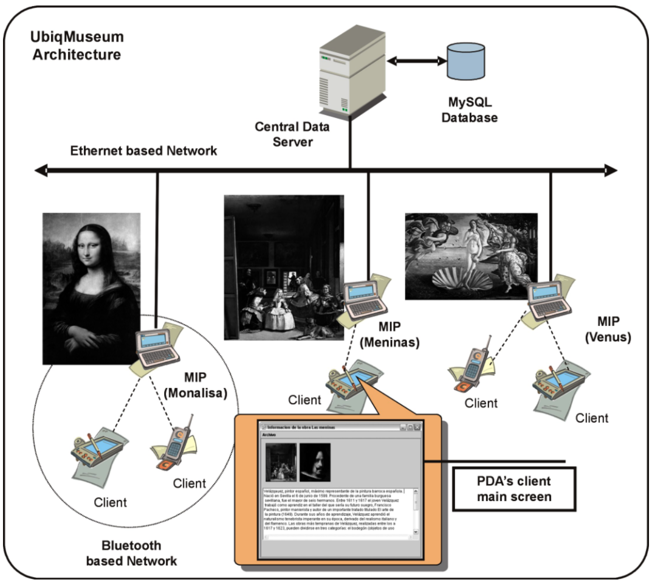

Figure 1: A Pictorial Representation of a Possible Configuration of the UbiqMuseum Architecture.

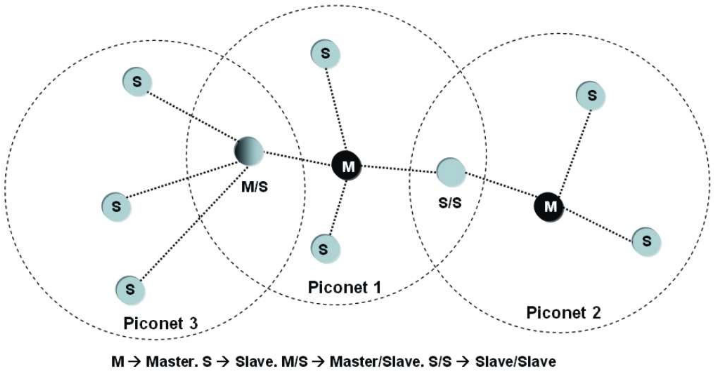

Figure 2: Example of a Topology where Three Piconets Are Connected to Form a Scatternet Network.

format and arrangement of the information delivered does not need to be pre-defined.

- *Scatternet support:* In a crowded museum it is expected that more than seven visitors (i.e., a piconet) may be looking at the same exhibit at the same time. For those cases we proposed an algorithm that forms a scatternet to interconnect various piconets.

5 The UbiqMuseum Scatternet Protocol

As previously stated, the overall network topology is maintained using a modified version of the OLSR routing protocol. Client devices, which are connected using Bluetooth, will form a scatternet around each MIP. The scatternet formation protocol is based on a previously developed cluster formation algorithm [18]. In our implementation, each MIP acts as the master of its own piconet which will allocate slots to all the clients. When we have a high density of clients around an exhibit we need to interconnect multiple nearby piconets to form a scatternet.

The Bluetooth standard does not specify a specific scatternet formation algorithm. To achieve an optimal scatternet topology is currently the subject of intensive research [19][20][21]. The different approaches try to obtain a scatternet topology similar to the one in Figure 2, where two piconets can communicate by sharing one or more 'bridge' devices. These bridges may act as a master in one piconet and as a slave in the other, or as a slave in both piconets, but not as a master in both.

However most studies have not directly addressed implementation related issues. For example, for the Master/Slave (M/S) bridge device in piconet 3 to operate, it needs to go into *hold* mode with regard to its piconet and active mode with regard to piconet 3. This means that communications in its piconet will be suspended until the *hold* period terminates. On the other hand, to connect piconet 1 and piconet 2, the slave/slave (S/S) bridge goes into *hold* mode in piconet 2 and becomes active in piconet 1. During the *hold* time no *POLL* packet is sent from piconet 2's master device. Whenever a bridge device is active in one piconet, it buffers data packets intended for the next piconet and delivers them to the next piconet when the *hold* time expires. Thus, all the messages from one piconet to another pass through these bridge devices.

Siegemund and Rohs [22] showed that master/slave bridges could result in reduced throughput, while slave/slave bridges require more complex negotiation and coordination protocols between masters sharing slave devices. Since nodes in the UbiqMuseum do not need excessive bandwidth we use bridge devices operating only in the master-slave scheme, passing all the inter-piconet communication via the masters. This approach also allows us to simplify the inter-piconets' scheduling protocols.

The scatternet algorithm we propose is based on using the *hold* mode to allow a device to leave one piconet and join another without any modifications to Bluetooth specifications. We limited one piconet to one master and a maximum of five slave devices. According to [23] using five slave devices allows a trade-off between path length and piconet congestion. We thus reserve two connections per piconet to be used for bridge connections. The MIP of each exhibit will create the first piconet of the scatternet. When more than five clients get within range of the same MIP, they will create successive piconets using the following mechanism.

When a client device cannot join the MIP's piconet, it will try to discover any other master that is acting as a bridge to the MIP's piconet. If no bridge is found the device creates its own piconet acting as the master and as a bridge to the MIP's piconet. For this new master to be discovered it will register a new service called Bridge_to_the_MIP. The master device will periodically POLL its slaves. The bridge device periodically goes into *hold* mode to relay packets from the MIP's piconet to its own piconet members.

When a client requires the associated exhibit information, its piconet master will relay the requested information to the MIP. To join the MIP's piconet, the bridge goes into *hold* mode in its piconet and then enables an INQUIRY SCAN status in the MIP piconet. The MIP master device discovers it using the periodic INQUIRY messages. When the *hold* time expires, the bridge leaves the MIP piconet, and relays the received information to the slave, which in this case is the client. The minimum interval that the bridge will spend "outside" its piconet is calculated according to the overhead incurred by going into *hold* mode, the time a bridge needs to join a piconet, and the time needed to get the information from the MIP. This period should not be greater than the maximum *hold* time specified in the standard (40.9 seconds or 65440 slots). Figure 3 shows the overall sequence diagram for a bridge device.

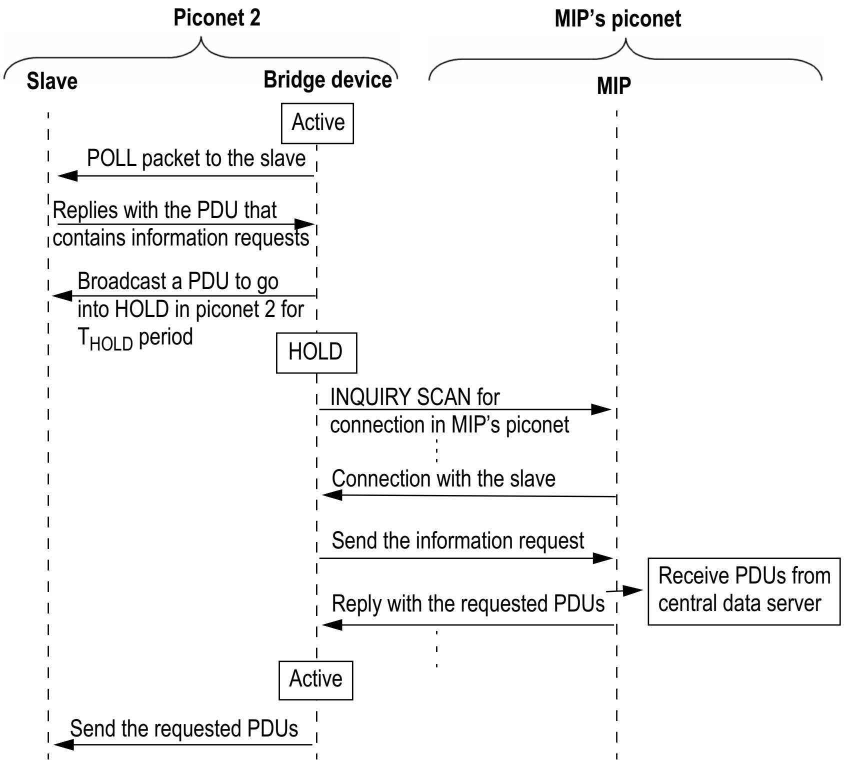

Figure 3: Sequence Diagram for the Bridge Operation.

5.1 Additional Remarks

We consider the scatternet to be formed around each MIP. We then assume that all the master nodes in the same scatternet are within direct radio range of the MIP. We believe this assumption to be reasonable in a scenario such as a museum where the application should offer context aware information to those visitors who are located in the vicinity of each exhibit. Moreover, we experimentally observed that Bluetooth offers a fairly steady throughput for distances up to 14 m.

The master of each piconet constantly updates its list of active slaves using round robin intra-piconet scheduling through the POLL data packet. When any of the slaves does not acknowledge the POLL packet, the master assumes that the node has left and will update its list of slave devices accordingly. Slave devices can also detect that the master has gone if they do not receive any POLL data packets from the master during a determined interval of time. In those cases the slaves will behave exactly like a node which has just been turned on.

Finally, the protocol could be simplified even more if we have multi-point Bluetooth devices that can act simultaneously as a master of one piconet and a slave to another. With multipoint devices our approach would thus be able to maintain the scatternet without going into *hold* mode.

6 Future Extensions

Our prototype application did not take into consideration some implementation issues that would make the application more feasible. As mobile device capabilities increase, so it becomes more viable to provide multimedia information. To provide multimedia content with a sufficient level of quality, QoS techniques must be introduced. Using UbiqMuseum as a testbed we are currently evaluating the problems that still persist when applying QoS techniques at the MAC level. We have observed that even when a video flow does not have to compete with other flows and the routing protocol operates in optimal conditions, video performance is still not optimal due to mobility. We have also noticed that as route length increases, multiple video flow disruptions (video gaps) increase, which means that from the user point of view the experience will be poor. In [24] we show that there is a close relationship between video gaps and route discovery events. We also show how to improve the routing activities to reduce the number and size of these video gaps by making some enhancements to the route discovery procedure. We are currently working on the development of traffic splitting (multipath) strategies to be applied to MANET routing protocols, in order to enhance the route selection mechanism that optimises the use of disjoint routes. We think that splitting video traffic on disjoint routes will reduce the video gaps caused by node mobility, and as a consequence the quality of received video will be significantly improved. The traffic splitting mechanism requires at least two different routes per destination node. In order to prevent possible route losses we supply a preventive route discovery mechanism able to provide the video flow with at least two disjoint routes.

Finally, ad hoc networks present security problems which are different from other networks. Prudent users might want to have a certificate to certify who is actually providing him with data. A public space like a museum might be the perfect place for intruders to get access to others devices in order to steal information. However, the present confidentiality mechanisms based on a central administration providing authentication based access control are not readily exportable to networks such as these with no central services and with limited power resources. More research must be carried out in order to propose new models of authentication based on a distributed certification authority applicable to mobile devices.

7 Conclusions

The main aim of this paper was to demonstrate that Bluetooth could be a candidate network support technology to provide ubiquitous context-aware services. Suitable programming interfaces, such as BlueZ and JSR-82, despite being still under development are mature enough to be used as the underlying technology for ubiquitous applications.

We have presented UbiqMuseum which is an experimental Bluetooth-based context-aware application developed in Java. UbiqMuseum combines the convenience and productivity of the Java platform with the universal connectivity of Bluetooth wireless technology. The system is designed to give visitors precise information about what they are viewing, aimed at their level of knowledge, and in their preferred language, while providing a GUI adapted to their device, thereby enhancing their experience.

We based the network on the cooperation of an edge wireless network with a core wireless/wired network. The edge side is based solely on Bluetooth technology. The core network is based on the integration of a fixed Ethernet local area network and a wireless IEEE 802.11b LAN. The edge network integrates one or more nearby user devices. From the user viewpoint, information points associated to any object are detected without user intervention, obtaining new information about what they are viewing. We extended the concept of a Bluetooth node to a scatternet and we introduced a scatternet formation protocol in order to improve the possibilities and flexibility of the topology.

We evaluated our application on a small test-bed, focusing on throughput and inquiry delay. We observed that Bluetooth offers a fairly steady throughput up to 14 m. The experiments also showed that the inquiry procedure is not highly sensitive to distance. We can approximately assume 5 sec. as the longest waiting time for the inquiry process.

UbiqMuseum still requires a lot of work in order to make it a really deployable application. In any event, we think it is a reasonable testbed on which to evaluate all the latest features related to ubiquitous computing in a realistic scenario. In Section VI we outlined a few of the future research lines that we are currently considering.

Acknowledgments

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