Bluetooth-assisted context-awareness in educational data networks

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Abstract

In this paper, we propose an auxiliary location network, to support user-independent context-awareness in educational data networks; for example, to help visitors in a museum. We assume that, in such scenarios, there exist service servers that need to be aware of user location in real-time. Specifically, we propose the implementation of a Bluetooth Location Network (BLN). The BLN is composed of small wireless nodes, which establish an spontaneous network topology at system initialization, and interact with Bluetooth-enabled user terminals (WLAN or GPRS PDAs, or WAP phones) or independent Bluetooth modems (badges). The BLN may coexist with any data protocol (IP over IEEE 802.11b or GPRS, WAP). We do not impose specialized terminal programming for location purposes, since we rely on basic Bluetooth signaling (responses to inquiry cycles). We evaluate BLN feasibility in two real educational scenarios, a school and a museum.

Keywords: Location-awareness; Context-driven services; User positioning; Bluetooth

1. Introduction

In this paper, we propose an auxiliary location network, to support user-independent context-awareness in educational data networks. Some examples of context-assisted network users could
be customers in a mall (m-commerce (Darling, 2001; Varshney, Vetter, & Kalakota, 2000)) or visitors in a museum (e-museums (Electronic Guidebook Research Project page, 2003)).

In this paper, we focus on educational applications of the technology, which include electronic guidance in museums or exhibitions, where visitors receive specific information associated to their current location.

We assume that, in such scenarios, there exist service servers that need to be aware of user location in real-time. We impose the following constraints to the location network that transmits user position to service servers:

- It must be user-independent. In other words, it must determine user position without user participation.
- The location technology must not be subject to line-of-sight constraints, due to the existence of physical barriers in museums or historical places that may prevent visitors from approaching objects (previous research decided to discard automatic location-awareness for that reason (Woodruf, Aoki, Hurst, & Szymanski, 2001)).
- The location technology must be available (embedded) in existing commercial handhelds.

We propose the implementation of a Bluetooth Location Network (BLN). The BLN is composed of small wireless Bluetooth nodes, which establish a spontaneous network topology at system initialization, and interact with Bluetooth-enabled user terminals (WLAN- or GPRS-enabled PDAs, or WAP phones) or independent Bluetooth modems (badges). There exists an increasing number of commercial handhelds, such as iPAQ H38xx Pocket PCs or Nokia 6310 WAP phones, which include Bluetooth modems for short-range communications.

In this research there are three contributions: first, the proposal of an auxiliary BLN that provides user-independent positioning, which may coexist with any data protocol (IP over IEEE 802.11b or GPRS, WAP). This BLN has been proposed by the authors in the field of e-commerce (García-Reino, Vales-Alonso, González-Castaño, Anido-Rifón, & Rodríguez-Hernández, 2001). Secondly, for Bluetooth-enabled user terminals, there is no need of terminal programming for location purposes, since we rely on basic Bluetooth signaling (responses to inquiry cycles). Third, we evaluate BLN feasibility in two real scenarios, a school and a museum.

Many user-positioning solutions have been proposed in previous research, but they are based on specialized devices that are neither standard or included in commercially available data terminals (Harter, Hopper, Steggles, Ward, & Webster, 1999; Priyantha, Chakraborty, & Balakrishnan, 2000; Texas Instruments, 2003; Werb & Lanzl, 1998). If we review positioning systems supported by commercial terminals, we find the following:

- Cell phone location services (ETSI) and GPS are quite effective for outdoor applications (especially GPS), and possibly the best choice. However, they are useless indoors.
- HP’s CoolTown (Kindberg & Barton, 2001) is based on IR beacons, which push position-dependent URLs into handheld IR ports (included in most state-of-the-art PDAs and WAP phones). CoolTown is user-dependent, because the user must aim the infrared port to location beacons. It could be argued that this is not a drawback, since automatic detection of location information (without user participation) may have severe consequences in terms of nuisance value. Other examples of IR-based systems are described in Want et al. (1996) and Abowd et al. (1997).

User-independence is not a disadvantage in educational systems, which we can expect to respect the user. Consider, for example, a museum, where updates could be associated with entries to new...
halls (once the user enters a hall, a tiny flashing icon at the bottom of the current page meaning “do you want to update context information” appears).

We can conclude that, depending on the specific application, user-dependent line-of-sight IR systems may be more advantageous than user-independent ones or viceversa. In fact, they are complementary. For example, in a museum, a PDA could use CoolTown to retrieve information on a single object, and Bluetooth-assisted context awareness to retrieve information on the surrounding hall (e.g., “Celtic fibula” vs. “Iron age”).

2. Bluetooth location network

In the m-Mall system (García-Reinoso et al., 2001), the users have Bluetooth-enabled terminals, or any mobile terminal and a Bluetooth location badge. The corresponding Bluetooth modems interact with a Bluetooth location network, or BLN, which provides service servers with real-time user position. The service servers may use this information to push URLs into user terminals via TCP/IP sockets, or to update WAP cards. Thus, no user action is required to generate context-driven updates.

The users must access the Web/WAP service server from their handhelds and enter their Bluetooth addresses. By doing so, those addresses become valid from the BLN’s point of view. The service servers associate the user’s IP address or WAP session to his badge number, for all subsequent transactions.

Bluetooth was also the base technology for the information offering system in (Yamasaki, Kishimoto, Komoda, & Oiso, 2001). There, the authors state that Bluetooth range does not provide enough location precision. Consider the example in Fig. 1. In principle, if the Bluetooth stations detect the user modem, the user could be located in any of the three halls (even outside them).

The key point in our BLN is cooperation. The BLN transmits the addresses of the Bluetooth stations that detect user terminals to a master node. In the example in Fig. 1, the master node will determine that the user is located inside the gray region. Note that most of that region intersects the hall were the user is actually located. This is interesting, because this particular arrangement could not be solved by the non-cooperative system in (Yamasaki et al., 2001).
3. Review of BLN protocols

3.1. Bluetooth

Bluetooth (Bluetooth SIG, 1999) is a short-range wireless technology. The maximum separation between class-2 Bluetooth devices is 10 m. It was originally intended for short-range applications such as wireless headphones and computer-to-peripheral communications.

A Bluetooth network is composed by piconets. A piconet is a spontaneous network whose configuration changes whenever a Bluetooth device enters or leaves its range. A piconet has one master and up to seven active connected slaves. It is possible to create nets of piconets, or scatternets. In a scatternet, the master of a piconet can be a slave in another piconet. In this scheme, inter-piconet communication is allowed. Note that the position of a given slave can be determined with 10-m precision in a scatternet, in the worst case.

From our point of view, the main advantages of this technology are low power consumption, small modem size and low cost, which allows the installation of a large number of devices in a target area. Consequently, Bluetooth seems a good alternative to deploy the BLN.

Next we will describe the BLN architecture.

3.2. BLN configuration

The BLN is composed of mobile badges and static Bluetooth units (located on the ceiling, for example). We will refer to the latter as static nodes (SNs). SNs are arranged in a network that covers the whole target area. Hexagonal tiling is a typical solution in 2D cellular network planning (Fig. 2). Other arrangements such that any SN has at most seven closest neighbors located less than 10 m away could be used as well (for class-2 Bluetooth modems). For example, a mesh for 2D target areas, or a k-ary 3-cube (Mao & Nicol, 1994) for 3D target areas.

Each cell in Fig. 2 has an area of 86.55 m². Static node units scan their surroundings periodically, by means of Bluetooth inquiry calls (Bluetooth SIG, 1999). All SNs are organized in a radial scatternet around a master node, SN0, connected to the service servers (not shown). The remaining SNs are arranged in “circular” layers around SN0. The notation SNX–Y stands for the Bluetooth address of SN Y in layer X. SNX-1 is placed right above SN0 in layer X, and the remaining Y values are increased clockwise. Our example shows the six cells in the first layer, SN1-1 to SN1-6, and two cells in the second layer, SN2-3 and SN2-4. Each SN is a slave of all six surrounding neighbor SNs. Therefore, each SN has six slaves.

All SNs perform inquiry cycles periodically, to publish their existence. If SN a detects an inquiry from SN b, and b is not currently listed in a’s routing table, a must send its minimum distance to the master node in number of hops to b in a distance packet, implemented as a Bluetooth DM-1 packet (Bluetooth SIG, 1999) with 1-byte distance field. All SN minimum distances are set to \( \infty \) at power up, excepting the master node’s, which is set to 0. Thus, the master node initiates the routing configuration process by sending 0-hop distance packets to its neighbors. Later, if SN c is performing an inquiry cycle and does not receive an answer from one of its neighbors, which was previously listed in the routing table, c must delete the corresponding table entry. If this changes the minimum distance from c to the master node, c must transmit a distance packet to all its slaves, indicating the change.
Whenever a SN receives a distance packet, it searches its routing table to check if the corresponding distance is lower than its current lowest distance to the master node. If so, the SN builds a new distance packet and transmits it to all its slave SNs.

If a SN receives a distance packet, it must update its routing table. The routing table stores pairs of neighbor SN addresses and their distances to the master node, and is sorted by distance. Thus, the best path to the master node is always the first entry.

**Remark 1.** A simple authentication handshake avoids connection establishment between SNs and invalid Bluetooth modems, which are considered invalid badges for simplicity. Typically, invalid badges will answer inquiry cycles with FHS packets, which is relatively harmless (see Section 3.3 below). However, in case they answered with another kind of packet, they would be easily detected by the SN authentication handshake and rejected.

**Remark 2.** If a SN has less than seven neighbors less than 10 m away, it is possible to implement permanent transmission links with all of them (the seven-slave transmission constraint of Bluetooth holds). This is valid for hexagonal-tiling, mesh and $k$-ary 3-cube BLNs. In case of a building with several floors, we can consider each floor an independent 2D surface. In order to avoid link establishment between SNs in different floors, we can set SN floor codes as authentication handshake inputs (obviously, all SNs in the same floor would share the same code).
Remark 3. Valid badges do not try to establish data connections with SNs. They simply answer inquiries with FHS packets, which does not violate the seven-slave constraint.

3.3. BLN location protocol

The main goal of the BLN is to track user movements in the target area. To meet that goal, all SNs have to send inquiries and collect badge responses. Every SN has a cache where it stores badge addresses. When it detects an inquiry response from a badge whose address was not in the cache, it builds a DM-1 location packet, and transmits it to the SN on top of its routing table. Location packets carry two Bluetooth addresses: SN address and badge address. The packets have a bit to report if the badge arrives to the cell or leaves it (we refer to the second case as out-of-range packets).

The SN that detects a badge is in charge of building location packets. All SNs placed along the transmission path to the master node simply forward them to the SN on top of their routing tables.

Remark 4. SN responses to SN inquiry cycles are ignored by the location protocol, because the corresponding SN addresses are listed in the routing table of the requesting SN.

Remark 5. Obviously, invalid badges that answer SN inquiries with FHS packets will generate location packets. However, those packets will be filtered by the master node. Moreover, if invalid badges correspond to static devices (such as printers), they will generate a single location packet, because SNs do not send unnecessary packets.

The interested reader may consult (González-Castaño & García-Reinoso, 2002) for a deeper description of the BLN location protocol and an evaluation of its performance.

4. Application scenarios

4.1. Hardware/OS

Fig. 3 shows a prototype of an educational data network with Bluetooth-based context-awareness support. The data network is an IP network over IEEE 802.11b or GPRS. The prototype has three SN computers to detect mobile Bluetooth modems, one per cell or zone. SN-zone 2 and SN-zone 3 are MS Windows 98 machines. SN-zone 1 is also the service server (SS) and BLN master node (MN). It runs MS Windows 2000 Server with MS IIS Web server.

SN-zone 2 and SN-zone 3 build and transmit location packets. SN-zone 2 also forwards SN-zone 3 location packets. The Bluetooth modem of SN-zone 2 is a CSR Microsira with BlueCore01. The Bluetooth modems of SN-zone 1 and SN-zone 3 are Ericsson evaluation kits based on the ROK 101 008/21 chipset.

The visitors have Windows CE 3.0 iPAQ H3630 or Pocket PC 2002 iPAQ H3870 PDAs and “external” Bluetooth badges (Nokia 6310 Bluetooth modems).
For IEEE 802.11b access, we use a D-Link DCF-650W IEEE 802.11b card in a compact flash iPAQ jacket. The service server is connected to a D-Link DWL-1000AP IEEE 802.11b access point. For GPRS access, we use an iPAQ GPRS jacket.

4.2. Software

The software modules in Fig. 3 are:

- **BLN-ZN3** (BLN-zone 3): In the prototype, SN-zone 3 is a slave of SN-zone 2, which is a bridge with the master node/service server, SN-zone 1. BLN-ZN3 initializes the ROK 101 008/21 modem in SN-zone 3, activates an inquiry cycle in SN-zone 3 and waits for a connection with the Casira modem in SN-zone 2. When SN-zone 3 registers responses from new mobile modems, BLN-ZN3 builds location packets and sends them to SN-zone 2 when a connection is available. BLN-ZN3 ignores subsequent responses from mobile modems that had been previously detected. However, if a mobile modem that had been previously detected does not answer inquiries, BLN-ZN3 builds an out-of-range packet and sends it to SN-zone 2.

- **BLN-ZN2** (BLN-zone 2): BLN-zone 2 builds and transmits location/out-of-range packets corresponding to mobile Bluetooth modems detected by the Casira modem in SN-zone 2. Also, it routes location packets and out-of-range packets from SN-zone 3 to SN-zone 1. Unlike the Casira modem, the ROK 101 008/21 cannot answer inquiries while in connected mode. Therefore, BLN-zone 2 alternates Casira inquiry cycles with connection establishment between the...
Casira modem and the ROK 101 008/21 in SN-zone 3, so that SN-zone 3 can transmit its location packets.

- BLN-SM (BLN-Server Module): This process runs in SN-zone 1 (the master mode and service server). It is quite similar to BLN-ZN3. However, in this case, location/out-of-range packets are passed to process BLN-CM instead of being transmitted.
- BLN-CM (BLN-Communication Module): This process runs in SN-zone 1. It is a socket-oriented interface between BLN-SM and BLN-PM.
- BLN-PM (BLN-Processing Module): This process translates location/out-of-range packets into positions of mobile Bluetooth modems, and sends context-dependent URLs to the corresponding data terminals. It uses the information in three auxiliary files that define specific scenarios:
  1. URL.txt associates an URL to each zone.
  2. Mobile.txt is a dynamic file that contains (mobile IP addr, mobile Bluetooth addr) pairs of current visitors.
  3. Nodes.txt is a static file with (zone id, SN Bluetooth addr) pairs. Since a zone may be defined by several SNs, there may be several entries with the same zone identifier.

BLN-PM stores (mobile Bluetooth addr, SN Bluetooth addr) pairs of incoming location/out of range packets in a dynamic list. When BLN-PM determines that a mobile Bluetooth modem has entered a new zone (from Nodes.txt), it reads the corresponding PDA IP address in Mobile.txt. Then, BLN-PM accesses the PUSH_IT connection server in the PDA, and delivers the new zone URL (indicated in URL.txt). Finally, PUSH_IT opens the Web page of that URL (served by the service server) on MS IE (note: the PUSH_IT connection server is described in (Costa-Monte negro, González-Castaño, García-Reinoso, Vales-Alonso, & Anido-Rifón, 2002)).

The educational network prototype can support WAP accesses with minor changes. Mobile WAP terminals are Nokia 6310 cell phones with internal Bluetooth modems. BLN-PM detects if an access comes from a WAP device (this is specified in the corresponding Mobile.txt entry). WAP users must register in the service server to obtain an identifier for subsequent accesses. They must update information pages themselves, because we have not implemented a push mode. Basically, there is a link in all pages that opens a context-dependent page (see examples in Section 4.4). Fig. 4 shows the WAP prototype. Obviously, both prototypes can be combined in one with dual IP/WAP access.

4.3. Application scenario 1

Application scenario 1 is a electronic guide for ETSI Telecomunicación laboratories at Universidad de Vigo, Spain. The purpose of this scenario was to test basic BLN principles and it is not currently deployed. The three SNs in the prototype were installed as shown in Fig. 5. BLN-PM defined the three zones as:

- Zone 1: at least SN-zone 1 detects the mobile modem,
- Zone 2: only SN-zone 2 detects the mobile modem,
- Zone 3: at least SN-zone 3 detects the mobile modem.

By changing SN position, and taking advantage of wall attenuations, it was possible to define zones that fit approximately into laboratory boundaries. Note that zone 1 is larger than the corresponding laboratory (due to the wide entrance doors). This could be corrected by placing an extra SN at the stairs entrance.
Once the visitor enters SN-zone 2 (Fig. 6), BLN-PM accesses PUSH_IT in the visitor’s PDA and submits the URL of the page in Fig. 7. The “map” icon after the page title is a link to a map of zone 2 and its surroundings (Fig. 8).

4.4. Application scenario 2

Application scenario 2 is an electronic guide for the Iron Age halls at Museo Provincial de Pontevedra, Spain, and, specifically, for the Caldas Treasure hall (Fig. 9). The Caldas Treasure is one of the most important collections of Iron Age gold jewelry in Europe.

The main goal of this scenario was obtaining feedback from museum curators, in order to plan the final system. A cost/benefit analysis of the final system is described in Section 4.5. For testing purposes, we simplified the prototype and installed a single SN in the Caldas Treasure hall (Fig. 10). As in the previous scenario, the walls constrained Bluetooth range, and we could define two zones without location errors:

- Zone 1: Caldas Treasure hall: The SN detects the mobile modem.
- Zone 2: Prehistoric Galicia, Iron Age: otherwise.

As in scenario 1, once the visitor enters the Caldas Treasure hall, BLN-PM accesses PUSH_IT in the visitor’s PDA and submits the URL of the page in Fig. 11. The “map” icon after the page title is a link to a map of the Caldas Treasure hall and surroundings (Fig. 12).
Fig. 5. Application scenario #1.

Fig. 6. Application scenario #1, zone 2.
Finally, Fig. 13 shows the initial Web page of zone 2 in scenario 2 (Prehistoric Galicia, Iron Age), and Fig. 14 shows a selection of WAP cards of both zones. Note the Actualizar link to force a context-driven card update.

4.5. Cost/benefit analysis of application scenario 2

In 2002, 121,166 people visited Museo Provincial de Pontevedra, with peaks in August (32,426), September (17,587) and July (14,835). Most of them were individuals and tourists.

Although PDAs are increasingly popular, few visitors to this museum have one with wireless extensions. Therefore, to save time of museum staff, we have evaluated the feasibility of providing groups with a PDA during their visits. Secondary school students seem the most appropriate target group, because:
Primary school students find it difficult to follow lectures or long presentations, and there are alternative resources for them: group games and multimedia PCs.

University students and scholars are mainly interested in laboratories, workshops and libraries, rather than in the exhibition.

Fig. 8. Map of zone 2 in application scenario #1 and surroundings, GPRS.

Fig. 9. Caldas Treasure.
Thus, we analyzed the relevance of target users (secondary school students), to determine if (i) there were enough visitors to justify the need of the system and (ii) if the cost of – at least – one wireless PDA per visiting group leader could be assumed (taking into consideration that several groups may be present at the museum simultaneously. Additionally, we have estimated the amount of Web pages to be generated by monitoring group interests).

Clearly, there were enough visitors to justify the need of the system, since there were 26,729 people in groups visiting the museum in 2002. Among them, 12,148 from primary and secondary schools (6,465 and 5,683, respectively).
When considering (ii), we noticed that there was a peak in May, with 1088 secondary school students, which were evenly distributed in labor days. Thus, in the worst case, there were \( \frac{1088}{60} \) target users per day. This means that, if we organized them in groups of 10, we would only need

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**Fig. 12.** Map of Caldas Treasure hall and surroundings, GPRS access.

**Fig. 13.** Web page of zone 2 in application scenario #2.

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When considering (ii), we noticed that there was a peak in May, with 1088 secondary school students, which were evenly distributed in labor days. Thus, in the worst case, there were \(~60\) target users per day. This means that, if we organized them in groups of 10, we would only need
six wireless PDAs to provide full service. Including two spare ones, this amounts for 6000 EUR/US$.

Obviously, the cost of the infrastructure (IEEE 802.11b access points and Bluetooth static nodes) cannot be ignored. We need one Bluetooth modem per hall, plus auxiliary electronics. According to our study, target users were mainly interested in the ten archaeology halls. The cost of the BLN is remarkably low if the static nodes are implemented with microcontroller boards with a Bluetooth modem. Even assuming the need of a PC board per Bluetooth modem in a first deployment stage, the cost of the BLN would be ~10,000 EUR/US$. The archaeology halls are arranged in two independent floors that could be covered with three IEEE 802.11b access points each (~1800 EUR/US$), which could also be used for Internet access. Therefore, the cost of the hardware required would be less than 18,000 EUR/US$. Note that, since the infrastructure is common, we would only need ~6000 extra EUR/US$ to give service to primary school students (eight extra PDAs), if it is finally considered interesting. On the other hand, the average number of secondary school students per day in 2002 was 24. This means that several PDAs may normally be available to other users, such as tourists.

Finally, we evaluated the number of Web pages required in an initial deployment. In principle, it is possible to write a vast amount of information on the exhibition. However, given the characteristics of target users, we basically need guidance for the group leader, possibly a teacher, who is expected to have a background on Spanish/Galician history. In a first approximation, we would need about 10 pages per hall, for a total of 60 pages. Nevertheless, Galicia has two official languages, Galician and Spanish, and a careful analysis reveals that a considerable amount of visitors come from Catalonia, plus a 3% of foreign students. This means that we need at least four

Fig. 14. Selection of WAP cards of zones 1 and 2 in application scenario #2.
languages: Galician, Spanish, Catalan and English, for a total of ~250 pages. Although this is feasible, an interesting idea is being proposed: to invite students to write pages as assignments, select the best one via contests, and enrich the system with them.

5. Conclusions

In this paper, we have proposed an auxiliary Bluetooth location network, BLN, to support context-driven services in educational data networks, as an extension of the results in (García-Reinoso et al., 2001). The BLN can complement short-range line-of-sight solutions like Cool-Town. We evaluated the BLN in two real scenarios, a school and a museum, for different data networks (WAP, IP over IEEE 802.11b and IP over GPRS) and mobile terminals (WAP cell phones, IP PDAs). An analysis of museum attendance has revealed that the system is of practical interest.

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