Bluetooth Broadcasting

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Bluetooth Broadcasting: How far can we go? An experimental study

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***Abstract*—Bluetooth is a wireless communication technology to build small networks of devices. It was designed as a cable replacement technology. Given its widespread adoption, especially in mobile devices, new uses are possible today. For instance, one can broadcast messages to nomadic users based on their location. In this paper, we perform an experimental evaluation of whether Bluetooth is indeed a suitable technology for spontaneous networking and broadcasting. The evaluation does not only consist of a review of current hardware and software, but also of a concrete implementation tested in a controlled indoor and in a not-controlled outdoor environment. The results of the experimentation show that, despite the intrinsic limitation of the original design, Bluetooth is indeed suitable for mobile location-based broadcasting.**

I. Introduction

Technologies are often used for a different purpose than for what they were originally designed. A classical example are SMS, which were originally designed as a service for the network operators, but ended up being the most used form of data exchange among mobile phone users. Another recent example is Yahoo!Pipes (pipes.yahoo.com), designed to be a tool to create mashups by Webmasters, today is used for more than 95% by ordinary Web surfers. Bluetooth might have a similar destiny. Bluetooth is a short-range wireless protocol thought for the internetworking of personal devices such as headphones, PDAs, printers and so on. The requirements of the technology include low battery consumption, robustness, and security. On the other hand, scalability and spontaneous networking were not strongly emphasized in the original design. Thus, the idea of Bluetooth is to create personal small area networks for users who 'own' all the devices, rather than creating spontaneous large networks of devices that are located in the same location. Today, the wide diffusion of devices equipped with Bluetooth interfaces opens new scenarios where almost every other person in a densely populated area carries a cell phone.

According to an independent survey of 50 brand names performed by Airwide Solutions, in 2007, over 200 million Americans carry mobile phones with them (more than half of the total population). Especially in densely populated areas this percentage increases considerably. This means that it becomes feasible and economically interesting to communicate using the mobile devices based on user location. If we consider the case of marketing, we report that 89% of major brands plan to market via mobile phones; 40% of major brands have deployed text messaging (SMS) campaigns in 2008; 18% of major brands have deployed multimedia messaging (MMS) campaigns. What makes this forms of communication attractive, is that the content is delivered based on the physical location of the user, and that it is possible to immediately know if a message has been delivered successfully. Marketing is however not the only application, one can think of social networking applications, file exchange, coordination of rescue teams, and so on. In other words, there are many potential applications of spontaneous networking and broadcasting that become feasible once most of the people have a device with a standardized interface such as Bluetooth.

In this paper, we look at Bluetooth with the goal of exploring its potential for location-based broadcasting to unknown devices. Our exploration is experimental in nature. Therefore, we review the current hardware and software to build Bluetooth broadcasting applications, we illustrate the architecture of the system we developed (`RuGBlue`) and illustrate a set of experiments showing the limitations but also the possibilities of Bluetooth.

A. Bluetooth

Bluetooth (IEEE 802.15.1) is a short-range wireless communications technology originally intended to replace the cables connecting portable and/or fixed devices while maintaining high levels of security. It operates at a frequency of 2.4GhZ with bandwidth of few Mbit/s. Each interface can have 7 simultaneous connections. One distinguishes three classes of Bluetooth interfaces depending on their transmission power and potential range.

Bluetooth is thus a technology for short-range networking of few elements. In general, there is a human mediated association of the devices: the person wanting two devices to interoperate has to physically manipulate the devices in order to allow the association. A typical example is a user wanting to pair his hands-free apparatus with a mobile phone.

The technology was originally designed for short range personal area networks, but the widespread use of Bluetooth interfaces in consumer portable electronics has opened the door to new forms of exploitation. Most notably, pushing mes-

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sages to devices discovered on the fly based on the location of the devices. That is, instead of point-to-point communication, using message broadcasting.

Since almost one in two people carry a mobile phone with Bluetooth, location-based broadcasting is feasible, though it presents strong challenges that originate from the underlying technology, most notably the *scalability problem.* One Bluetooth interface can only manage 7 simultaneous connections at any given instant, while in a crowded space there may be hundreds of devices reachable by the communication. For instance, at a train station in the rush hour, at a concert or on a shopping street on Saturday afternoon. Using park mode—a modality saving battery power during which the device is synchronized with a master node without being part of a piconet—it is possible to connect to up to 255 devices. Problems occur when trying to deliver data to a large group ($>$ 7 devices) of people that are on the move. The other challenge is to cover enough physical space with one broadcast. But what could broadcasting be useful for in the first place? An interesting example, with a huge potential market is that of proximity marketing. Something that could become a huge share of the global mobile advertising market, which is estimated by M:Metrics1 to be at $16 billions by 2011.

B. Proximity Marketing

One of the latest trends in advertising is called proximity marketing. *Proximity marketing* is the localized wireless distribution of advertising content associated with a particular well identified place. One way of transmitting the messages is by doing a broadcast to nearby devices via the Bluetooth protocol. This broadcast can vary from simple text messages to multimedia content such as video, business cards or applications. For instance in Summer 2005, the British rock band Coldplay used Bluecasting [1] to promote its newly released album X&Y. During a two-week period, approximately 20,000 people downloaded pre-release video clips, never-before seen interviews, audio samples and exclusive images directly from posters in London's main rail terminals by using their mobile phones or other Bluetooth enabled devices [2]. At the moment, the number of companies trying to ride this hype is overwhelming.[1] Their products usually include both a hardware component, see Figure 1, and software that can manage from 7 to 21 connections. Some of the more expensive products are able to handle up to 28 connections. We have found no evidence of products that go beyond this number. To the best of our knowledge, there are no open source projects that cover this commercial need.

[1]Advatex, Alterwave, Assertivemedia, Blipsystem, Bloozone, Bloozy, Bluead, Blueblitz, Bluebot, Bluecasting, Bluecell, Bluegiga, Bluehotspot, Bluepulse, BluetoothAdvertising, Bluetotem, Breeze-tech, CmoGlobal, Futurlink, Goyya, Halfbakery, Hypertag, Jellingspot, Kameleon, Midray, Norkatech, Panther Bluetooth Proxi-ma, Proximitymedia, RTX, Smart and wireless, WCIT and Zonablu are just a few in a field of many.

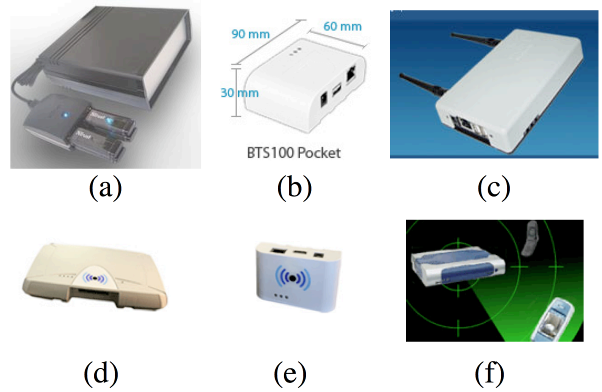

Fig. 1. Proximity marketing products: (a) MobiTouch, (b) BlueSixty, (c) Blip, (d,e) Bloo2, (f) BlueBlitz.

C. Pushing the Bluetooth technology

The issue is that Bluetooth does not scale. Kettimuthu and Muthukrishnan [3] have researched whether Bluetooth is suitable for large-scale sensor networks. Their focus is on making large piconets and they identify an number of challenges including scalability. Siegemund and Rohs [4] also mention the difficulties of Bluetooth scalability. Though all these studies fail to provide quantitative data on the possibilities of the technology especially when it comes to the issue of applications such as proximity marketing.

Other studies also point out additional Bluetooth concerns. BlueMediaServer, a company that is into active broadcasting provides some statistics about broadcasting via Bluetooth from a central location. They claim the following[5]: 90% of all users have Bluetooth turned off. From the 10% that remains, when asked if they will receive a file, 75% will say no, and of the 25% that says yes, 50% of the times the transmission is dropped because the mobile phone cannot communicate well from a large distance. So if one wants to broadcast messages via Bluetooth from a central location, one should expect a hit rate of less than 1.25% of all possible clients.

In this paper, we perform an experimental study of Bluetooth with respect to the application of broadcasting to nomadic unknown users. We design and implement a broadcasting solution and we perform experiments in open real world environments. The results show that indeed Bluetooth has limitations, but that these are not so stringent to prevent its use as a location-based broadcasting mean.

The reminder of the paper is organized as follows. In Section II, we present the hardware/software architecture we realized to test the Bluetooth technology. Section III is dedicated to the presentation and discussion of the experiments . Related work is summarized in Section IV, while concluding remarks are presented in Section V.

II. RuGBlue

We implement a hardware/software architecture to go beyond the single 7 connection limitation intrinsic of Bluetooth. The implementation based on the architecture is named

RuGBlue and consists of five main components, Figure 2. We implemented these as Linux based servers running the RuGBlue software, the Bluetooth antennae, an internal database for logging and synchronization, an external database which delivers the contents that are to be distributed and, finally, the clients of the system: Bluetooth enabled devices. The red area in Figure 2 is the object of the paper. The rest of the architecture is used for broadcasting course related information to the students of the faculty of science of the University of Groningen, The Netherlands. Next, we provide more detail on the implementation choices made.

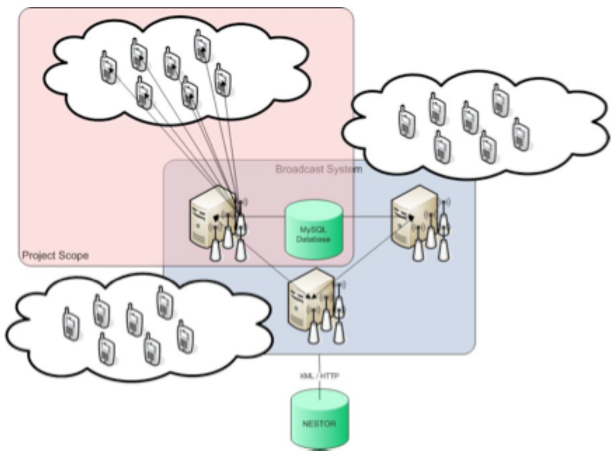

Fig. 2. The RuGBlue architecture.

The first design decision concerns the operating system, as the implementation of the Bluetooth stack varies. In particular, Microsoft Windows (stacks: Widcomm, BlueSoleil) and MacOS X do not support multiple dongles. The only option to push the scalability limit by using more dongles is using Linux / Unix and the BlueZ stack [6]. In particular, we use Ubuntu 8.04 given its well-known stability.

The choice of the hardware on which to run the broadcasting program, is not too relevant, as long as it has enough resources to run Linux and the software. We choose to use a laptop to facilitate the mobility while testing. In particular, we use a DELL Inspiron 5150 after a DELL Inspiron 1150 proved to be too lightweight. To plug in multiple dongles, we use a 10-port Sitecom CN-052 USB-hub, widely available in consumer electronics stores. As for actual Bluetooth interfaces, also known as *dongles*, we have tested a number of them (cf. Figure 3) and decided to perform the test using one of per brand.[2]

Finally, as for application software, we choose Java for its known portability features and the greater availability of Bluetooth libraries (cf. Figure 4 for a comparison). In particular, we opt for the BlueCove library [8]. To manage the data of the broadcasting application we use MySQL.

[2]Tests we performed and not reported here indicate that the Conceptronic 2.0 USB Adapter 200m C04-104 is the best performing dongle with respect to range and reliability [7].

	Brand	Specification	Class	Price
	Linksys	Bluetooth USB Adapter Class 1 USBBT100 ver. 2 Bluetooth 1.1, USB 1.1 Max data speed 721 Kbps	1	€29.99
	Sweex	Bluetooth 2.0 Class 1 Adapter USB Bt211 Bluetooth 2.0 EDR Max data speed 3 Mbps	1	€9.58
	Sitecom	Bluetooth 2.0 USB Micro Adapter CN-523 Bluetooth 2.0 Max data speed 3 Mbps	1	€9.95
	Sitecom	Bluetooth 2.0 USB Adapter CN-521 Bluetooth 2.0 Max data speed 3 Mbps	1	€9.99
	Conceptronic	2.0 USB Adapter 200m C04-104 Bluetooth 2.0, USB 1.1 Max data speed 3 Mbps	1	€14.99
	MSI	Bluetooth USB Dongle BToes Bluetooth 1.2, USB 1.1 Max data speed 723 Kbps	2	n.a.

Fig. 3. Tested Bluetooth dongles.

Company Name	javax bluetooth Support	javax obex Support	Java Platforms	Operating Systems
Avetana	Yes	Yes	J2SE	Win-32, Max OS X, Linux Pocket PC
Blue Cove	Yes	Yes	J2SE	Win-32, Max OS X, Linux Pocket PC
Electric Blue	Yes	Yes	J2SE	WinXP SP2
Harald	No	No	Any platform that supports **javax.comm**	Many
JavaBluetooth.org	Yes	No	Any platform that supports **javax.comm**	Many
Rococo	Yes	Yes	J2ME, J2SE	Linux, Palm OS

Fig. 4. Available Bluetooth software.

III. Experimentation

To test how to go beyond the limitation of the single Bluetooth interface and connect to nomadic users, we design and perform four tests. In the first test, we check the responsiveness of Bluetooth broadcasting, then we test the scalability with respect to simultaneous connections, then we test the coverage of broadcasting and, finally, we perform a long running test. The first three test are indoor, namely, in the Bernoulliborg building of the University of Groningen. The choice is made as the system we develop is intended for use to broadcast to students relevant information regarding exams, lectures and daily news. The last test is performed outdoor in a central area of the city of Groningen.

A. *Responsiveness test*

The speed at which Bluetooth devices coming in range find each other and exchange a message are important factors for broadcasting to mobile devices. We measure this responsiveness in the classical way by considering the time difference between the initial transmission of a message and its total reception (thus merging the contributions of latency and bandwidth). We measure this time delta in seconds and consider it infinite if the devices in range cannot be found or the message is not delivered.

The responsiveness test is performed during a bachelor course at the University of Groningen with about 50 students present, 37 of which have a Bluetooth enabled device. Four Class 1 dongles are used, two of them from Conceptronic, one from Sitecom and one from Linksys. Phone users are given a questionnaire to report the instant of eventual message receipt. The test is run in four rounds. In the first round one dongle is used for discovery and 1 for message delivery, in the second two for delivery, then three and in the final round 2 dongles are used for discovery and 2 for delivery. The software is left to run for one minute. This value is set based on the range of a dongle of 30 meters and the average speed of a walking person of 4 Km/h or 67 meters per minute. The

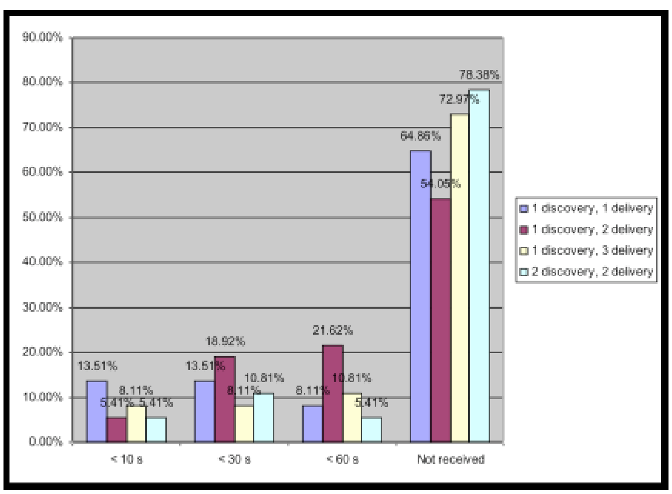

Fig. 5. Responsiveness test results.

results are summarized in Figure 5 where we see that, although nearly all devices are discovered, only a small fraction of devices receives a message within 10 seconds, while a consistent amount of devices never receive the message. Using a questionnaire distributed to the students, we notice differences in the hardware of the devices. These are reported in Figure 6. As expected, there is a substantial difference among different hardware. For instance, no messages are delivered to Apple iPhones while Nokia handsets seem the more robust with respect to Bluetooth connections. Considering the various test rounds, we also report that 28 devices received a message at

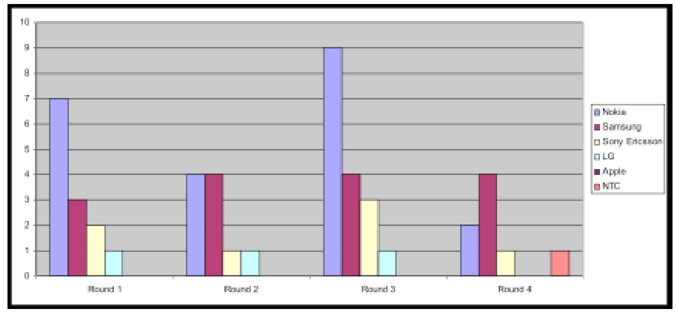

Fig. 6. Responsiveness test results.

least once in the tests, while with 9 a connection could never be established.

B. *Simultaneous connections test*

The maximum number of active connections we can serve per dongle is seven. Fortunately, the number of active connections is not the maximum number of connections one dongle can hold. Other devices (up to 255) can be inactive or parked, waiting for the master device to activate them at any given time. Usually this is done in a round-robin fashion.

The purpose of the simultaneous connection test is to show if it is possible to have simultaneous connections with more than seven active Bluetooth devices at the same time. To achieve this, one has to use multiple dongles given the inherent limitation of Bluetooth. The first test is executed together

Round	# Delivery dongles	Max. possible # simultaneous connections	Max. # simultaneous connections reached
1	1	7	7
2	2	14	13
3	3	21	14
4	2	14	14

Fig. 7. Simultaneous connections test indoor.

with responsiveness test, that is with the 37 active Bluetooth devices reported in the previous section (Section III-A). The results are summarized in Figure 7, illustrating the theoretical upper bound to simultaneous connections with respect to the number of dongles used, and the actual maximum number of connections registered during the experiment. We note that the theoretical maximum is not reached as soon as we have more dongles on the same USB hub.

Round	# Delivery dongles	Max. possible # simultaneous connections	Max. # simultaneous connections reached
1	3	21	21
2	4	28	19
3	4	28	22

Fig. 8. Simultaneous connections test outdoor.

The second test is run with the long running test (Section III-D). The results are summarized in Figure 8 where we remark the breaking of the 21 connection limit.

C. Reception test

Given the heterogeneity of implementations of the Bluetooth stack, it is also interesting to test how the same message is delivered on different devices. In particular, we look at the following characteristics: if the message is delivered, how it is delivered, if and what kind of agreement is necessary from the user. The results of the test are presented in Figure 9, while some screenshots of actual devices are shown in Figure 10.

Brand	Model	Message	Remarks
Nokia	6210	Successfully delivered.	Displayed as text message in inbox.
	6300	Successfully delivered.	Displayed as text message in inbox.
	E71	Successfully delivered.	Displayed as notice.
Samsung	SGH-E770	Not delivered.	Asked for PIN-code.
	SGH-E900	Not delivered.	Asked for PIN-code.
	Omnia	Successfully delivered.	Displayed as text message.
Sony Ericsson	K770i	Successfully delivered.	Displayed as webpage.
	W710i	Successfully delivered.	Displayed as webpage.
	W810i	Successfully delivered.	Displayed as webpage.
Sharp	920SH	Not delivered.	Asked for PIN-code.

Fig. 9. Reception test on different devices.

Fig. 10. Screenshots of message receipt on different devices (Dutch interface).

D. Long running test

Finally, we test the system by letting it run in a densely populated area for several hours. We performed three tests during three consecutive nights (Thursday, Friday and Saturday in the first week of July 2009) in one of the most popular streets (Peperstraat) for going out in Groningen, The Netherlands. For the first test, we use two discovery dongles and three delivery dongles, namely, two Conceptronic and three Sitecom CN-521 dongles. For the second and third day, we use two discovery dongles and four delivery dongles: two Conceptronic and four Sitecom CN-521 dongles. The Sitecom dongles are used as discovery dongles in all three tests. After the test on Friday night the OS on the laptop is updated from Ubuntu version 8.04 to Ubuntu version 9.04. During the first test the system runs from 18:30h until 2:30h. The second test is performed between 22:45h and 18:00h and the third test from 18:30h until 12:00h. One small modification is made for the third test with respect to the other two: the name of the sender is changed from `Bluetooth_laptop_1` to the more intriguing `Priscilla`.

Round	Running time	Unique devices	Delivery attempts		Successfu l attempts	Connectio n terminated		No services found	
1	8h	439	241	136	8	233	129	1567	412
2	19h	612	228	140	13	215	127	5314	606
3	17.5	883	568	288	26	542	270	8286	872
total	**44.5h**	**1934**	**1037**	**564**	**47**	**990**	**526**	**15167**	**1890**

Fig. 11. Long running test.

Each test has a different length. The duration of the first test is eight hours, the second test lasts for almost 19 hours and the third test takes 17.5 hours. Results are presented in Figure 11. From left to right the columns list the test round, the duration of the test, how many unique devices are found, how many times the software tries to send a message (delivery attempts), how many of these attempts are successful, how many times the connection is terminated prematurely and, finally, how many times the software fails to open a connection (no services found). Whenever a column is divided into two, the left box lists the total number of events whereas the right box lists the number of unique devices for which this event occurred. In total, 47 messages have been successfully delivered after a total running time of 44.5 hours. This means an average of slightly more than one (1.06) successful delivery per hour. The first night eight devices out of 439 receive a message which means a success rate of 1.8%. The second night this percentage increases to 2.1% reaching 2.9% on the final night. If we consider the statistics reported in Section I-C, which determine the success rate of delivering a message to an unknown device to be 1.25%, we conclude that `RuGBlue` performed better than average. Furthermore, we estimate the total number of people with a mobile phone potentially being reachable by RuGBlue during the tests to be 19.340 (4390 people the first night, 6120 the second and 8830 people the third night).

E. Discussion

The results of the test do enforce the fact that Bluetooth can be used for broadcasting to unknown devices based on their location. The first test has shown that one can easily go beyond the 7 concurrent connections. In fact, the number of actual messages delivered is 17 or 45.95% of the present devices. This with the software only running for a minute.

One can then wonder whether the number of received messages may increase when extra delivery dongles are added to the system. From the analysis of the data, it appears that the relation dongles—number of delivered message is not straightforward. Although the maximum number of successfully delivered messages was achieved during the third test round, there is an unexpected decrease during the second round. Considering the fact that, in comparison to round one, fewer devices were not found and that the number of delivery attempts to unique devices was higher, more messages should have come through. Why the data proves otherwise is difficult to explain. Increased interference from the fact of using more dongles could be an answer, but first of all this is hard to measure and secondly the software did not appear to have this problem during the third round. Despite all these apparent disadvantages 17 messages were delivered during the 3^{rd} round compared to 9 messages during the 2^{nd} one. During our own test phase [7], we encountered a similar problem.

With respect to the reception test, the question arises about why some devices receive a message during one of the rounds, but fail to receive it during the other ones in the same session. As a possible explanation, we remark that there is no fixed order in the discovery of devices by the dongle. This means that a device that receives a message during one or more of the rounds can be ignored during a subsequent round.

Considering the size of the group of people and the speed at which a group can be moving, broadcasting has its limits. Successful message delivery can be increased by plugging in extra transmitters, but it is not clear if and when interference starts playing a crucial role. The number of transmitters that can be added also depends on the underlying hardware. `RuGBlue` uses dedicated dongles. One dongle is always used for discovery. Since one discovery dongle is perfectly able to find devices quickly, other tests not reported here show that this method is faster than letting all dongles alternate between roaming for devices and sending them messages [7].

In summary, from the experimentation we conclude that broadcasting to unknown devices via the Bluetooth protocol to nomadic users moving rapidly is difficult, because there are so many factors to reckon with: interference, time constraints, opening a stable connection to a device, limitations of the operating system of the broadcaster, heterogeneity of the receiving devices, to name the most evident ones. Nevertheless, it is indeed feasible to build broadcasting to unknown devices using Bluetooth as physical layer.

IV. Related Work

Before starting the enterprise of building a message notification system for indoor mobile users, one has to perform a feasibility study on the technology to be used for delivering messages. When we started the feasibility stud, we were unable to find any such study, especially we could not find an experimental and quantitative analysis. Nevertheless, there is a wide spectrum of research on using the Bluetooth technology for sensor networks, car networks, and pervasive systems more generally. We already reported on the study of Kettimuthu and Muthukrishnan [3] and Siegemund and Rohs [4]. Eliasson, Lundberg and Lindgren discuss time synchronous sensor networks based on Bluetooth [9]. They suggest that communication delays and energy consumption can be optimized with the combination of clock synchronization and a time activation schedule. Additionally, the study of Yan, Zhong and Jha [10] considers energy consumption of Bluetooth vs. ZigBee devices and also contains some considerations on Bluetooth scalability. Finally, we mention the work of Agostini et al. [11] which studies user device profiles also in relation to proximity marketing.

V. Concluding Remarks

Bluetooth is a technology massively available today. Most people carry a cellphone with such an interface. This opens the opportunity to communicate with devices on the go based on their location. In the presented study, we have performed an experimental evaluation to see what are the limitations and the possibilities for using Bluetooth as a vehicle for broadcasting concurrently messages to unknown devices based on their location. Given the positive result of the feasibility study, in the future research we will proceed in building a system to deliver notifications to students of the University of Groningen based on their location or on their identifier (namely, the mac address of their Bluetooth interface).

Acknowledgment

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