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Influence of the the Distance Between Bluetooth 2.0 Nodes and Their Link Mode with the Communication Delay

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***Abstract*— In this paper, the relationship of the distance between Bluetooth 2.0 nodes and their link mode with the delay in a monitoring wireless network is analyzed. The carried out measurements have demonstrated that within medium distances, from 6 to 24 meters, the overall time delay keeps nearly constant, but RSSI reading changes significantly. There has also been estimated the time delay each communication hop adds to the overall delay for some link modes a Bluetooth node can be in, i.e., active, sniff and park. These measured low values for time delay in this Bluetooth 2.0 wireless network allow some real time applications as, for example, those in the areas of avionics, domotics, health or industrial monitoring.**

Keywords-Bluetooth; wireless; network; delay; link mode; RSSI; analysis; implementation; testbed.

I. INTRODUCTION

The Electronic Design Group (also known as GDE research group) in the University of the Basque Country has been working for years with Bluetooth technology applied to monitoring in the areas of domotics [1] or health care [2], for example.

As a result of this work, this paper is introduced. This research puts forward a research which main objective is to determine the influence of some important variables in one of the wireless sensor networks' main metrics [3]. This network performance metric is the end to end delay present in Bluetooth multi-hop communications. The variables are the distance between wireless nodes, the number of hops in the communication and the link mode they are in. This metric might become very important in such networks dedicated to gather data from the environment, as in our case, wireless sensor networks for the railroad world.

The paper is organized as follows. Section II describes the test bed used to measure communication time delay. The tools needed to do these measurements are explained in Section III. Section IV deals about the limitations that have been considered when doing these measurements, and the results obtained are in Section V. The conclusions are summarized in Section VI, and finally, future steps in Section VII.

II. DESCRIPTION OF THE TEST BED AND MEASUREMENTS

First, as stated in [4] it is important to analyze the network performance in a real testbed, i.e., in a real world implementation of the Bluetooth network, cause empirical results may differ noticeably from theoretical foresights. Thus, in these experiments, there have been considered own developed nodes, i.e., nodes based on a Bluetooth communications module, WT-11 manufactured by Bluegiga [5], with an integrated microprocessor inside (BlueCore04® by CSR [6]). This hardware has been programmed with a proprietary firmware, as an evolution of previous work in developing Bluetooth nodes [7].

Next, the network topology scheme considered for these experiments is a chain of wireless nodes that work as gateways in the resulting multi-hop communications. The length of this chain varies from having 12 hops till 4 hops. This scheme can be observed in Figure 1.

There can be seen a WT-11 evaluation kit node (red) connected by wire to a PC serial port. The other links or hops that take place in this research are wireless (depicted as curved arrows).

In order to duplicate the number of hops in the communications with a limited number of nodes, the end terminal is emulated with another WT-11 evaluation kit board (blue) connected by wire to the PC by another serial port. An immediate response has been programmed in the serial port monitoring software, so that the time taken upwards and downwards can be differentiated.

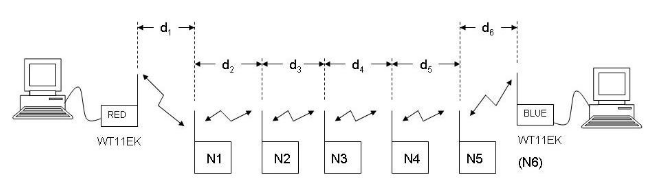

Figure 1. Schematic representation of the wireless networking

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As far as d_1 and d_6 are not between two proprietary nodes their importance in our delay measurements is minor, hence, here d is fixed as follows:

$$d_2 = d_3 = d_4 = d_5 = d \quad (1)$$

In the case considered, shown in Figure 1, N1, N2, N3, N4 and N5 nodes work as a gateway of communications, because they are master of a piconet and slave of another piconet as well. Therefore, they are called master-slave gateways, and they are the key nodes when composing scatternets. On the other hand, N6 node is always a slave of the piconet where N5 is the master.

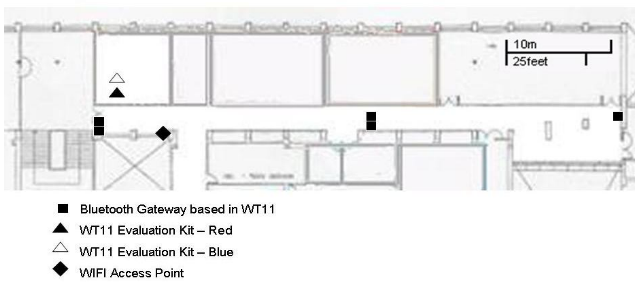

Figure 2. Node disposition in the corridor

Last, the scenario that has been considered is one of those available in our research center, a corridor. This way, separations of up to 24 meters among wireless nodes have been possible. The node disposition in this corridor, for the maximum number of hops considered, has been depicted in Figure 2. There can also be seen the exact location of the unavoidable WiFi hot spot.

III. HELPFUL TOOLS

Here are summarized the main tools needed to attain the objectives of this research.

A. Integrated development environment (IDE)

With the help of BlueLab® 3.6.2 xIDE, a software development system, some specific commands have been added to the operative developed firmware [1] for each wireless node. These specific commands are divided into HCI level commands and application level commands.

First, two are the added HCI level commands. A command to ask for the RSSI (Received Signal Strength Indication) reading in each node for upwards (towards its master) and downwards (towards its slaves) links has been included. Since, for example, links between nodes might be parked a command to change the link policy settings for each link of each node has been included.

The other specific command it has been added to the operative firmware, is an application level command to query the status of the inputs and outputs of each node. This is the command the end terminal has to answer when delay measurements are done.

B. Serial port monitoring software

A serial port monitoring software is used with a personal computer so that useful data can be logged. These data consist of the commands sent from the PC to the end terminal (N6 node, in case 12 hops are considered, as shown in Figure 1), the automatic response sent from this last node to the PC, and the moment they all happen. The choice of this tool is critical, as far as it is the main tool for the achievement of the main objective, to determine the relationship among some important factors in wireless communications. Docklight® evaluation software has been chosen.

C. Mathematical calculus sheet

These entire huge amounts of data collected by the serial port monitoring software must be processed in order to obtain meaningful results. In this case, overall statistical parameters (as mean or standard deviation) are obtained [8], as it can be seen later.

IV. CONSIDERED LIMITATIONS WHEN MEASURING

There have been considered some important limitations when measuring delay time in this kind of wireless network.

First, time resolution is limited by the equipment and tools used. In this case, there is no need of a greater precision in the measurements, because these are much greater than the available precision threshold. This threshold or an unavoidable handicap is about tens of milliseconds.

Second, is it important to notice that a WiFi hot spot is present in the corridor, as depicted in Figure 2. It is always on. As far as this hot spot is not GDE's responsibility, there was no way to switch it off while measuring.

Finally, there has been considered a finite number of measurements. In case the measuring is repeated, some differences will appear in statistical parameters, as the mean value or the maximum [9]. Here, no less than 150 measurements have been considered, which involved up to thirty minutes of observation, for each point in the figures obtained as results.

V. RESULTS OBTAINED IN THESE EXPERIMENTS

Here are summarized the results obtained in this research.

A. Time delay and RSSI as a function of the distance between wireless nodes

First of all, the relationship of the RSSI reading and the time delay with the distance present between the wireless nodes, considering the connection scheme that appears Figure 3, has been analyzed.

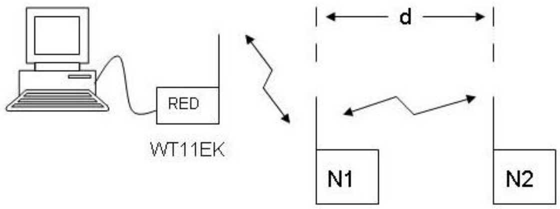

Figure 3. Schematic representation of the networking for the delay and RSSI measurement

In this experiment, all links worked in 'default' mode. When there is no data to send, the links are in sniff mode. If nodes must transmit data, the link is switch over to active mode, where it remains like that during five seconds. After, the link returns automatically to sniff mode. This working mode is not defined in Bluetooth 2.0 specifications [10].

In this case, as far as the query command to the end terminal is sent every three seconds and links are working in 'default' mode, they are in 'active' mode all the time, except in the first measurement.

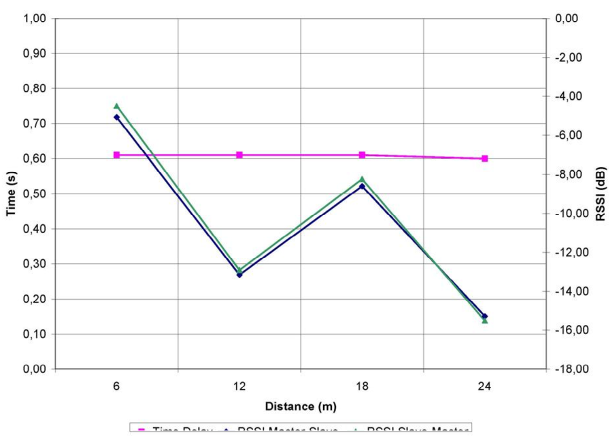

Figure 4. Time delay and RSSI reading as a function of the distance between wireless nodes

As it can be seen in Figure 4, the time delay doesn't change when separating wireless nodes from 6 to 24 meters. On the other hand, the reading of the RSSI changes as the distance between nodes increases. Two readings have been taken for the link N1-N2: a reading of the RSSI the master (N1) receives from its slave (N2), called RSSI Master-Slave, and a reading of the RSSI the slave (N2) receives from its master (N1), called RSSI Slave-Master.

It is important to notice that the reading of the RSSI is not as precise as we would expect [10]. But it gives us a first approach to the quality of the link depending on the distance between nodes.

B. Time delay as a function of the number of hops and the link policy in each node

Next, there has been analyzed the relationship the number of hops has in time delay depending on the link policy of each wireless node.

The topology of the network considered can be seen in Figure 1. Here, all links are in the same mode (default, active, sniff or park). 'Default' mode has already been explained in Section V.A [6]. When working in 'active' mode, all links are active all the time and slave nodes are listening in all time slots to their master for incoming commands. When working in 'sniff' mode, slave nodes are only listening in some specific slots to their master for incoming commands. Data transmission in those time slots is available. When working in 'park' mode, slave nodes are only listening in some specific time slots to their master for incoming commands. Data transmission is only available after changing its state to 'active' [10].

In this experiment, an immediate query command has been programmed after receiving the response to the previous query command when working in sniff, active and park mode. On the other hand, when working in default mode, query commands have been programmed every ten seconds, no matter when the response to the previous query is received. This way, each node can change from active state to sniff state while not sending commands.

This networking disposition allows measuring not only downward time delay but also upward time delay. Overall time delay is the sum of the downward delay plus the upward delay plus the processing time in end terminal. Here, this last addend has a mean value of ten milliseconds, negligible compared to the other ones.

The differences between the two first addends can be appreciated in Figure 5, where downward time delay and upward time delay are discriminated.

The overall time delay from end to end as a function of the number of hops and the link policy in each node can be seen in Figure 6. Here each point reflects the mean value of measurements in some specific conditions (as, for example, link mode of nodes, distance between nodes and network topology). These points are obtained after measuring time delay (overall and partial ones) during no less than fifteen minutes.

As far as the curves obtained in Figure 6 are nearly lineal, there can be done an estimation for the added time delay each wireless communication hop puts into the overall time delay. It depends on the link mode and gives us the following results: 'active' (140 ms), 'default' (168 ms), 'park' (484 ms) and 'sniff' (715 ms)

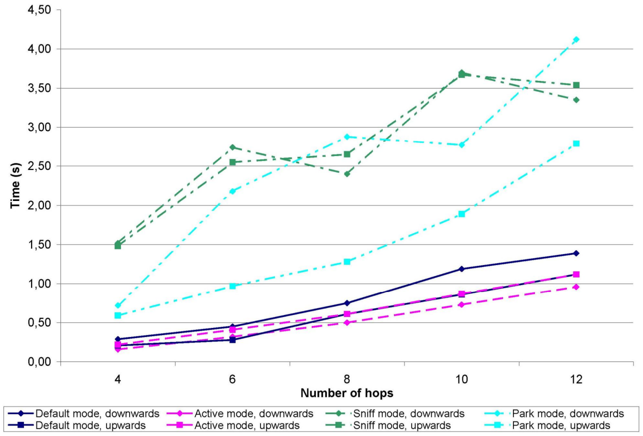

Figure 5. Upward and downward time delay from end to end as a function of the number of hops and the link policy in each node

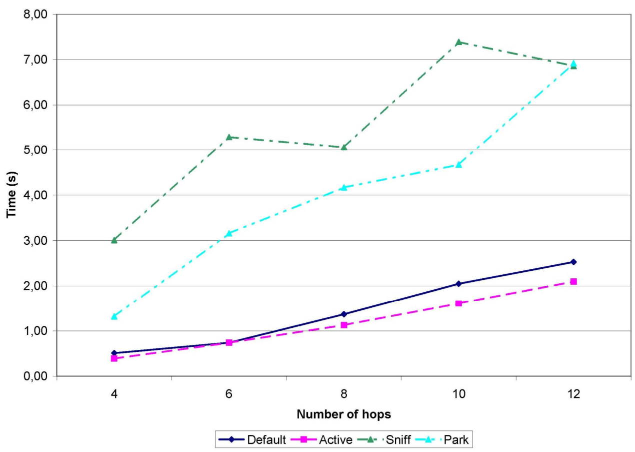

Figure 6. Overall time delay from end to end as a function of the number of hops and the link policy in each node

VI. CONCLUSIONS

These are the main conclusions derived from these steps of the research authors are in.

- Within medium distances, from 6 to 24 meters, the overall time delay keeps nearly constant.
- The power each node gets from the other extreme of the wireless link, i.e., the RSSI reading in each node, is supposed to decrease when distance between wireless nodes increases. But this tendency is not as clear as expected, due to the inaccuracy of the RSSI reading itself [10].
- The power the master gets from its slave and the power this slave gets from this master are very similar. Most of the times, this second reading is bigger than the first one, i.e., the slave gets more power than the master.
- As shown in Figure 5, the differences between upward and downward time delays are not negligible, especially when working in park mode. In relative terms, these differences go from 5% (in sniff mode) to 73% (in park mode).
- When working in park mode, this big time difference lies on which node starts the unpark procedure. When the communication is downwards the procedure is started by the master immediately. When the communication is upwards it is requested by the slave, and this node waits until the master can start the unpark procedure [10].
- Moreover, there has been done an estimation for the time delay each communication hop adds to the overall time delay.
- These low values for time delay in this Bluetooth 2.0 wireless network allow some real time applications as, for example, those in the areas of avionics, domotics, health or industrial monitoring.

VII. FUTURE STEPS

The immediate next step to complete this research is to analyze the relationship of the power consumption of wireless nodes depending on the communication number of hops and the link policy each node has. Thus, there can be determined the trade-off between time delay and network energy consumption. The influence of the environment chosen for this wireless network, i.e., the corridor, can be analyzed repeating these experiments outdoors.

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REFERENCES

[1] J. Etxaniz and G. Aranguren, “Bluetooth 2.0 based wireless network testbed development”, in Proc. International Conference on Advances in Electronics and Microelectronics ENICS '08, Valencia (Spain), Sep. 2008, pp. 7-10, ISBN 978-0-7695-3370-4.

[2] J. Etxaniz, G. Aranguren and J. J. Gude, “Proposal of health care monitoring by wireless ad-hoc networking”, in Proc. 4th ITI - IEEE International Conference on Information & Communications Technology, ICICT 2006, Cairo (Egypt), Dec. 2006, pp. 31-40, ISBN 0-7803-9770-3.

[3] Tilak, S., Abu-Ghazaleh, N. B., and Heinzelman, W. 2002. “A taxonomy of wireless micro-sensor network models,” SIGMOBILE Mobile Computing and Communications Review 6, 2 (Apr. 2002), 28-36. DOI= http://doi.acm.org/10.1145/565702.565708

[4] J. Beutel, "Metrics for Sensor Network Platforms," in ACM Workshop on Real-World Wireless Sensor Networks (REALWSN), Uppsala, Sweden, June 2006..

[5] Bluegiga Technologies, www.bluegiga.com, 2010

[6] Cambridge Silicon Radio Ltd, www.csr.com, 2010

[7] J. Etxaniz and G. Aranguren, "Bluetooth based wireless network for patients’ monitoring", in Proc. International Conference on Telecommunications and Computer Networks, IADAT-tcn2004, Donostia, Dec. 2004, ISBN: 84-933971-1-3

[8] D.E. Newland, An introduction to random vibrations and spectral analysis, Longman Group Limited, 1975

[9] J. Etxaniz and G. Aranguren, “Delay time analysis in Bluetooth 2.0 wireless networks”, in Proc. 8th International Conference on computing, Communications and Control Technologies, CCCT 2010, Orlando, Florida (USA), Apr. 2010

[10] Bluetooth SIG, www.bluetooth.org, 2010