Comparison study of ZigBee and Bluetooth with regards to power consumption, packet-error-rate and distance

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***Abstract*—This paper present a empirical measurement comparison study of ZigBee and Bluetooth. The parameters investigated are power consumption, packet-error-rate or retransmissions and distance in different environments. This study shows the differences and similarities for the two different short range radio technologies.**

A measurement set-up and procedure that makes it possible to investigate power consumption of the radio module, retransmissions and packet-error-rate as well as ambient noise is presented. For both the Bluetooth and the ZigBee modules used in this study the distance itself have no influence of the power consumption. However the retransmission rate and packet-error-rate have a large influence on the power consumption. This study have show that the environment has a great impact on the range of the radio modules and the behaviour concerning the retransmission rate and packet-error-rate.

***Index Terms*—Distance, environmental, Wireless Sensor Network, Radio models, Power consumption, Bluetooth**

I. Introduction

This paper presents a comparison of the wireless communication standards Zigbee and Bluetooth 2.0 with regards to energy consumption and packet-error-rate and as well a measurement procedure to determine these parameters.

How distance affects the energy consumption is an issue concerning energy consumption for 2.4 GHz based radios. Heinzelman *et. al* refers to both the free space propagation model and multi-path fading when presenting the LEACH energy model to describe the relation between distance and energy consumption in [1]. Whereas Macii *et. al.* states that the increased energy consumption depending of distance or transmission power can be neglected when transmitting in tens of meters in [2].

Lee *et. al.* has in [] conducted a broad comparitive study of Bluetooth, ulra wide-band (UWB), ZigBee and Wi-Fi with regards to their transmission time, data coding efficiency, and power consumption. In [], Siekkinen *et. al.* investigates Bluetooth Low Energy with regards of power consumption and compares it to Zigbee. The power consumption for Bluetooth modules has been investigated by Negri *et. al.* in [3] and Ekström *et. al.* in [4].

Hajian *et. el.* states that one of the main sources of energy waste are retransmission due to injury in [5]. This study aim to investigate how much distance influence the retransmissions in terms of energy consumption as well as the additional time each retransmission will cause.

A embedded real-time measurements system with wireless sensor network capabilities will be used to measure the energy consumption and the time parameters required to transmit or receive the different data packets described in Section VI. The measurement system will presented in Section IV.

The aim of this study is to present a comparison between Zigbee and Bluetooth energy consumption based on hardware measurements. A measurement procedure is presented to enable comparison of various short range radio technologies in different environments. This paper presents the behaviour of a Bluetooth radio version 2.0 + enhanced data rate (EDR) and a Telegesis ZigBee module depending on the transmission distance and environmental settings. A better understanding of how these parameters effects the packet-error-rate or retransmissions and the overall energy consumption for the radio can simplify the implementations of wireless systems in real life applications.

II. Bluetooth basics

The Bluetooth system provides point-to-point connection or point-to-multipoint connections as described in [6]. Two or more devices sharing the same physical channel form an adhoc network or piconet. With one device acting as a master, up to seven other devices or slaves can be actively operating in the piconet. All devices in the piconet are synchronized to a common clock reference and frequency hop pattern, provided by the master. Bluetooth devices may operate in two or more overlapping piconets creating what is referred to as a scatternet. Figure 1 shows the network topology for a scatternet consisting of five separate piconets. A device can act as a master in one piconet and a slave in another or have duplicate slave roles for two different piconets. A single device may not operate as a master in more than one piconet as this would imply synchronization between the separate piconets, however a slave may act as slaves for two different piconets.

As stated in the Bluetooth specification version 2 + EDR each piconet is required to operate independently using a distinct hop pattern and master clock. Bluetooth is a technology that is suitable for short range, up to around 100 meters when using Class 1 modules, wireless sensor network applications

Fig. 1. Wireless Sensor Network Using Bluetooth

were low power consumption is important, and where it at the same time is able to support relatively high data transfer rates up to 3 Mbit/s [7].

For class 1 devices it is mandotary to implement a power control scheme for transmission power over 4 dBm. The scheme contains a radio power table with discrete tranmission power levels. If a receiving device received signal strength is to low or to high it sends a request to the device it communicates with to increase or decrease its transmission power one step in the power table.

Bluetooth utilizes frequency hopping on 79 channels 1 MHz wide in 2.45 GHz band. The hop rate is 1600 hops per second. Devices has the possibility to use an adopted frequency hopping pattern where occupied freqeuncies may be excluded.

A. *Sniff mode*

Being a technology optimized for portable devices with constrained power resources, Bluetooth offers various power saving modes which are used to reduce the duty cycle of devices: hold, park and sniff mode. In this study the Sniff mode has been used for its low energy and wireless sensor network capabilities. The basic idea of sniff mode is to reduce the duty cycle on a link between two devices by negotiating specific slots (sniff slots) where communication between devices can begin. If no communication takes place at these slots, the devices may spend the time until the next sniff slot in a low power mode. In case of communication activity, the communication period (sniff event) can be extended dynamically until one of the devices decides to end the communication. The other device aborts the communication if it does not receive anything on the link for a configurable amount of slots. In fact, this behaviour is specified only for the slave. However, if a master does not receive anything from a slave for some time (*e.g.* due to transmission errors), it has to assume that the slave has already gone back to low power state.

The sniff slots are determined by the user who is able to change the interval between the start of each sniff event or sniff peak. The interval setting is given in number of time slots. Each time slot is 625 μseconds long. Each sniff peak in this study is able to allow 1 to 5 attempts to transmit and/or receive data. These settings can be determined by the user to adapt the radio for the specific application.

III. ZIGBEE BASICS

ZigBee is a standard based technology, not a standard itself, aimed towards low-cost, low-power sensor- and control networks. The specification aim for easy implementation and self-organizing networks. The ZigBee Alliance has developed the ZigBee specification since 2002 is aimed to enhance the IEEE 802.15.4 standard by adding network, security layers and a application framework. ZigBee is build upon the PHY and MAC as it defined in the IEEE Standard 802.15.4 in 2003 [8]. The main characteristics for the ZigBee specification is:

- ZigBee uses **DSSS** and **OQPSK** with carrier sense multiple access with collision avoidance in 1 channel in 868 MHz (Europe), 10 channels in the 915MHz band (USA and Australia) and 16 channels in the 2.4GHz ISM band according to IEEE 802.15.4 [9].
- **Power saving mechanisms** for all device classes
- **Security key generation mechanism** and utilizes industry standard AES-128 security scheme
- Zigbee network layer supports multiple **Star topology**, **Tree** and generic **Mesh** networks.

IV. MEASUREMENT SYSTEM

The four main parts off the measurement system for this study are;

1) Embedded energy measurement system with interchangeable radio modules
2) Wireless sensor network controller
3) Measurement system for investigate the ambient radio activity
4) Packet sniffer that enable us to listen in and record the radio communication

These parts will be described in detail in the following sections.

A. *Embedded energy measurement system*

An embedded energy measurement system has been developed to measure the energy characteristics in real-time on each sensor node while operating in the sensor network. The POMPOM platform used is a programmable testbed with embedded *in situ* micro power meter. The most significant difference compared to other systems is that POMPOM is a programmable testbed with interchangeable radio modules. This implies that the energy consumption can be compared for different radio modules that implement the same radio standard.

The POMPOM platform is shown in Figure 2 .

The specification of the POMPOM platform is:

- Interchangeable radio modules, the same hardware testbed independent of what radio standard is used to be able perform comparison studies.
- Programmable, the need for hardware development when changing radio technology is minimized.
- The testbed can act as a controller for the communication and simultaneous make accurate *in situ* measurements of the energy consumption of the radio.

Fig. 2. POMPOM platform with interchangeable radio module

- The testbed is able to perform both integrating long term measurements of the energy consumption as well as be able to capture high resolution period measurements with high sample frequency.
- The sample rate is set to 50kSamples per second.
- The range of the current measurement is 0.5 μA to 150 mA
- The mobility of POMPOM enables deployment several measurement testbeds to act as distributed sensor nodes in a wireless sensor network to capture the behavior of the whole network.

In this study the Mitsumi WML-C40 class 1 module was used [10]. The module uses a radio power table I to choose the appropriate transmission power for the the radio link.

TABLE I
RADIO POWER TABLE BLUETOOTH

Basic Internal Power Amplifier	Transmission Preamplifier	Transmission Power [dBm]
7	68	-5
14	71	0
24	75	5
34	78	10

The ZigBee module used for this study is the Telegesis ETRX357. With an maximuim transmit power of 18 dBm and sensitivity of -99 dBm. The module has a maximum data rate of 250kbit/s over the air [11].

B. Network Control

To be able utilize the Bluetooth wireless sensor network capabilities the Network Control has been developed to act as both data acquisition system (DAQ) and to control the network. The software has been developed in LabWindows CVI [12]. The Network Control allows the user to setup a wireless sensor network and monitor the energy consumption for all sensor nodes. This means that the wireless sensor network capabilities are used to create the measurements needed to understand the behavior for the Bluetooth radio in different environmental settings. The advantages are that the power consumption and time characteristics can be recorded for several nodes simultaneously *e.g.* both a master's and a slave's power consumption can be recorded while the master is transmitting a packet to a slave

C. Ambient radio level measurements

To investigate the surrounding ambient radio activity in the 2.4 to 2.5 GHz frequency band a frequency spectrum analyzer was used. Maximum hold measurements with peak detector were used to detect interference sources. The resolution band-witdh was 1 MHz and the video bandwidth was 10 MHz. The sweep time was 2.5 ms with 501 measurement points distributedfrom 2.4 GHz to 2.5 GHz.

D. Packet sniffer

The FTS4BT™ Bluetooth® Protocol Analyzer and Packet Sniffer enables the user to monitor and trace the Bluetooth radio communication [13]. The Bluetooth sniffer makes it possible to trace any retransmissions or lost packets. The SmartRF Protocol Packet Sniffer [**?**] is used to overview the ZigBee communication.

V. ENVIRONMENTS

The investigated environments ranges from indoors, outdoors in urban environment and outdoors on grass field. The indoor measurements were performed in two different corridors in an office space with multiple WLAN routers. The first corridor is approximate 4.5 m wide and 76 meters long and is shown in Figure 3. The second Corridor is approximate 9 meters wide and 135 meters long, this is depicted in figure 4 The grass field used is a three consecutive soccer fields with a total length of 320 meters, this is depicted in Figure 5 The urban outdoor environments used for the measurement setup is shown in Figure 6.

Fig. 3. Test environment corridor 1

VI. EXPERIMENTAL SETUP

This section will present the most important part of the experimental setup, including the parameters that influence the measurements, the environmental differences for the various setups, what parameters that will be measured and the ambient radio levels.

Fig. 4. Test environment corridor 2

Fig. 5. Test environment soccer field

1) Radio settings: In this study the low power mode sniff will be used for the Bluetooth module. The different settings that will have an effect on the overall power consumption of the radio are *Interval*, *Role* and *Number of attempts*. The interval used is 800 time slots, corresponding 500 ms between the start of the sniff peaks. The number of attempts is set to five for each sniff peak. The role will be set to Master in this point-to-point setup. The role for the ZigBee radio is set to mobile end device (MED) and transmission interval is set to 500ms.

A. Parameters

During the experiment there are two parameters that influence the measurements and will the altered throughout the experiment. These are as follows.

Fig. 6. Urban test environment

1) Distance: The distance will range from 1 meter to the maximum distance that the environment or radio allows.

2) Payload: The payload will vary from 10, 30 and 60 bytes. The header for the payload is determined by the firmware on the Mitsumi and Telegesis module described in IV-A.

B. Measured parameters

- Ambient radio levels
- Power and time characteristics for transmission
- Distance of transmission

VII. Experimental Results

The follow section will present the results for the different measurements described in VI for all environments presented in V. The ambient noise, packet-error-rate, average power consumption and distance of transmission for the Telegesis ETRX357 ZigBee and Mitsumi WML-C40 Bluetooth module are presented in the following sections.

The transmission peak in power consumption for Telegesis ETRX357 ZigBee and Mitsumi WML-C40 Bluetooth modules are presented in Figure 7 and Figure 8.

A. Corridor 1

In this section the measurement results for Corridor 1 is presented. In Figure 9 the power consumption for the Mitsumi Bluetooth module is presented as a function of retransmissions.

In Figure 10 the power consumption for the Telegesis ETRX357 ZigBee and the Mitsumi WML-c40 Bluetooth module is presented as a function of distance. In Figure 11 the result for the ambient interference spectrum in corridor 1 measurements are presented.

Fig. 7. Power consumption during a transmission peak for the Telegesis ETRX357 ZigBee module

Fig. 8. Power consumption during a transmission peak for the Mitsumi WML-C40 Bluetooth module

Fig. 9. Average power consumption as a function of retransmission for a the Mitsumi Bluetooth module in corridor 1

Fig. 10. Power consumption as a function of distance for ZigBee and Bluetooth module in corridor 1

Fig. 11. Ambient interference spectrum in corridor 2

B. Corridor 2

In this section the measurement results for Corridor 2 is presented. The average power consumption for the In Figure 14 the ambient interference in corridor 2 is presented.

In Figure 14 the result for the ambient interference spectrum in 2.4-2.5 GHz measurements are presented.

C. Outdoors

The average power consumption depending on packet-error-rate and distance is presented in this section for the Telegsis ETRX357 ZigBee module.

VIII. Conclusion

In Figure 9 and Figure 13 the measurements show that the power consumption for the Bluetooth module increases when the retransmission rate is higher than 13 %. The amount of increment of the power consumption for the Bluetooth module differs for the two different environments. Comparing the power consumption for the Bluetooth module in Figure 10 and in Figure 12 the peaks at 30m in Corridor 1 and the peaks in Corridor 2 at 40m and 75 correlates directly to

Fig. 12. Power consumption as a function of distance for ZigBee and Bluetooth module in corridor 2

Fig. 13. Average power consumption as a function of retransmission for a the Bluetooth module in corridor 2

Fig. 14. Ambient interference spectrum in corridor 2

Fig. 15. Packet-error-rate as a function of distance for ZigBee module in soccer field and urban outdoors environment

Fig. 16. The average power consumtpion as a function of packet-error-rate for a ZigBee module in soccer field and urban outdoors environment

increased retransmission rate. The indoors measurements for the ZigBee module resulted in that no packet-errors were detected. This means that the there is no change in power consumption due to distance for the ZigBee module. The ambient noise interference for both corridors is similar with a spectrum analysis that could be explained with the WLAN traffic. The outdoor measurements for the Zigbee module show that the maximum range differs for the different environments as shown in Figure 15. The open soccer field has a maximum of 145 meters whereas the urban environment has a range of 170 meters. The influence of the distance of the packet-error-rate has a comparable behavior for both environments where the PER increase rapidly near the end of the range a reaches near zero just at the end of the range. In Figure 16 the relation of increase of power consumption due to the packet-error-rate is shown. The increase of power consumptionof the ZigBee module is similar for both in both environments in contrast to the Bluetooth module in the indoor measurements. For both Bluetooth and ZigBee modules in this study the distance itself have no influence of the power consumption. However the retransmission rate and packet-error-rate have a large influence on the power consumption. This study have shown that the environments have a great impact on the range of the radio modules and the behaviour concerning the retransmission rate and packet-error-rate.

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