ANNUAL JOURNAL OF ELECTRONICS, 2011, ISSN 1313-1842

Evaluation of Zigbee-based Body Sensor Networks

Mitko Petrov Shopov, Galidiya Ivanova Petrova, Grisha Valentinov Spasov

Abstract – **The paper presents a testbed configuration for evaluation of performance parameters of a zigbee-based body sensor network operating in ISM 2,4GHz radio frequency band. Both stand-alone and co-existence scenarios are included in experiments. Since security is an important characteristic of body sensor networks, both encrypted and non-encrypted traffic were used in evaluation. The parameters under study are packet delay, packet delay variation, and packet loss.**

Keywords – **Body sensor networks, Zigbee, IEEE802.15.4.**

I. INTRODUCTION

Body sensor networks are one of the key components of the new and emerging personal healthcare systems. They are formed by low-power wireless devices placed on or around the human body and should enable new healthcare and wellness applications, by allowing humans and healthcare professionals to access more accurate data obtained through continuous monitoring of physiological parameters, under natural activities and environment [1].

The increasing number of application for continuously monitoring of human physiological parameters through wireless sensor networks and Internet services has led to new research efforts in the healthcare domain. While body sensor networks share common functional architecture, the difference in their operational parameters puts new research challenges such as energy efficiency, local storage and processing, wireless communication, device integration and interoperability, security [2], [3], [4].

Communication plays essential role to node coordination. Body sensor networks (BSN) are characterized by limited transmission radius restricted to body's periphery. Both standard and non-standard communication protocols exist. Standard protocols are preferred because of integration issues within products of different vendors. Among standard communication protocols Personal Area Networks (IEEE 802.15) more closely cover the specific requirements of BSN and wherever energy efficiency is prioritized ZigBee (IEEE 802.15.4) is the most prospective candidate [4], [5], [6].

Quality of Service (QoS) is a fundamental factor to achieve reliable and timely data delivery in healthcare applications. Primary QoS parameters are packet loss, delay, delay variation (jitter), availability and security. Another factor that could considerably influence the performance of BSN is the co-existence with other wireless networks. While in some application scenarios like bed-side monitors in hospitals and clinics it could be ensured a controlled and well planed environment. In contrast scenarios like home/office BSN gateways and personal mobile monitors it could be expected that commonly a BSN will co-exist with a Wireless LAN network. It could be a typical for the user to watch video streams and download files over the Internet [7], [8].

In this paper a testbed experiments for evaluation of packet loss, packet delay, and delay variation of Zigbee-based body sensor networks is proposed. The testbed consists of an embedded gateway, a set of wireless sensors, and a script-based framework for rapid prototyping and applications development.

II. TESTBED ARCHITECTURE AND SETUP

The testbed environment used in experiments consists of several Zigbee modules, gateway, packet capturer, WLAN router, mobile station, and a measuring and control station (figure 1). Each Zigbee modules consist of an RS232/USB interface board and an Xbee radio module [9]. Xbee radio modules are compliant with IEEE 802.15.4 and Zigbee standards and operate in ISM 2.4 GHz radio frequency band. Their key features include: up to 30m indoor communication; 0dBm transmit power; -92dB receive sensitivity; up to 250kbps data rate; supports retries, acknowledgments, 16 and 64 bits addressing; transparent and API modes of operation; 128 bits AES encryption.

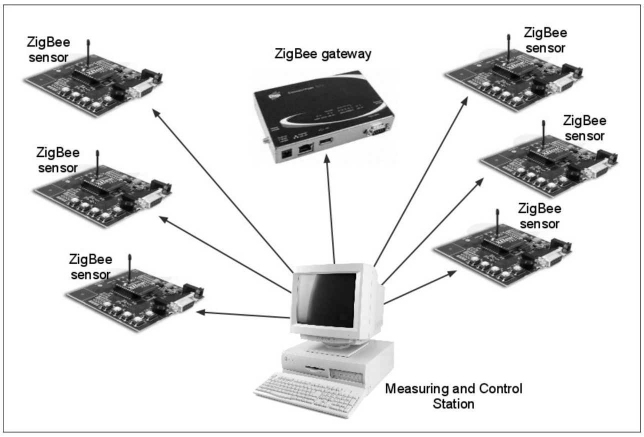


FIG 1. TESTBED CONFIGURATION

The Zigbee gateway used is ConnectPort X4 [9]. It offers Ethernet, Zigbee, WiFi communication interfaces and USB/RS232 serial interfaces. It can be configured to route and filter the traffic between different networks. In the experiments taken out the ConnectPort X4 is used as a Zigbee coordinator and data collector. The X4 gateway

M. Shopov is with the Department of Electronics, Faculty of Electronics and Automation, Technical University of Sofia, Plovdiv branch, 61 St. Petersburg blvd., 4000 Plovdiv, Bulgaria, e-mail: mshopov@tu-plovdiv.bg

G. Petrova is with the Department of Electronics, Faculty of Electronics and Automation, Technical University of Sofia, Plovdiv branch, 61 St. Petersburg blvd., 4000 Plovdiv, Bulgaria, e-mail: gip@tu-plovdiv.bg

G. Spasov is with Department of Computer Systems and Technologies, Faculty of Electronics and Automatics, Technical University – Sofia, branch Plovdiv, 61 Sankt Petersburg Blvd., 4000 Plovdiv, e-mail: gvs@tu-plovdiv.bg

comes with a custom version of operating system and a python-based framework iDigi Dia (Device Integration Application) [9].

Dia framework provides the core libraries and functions for remote device data acquisition, control and presentation between devices and information systems. Its functionality is distributed in three layers as shown on figure 2. The function of device layer is to provide connectors that extract real-world data, represent it as a set of properties and publish them to the appropriate channel on the next layer. Channel layer provides and manages publish-subscribe infrastructure that gives ability to create, remove, and publish to a channel, read from channel and subscribe for channel changes. Presentation layer provides the interface with the outside world. It could be as simple, as a telnet connection or a form of web service interface and even device cloud integration [9].

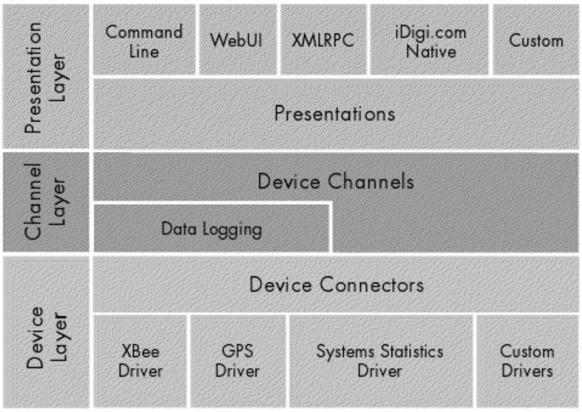


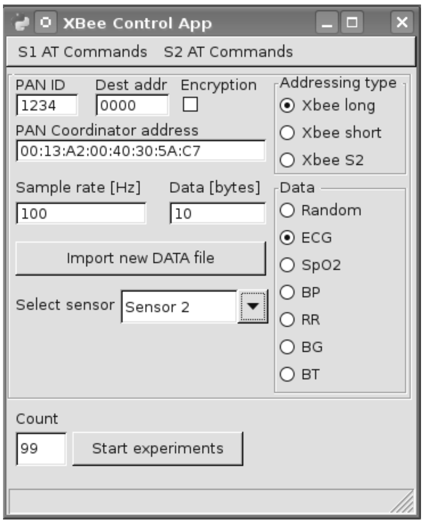
Fig 2. iDigi Dia functional blocks [9]

For more control over the experiments a packet capture was introduced. The packet capturer used is based on the SmartRF protocol packet sniffer [TI]. It utilizes a hardware component consisting of one SmartRF05 evaluation board and one CC2520EM radio module [10].

A wireless router and a mobile station are also used in the experiments as a source of interference. The router was configured to use a frequency channel that closely matches the frequency channel used by the Zigbee coordinator. Two different traffic loads were used in experiments: a video stream (www.youtube.com) and transfer of files through FTP protocol.

The measuring and control station is directly connected to Zigbee modules and the gateway through serial connection. The advantage of using a single computer for the measurements of time-related parameters is that there is no need for clock synchronization. For the purpose of test-bed experiments a python-based application has been developed (figure 3). The application is used to set the network parameters of each Zigbee module and to configure the protocol for generation of data traffic to follow the pattern of real medical sensors.

The packet propagation delay is measured through the C function *clock_gettime()* that is part of the Linux *libc* library. The function returns the time since the Epoch and provides a nanosecond resolution. The propagation delay is calculated by subtracting the time the whole packet is received in the gateway from the time first byte is sent to the zigbee sensor.



PAN ID 1234
Dest addr 0000
Encryption ☐
PAN Coordinator address 00:13:A2:00:40:30:5A:C7
Addressing type
● Xbee long
○ Xbee short
○ Xbee S2
Sample rate [Hz] 100
Data [bytes] 10
Data
○ Random
● ECG
○ SpO2
○ BP
○ RR
○ BG
○ BT
Select sensor Sensor 2
Count 99

Fig 3. Testbed configuration software

III. Experimental analysis and Results

Evaluation of the zigbee-based BSN includes measuring the packet transmission delay, packet delay variation (PDV), and packet loss ratio. Six experiments are selected and each of them is executed a hundred times in relatively high intervals, for providing good statistical results for approximations. The six groups of experiments are selected as the most indicative for the performance of BSN. The short labels used as a reference in the graphics together with a short description of the experiment are included in table 1. All experiments are conducted in a single room with a maximum distance between transceivers of 5 meters. The maximum transmit power for Xbee modules was used (+10dBm). In the scenarios with encryption of zigbee traffic 128 bits Advanced Encryption Standard (AES) symmetric encryption algorithm was used.

Table 1. Experiments description and Packet loss results

Label	***Description***	***Packet loss***
- / -	No interference from external sources / No encryption applied	0 %
- / AES	No interference from external sources / AES encryption	0 %
Video / -	Interference from IEEE802.11g station playing video stream / No encryption	4 %
Video / AES	Interference from IEEE802.11g station playing video stream / AES encryption	5 %
SFTP / -	Interference from IEEE802.11g station transferring over sFTP / No encryption	32 %
SFTP / AES	Interference from IEEE802.11g station transferring over sFTP / AES encryption	37 %

For the measurements of packet loss ratio all zigbee level retransmissions are turned off, excluding the IEEE 802.15.4 MAC layer retransmissions that are always on. In the experiment ten thousands packets were sent. The obtained results are included in table 1. When the zigbee level retransmissions are turn on (three retransmissions multiplied by the number of MAC retransmissions), the packet loss decrease to less than 0.01%.

The calculated average packet delay for the six groups of experiment groups are given on figure 4. The graphic includes the dispersion of the values as a min-max range. The results …

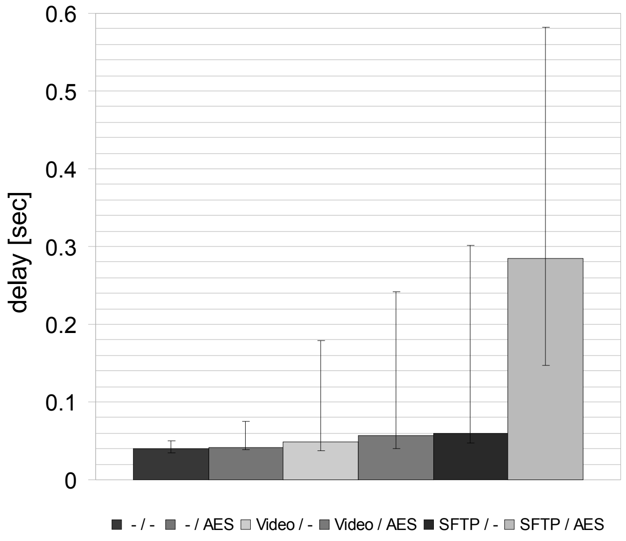


FIG 4. AVERAGE PACKET DELAY

To calculate the packet delay variation (PDV) [11] for each packet, the minimum delay has been selected as a reference value. A one-way PDV has been selected and the lost packets are excluded from calculation. The possible errors and uncertainties that affect the measurements are the same as those for one-way delay measurement: errors/uncertainties from clock synchronization and errors/uncertainties due to difference between 'wire-time' and 'host-time'. The first one is eliminated (or at least limited in reasonable range) by using a single station for control and measurements. The second one has two components: a constant and a variable. Only the variable component could introduce errors in measurements of PDV since the constant one is canceled in calculations. However, it is difficult to estimate and eliminated the variable component. The average, minimum, and maximum values of this component is presented in table 2. Histograms of the results from calculation of one-way PDV for three of the scenarios are presented on figures 5, 6, and 7. It is visible that the packet delay variations are in high relation with the traffic load and co-existent networks. It should be taken into account for applications where real-time requirements are important.

TABLE 2. ERRORS/UNCERTAINTIES FROM PC UART PORT

PC RS232 port (baud rate 115200), 20 bytes	
Average	137.641 us
Minimum	222.921 us
Maximum	111.342 us

IV. CONCLUSION

The results from the evaluation of a zigbee-based body sensor network shows that in stand-alone scenarios the time related and packet loss parameters are in acceptable range. In a co-existence scenario and especially with extremely high traffic loads the interference causes a high degradation of the BSN performance. The activation of retransmission can significantly reduce packets loss, but for the price of increased delay. The packet delay variation is also in a high relation with the traffic load in co-existent networks. Therefore, it could be concluded that in a scenarios where it is possible to observe a high level of interference from external sources in the same radio frequency band BSN are not yet capable to support applications with highly constrained real-time requirements. However, body sensor networks are still capable of monitoring human physiological parameters where acceptable delay and delay variation are not so constrained or could be resolved by on-sensor buffering.

V. ACKNOWLEDGMENTS

The presented work is supported by Technical University of Sofia, project "102ПД078-19/2010" - entitled "Experimental environment for analysis of protocols and processes within web-based multi-tier personal health-care systems".

References

[1] M. Hadjiiski. "*Perspectives of sensors and sensor systems*", Journal of Automation and Information, no 1, pp. 13-15, 2010, ISSN: 0861-7562.

[2] M. Hanson, et. al. "*Body Area Sensor Networks: Challenges and Opportunities*", IEEE Computer Magazine, pp. 58-65, 2009.

[3] B. Lo and G. Yang. "*Body Sensor Networks – Research challenges and opportunities*", IET Seminar on Antennas and Propagation for Body-Centric Wireless Communications, pp 26-32, 24 April 2007.

[4] M. Shopov. "*Body sensor networks – research challenges*", Journal of Automation and Information, no 2, pp. 45-49, 2010, ISSN: 0861-7562.

[5] R. Istepanian R., E. Jovanov, and Y. Zhang. "*Beyond Seamless Mobility and Global Wireless Health-Care Connectivity*", IEEE Transactions on Information Technology in Biomedicine, vol. 8, no. 4, pp. 405-441, Dec. 2004.

[6] V. Shnayder, et.al. "*Sensor Networks for Medical Care*", Technical Report TR-08-05, Harvard University, 2005.

[7] A. Sikora, V. Groza. *"Coexistence of IEEE802.15.4 with other Systems in the 2.4 GHz-ISM-Band"*, Proc. of IEEE Instrumentation and measurements, pp. 1786-1791, May 2005.

[8] J. Delsing, J. Eliasson, and V. Leijon. *"Latency and Packet Loss of an Interferred 802.15.4 Channel in an Industrial Environment*", Proc. of IEEE Sensor Technologies and Applications (SENSORCOMM '10), pp. 33-38, 2010.

[9] http://www.idigi.com

[10] http://www.ti.com

[11] http://www.ietf.org/rfc/rfc3393.txt

[12] http://dsnet.tu-plovdiv.bg

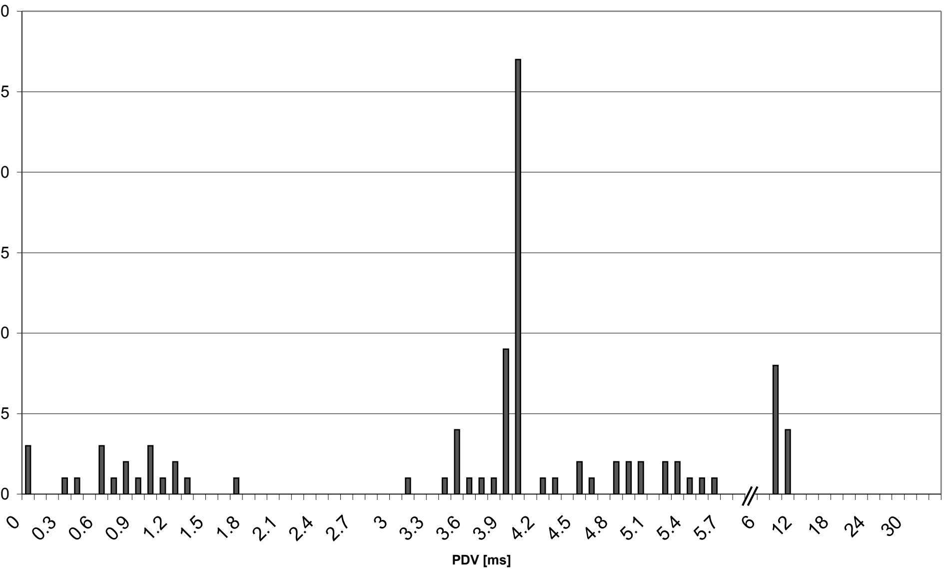


Fig 5. Histogram of PDV for -/AES

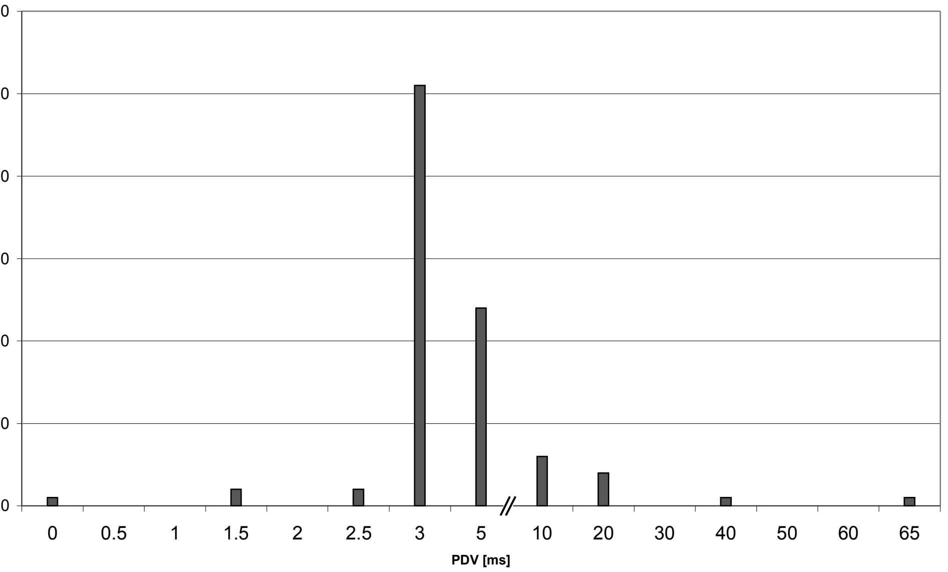


Fig 6. Histogram of PDV for Video/AES

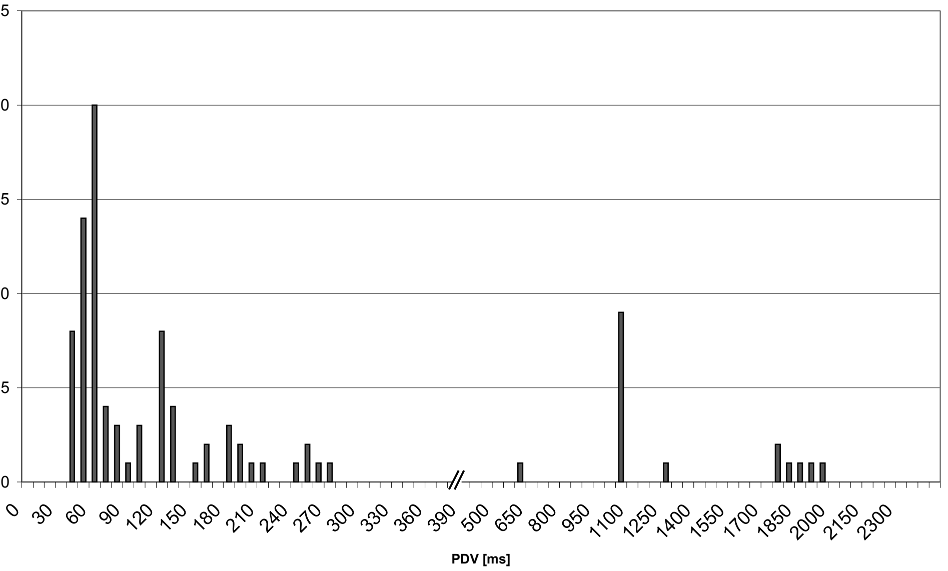


Fig 7. Histogram of PDV for sFTP/AES