

Experimental Testing of Wireless Sensors Network Functionality

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Abstract Paper deals with wireless communication networks. Goal is to describe the most commonly used wireless protocols and test their reliability, range and coexistence with others wireless protocol, especially WiFi. The biggest problem in sensor networks using wireless networks PAN (e.g. IEEE 802.15.4, ZigBee, ZWave ...) is their range, especially in an urban area. In most cases it is very difficult to achieve distance stated by the manufacturer in the technical specification. XBee platform has been tested on common building where monitored variables are number of sent packets, number of received and lost packets and lost ratio for different distance from server and several time differences between sending messages from server.

Keywords: wireless sensor network, reliability, XBee, indoor testing

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1. Introduction

The advantages of a wireless sensors network take effect in their implementation especially in older buildings. During the design of majority older buildings the realisation of system for physical parameters measuring such as temperature, humidity, intensity of lighting was not assumed. So the introduction of such a wireless system in older building will not require construction work, thereby substantially reduce the cost of its implementation.

Being reliable and real-time are the two most challenging requirements of wireless sensor network (WSN) technology. As IEEE 802.15.4 has relatively short range and low bandwidth, but is widespread in home automation it poses a significant limitation in application of WSN in bigger old buildings. Performance of WSN should be evaluated for every implementation of WSN in older building. Depending on the operating environment, significant signal loss can occur, particularly when the radios require line-of-sight for optimal performance, with 2.4 GHz more susceptible than 900 MHz. Among the different performance parameters, the packet lost ratio should be evaluated for any application.

Our goal was to describe the most commonly used wireless protocols and test their reliability, range and coexistence with others protocols.

Verification of a range for different communication protocols based on XBee platform and their coexistence with other wireless protocols (especially WiFi) implemented in three stored house was realised [1].

2. Methods

IEEE 802.15.4 is included in group of standards LR WPAN (Low rate - Wireless Personal Area Network). These networks are designed to transmit data over short distances. Unlike conventional WLANs (e.g. WiFi), WPAN networks have simple infrastructure, hence are suitable for cheap and effective solution with low power consumption. IEEE 802.15.4 defines two layers - physical and MAC sublayer (Medium Access Control) for low power and short distances (typically up to 10 m). Standard supports multiple frequencies for its operation.

Communication based on this standard consists of two types of devices FFD (Full-function device) and RFD (reduced-function device). FFD is capable communicate as coordinator of PAN (Personal Area Network). PAN coordinator is the main elements of the network that initiates and sets up networks. RFD is a device that is designed as a terminal and communicates only with one superior FFD device. RFD devices send only small amounts of data to have the requirements for energy as small as possible, and they can be long term supplied by the battery [2].

Depending on the needs of different applications, the standard offers two types of topologies: star and peer-to-peer topology with mesh support. In the standard there are three types of transmissions. The mechanism for each type of transmission depends on whether the network supports a beacon frames and super frames, i.e. networks, where synchronization is required or networks where fast response is required. The first type of transmission is to the coordinator from device, where the device is sending data and coordinator receiving data. The second type of transmission is from the coordinator to the device. The third type of transmission is peer-to-peer network where each device communicates with each device in an accessible range [2]. Technologies based on IEEE

802.15.4 operate in a non licensed ISM band (Industrial Scientific and Medical).

XBee from Digi International offers several models to support the ZigBee protocol and its XBee protocol on open ISM band 868 MHz, 2.4 GHz and 900 MHz. Communication chips are divided into two main categories: Standard and PRO. Chips marked as PRO have higher transmission power and are also larger in size.

XBee 802.15.4 These modules use a standard implementation of the IEEE 802.15.4 protocol. They are produced in two versions XBee 802.15.4 and 802.15.4 XBee PRO. The speed of modules is 250 kbps and operate in an open 2.4 GHz ISM band. They support point-to-multipoint or peer-to-peer communication. Chip has no support for mesh networking. XBee 802.15.4 IEEE are mainly used as terminal devices for different areas, especially for home and building automation and industry. Their main advantage is low cost and power of 1 mW with range of 100 meters. PRO version range is 1.6 km with direct visibility, but also much more power (60 mW). [3], [4].

XBee ZB Radio communication chip, which has an implementation of an open Zigbee protocol. The baud rate is 250 kbps. Support type of communication is mesh, point-to-point, point-to-multipoint and repeater. Open transmission operates in the 2.4 GHz band, 2 mW power and reach of 120 meters. In the PRO version has power of 50 mW and range 1.6 km. This communication chip advantage is that the ZigBee protocol is included in, and is compatible with equipment from other manufacturers operated with Zigbee protocol.

XBee Pro 868 The radio module for wireless communication with a long range. XBee PRO 868 OEM RF module operates in the 868 MHz ISM band, with better RF signal propagation, for example, in urban areas. Larger transmission distances can be achieved thanks to higher radiated power compared to modules, operating in the 2.4 GHz band. Radiated power can be adjusted. The current version supports peer-to-peer, point-to-point and point-to-multipoint topology. Typical areas of application are telemetry, monitoring and industrial control systems and data acquisition systems. Transmission speed is 24 kbps. The outdoor range with line sight is up to 40 km and at built-up area 550 m. Adjustable transmitting power is up to 500 mW. [4]

XBee WiFi On-chip is implemented communication network protocol WiFi – standard IEEE 802.11. The modules can easily communicate with existing 802.11 infrastructures, with security WPAPSK or WPA2PSK. Supported standards are 802.11a /b/g /n. Modules provide 10 digital input/output lines, 4 analogue inputs and during standby mode their consumption is only 2uA. The main applications are sensor networks, automation of processes, buildings and household energy management.

2.1. Testing

We evaluated the working range of sensor network in a common older building. Testing was realised by queries randomly selected for a particular pin of each tested device from a static server location. Server was placed on 1st floor in an edge room with balcony, marked with black dot at Figure 2. We created a single application for testing (Figure 1).

During testing were monitored variables as follows:

- number of sent packets - in each test for each device it was sent 1000 reports,
 - number of received packets – answers,
 - the number of lost packets - the difference between the sent and received messages,
 - lost ratio - the ratio of lost and outgoing messages.
- Parameters for test performing were:
- distance from the server,
 - time difference between sending messages from the server: 0.3s, 0.15s, 0.1s, 0.05s, 0.03s, 0.025s.

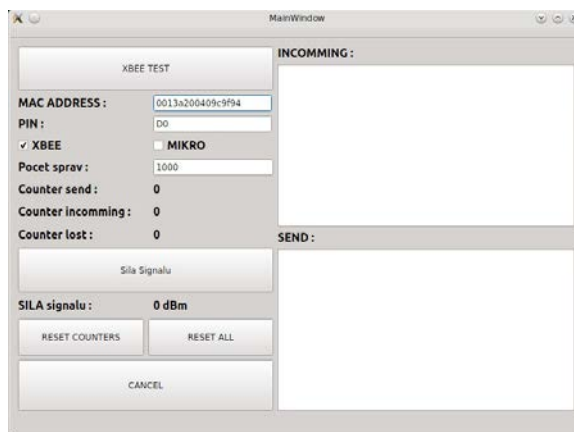


Figure 1. Testing application

Testing was done with chips:

- XBee IEEE 802.15.4
- Digi XBeePRO 868
- XBee DigiMesh 2.4
- XBee DigiMesh 2.4 PRO
- XBee ZB

Figure 2, Figure 3 and Figure 4 describe floor plans of individual rooms around the house. In the upper room is placed main server – black dot, from which were all tests of communication triggered. Red ring determines the location of the test units.



Figure 2. 1st floor plan



Figure 3. Ground floor plan

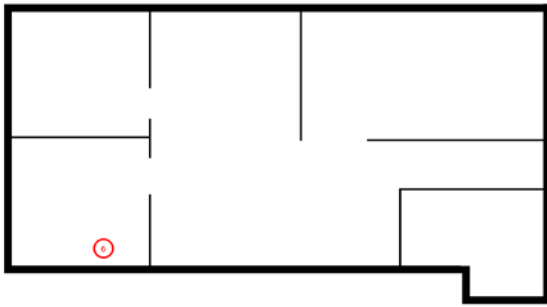


Figure 4. Plan of basement

2.1.1. Test XBee 802.15.4

Testing took place only with node number 1 because, it was not possible to reach with this device to another nodes placed further.

Table 1. Measurement Protocol for XBee IEEE 802.15.4 and compatibility with WiFi

Device XBee IEEE 802.15.4			
Measurement Protocol			
MAC Coordinator 0013a2004069822c		MAC- End device 0013a20040698219	
Delay	Received	% Packed lost ratio	
0,3	994	0,006	
0,15	995	0,005	
0,1	990	0,01	
0,05	899	0,101	
0,03	733	0,267	
0,025	620	0,38	
Compatibility between XBee 802.15.4 and WiFi			
Distance	Send packets	Received packets	% Packed lost ratio
0	1000	98	90,2
30	1000	150	85
70	1000	547	45,3
150	1000	993	0,7

This test shows that the IEEE 802.15.4 chips are suitable for use in the room. Communication to another room through the wall was impossible.

2.1.2. Test XBeePRO 868

Table 2. Measurement Protocol for XBeePRO 868

Device XBeePRO868				
Measurement Protocol				
MAC Coordinator 0013a20040670c72			MAC End device 0013a20040670be4	
End device placement -1			End device placement -2	
Delay	Received	% Packed lost ratio	Received	% Packed lost ratio
0,3	994	0,006	992	0,008
0,15	992	0,008	997	0,003
0,1	995	0,005	991	0,009
0,05	991	0,009	995	0,005
0,03	688	0,312	655	0,345
0,025	598	0,402	588	0,412
End device placement -3			End device placement -4	
Delay	Received	% Packed lost ratio	Received	% Packed lost ratio
0,3	997	0,003	992	0,008
0,15	992	0,008	996	0,004
0,1	995	0,005	991	0,009
0,05	993	0,007	990	0,010
0,03	647	0,353	628	0,372
0,025	530	0,470	520	0,480
End device placement -5			End device placement -6	
Delay	Received	% Packed lost ratio	Received	% Packed lost ratio
0,3	991	0,009	993	0,007
0,15	987	0,013	992	0,008
0,1	986	0,014	982	0,018
0,05	988	0,012	971	0,029
0,03	671	0,329	670	0,330
0,025	510	0,490	520	0,480
Compatibility between XBee PRO 868 and WiFi				
Distance	Send packets	Received packets	% Packed lost ratio	
0	1000	759	24,1	
30	1000	991	0,9	
70	1000	994	0,6	

XBeePRO had no problem to communicate with the most delayed node in building without the difference in packet lost from nearest to most farthest node.

Its disadvantage is high energy consumption, but its high transmission power is suitable for automation of bigger buildings or in industry, where more robust solution is necessary for bigger distances.

2.1.3. Test XBee DigiMesh 2.4

DigiMesh protocol is similar to the ZigBee protocol and is designed for the same applications - home and building automation and sensor networks. It is a proprietary (description of the implementation is not public)

Table 3. Measurement Protocol for XBee DigiMesh

Device XBee DigiMesh 2.4				
Measurement Protocol				
	MAC Coordinator 0013a20040b65e78		MAC End device 0013a20040b65e30	
	End device placement -1		End device placement -2	
Delay	Received	% Packed lost ratio	Received	% Packed lost ratio
0,3	992	0,008	987	0,013
0,15	991	0,009	984	0,016
0,1	992	0,008	962	0,038
0,05	991	0,009	846	0,154
0,03	740	0,260	715	0,285
0,025	612	0,388	611	0,389
Compatibility between XBee DigiMesh and WiFi				
Distance	Send packets	Received packets	% Packed lost ratio	
0	1000	236	76,4	
30	1000	992	0,8	
70	1000	995	0,5	

2.1.4. Test XBee DigiMesh 2.4 PRO

Table 4. Measurement Protocol for XBee PRO DigiMesh

Device XBee PRO DigiMesh				
Measurement Protocol				
	MAC Coordinator 0013a20040a6bdd9		MAC End device 0013a20040a6bddb	
	End device placement -1		End device placement -2	
Delay	Received	% Packed lost ratio	Received	% Packed lost ratio
0,3	993	0,007	991	0,009
0,15	994	0,006	994	0,006
0,1	994	0,006	993	0,007
0,05	993	0,007	994	0,006
0,03	680	0,320	688	0,312
0,025	560	0,440	547	0,426
	End device placement -3		End device placement -4	
Delay	Received	% Packed lost ratio	Received	% Packed lost ratio
0,3	996	0,004	990	0,010
0,15	991	0,009	994	0,006
0,1	994	0,006	993	0,007
0,05	995	0,005	996	0,004
0,03	688	0,312	667	0,333
0,025	549	0,451	570	0,430
	End device placement -5		End device placement -6	
Delay	Received	% Packed lost ratio	Received	% Packed lost ratio
0,3	986	0,014	993	0,007
0,15	983	0,017	902	0,098
0,1	970	0,030	899	0,101
0,05	995	0,005	911	0,089
0,03	636	0,364	588	0,422
0,025	536	0,464	492	0,508
Compatibility between XBee DigiMesh 2.4 PRO and WiFi				
Distance	Send packets	Received packets	% Packed lost ratio	
0	1000	236	76,4	
30	1000	992	0,8	
70	1000	995	0,5	

2.1.5. Test XBee ZB

Test shows that the XBee ZB is suitable for home automation and one chip embraces without a problem two rooms.

Table 5. Measurement Protocol for XBee DigiMesh

Device XBee DigiMesh				
Measurement Protocol				
	MAC Coordinator 0013a20040		MAC End device 0013a20040	
	End device placement -1		End device placement -2	
Delay	Received	% Packed lost ratio	Received	% Packed lost ratio
0,3	997	0,003	992	0,008
0,15	996	0,004	995	0,005
0,1	998	0,002	994	0,006
0,05	999	0,001	874	0,126
0,03	789	0,211	769	0,231
0,025	656	0,344	645	0,355
Compatibility between XBee ZB and WiFi				
Distance	Send packets	Received packets	% Packed lost ratio	
0	1000	178	82,2	
30	1000	875	12,5	
70	1000	996	0,4	

3. Results

The reliability of chips regarding to distance and coexistence with other wireless protocols - primarily with the protocol WiFi was tested.

Devices XBee PRO DigiMesh and XBee PRO 868 had very similar performance regarding the distance from server and time difference between sending messages from the server. They were able communicate reliable with all nodes even with the farthest node number 6 placed in basement.

Packets lost rate increased with smaller time difference between sending messages from server and it was not influenced by distance from server (Figure 5, Figure 6).

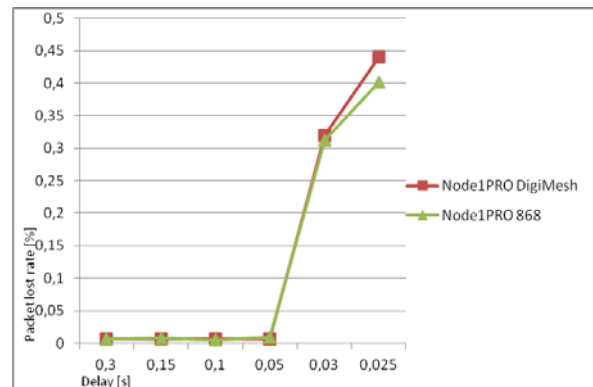


Figure 5. Packet lost rate with delay between sending messages to next node

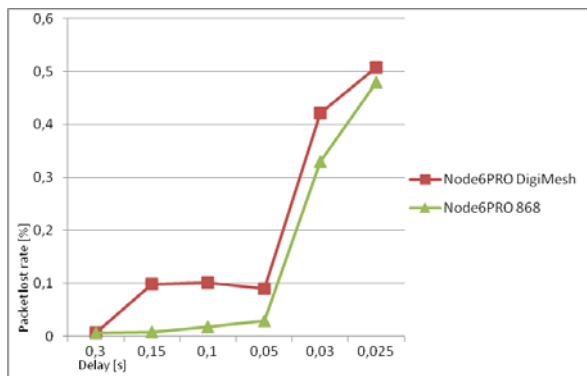


Figure 6. Packet lost rate with delay between sending messages to farthest node

The test results differed significantly from statements of manufacturer. According results of these tests with XBEE platform, several recommendations for installation and use in older buildings environment were created.

In the frame of availability, reliability and coexistence of XBEE network testing, the interaction between the individual chips was also tested. During testing it was found that the chips do not influence each other.

4. Conclusions

As a result of testing we worked out followed recommendations for the use of wireless protocols in older buildings:

- Verify the coexistence of selected protocol with other wireless networks already used in buildings - especially WiFi.
- The maintaining of sufficient distance from other wireless devices (for example for XBEE chips)
- The maintaining distance from the interference of high-voltage power components, which can affect any wireless networks, such as electric motors, power cables above 1 kV.

- When installing in buildings or houses, it is necessary to know the current electrical installation and to place chips out of main wiring routes.
- Ensure a sufficient distance (maximum and minimum) between communication chips for reliable communication (distance needs to be experimentally verified).
- Chips placing away from large metal surfaces - metal surfaces cause interference, attenuation and signal reflections.
- Ensure of network partial redundancy - in the case of communication chip loss, the chips must be linked to other alternative route.
- Appropriate management of asynchronous communication - as in the case of an insufficient response to the request, this request has to be repeated, or possible transmission errors have to be detected.

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