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WIRELESS SENSOR NETWORKS FOR ROAD TRAFFIC MONITORING

The paper presents an analysis of communication technologies that should lead to choosing technology appropriate for road traffic monitoring. One of the best available communication technologies is standard ZigBee. Experimental measurements of data rate with respect to distance under different operating conditions are presented. Based on obtained results it is possible to say that using ZigBee technology in wireless sensor networks is appropriate if we expect lower data rates (70 kbps).

1. Introduction

Wireless sensor networks (WSN) represent new technology for effective solving of tasks that include distributed information sources. According to [2] contemporary applications of sensor networks can be divided into four basic groups:

Environmental and habitat monitoring. Nowadays mankind stands in front of many unsolved environmental issues that can drastically influence quality of life in the future. The monitoring of changing parameters of environment is one of the first tasks on the way to reduce undesirable effects. Collection and processing of huge amount of data is possible using well organized WSN network. WSN networks can essentially contribute to improving long-term weather and climate change prediction.

Medical diagnostics and health care. Wireless sensor network technology is ideal for monitoring health conditions of patients and elderly people. Interesting practical application of WSN in health care monitoring is described in [5]. Example of monitoring vehicle drivers to determine their ability to drive can be found in [4].

Military surveillance and industry security. Due to its intensive nature, distributed wireless sensor networks are suitable to monitoring military strength, equipment and material. Wireless network is part of "Smart Dust" technology that is based on large amount of tiny wireless microelectromechanical sensors that could be spread over a large battlefield area, monitoring enemy movements and detecting everything from light to vibrations in a covert manner, [6], [7]. WSN are often used to improve security in some dangerous industry environments such as mines and nuclear power stations.

Industry applications. Wireless sensor networks can be found in factories in technology processes monitoring, safety systems

and others. Nowadays WSN are used more and more in control systems.

WSN could be characterized by following features:

Large-scale networks consisting of huge amount of sensors arranged in space with defined granularity. Using distribution management system methods to execute complex and large numbers of data could increase monitoring accuracy (signal-to-noise ratio is increased) and decrease accuracy requirement of each nodes. The existence of the redundant node can improve the lifetime of the whole wireless sensor network and provides the system with strong capacity of fault tolerance. A high density of sensor nodes enables increased monitoring coverage and provides chances to eliminate caves or fade zone.

Self-organizing networks make it possible to place nodes without preexistent infrastructure. Individual sensor nodes can be scattered randomly while respecting their communication range. After arranging, nodes are able to create functional network. In the case of node failure or energy blackout the network topology is dynamically changed. Likewise new nodes can be added on the fly. This could prolong the networks' lifetime and greatly improve their performance.

Multi-hop routing is used to allow communication between any two nodes whose separation is larger than maximum communication distance (usually few hundred meters). In such a case intermediate nodes have function of repeaters. This area is continually improved using new, interesting methods of routing.

Besides mentioned three basic properties wireless sensor networks are characterized by other properties that are described in detail in [2].

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2. Applications of WSN in traffic

One of the most perspective areas of WSN application is traffic. Traffic systems are large-scale with distributed information sources by nature. Traffic systems controlling requires different approaches from those used in classical technology processes controlling. Wireless sensor networks provide effective means for data collecting and transport. This makes from them an inseparable part of intelligent transport systems (ITS). Among the first successful applications of WSN in traffic were systems for monitoring transport flow parameters in order to determine transport intensity, to control crossroads with traffic lights, to forecast trends in traffic and so on.

Developing the WSN is a complex problem with many particular parts: network nodes design, development of effective methods of data preprocessing and methods of reliable communication.

The network node consists of a sensor module, control and signal processing module and RF transceiver, Fig. 1.

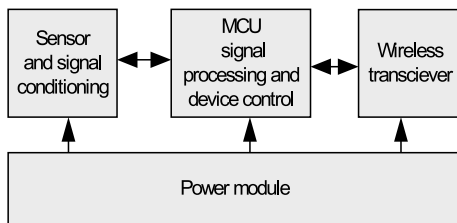


Fig. 1 Wireless network node

Each node must be able:

- to relay wireless data with defined data rate and communication range
- to operate reliably without maintenance
- to provide qualities required from dynamic ad-hoc mesh communication network.

To satisfy the presented requirements is often an unsolvable problem. Increasing of communication range and data rate dramatically influence energy consumption and lower device lifetime. Therefore, in most cases it is necessary to make compromise bet-

ween energy consumption and data rate or communication range. From this point of view one of the most important decisions is to choose an appropriate communication standard.

3. Communication subsystem

If we don't take into consideration the frequency band defined by standard 802.11.p then there is no dedicated frequency band for wireless sensor networks. The only chance is to use some of the free ISM (Industrial, Scientific and Medical) frequency bands. In EU we can use one of the following ISM/SRD (Short Range Devices) bands: 40.66 - 40.70 MHz, 433.05 - 434.79 MHz, 863 - 870 MHz (SRD), 2.400 - 2.500 GHz, 5.725 - 5.925 GHz, 24.0 - 24.25 GHz, 59.3 - 62.0 GHz, 122.02 - 123.0 GHz (SRD), 244.0 - 246.0 GHz (SRD). Most frequently used is ISM band 2.400 - 2.500 GHz. This band is used by several communication systems that can influence each other (Table 1).

Wireless sensor networks belong to the group of networks known as WPAN (Wireless Personal Area Network). According to data rate are WPAN networks divided into following groups:

HR WPAN (High Rate) - high-speed networks used mainly for RT and multimedia applications. Defined by standard IEEE 802.15.3 with maximum data rate of 55 Mbps or by standard UWB 802.15.3a with speed up to 110 Mbps within range of 10 m.

MR WPAN (Medium Rate) - networks with medium throughput rate used as replacement of cables in consumer electronics. According to standard IEEE 802.15.1 Bluetooth the data rate originally was only 1 Mbps, nowadays it is up to 3 Mbps (standard SIG 2004).

LR WPAN (Low Rate) - low-speed networks dedicated to wireless sensor systems and other simple applications. A typical representative of standards in this group is 802.15.4 IEEE 2003 and 2006 with data rate up to 250 kbps.

Acronym LR WPAN represents a low-speed personal data network. It is a cheap, low power communication network that is intended for applications with a limited communication range, data rate and energy consumption.

Wireless technologies used in frequency band ISM 2.4 GHz (2.4000 - 2.4835)

Table 1

Technology/ interference source	Modulation	Frequency [MHz]	Channel number	Channel width [MHz]	Channel spacing [MHz]
Wi-Fi, 802.11.b	DSSS	2.412-2.472	13	22	5
Bluetooth, 802.15.1	FHSS	2.402-2.480	79	1	1
LR WPAN 802.15.4	DSSS	2.405-2.480	16	3	5
Wireless USB	DSSS	2.402-2,479	78	1	1
Cordless phones	Different	2.400-2.483	Different	Different	Different
Microwave ovens	Impulse	2.400-2.500	-	-	-

Some of the basic properties of LR WPAN are:

- Data rate of 250 kb/s, 40kb/s or 20 kb/s,
- Short 16-bit or extended 64-bit addressing,
- Channel accessing using CSMA-CA, (Carrier Sense Multiple Access with Collision Avoidance),
- 16 communication channels in 2.45 GHz band, 10 channels in 915 MHz band and 1 channel in 868 MHz band.

Standard 802.15.4 defines properties, characteristics and parameters of two lowest layers of ISO/OSI communication model. The link layer is reduced to a medium access control (MAC) sub-layer.

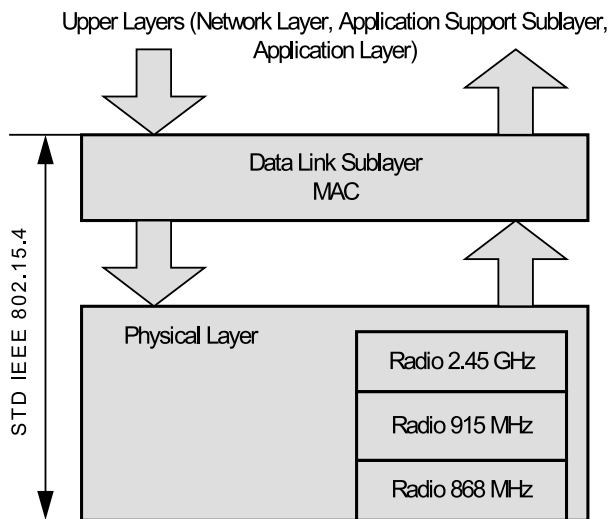


Fig. 2 Structure of standard IEEE 802.15.4

The communication system defined by standard 802.15.4 can operate in three ISM frequency bands. Transfer parameters used in individual frequency bands are summarized in table 2.

Physical layer parameters

Table 2

Frequency band	Frequency range	Channel number	Maximum transfer speed	Modulation	Region
868 MHz	868-868.6 MHz	1	20 kb/s	DSSS w. BPSK	Europe
915 MHz	902-923 MHz	10	40 kb/s	DSSS w. BPSK	USA, Australia
2.4 GHz	2.4-2.4835 GHz	16	250 kb/s	DSSS w. O-QPSK	other countries

Maximum transmit power must obey regulations defined by individual countries. Approximate values of maximum transmit power are shown in table 3.

Maximum allowed transmit power

Table 3

Frequency band	Region	Max. transmit power	Regulation nr.
2.4 GHz	Japan	10 mW/MHz	ARIB STD-T66, B14
	Europe	100 mW EIRP	ETSI EN 30 328
	USA	1000 mW	15.247 FCC CFR47,B14
	Canada	1000 mW	GL-36, B15
902-928 MHz	USA	1000 mW	15.247 FCC CFR47, B14
868 MHz	Europe	25 mW	ETSI EN 30 220, B10

Standard 802.15.4 defines 27 communication channels in three frequency bands. Their numbering and center frequency, F_c are as follows:

$$F_c = 868.3 \text{ MHz for channel } k = 0,$$

$$F_c = 906 + 2(k-1) \text{ MHz for channels } k = 1, 2, \dots, 10,$$

$$F_c = 2405 + 5(k-11) \text{ MHz for channels } k = 11, 12, \dots, 26.$$

Frequency band 2.45 GHz is used by several wireless transfer systems. In this band one can expect the biggest interferences caused by Wi-Fi technologies (standard 802.11) that are presently used in a large scale for data transfer. The assigning of transfer channels in frequency band 2.45 GHz according to standards 802.11 and 802.15.4 is depicted in Fig. 3. The fact that standard 802.15.4 defines only two lowest layers of transfer system allowed creation of different data transfer systems that are used in various applications. Let's mention three mostly used technologies for area of industrial automation: Wireless HART, SP 100.11 and ZigBee. ZigBee technology is the most popular.

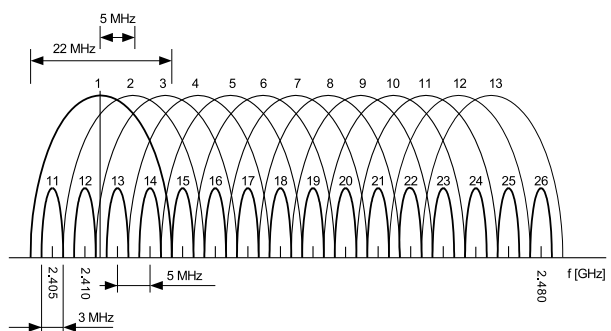


Fig. 3 Transfer channels according to STD 802.11 and 802.15.4

Communication standard ZigBee is designed especially for building automation, wireless telemetry, industrial automation, consumer electronics and other applications with low demands for data transfer rate. Development of this standard was started in 2002 by ZigBee alliance. By the end of year 2004 version 1.0 was finished as extension of physical and MAC layers of standard 802.15.4.

There are two types of devices that can act as communication nodes of ZigBee network:

- Reduced functionality devices (RFD) - relatively simple devices with low memory capacity, limited performance and low energy consumption. They are used as end devices in the network. They lack features such as routing and/or coordinating.
- Full functionality devices (FFD) - more complicated devices whose hardware and software enables implementation of more sophisticated functionalities. They can take the role of router, coordinator and/or end device.

Basic types of ZigBee network nodes are:

- Coordinator, or PAN coordinator, establishes the network, assigns addresses, stores security keys and so on. There can be only one coordinator in each network. It is FFD type of device.
- Routers act as intermediate nodes, relaying data from other devices. Router must be able to establish and control relations between other nodes. Router is FFD device.
- ZigBee Trust Center (ZTC) is a main security element in the network. It provides services related to security and message confidence.
- End devices have sufficient functionality to talk to their parents (either the coordinator or a router) and cannot relay data from other devices. This reduced functionality allows for the potential to reduce their cost. It can be RFD or FFD device.
- ZigBee gateway allows interconnection of ZigBee network with other networks. Its main function is to converse communication protocols.

Number and types of devices used in particular ZigBee network depends upon its scale, complexity and application requirements. Network layer of ZigBee supports these network topologies: tree, mesh and star. Network securing, interconnection with other networks, multi-hop routing algorithms and other additional properties are not mandatory for ZigBee networks. This is a reason why we can see in praxis networks ranging from most simple ones (with only one FFD as coordinator and some RFD's) to complicated, well secured networks designed for industrial applications.

ZigBee alliance released new specification for wireless communication named ZigBee PRO in the year 2007. This standard has following improvements over the previous version:

- enhancements in the area of addressing and routing such as: random address assigning with collision detection, limited broadcasting, using AODV (ad-hoc on-demand distance vector) routing with possibility for many-to-one communication.
- Communication channel change. Interference with other communication systems in ISM band can severely reduce network throughput. ZigBee PRO uses a frequency agility method which allows the coordinator to adaptively change used channels in order to minimize influence of interference on network throughput.
- Power management of end devices allows sleep periods with a maximum period of 7.5 s. Routers are able to remember messages addressed to "sleeping" devices so there is no data loss during a sleep period.
- Securing of data transfer is accomplished by symmetrical encryption AES 128. ZigBee PRO network should have one trust center that provides security services to all other network devices.

ZigBee PRO standard has substantially better properties over ZigBee standard in the fields of data rate, security and robustness especially in the case of large scale communication networks.

ZigBee technology was chosen as a key part of experimental wireless sensor network for monitoring traffic parameters.

4. Experimental verification of XbeePro nodes properties

OEM RF modules developed according to standard 802.15.4 are marked as Xbee and XbeePro. These modules allow rapid development of wireless sensor networks. Modules are able to operate in ZigBee Mesh communication networks. In order to verify properties of modules we realized following three experiments.

Two experiments were realized in full traffic in the middle of day. The first experiment was focused on the influence of antenna type on a data rate. The modules used maximal power output (North American version). In the second experiment we examined the influence of modules placement on a data rate. The placement of receiver (point o) and transmitter is depicted in Fig. 4. First two experiments took place in the centre of Prievidza.



Fig. 4 Transmitter and receiver placement

There were 5 available Wi-Fi networks in 2.4 GHz band at the place of receiver during measurements. Four of them had a low level of signal (1/5 - 2/5) and one had high level of signal (4/5).

The third experiment was focused on comparison of the antenna type on a data rate under almost ideal circumstances - outside the town, direct line of sight, none Wi-Fi networks. Second and third experiments were carried out with modules set to comply with European norms (maximum transmitter power output 10 dBm).

All the experiments were based on a simplex operation of modules. The maximal data rate under ideal circumstances is about 76 kbps. For duplex communication the data rate is halved. The term "data rate" means the rate of transfer of useful data.

Experiment 1 - influence of antenna type on data rate in urban area

Parameters:

- Transmitter output power: 18 dBm (63 mW)
- Wire antenna of length 2.8 cm or ceramic antenna
- Length of measurements: 10 s
- Receiver placed 50 cm above ground
- Transmitter placed 120 cm above ground

Different antenna types in urban area

Table 4

Measurement	1	2	3	3a	3b	4	5	6	7	8	9	10	11	12	13	14
Distance [m]	54	214	300	381	383	305	207	165	60	55	119	203	245	144	91	51
Wire antenna [kbps]	75.2	67	25.3	18	2.6	47.2	42.8	59.2	75	73.9	41	32.3	11.1	50.2	37.9	67.4
Ceramic antenna [kbps]	52	55.8	2.6	0	0	20.3	44.3	37	71	68.4	13.3	11.9	6.4	4.2	9.6	53.6

The ceramic antenna was in vertical position during measurements because of its better performance over horizontal position. The influence of antenna placement depends on the distance of modules and ambient circumstances.

Practically in all the measurements the wire antenna shows a better performance. The data rate for distances under 60 m is close to maximal. In special cases (no obstacles) the data rate remains quite high even for greater distances (see measurement 2).

Experiment 2 - influence of modules placement on data rate in urban area

Parameters:

- Transmitter output power: 10 dBm (10 mW)
- Wire antenna of length 2.8 cm
- Length of measurements: 20 s
- Receiver placed 50 cm above ground
- Transmitter placed 120 cm above ground (placement 1) or direct on ground (placement 2)

The placement of modules has a significant impact on the data rate. If the transmitter was placed direct on ground, the data rate often was reduced below half of a normal data rate. However, the influence of ambient circumstances sometimes allows a higher data rate (measurements 2 and 3). Comparing tables 4 and 5 (rows "Wire antenna" and "Placement 1") one can see negative influence of the lowered transmitter output power on the obtained data rate especially at greater distances. For short distances (about 60 m) the data rate is usually about 10 % lower.

Experiment 3 - data rate under almost ideal circumstances

Parameters:

- Transmitter output power: 10 dBm (10 mW)

- Wire antenna of length 2.8 cm or ceramic antenna
- Length of measurements: 20 s
- Transmitter and receiver placed at least 120 cm above ground

The result of this experiment is similar to the first experiment. It confirms that the wire antenna has a better range than the ceramic antenna. The difference is about 130 m if we define the lowest usable data rate to be 2 kbps.

5. Conclusion and future work

The paper addresses the problem of wireless sensor networks in traffic monitoring. It is focused on choosing proper communication technology, which satisfies basic requirements. One suitable technology is standard ZigBee. The results of experiments in an urban area show that the communication range of modules is quite dependent on modules placement, antenna type and ambient circumstances. For a good modules placement with the wire antenna it is possible to obtain data rates of about 67 kbps for distances of at least 60 m. For lower data rates the distance can be extended beyond 200 m. According to acquired data we can say that ZigBee technology is suitable for WSN applications in transport systems. In the next phase we will focus on developing network nodes capable of sensing acoustic signals, vibrations and with optical distance sensor. The network will be used for the monitoring of transport flows in real world.

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Influence of modules placement

Table 5

Measurement	1	2	3	3a	3b	4	5	6	7	8	9	10	11	12	13	14
Distance [m]	54	214	300	381	383	305	207	165	60	55	119	203	245	144	91	51
Placement 1 [kbps]	74.6	23.6	5.6	0	0	31.2	35.5	54.6	66.8	67.7	4.1	2.6	1.1	28.7	38.8	72.6
Placement 2 [kbps]	30.3	25.8	6.1	0	0	0.6	10.2	21.9	45.7	21.8	1.5	0	0	0.4	34.3	39.1

Data rate vs. antenna type

Table 6

Distance [m]	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380
Wire antenna [kbps]	74.3	74.7	74.9	76.8	74.3	71.9	63.9	74.5	52	71.5	25.4	17.3	31.7	12.5	0.8
Ceramic antenna [kbps]	74.6	74	73.6	59.1	72.2	32.4	14.3	2	0.2	0	0	0	0	0	0



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References

- [1] HERMS, A., NETT, E., SCHEMMER, S.: *Real-time Mesh Networks for Industrial Applications*, Proc. of the 17th Congress IFAC, Korea, 2008.
- [2] HUANG, M.: Visualization of Urban Transportation Data Generated by Wireless Sensor Network Using Modern Approaches, *Modern Applied Science*, Vol. 3, No. 6, 2009.
- [3] KOVAR, O., MICEK, J.: *Wireless Networks in Automation Equipment*, Proc. of workshop ARTEP2009, Stara Lesna, 2009.
- [4] FORDOS, G. et al.: Sensor-net for Monitoring Vital Parameters of Vehicle Drivers, *Acta Polytechnica Hungarica*, Vol. 4, No. 4, 2007.
- [5] VIRONE, G. et al.: *An Advanced Wireless Sensor Network for Health Monitoring*, <http://www.es.virginia.edu/paper/d2h206-health.pdf>
- [6] ARIEF, B., BLYTHE, P., TULLY, A.: *Using Smart Dust in Transport Domain*, Position paper, UbiComp Grand Challenge Workshop, London, 2009.
- [7] Arief, B. et al.: *Integrating Smartdust into Intelligent Transportation Systems*, Proc. of the 10th Intern. conference AATT2008, Athens, 2008.