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Wireless Sensor Network – Value Added Subsystem of ITS Communication Platform

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***Abstract*—The article is dedicated to the analysis of design of WSN road transportation system for developing applications related to parking management, traffic flows and emergency vehicles monitoring, weather and environmental conditions monitoring as well. The analysis is done for all units of sensor node. Many technical aspects of the design are discussed in the paper.**

I. Introduction

COMPARING to railway, civil aviation and marine transportation modes, road one is characteristic by the most of accidents and passenger fatalities, passenger and freight transport as well as CO_2 emission production. This is reason why safety, effective transport and environmental questions are core topics of research and development activities in the field of the Intelligent Road Transportation Systems (IRTS), [1].

In the ninetieth of last century, public and industry authorities decided about deploying electronics, information and communications technologies to improve negative situations by developing new V2X technology (V2V- vehicle-to-vehicle, V2I – vehicle-to-infrastructure sensor/dedicated short-range communications technology), [2] [3]. The technology is expected to guarantee reliable driving car coordinating movement and timing, particularly through detection of the vehicle´s position relative to other vehicles, intersections and infrastructures behind 250 m as well as self-driving car in case of critical situations, smooth traffic flows based on V2V and V2I communications to inform driver about recommended driving speed, in order to reduce unnecessary acceleration or slowdown. Unfortunately, V2X research and development works has still not been finished by now. It is expected that practical deployment of the technology could become reality in the second half of next decade. In present days it is possible to follow intensive discussion about future of V2X technology. Many other sensor, communications technologies have been developed during last fifteen years. No one expected so fast growing of especially mobile communications. Using personal digital devices is standard today. Simply said, situation has changed during last 25 years.

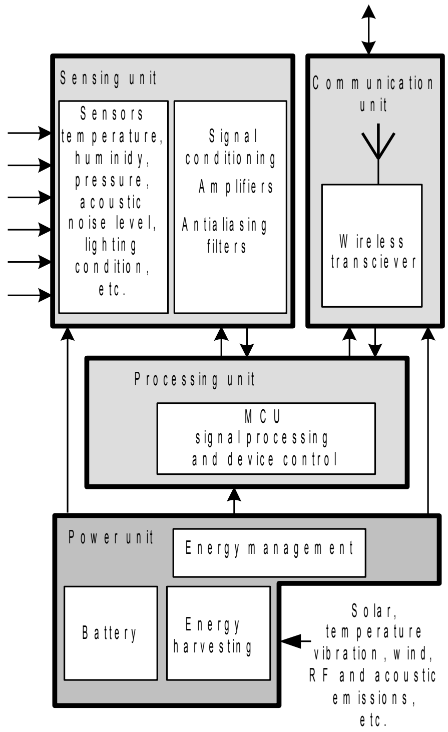

Fig 1.Block structure of wireless sensor node

This is reason why research and industry authorities in the USA and EU split into two groups concerning future development of V2X technology. While the goals of both of them are the still the same: decreasing traffic accidents, traffic congestion and improving fuel economy, European authorities focused on developing Advanced Driver Assistance Systems (ADAS) supported by mobile communications 4G

LTE technologies and services for upcoming events within 250 meters. The USA authorities prefers developing V2X technology for communication distance 1000m. It is expected that both of above mentioned technologies will be developing simultaneously to operate independently concerning V2V services and cooperating with each other in case of V2I ones.

Referring to above mentioned information, it would be suitable to answer question if WSN could be integrated in sensor/communication platform of future intelligent transportation systems. Since road transportation mode is dominant one in ITS, next part of article will be focused on analysis of specific features of WSN, particularly core subsystems of its sensor node (figure 1), supporting development of road traffic services keeping in mind value added complementary character of WSN.

II. Sensor Node – Sensing Unit

Mote is sensing of selected signals values by proper sensors and transforming of measured signals to ones which are suitable for additional processing (most often electrical voltage).

Respecting two facts:

- Sensor node is stationary in WSN
- Vehicle acts as mobile mote of ad-hoc wireless network

sensing of chosen signals must cover larg area. In such case WSN keeps value added complementary character to V2X and ADAS technologies. Selection of sensors is closely related to precision of measurement and developing applications. Thinking about road traffic, it is clear that WSN will be optimally used for monitoring purposes to support control, maintenance and planning processes. Core applications could be defined as follows:

- Parking monitoring and management
- Traffic flows monitoring
- Emergency vehicles monitoring
- Weather conditions monitoring
- Environmental conditions monitoring.

Parking monitoring and management

Vehicles detection at parking places is main task of the application. Sensors choice depends on indoor or outdoor detection. Magnetometer is proper sensor for both of cases. Measurement accuracy is not depended on weather conditions using the sensor. Numerous other ones are available for indoor detection: infrared, ultrasonic, acoustic, cameras, etc. Collected data are processed and information about free spaces can be presented on navigation tables (signs) in the street or distributed via communication channels to personal devices. Entry gate to parking lots is controlled on the basis of occupancy of them.

Traffic flows monitoring

mainly supports:

- *Vehicle detection* – at stop lanes of intersections
- *Vehicles counting* – counting number of vehicles waiting in queues of intersections, valued information for traffic lights control
- *Vehicle classification* – vehicle type identification for planning applications
- *Traffic flow intensity measurement* – in vehicles per time period, necessary information for effective road surface maintenance, planning of road network extension, traffic light control, see figure 2 and figure 3
- Vehicle speed measurement – supports safety and effective driving.

Referring to precision measurements, magnetometer sensor is proper for traffic flows monitoring.

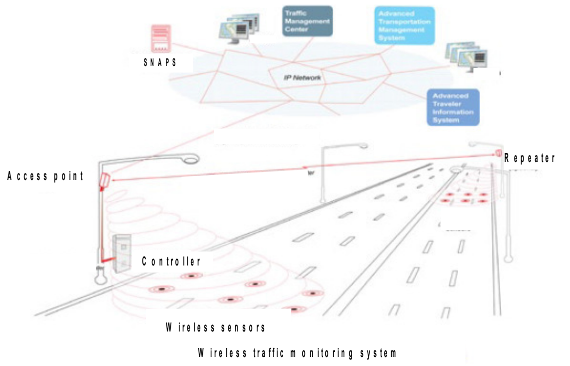

Fig2. Wireless traffic flows monitoring system

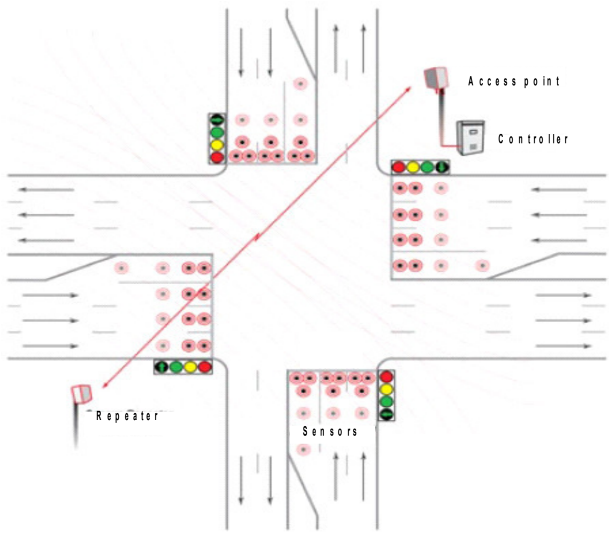

Fig3. Traffic lights control system

Emergency vehicles monitoring

Due to using sirens, emergency vehicles are effectively detected and classified by acoustic sensors. Monitoring of them allows safety crossing intersections.

Weather conditions monitoring

allows drivers to adapt style of driving in time to avoid accidents.

Environmental conditions monitoring

collects information about air pollution: CO_2 emissions, dust concentration, acoustic noise related to traffic in the area. Information is valuable for:

- Developing applications in compliance with citizens health protection
- Planning of reconstructions of historical buildings plasters.

III. Sensor Node – Processing Unit

Basic functions of processing unit are: digital processing of measured signal values, control of sensor node units, security of transmitted data, potentially another additive functions required by particular applications.

Keeping in mind value added complementary character of WSN to V2X and ADAS technologies (high speed transmission), processing unit very often uses reformatting, compression, classification technics and algorithms to transmit low amount of data. This approach supports low data rate transmission over communication channel (will be discussed in communication unit section). Referring to mentioned monitoring applications, number of transmitted bits vary from 1 bit to maximally 16 bits. It opens possibilities for developing of variable and reliable communication strategies.

IV. Sensor Node – Power Unit

Energizing of sensor node by electrical energy is main function of the unit. Time period of network operation without maintenance is important WSN feature.

Energy sources could be split as follows:

- *Mobile* – energizing of sensor node from primary batteries, rechargeable batteries, system exploitation for collecting energy from surrounding environment – energy harvesting, combination of rechargeable batteries and energy harvesting. This approach is standard in WSN applications.
- *Static* – energizing of mote is from standard electrical network. The option could be used in case of nodes responsible for communications services. They represents communication backbone of WSN. Such solution outgoing from the fact that communication unit consumes the most of energy of the battery. This option of motes energizing would be used, if necessary, in case of requirements for: increasing communication distance among nodes (to compensate path losses on frequency channels), guarantee of reliable communication and life time of motes operation as well.

Selection of energy source is strongly depended on requirements of application which WSN is designed for. Primary battery is expected to be preferable solution for road transportation applications (operational life time could be even 10 years).

V. Sensor Node – Communication Unit

Any sensor node must be able to communicate with adjacent ones, potentially with base station via wireless communication channel. Communication unit is main consumer of energy of the battery.

Analysis of WSN features, assuring successful communications in road transportation, area will be done in several steps.

Frequency bands allocation for WSN road transportation applications

In 5.8.2008, EU Committee decided to allocate frequency band from 5875 to 5905 MHz for ITS applications, which is going to be used on non-exclusive basis. Referring to 5.9 GHz center frequency, channel bandwidth is 10 MHz and default data rate 6 Mbps. Detailed information about V2X communication frequency band as well as maximum limit of mean spectral power density (EIRP) and European channel allocation is presented in [4].

It is clear that for 2-byte useful information transmission (low data rate is expected for WSN applications) above mentioned frequency channel parameters are not defined properly. That is why lower frequency bands are subjects of interest for successful WSN communication in road traffic applications.

Selecting lower frequencies for communication among communication units of motes has positive influence in general:

- *Channel bandwidth is more narrow* – saving frequencies for other applications, increasing number of channels for defined frequency range
- *Communication distance is increased* – competitive argument for WSN, development of cooperative services
- *Path Loss is decreased* – less energy losses higher quality and reliability of communication
- *Lower influence of obstacles on signal strength*
- *Improved radio receive sensitivity* – increased communication distance, weaker signal could be successfully received
- *Better resistance against weather conditions*-lower Bit Error Rate

Lower frequencies require larger antennas to achieve the same gain and improve signal robustness against interference in general. On the basis of above mentioned information it is possible to state that lower frequency band is attractive solution for design of WSN road transportation services, especially, when low data rates are required. It strengthens competitiveness of designed solutions.

For assuring successful wireless communications, it is suitable to mention practical path loss rules of thumb, [5]:

- To ensure basic fade margin in a perfect line of sight application, never exceed 50% of the manufacturer´s rated line of sight distance. This in itself yields a theoretical 6dB fade margin – still short of the required 10dB.
- Decrease data rate more aggressively if you have obstacles between the two antennas, but not near the antennas.
- Decrease data rate to 10% of the manufacture´s line of sight ratings if you have multiple obsta-

cles, obstacles located near the antennas, or the antennas are located indoors.

Defining frequency band for wireless communications in the ITS field must take into account one very important actuality. 5.9 GHz frequency band for V2X technology is used in non-exclusive basis. Drivers do not pay monthly recurring charges for using services requiring the band. This is reason why WSN road transportation applications must typically operate in “license free” frequency bands, also referred to as ISM (Industrial, Scientific and Medical). The most common frequencies encountered are:

- 2.4 GHz – nearly global coverage
- 915 MHz – North America, South America
- 868 MHz – Europe.

For any given distance, a 2.4 GHz installation will have roughly 8.5 dB of additional path loss when compared to 900 MHz. However, lower frequencies require larger antennas to achieve the same gain. Antenna type must be selected during in a proper way and earlier physical installation on site. Antennas increase the effective power by focusing the radiated energy in the desired direction. This fact could be evaluated during time period of WSN application design.

Table 1 presents result of simulations described in [6]. Mathematical backround is covered in the article as well. The paper is easily accessible via Internet in IEEE Digital Library, respectively in SCOPUS one.

Communication distance of V2X technology is required up to be 1000m. From the table is clear that no theoretical model satisfied expectations. Testing of V2X communication reliability was done at road infrastructure in California two years ago. Unfortunately, reliability of wireless communication was on the level of 85%. Still not satisfactory. It is discussed that the technology could be practically operating even in 2027. This is reason why European authorities prefer developing of ADAS system supported by mobile 4G LTE communication technologies.

Lack of reliable communication up to 1000m has negative influence on cooperative services development. This is chance for WSN road applications.

Selection of RF technology for WSN based road transportation applications

Table 2 presents chosen RF transmission systems applicable in the field of transportation.

Referring to battery life item, only ZigBee® technology is applicable in WSN networks in present days. It is designed for short range low power operation. The radio is relatively low data rate (up to 250 Kbps); the packets are short (< 128 bytes) and low energy. For example, sending a few bytes of sensor data, with routing, cryptography and other headers takes less than 1ms and burns less than 30 μJ of energy, including receiving a secure link-layer acknowledgment. Sensors can forward radio packets from peers, extending the range of the network far beyond the range of single radio and providing the network with immunity to any single radio link failure.

TABLE I.
COMMUNICATION DISTANCE LIMITS AT MAXIMAL TRANSMIT POWER

Models	**Communication distance limit [m]**	
	G_R = 5 dBi	**G_R = 8 dBi**
Free-space model	1278	1805
ETSI model	405	523
ECC model ***Urban***	279	328
ECC model ***Suburban***	471	565
ECC model ***Rural***	933	1033

Every ZigBee standard and specification is the powerful IEEE 802.15.4 physical radio standard. It delivers raw data throughput rates of 250Kbs at 2.4GHz (16 channels), 40Kbs at 915MHz (10 channels) and 20Kbs at 868MHz (1 channel). Further information about Zigbee technology is possible to find in [7].

Design of WSN road transportation monitoring/control systems must meet a four core performance targets:

- *The first, the system must meet a minimum reliability goal.* For industrial applications, the target is typically to receive at least 99.9% of the generated data. Referring to RF communications, 99.5% link availability is defined as standard. 99.9% availability is considered as high one. This target is not met in current V2X technology.

TABLE II.
COMPARISON RF TECHNOLOGIES SUITABLE FOR INTELLIGENT ROAD TRANSPORTATION SYSTEMS

Market Name **Standard**	**ZigBee®** **802.15.4**	**---** **GSM/ GPRS/ CDMA / 1xRTT**	**Wi-Fi™** **802.11b**	**Bluetooth ™** **802.15.1**
Application Focus	Monitoring & Control	Wide area voice& data	Web, Email, Video	Cable replacement
System Resources	4KB-32KB	16MB+ 1-7	1MB+	250KB+
Battery Life (days)	100 - 1000+	1-7	1-5	1-7
Network Size	Unlimited	1	32	7
Maximum Data Rate (KBps)	20-250	64-128+	11000	720
Transmission Range [m]	10-1600	1000+	1-100	1-10+
Success Metrics	Reliability, Power, Cost	Reach, Quality	Speed Flexibility	Cost Convenienc e

- *The second, the system must support a certain throughput, a number of sensor data packets per second.* In low rate ITS applications only a few data packets are expected to be transmitted, so that performance criteria will be satisfied. BER (Bit Error Rate) is expected to be equal and better than 10^{-6}.
- *The third, these data packets are only useful if they are received within a maximum latency period.* It must be verified for every project.
- *The fourth, many systems must operate under severe conditions and intrinsic safety restriction*.

All of four mentioned targets must be satisfy to continue in further design evaluation. For detailed information read [8].

VI. Experimental Part

Figure 4 presents sensor node developed for measuring of traffic flows parameters. Referring to sensing of magnetic field changes and vibration, sensor LSM303 is used. Magnetometer measurement interval is adjustable in range from ±1.3G to ±8.1G. Acceleration-meter range is possible to adjust in interval from ±2g to ±8g. Signal processing and control unit is realized on the basis of 32-bit microcontroller STM32F100 in small pocket LQFP48. MCU is realized on the basis of ARM-Cortex M3 core with maximal frequency 24MHz. SRAM memory capacity is from 4 to 8 KB. Flash memory capacity is from 16 to 128 KB. Memory subsystem is extended by microSD cart whose allows saving of big data content. Basic PCB consists of connector for connection of communication unit. This solution allows to experiment with various communication modules. XBee PRO communication module in 2.4GHz band was used. Sensor node is realized on 2-layer PCB with dimensions 32x38 mm.

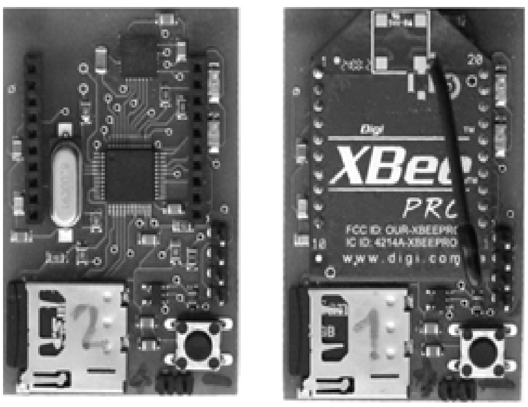

Fig4. Wireless sensor nodes

Proving functionality of the nodes, average speed of vehicle calculated on the basis of measured signals of magnetic induction is presented. Two nodes were well-situated at road side in the distance of 10m from each other. Synchronization of them was secured by RF communication. Both of sensors were sensing changes of Earth magnetic field in axes x, y and z depending on car detection, in case of sampling period 50ms. Measurements were transmitted to PC via communication module XBee. All measured data including time mark were stored on microSD card in the same time. Magnetometer measurement range was set to value ± 2.5 G. Direct components of waveforms were filtered. Cars moving about 1.5m far away from sensor nodes evoked changes of magnetic field induction in order of ten-miliGauss (mG). Amplitude of magnetic induction range is related to the distance between vehicle and a sensor.

Time difference between measured signals is depended on localization of sensor elements and speed of passing vehicle. Average speed of vehicle passing the sensors can be calculated on the basis of the evaluation of time difference between corresponding changes of magnetic induction measured by sensors 1 and 2. Comparing behaviours of magnetic induction both of sensors can be used to filter incommensurate signal elements related to other influences than vehicles movements (pedestrians on pavement, inverse direction moving vehicles, etc.). Average vehicle speed could be stated on the basis of total magnetic induction change (S) calculation:

$$S = \sqrt{(x2 + y2 + z2)} \quad . \tag{1}$$

Figure 5 shows plots of total magnetic induction change for sensor1 and sensor2. Average speed of vehicle between sensors1 and 2 can be derived on the basis of measured signals of magnetic induction. Time shift of maximal induction change between sensor1 and 2, for the first vehicle, is 1.28s. Average speed of first vehicle is (for 10m distance between sensor1 and 2):

$$v = 10/1.28 = 7.8 \quad [m/s] \quad . \tag{2}$$

In case of the second vehicle, for its average speed is valid:

$$v = 10/1.01 = 9.9 \quad [m/s] \quad . \tag{3}$$

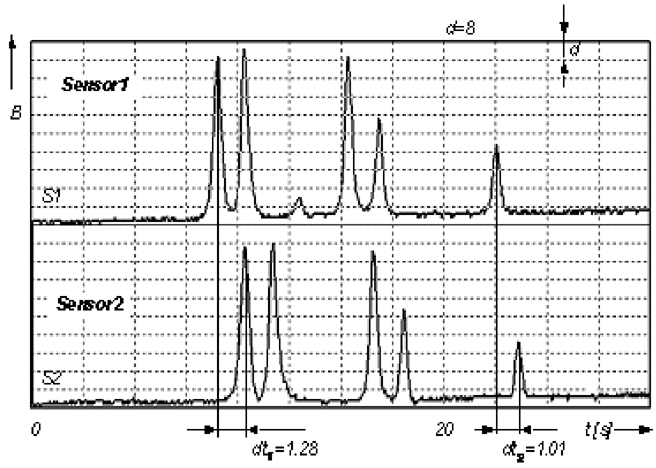

Fig5. Plots of total change of magnetic induction for sensor1 and sensor2

For more precise calculation of time shift could be used more sophistic method of estimation error elimination. It is necessary to notice that the precision is always limited by real period of sampling frequency. Precision of vehicle average speed calculation between two nodes could be increased by decreasing sampling frequency as well as increasing of distance between sensors.

Presented measurements illustrate usability of sensor nodes with magnetic induction sensing for monitoring of traffic flow parameters. Vehicles classification is presented in literature [9]. Firmware reprogramming is described in [10].

VII. Conclusion

Presented paper is focused on design of WSN road transportation systems for parking management, monitoring of traffic flows, emergency vehicles, weather and environmental conditions. The design must meet many targets and requirements principally discussed through the paper. The system must be value added and complementary to V2X technology as well as ADAS system.

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References

[1] EC: "EU Transport in figures", *Statistical pocketbook*, ISBN 978-92-79-19508-2, 2011

[2] Junko Yoshida: "Counter Argument: 3 Reasons We Need V2X", *EETIMES*, 2013

[3] Junko Yoshida: "If a Car´s ReallyAutonomous, Why V2X?", *EETIMES*, 2013

[4] ETSI EN 302 571 V1.1.1, September 2008: ITS; Radiocommunications equipment operating in the 5 855 MHz to 5 925 MHz frequency band;

[5] *http://www.bb-elec.com/Learning-Center*

[6] Juraj Miček, Ján Kapitulík: "Transmit power control analysis in V2X communication system", *Communications: scientific letters of the University of Žilina*, Vol. 12, No. 3A, s. 55-59, 2010, ISSN 1335-4205

[7] *http://www.zigbee.org*

[8] Lance Doherty, Jonathan Simon, Thomas Watteyne: "Wireless Sensor Network Challenges and Solutions", Linear technology, WP001, *http://www.linear.com*

[9] Ondrej Karpiš: "System for Vehicles Classification and Emergency Vehicles Detection", Proceedings of 11th IFAC/IEEE International Conference on Programmable Devices and Embedded Systems, PdeS, pp.155-159, Brno University of Technology, 2012

[10] Ondrej Karpiš: "Software actualization in Wireless Sensor Networks", Proceedings in Information and Communication Technologies - International Conference, ICTIC 2012, pp.51-54, EDIS-ŽU, 2012

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