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EMBEDDED MICROPROCESSOR SYSTEMS AND WIRELESS COMMUNICATION IN MOTOR VEHICLES

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Abstract: This paper considers, describes and proposes possibilities and ways for application of embedded microprocessor systems and wireless communication in motor vehicles. Modern motor vehicle is a system with well-connected diverse embedded microprocessor systems. There are dozens of microprocessor systems that monitor and control individual elements in the vehicle and that mutually communicate. Ways of application and tendencies in development of embedded microprocessor systems in motor vehicle are described. In the practical part of the paper, based on developed programs for simulation and results of simulations, are analyzed and tested possibilities of application of wireless communication of embedded microprocessor systems in automobiles. It was proposed and described possibility of application of wireless communication in automobile using the ZiggBee protocol, particularly in some subsystems of the car. Simulation of such wireless communication in automobile, results of simulations and conclusions obtained on the base of that results are given in the paper.
Keywords: motor vehicles, wireless communication, embedded microprocessor systems, simulations

1. INTRODUCTION

Usages of embedded microprocessor systems in automobile production industry are between the earliest practical applications of such systems. Specificities of motor vehicle as a complex object are very suitable for application of embedded microprocessor or microcontroller systems in such vehicles. Such systems are used for acquisition and processing of data from vehicle sensors and for regulation of processes that are performed during operation of different systems in the vehicle and that have to be very carefully controlled. Modern motor vehicles are systems with dozens of connected and networked embedded microprocessor or microcontroller systems [1-4].

Permanent and rapid development of wireless communication technologies creates possibilities to use such technologies in a motor vehicle. It is possible to use different wireless communication technologies in networking and communication of some parts, elements and systems of motor vehicle, for different applications. It gives many advantages and has great potential in comparison with usual wired communication and networking technologies.

Application of embedded microprocessor systems and wireless communication in motor vehicles is considered and proposed in the paper. In the modern vehicle there are many microprocessor systems for monitoring and control of elements in the vehicle that mutually communicate. Ways of application of embedded microprocessor systems in motor vehicles and tendencies in development of such systems are described. The possibilities and advantages of application of wireless technologies for networking and communication in automobiles are also proposed and described. The practical part of the paper describes results of analysis of application of wireless networking and communication of embedded microprocessor systems in automobiles, based on developed programs for simulation and results of simulations. It is proposed and described possibility of application of wireless communication in automobile using the ZiggBee protocol, particularly in some subsystems of the car [5]. In the simulations were used OMNET++ development environment [6] and Castalia development platform [7]. Simulation of such wireless communication in automobile, results of simulations and appropriate conclusions are presented in the paper.

2. EMBEDDED MICROPROCESSOR SYSTEMS IN AUTOMOBILE

Initially the microprocessor or microcontroller based embedded systems were used as replacement for some already existing systems in the motor vehicle. Development of such systems and motor vehicles created introduction and implementation of many systems connected with new possibilities and new applications in the vehicles [1-4].

Some of the most significant improvements achieved by using the embedded microprocessor or microcontroller systems in motor vehicles are:

— Increasing of safety and security of driving and travelling,
— Reduction of total fuel consumption,
— Reduction of environment pollution,
— Increasing of comfort of driving and travelling,
— Improvement of diagnostic functions,
— Improvement of communication and networking.

Practical development of embedded microprocessor systems in motor vehicles was following development of embedded microprocessor systems in general. But, the automotive production industry has always tried to have and use microprocessors specifically designed for automotive applications and environment. That type of microprocessors is needed to operate in wide temperature ranges and wide temperature changes, in constant vibration, and not to fail and not to make errors. There were developed appropriate standards for such microprocessors production taking into account all requirements of automobile producers. Requirements for such microprocessors are significantly different for different application places in automobiles. For example, for microprocessors in the vehicle drive unit system needed precondition is functionality without errors on temperatures up to 170°C. But, such precondition not exists in applications in interior of vehicle that are mainly of informative, controlling or security nature. In such applications are primary some other requirements, for example processor speed and graphical speed of data processing [1-4].

Such diversity of working conditions was created division of motor vehicle into application domains. That approach makes easier to use embedded systems, because the system not have to look at the complete vehicle but only on its own vehicle domain. But, such division on vehicle domains creates problems in data exchange between different functional units of the vehicle. It requires implementation of appropriate devices (so called gateways). For example, the ECU (Electronic Control Unit) that with functionality belongs to one domain, because of needed information of/for operation of some other ECU, has to be connected to its network or directly connected to it, even if it is ECU of some other domain. Practice is to perform data transfer between the domains using intermediary device, usually called vehicle body central electronic, that is in the vehicle body domain. It is critical subsystem of the vehicle because it is unique point of failure. The vehicle domains are limiting factor for communication between applications in different vehicle domains and in different sub-networks. Great progress in improvement of the required characteristics was made by the AUTOSAR project [1-4], with its intermediary layer. But, for the automotive industry the most important requirement is reliability. For example, the system cannot tolerate any single failure in the control of vehicle or in the control of breaking.

Practically, there are two main classes of electronic systems embedded into vehicles [1-4]:
- Real time working systems that control vehicle mechanical parts,
- Information systems and systems for control and security.

Generally, real-time systems in motor vehicle include:
- Systems in the control of the vehicle chassis,
- Vehicle air conditioning systems,
- Vehicle control board systems,
- Vehicle driving systems.

Real time system (RTS) in the vehicle can be of the hard or the soft type. The hard type RTS has to perform task in a predetermined time limit. Exceeding the time limit will cause partial or complete system failure. Such system example in automobile is engine control system. For such systems the wireless communication is not suitable, recommended and applicable because it cannot provide sufficient level of reliability that such systems require. The soft type RTS has not task performing time limits. Exceeding of time limit will not cause failure but only degradation of some system performances. Example of such system in automobile is air conditioning system. For such systems the wireless communication is suitable, applicable and recommended for use because there is not required high level of reliability.

Information systems and systems for control and security in motor vehicle generally include:
- External communication systems,
- Informative, multimedia and entertainment systems.

Information systems and systems for control and security in the vehicle usually are not real time systems. Such systems should provide drivers and passengers needed information, safety and comfort. In such systems the wireless communication is suitable, applicable and recommended for use because is not needed high level of reliability.

There are many systems within automobile chassis that control interaction of car with road surface and with all chassis components. Such systems are: central electronic system of the vehicle body, wheels anti-blocking braking system (ABS), electronic stability control system (ESC), four wheel drive system (4WD), vehicle control board system, information and entertainment system, external communication system, remote unlocking system [1-4]. In many of those systems the wireless communication is used or is applicable and recommended for use.

Systems in motor vehicles were developed from completely mechanical systems to fully electronic systems. Electronic systems in vehicles were initially analogue. Digital systems are mostly used in modern vehicles [1-4]. The first electronic systems installed in motor vehicles were systems such as:

- Electronic fuel injection regulation system (Common Rail),
- Light control system,
- Speed measurement system,
- Safety and assistance in the driving by use of anti-lock braking systems (ABS).

The modern motor vehicles have many other systems, such as:

- Communication between different sensors controlled by central processor,
- Autonomous cruise control (ACC),
- Autonomous vehicles that use artificial intelligence and operating systems in real time,
- Systems for safety of vehicle, driver and passengers,
- Global positioning system (GPS),
- Systems for improving energy efficiency,
- Parking assist systems,
- Cruise control systems,
- Vehicle networking systems.

Newer types of applications of embedded microprocessor systems in vehicles are communication between vehicles and communication between vehicles and the environment. Such systems are rapidly developing and parts of such systems are embedded specialized microprocessor systems within vehicle itself. In those systems the wireless communication is used or is applicable and recommended for use.

Modern vehicles are networked microcontrollers where sensors provide connection to real environment. Sensors collect information from outside environment, that is transmitted to microcontrollers where are made decisions about the possible need for action of certain functions of vehicle [1-4]. Many physical, mechanical, thermal and other characteristics are measured in many locations in vehicle and send to microcontroller. The microcontroller monitors measured values and starts appropriate control functions. In modern vehicles, number of sensors exceeds several hundreds. In such many such situations for sensor connection the wireless communication is suitable, applicable and recommended for use.

Some of the most common functions and systems implemented electronically in modern cars are [1-4]:

- Anti-lock braking system (ABS),
- Electronic stability improvement system or Electronic stability program (ESP),
- Automatic maintenance of the distance or Adaptive cruise control (ACC),
- Minimizing of harmful gases emissions by monitoring of exhaust gases and optimizing the mixture of fuel and air,
- Blocking the window lifters if they encounter unknown resistance when lifting,
- Warning signals for doors that are not adequately closed, insufficient fuel in vehicle tank, slippery road, not applied safety belts, etc.,
- System for airbags management,
- System for noticing and warning driver about vehicle in the "dead angle",
- Driver warning system when leaving the traffic lane,
- Parking aid system,
- Adaptive light management system,
- Recognition and identification of traffic signs.

Embedded systems and applications in modern vehicle, depending on the vehicle performance and/or safety requirements, can be generally classified into following domains [1-4]:

- The Body domain - provides user comfort features that are not safety critical and have low quality of service requirements,
- The Power train domain - performs engine control, power delivery and transmission and has hard real-time requirements,

- The Chassis domain - includes systems that affect vehicle dynamics and controllability like steering, brakes, and suspension. These are safety-critical functions since they affect the behaviour of the vehicle and its response to driver inputs,
- Telematics and In-Vehicle Infotainment (IVI) domain – includes systems that integrate high speed multimedia, driver assistance systems and the human-machine interface (HMI). This domain typically has soft real-time constraints,
- Occupant safety domain - includes systems primarily concerned with active protection for passenger safety and thus has strict real-time requirements,

Each of the domains requires different levels of service, such as response time, bandwidth, redundancy and error detection [1-4]. In many of the domains and services it is applicable and recommended to use the wireless communication technologies.

General architecture of an ECU (Electronic Control Unit) is shown in Figure 1 [1-4]. It is typically consisted of processing element, network interface and associated storage. The processing element may be microcontroller, general purpose processor or application-specific controller. The processing element usually integrates common peripherals (like timers and ports) and interfaces (like I2C or SPI interfaces). Using and placing of many ECUs, sensor units and actuator units in certain parts of the vehicle create distributed computing architecture. ECUs integrate automotive standard network interfaces to support the distributed model. ECUs that handle an extensive amount of data and computation may also incorporate dedicated accelerators (additional hardware) and memory systems like DRAM. ECUs can also incorporate additional features like security extensions, hardware cryptographic blocks, or others.

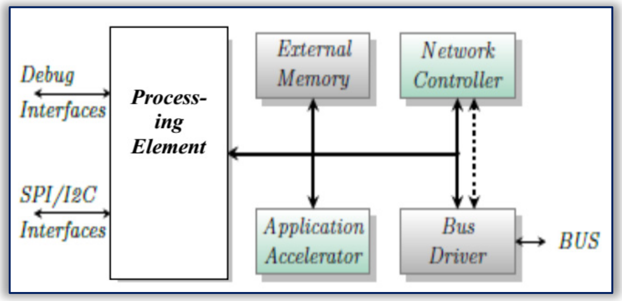

Figure 1. General ECU architecture

There are many developed networks and network protocols for application in the motor vehicles [1-4]. Modern vehicles use different network protocols in different domains. Choice of used protocol depends on real factors such as the functional requirements of the domain, criticality, cost and similar. The most widely used protocols of the many protocols in motor vehicles are [1-4]:

- Local Interconnect Networks (LIN),
- Controller Area Networks (CAN),
- FlexRay,
- Media Oriented Systems Transport (MOST).

The network in the vehicle is partitioned into different functional domains. A backbone network is used to interconnect the different domains and to transfer data between them. High Speed CAN (HS-CAN) or FlexRay are usually chosen as network backbone because of their higher bandwidth. The different domains connect to the backbone through gateways. Gateway provides interfaces to multiple networks like Low Speed CAN (LS-CAN), HS-CAN, FlexRay, LIN and MOST, depending on functional requirements of the domain and network protocols used. Gateway also provides interface with the backbone network.

3. WIRELESS COMMUNICATION IN AUTOMOBILE

There are few wireless communication technologies that are used or could be used in the motor vehicle:

- Wi-Fi technology,
- Bluetooth technology,
- NFC technology,
- ZigBee technology.

The wireless communication is already used in information and entertainment systems of the vehicle. It is primarily the Wi-Fi wireless standard for communication that is widely used on smart mobile phones, tablets and mobile personal computers. Because of its characteristics this standard is not appropriate for application in vehicle for communication of vehicle systems. It could be used for communication of vehicle with Internet.

For usage in some systems in the vehicle interesting is application of the Bluetooth wireless technology. It is possible to use, by the Bluetooth technology connected, sensors and actuators at many places in the vehicle. Especially suitable for such connection are time non-critical places of application in the vehicle, such as fuel consumption indicators, tires pressure measurement, open door indication and similarly. The main disadvantages of the Bluetooth technology are that this technology is not yet in adequate industrial usage and that there is limit in number of nodes that can communicate in the network. But, application of this technology in automobile certainly has successful future and many automobile manufacturers already implemented or will be implementing it at different places in the automobile (for example Bluetooth headphones that can be used in automobile).

The NFC (Near Field Communication*)* wireless technology can be also used in the automobile, mainly for user identification, for example using smart mobile phone. But, application of this technology in embedded systems in the vehicle is limited due to the small communication range of such technology. It could be used for user identification for car entrance, car starting and similar.

Application of the ZigBee wireless communication technology in the automobile is very promising for connection and communication of many systems, sensors and actuators in the vehicle. The advantage is that the ZigBee technology is very used in the industrial applications. Also, there is not limit in the number of nodes that can communicate in the ZigBee network. The ZigBee as a standard with very low emitting energy is successfully dealing with the problem of coexistence with other networks in 2.4 GHz range. It uses low signal energy what is very important for automotive industry because of standards used in this industry [5]. Because of characteristics of the ZigBee wireless communication it is proposed in this paper to use the ZigBee technology in many places in the vehicle.

ZigBee Alliance developed wireless technology to eliminate certain lacks in WiFi and Bluetooth wireless technologies [5]. ZigBee is low cost and low power consumption standard for wireless monitoring and control. Many of the features that have this technology can be classified according to the application. For example, where security is important, it is possible to implement encrypted data exchange. In applications where energy consumption is significant, wireless sensor nodes based on ZigBee technology are configured to have minimal energy consumption. This technology also supports different network topologies. Table 1 shows the basic features of ZigBee wireless communication technology [5]. Devices based on ZigBee technology are referred to as nodes. These nodes consist of a number of electronic components, including sensors for measurements of some physical parameters.

Table 1. Basic features of ZigBee wireless technology

Feature	Value range
Frequency band and data transfer rate	868 MHz, 20 Kbit/s, 915 MHz, 40 Kbit/s, 2.4 GHz, 250 Kbit/s
Range	(10 - n10) m
Delay	Under 15ms
Addressing mode	All devices have 64-bit addressing support
Channel access	CSMA-CA
Cryptographic protection algorithm	128bit AES
Number of devices in the network	2^{64}
Working temperature	-40°C - +80°C

ZigBee technology is based on the IEEE 802.15.4 standard that defines basic features of this technology. ZigBee uses two lowest layers of 802.15.4 standards and operates at three different frequencies: 868 MHz (for Europe), 915 MHz (for North America) and 2.4 GHz (for all countries). Frequency of 2.4 GHz is most often used as it is accepted and free for any country. In the ZigBee system it is possible to use different network topologies. In all topologies it is possible to use three different types of ZigBee devices: FFD (Full Function Device), RFD (Reduced Function Device), ED (End Device) and ZigBee (PAN) coordinator. The ZigBee coordinator is used to manage and initialize ZigBee network and to control the data exchange within the network. RFD type devices are end devices that implement tasks defined by the ZigBee coordinator.[5] FFD type devices have functionality of data routing between the RFD devices and the ZigBee coordinator and performing all tasks in the ZigBee network.

Depending on the frequency used, it is possible to achieve the data transfer speed in the range (20 - 250) Kbit/s and the distance to 100m [5]. In applications in motor vehicles, there is no need for great distance between the devices (up to several meters). Which of the above topologies will be used depends on the complexity of the application, the complexity of entire system and the environment. Figure 2 shows examples of the ZigBee network topology [5]. Although the speed of communication between devices is relatively low, for many applications in motor vehicles this speed satisfies required conditions.

Used frequency bands create channels for transmission of data. ZigBee contains two layers: the physical layer and the layer of media access (so-called MAC - Medium Access Control) [5]. It is used in wireless personal area networks (WPAN) of short range and low power consumption [5]. The standard uses different frequency bands and three different modulation schemes are used for each of the frequency bands. Each of the channels within one band has predefined speed of data transmission. As a mechanism for resolving collisions and accessing channels by multiple devices (nodes) it is used the Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA). With this mechanism, each device checks whether particular data transmission channel is busy, going to the data receiving mode.

ZigBee standard defines two types of network topologies. One network topology is the star and the other is the node-to-node (or peer-to-peer) topology in which can be FFD and RFD devices (Figure 2) [5]. These network topologies define roles of nodes, their priority and way of communication that occurs between nodes. Both of topologies use PAN coordinators that manage network by providing needed activities.

All devices communicate on the basis of address that is unique to each device or is defined a unique address by the programmer. In this way, the packet transmission to particular node is defined and it is possible to identify other nodes in the network. All devices in any network topology of ZigBee standard can have 64-bit address [5]. This address represents 64-bit address or serial number of the wireless module. In addition to that address it is also used 16-bit address defined by nodes (by programmer) in order to specify the unique device in the network.

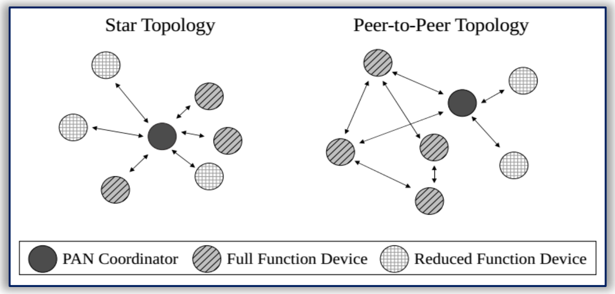

Figure 2. Examples of the ZigBee network topology

The physical layer of the network is closest to the hardware and performs the functionality of connecting devices and switching data transfer. By realizing these functionalities, the physical layer is serving layer of higher level, the MAC layer that enables data operations and management service. The physical layer provides two services in its functional architecture: data service and management service. The data service performs data transmission to the MAC layer. The management layer performs management and transport of commands. In addition, physical layer has predefined constants that define certain properties of the layer and its data frame, attributes that represent variable values.

The MAC layer controls access to transmission media in the form of access control to particular channel by a node. This is realized in form of association and deassocation of nodes in the network. If at some moment it is necessary for device to realize packet transmission, the MAC layer checks potential channel occupancy so that at certain moment only one node can realize transmission of the packet over that channel. This checking process is implemented by the CSMA-CA technique. In case that the channel is not free then a certain period of time is stopped in order to avoid collision. In this wireless technology, the MAC layer is in direct conection with the network layer for which it provides various services.

Important feature of MAC layer is use of so-called superframes. Using superframe it is possible to realize efficient access to the channel and packet transmission, which has advantage of energy saving in wireless nodes. The superframe used by the coordinate node can contain an active and inactive period and is divided into 16 equal slots. In case of an inactive period, the coordinator can switch to low-power mode. This framework is combined of two so-called beacon frames and uses the features of Guaranteed Time Slots (GTS). There are three types of periods in the superframe: the Contention Access Period (CAP), the Contention Free Period (CFP) and the inactive period. Beacon frame is used for synchronization of connected nodes, identification of PAN network, and description of the super frame structure [5].

Figure 3 shows structure of the superframe [5]. If the corresponding node wants to achieve communication session during the CAP between two beacons, then it "competes" with other nodes using the CSMA-CA mechanism to access particular channel. In this case, the channel is equally available to all nodes of the network. When the node takes the channel, it uses it until completes the transmission. However, it is not certain that the node during CAP can take the channel it needs. This is important when the delay is not acceptable and in such situations the node uses the CFP period. This CFP is enabled for special nodes and in this case the CSMA-CA mechanism is not used. In the inactive period, which is intended to reduce energy consumption, the coordinator can switch off its radio transmitter and switch to power save mode of low power consumption [5]. It can be seen from Figure 3 that one GTS takes one or more time slots. However, the total number of GTS can not be greater than seven. Also, it can be seen that GTSs belong to time slots that occupy part of the frame intended for the CFP time interval. The inactive period in which the coordinator (potentially and other nodes) in the network can go into state of low-power operation is important if no activity

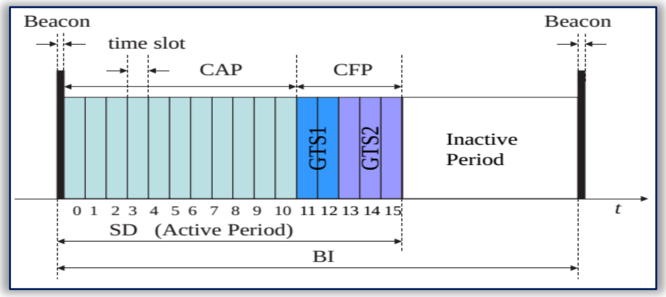

Figure 3. Structure of MAC superframe

of nodes is required which results in energy savings. In addition, each node has a defined time of beeing in this mode. The structure of the superframe uses GTS for individual time slots, but there is also a structure that does not use the GTS and as such contains an active and inactive period (which is important in order to save energy). Figure 3 shows the time interval of the beacon (BI) and the duration of the superframe (SD) in active period. The BI and SD information is contained in the beacon framework that sends the coordinator to the PAN network. After that, each node that receives the beacon frame must decode the information at the level of the superframe in order to synchronize with the PAN coordinator and other nodes. The total duration is defined by 960 symbols, each of which corresponds to 4 bits, assuming transfer speed of 250 kbit/s at 2.4 GHz frequency band. If a node does not use GTS for a certain period of time, the identical GTS coordinator can assign to another node.

The MAC layer in wireless networks plays important role in association and deassociation of nodes, establishing reliable connection, enabling energy savings, using GTS and CSMA-CA, and synchronizing between nodes. These capabilities are fundamental for establishing reliable wireless data exchanges in the wireless network, primarily in applications and systems with high reliability.

4. SIMULATION AND ANALYSIS OF ZigBee WIRELESS COMMUNICATION IN AUTOMOBILE

For the purpose of simulation and analyze of possibilities and characteristics of application of the ZigBee wireless technology for communication between elements in the vehicle there were created, developed and implemented appropriate simulation models in OMNET++ [6] development environment using development platform Castalia [7]. Obtained results and conclusions are presented in the paper.

In the simulation there were created and used three simulation models to analyze some real influences on the communication. There were also created two variations of the last third model to test different influences on that simulation model and communication parameters.

The initial observed model is an ideal model of an imaginary vehicle of dimensions of 2x3x1meters (Figure 4). In this case the vehicle is stationary without movement and there are not any external or internal noise and interference that influence on the vehicle. Figure 4 also shows positions of five of the ZigBee wireless nodes used in the vehicle. It is supposed that this nodes monitor and control vehicle side door windows.

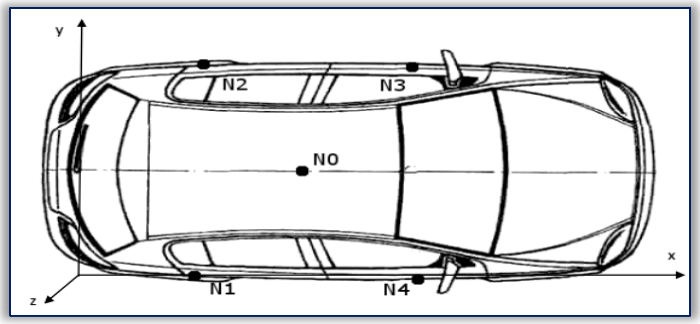

Figure 4. Vehicle and positions of wireless nodes

Table 2. Positions of nodes in vehicle

Node	Coordinate x	Coordinate y	Coordinate z
N0	2	1	0
N1	1	0	1
N2	1	2	1
N3	3	2	1
N4	3	0	1

The vehicle has one main coordinator node (node N0) and four sensor nodes (node N1 to N4) that are connected wirelessly using the ZigBee protocol. The nodes are placed at precisely defined positions and distances, with appropriate coordinates, as it is shown in Table 2 (all dimensions are given in meters).

It is supposed that the nodes exchange data packages of 2500 bit length. It is also supposed that sensor nodes monitor and control are the vehicle side door window glasses open or closed. Node N0 is coordinator node while other nodes are placed in positions of side door windows of the vehicle. Duration of simulation was set to 60 seconds.

In all the simulations it was observed and analysed:
- Number of correctly received data packages of each node,
- Energy consumption of each node,
- Number of errors of each node,
- Number of sent data packages.

Some obtained results for the first ideal model are shown in Figure 5. It can be seen from Figure 5 that in the ideal case there is negligible number of rejected (non-received) data packages.

The next observed model was the model with noise influence (the second model). In that model it is the same vehicle but there exists a noise that occasionally disturbs communication of the nodes. The noise is generated in the vehicle or out of the vehicle. There were observed and analyzed the same parameters as in the first model. Time of simulation was also 60 seconds. Some obtained results for the second model are shown in Figure 6. It can be seen from Figure 6 that there is slight increase of number of rejected (non-received) data packages compared with the first model.

The last observed model (the third model) is the closest to the real situation. In that model it was analysed influence of vehicle movement and it was taken in the consideration that the vehicle is moving with certain speed. There were simulated and analysed two vehicle speeds. The first speed was 30km/h, and the second speed was double of the first speed, 60km/h. In the model was not included noise influence. It is obtained and determined in this case that the vehicle movement speed does not influence negatively on observed communication parameters.

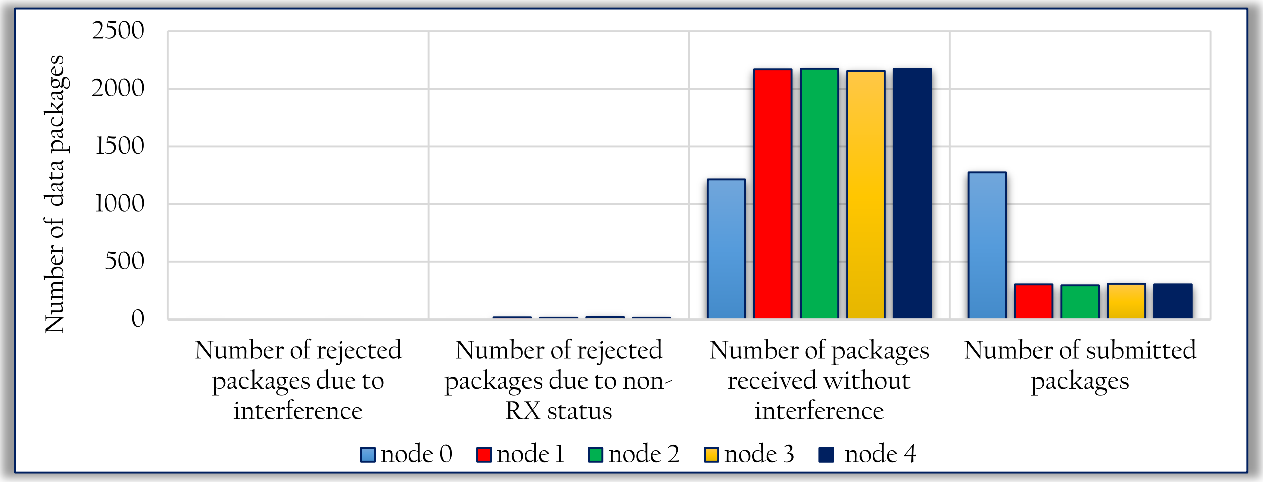

Figure 5. Number of exchanged data packages on physical layer for first model

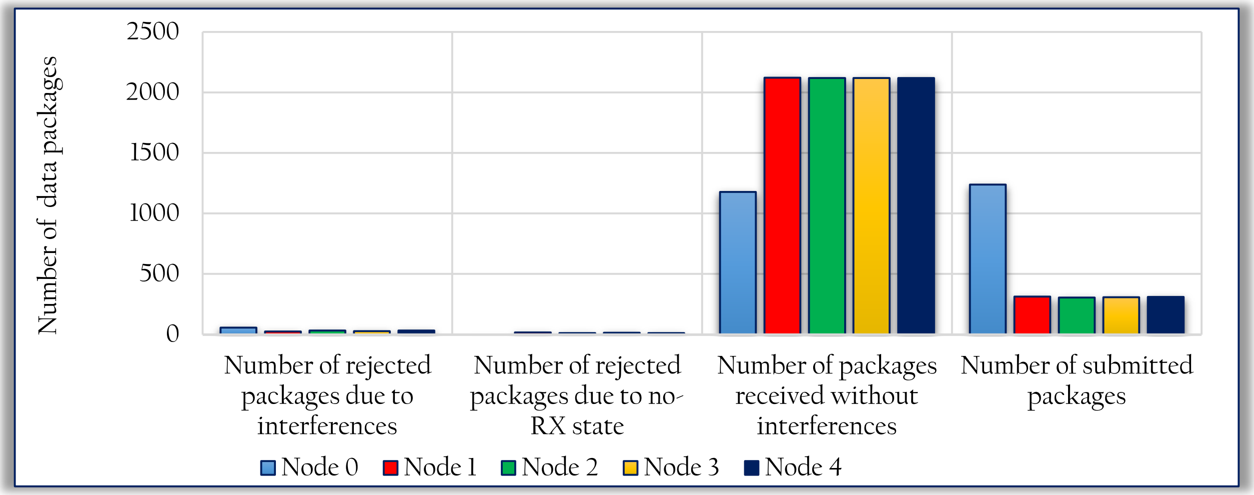

Figure 6. Number of exchanged data packages on physical layer for second model

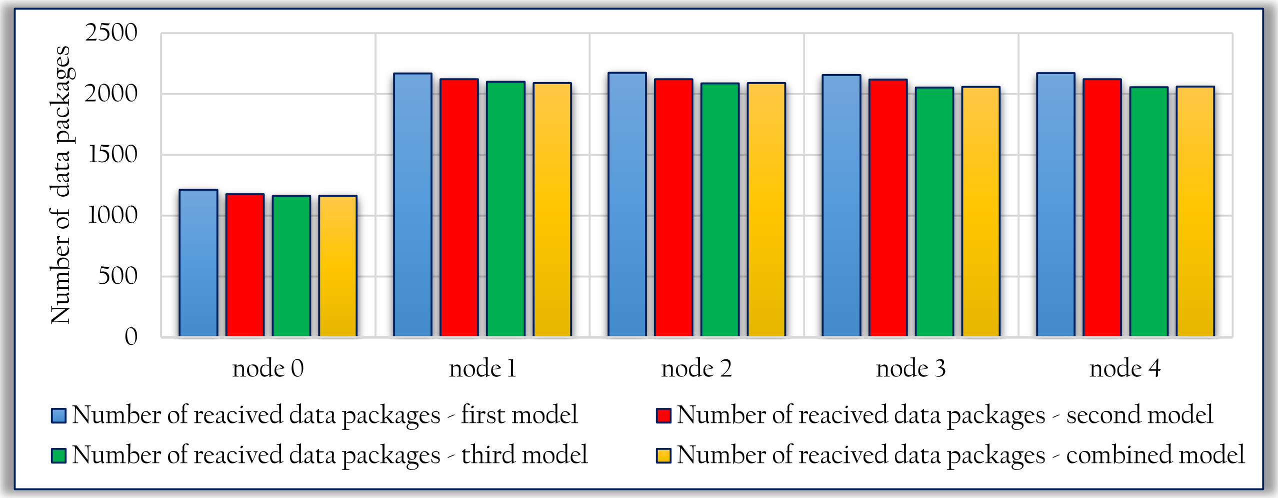

Figure 7. Number of received data packages for different simulation models

Finally, the third model was modified including noise influence as in the second model. Such was obtained so called combined model, closest to the real situation, where there are existing vehicle movement and noise influence. This model combines models and parameters of the second and the third models of simulations. There were used model and parameters of noise signal from the second simulation model, and model and parameters of vehicle movement from the third simulation model. Such was simulated and analyzed influence of both, influence of noise and influence of vehicle movement in the same time. Some obtained results for this combined model are given in Figure 7 and 8, compared with results obtained for previous three simulation models.

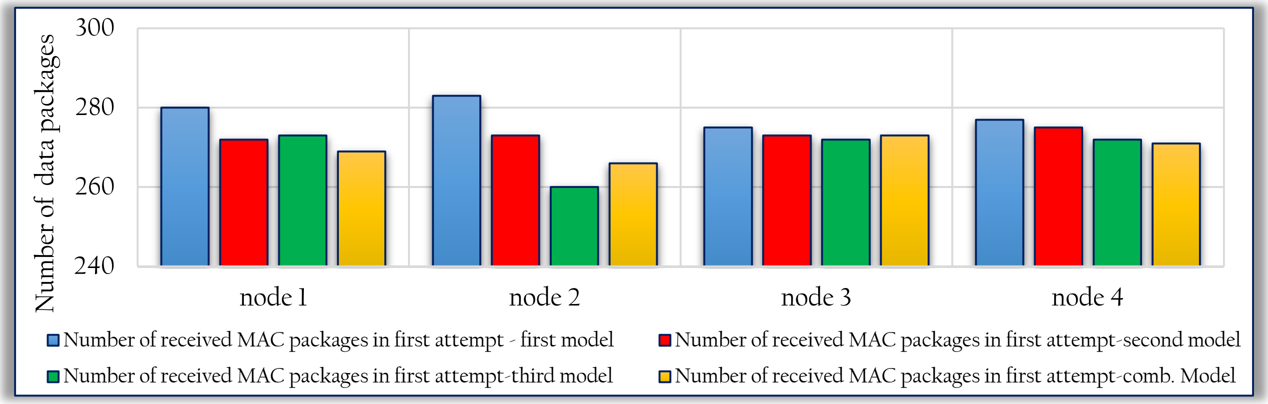

Figure 8. Number of received MAC packages in first attempt for different simulation models

It was also observed, simulated and analyzed energy consumption of each node for different simulation models. Some of obtained results are shown in Figure 9. As it can be seen in Figure 9, there are no greater deviations in energy consumption of nodes for different simulation models. It also can be seen that total energy consumption of each node is very small (less than 0.42 mW). The main coordinator node (node 0 or N0) has the greatest energy consumption. Other nodes have approximately the same energy consumption.

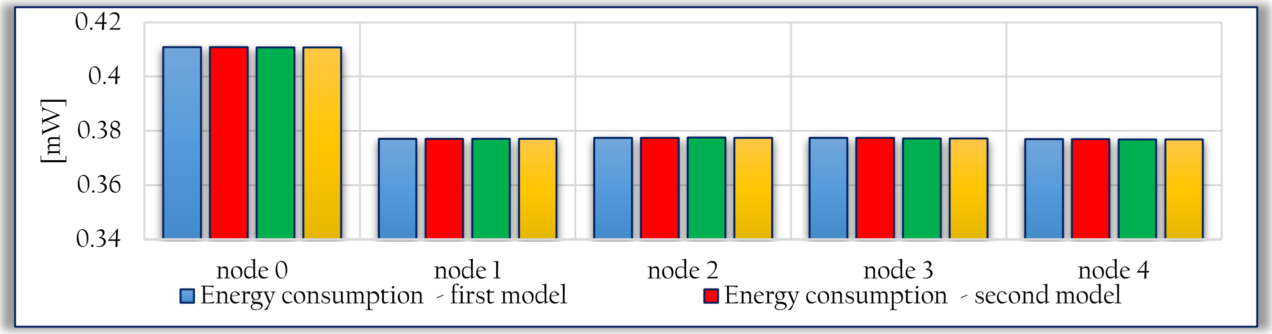

Figure 9. Comparison of nodes energy consumption for different simulation models

5. CONCLUSIONS

Modern motor vehicles as very complex objects are very suitable for application of embedded microprocessor or microcontroller systems. Such embedded systems are used for acquisition of data from vehicle sensors, for processing the data and for monitoring and control of processes that are performed during operation of different systems in the vehicle. Modern motor vehicles are systems with dozens of connected and networked embedded microprocessor or microcontroller systems.

Permanent and rapid development of wireless communication technologies creates possibilities to use such technologies in a motor vehicle. It is possible to use different wireless communication technologies in networking and communication of some parts, elements and systems of motor vehicle. It gives many advantages and has great potential in comparison with usual wired communication and networking technologies. The main advantages and benefits of using the wireless communication technologies in the motor vehicle are: decreased complexity of interconnection, decreased weight of vehicle, decreased vehicle occupation space and decreased vehicle cost. As the wireless communication technology that is the most appropriate for application in the most applications in the motor vehicle in this paper was identified, recommended and proposed the ZigBee wireless technology.

On the basis of all obtained and shown results of simulation of wireless ZigBee communication in motor vehicle, it can be made one general conclusion that the communication between vehicle network nodes is performed successfully in all the communication models. Noise, internal or external, as well as the vehicle movement, were not significantly disturbed such ZigBee wireless communication of the vehicle nodes. Obtained results and analyses show that it is very small percent of rejected data packages on the physical and data layer. It is evidently that there are not greater obstacles to be achieved very successful wireless ZigBee communication between nodes in the automobile.

Based on theoretical considerations and analysis of simulation results, it was concluded that application of wireless communication between the embedded microcomputer systems in automobiles using ZigBee standard (IEEE 802.15.4 standard) is justified and cost-effective. Wireless communication of embedded microprocessor systems is possible, especially in time noncritical systems and applications. It was proved by simulations on the model of communication of sensors for opening and closing side windows of vehicle doors. This application is not time critical but is not insignificant for the security in the automobile. This embedded system was used for check of the functionality of application of the ZigBee communication in automobile. Obtained simulation results of operation of such wireless system show that the wireless communication is feasible as functional in automobile, in time uncritical and less processor time demanding systems. Such systems in motor vehicles where can be used wireless ZigBee communication are for example: measurement and indication of internal and external temperature, oil temperature and cooling liquid temperature in the engine, pressure in tires, fuel quantity, oil quantity, cooling liquid quantity, amount of windscreen washer fluid, harmful gases emissions, control of the doors and windows closure, seat belts control, control of the exterior mirrors, air conditioning system, light control system. The ZigBee wireless communication can also be used for communication between vehicles, and for communication of vehicles and the environment. It is really real to expect that such way of communication using ZigBee wireless standard will be more and more used in the automobile because it resolves two important problems. Those problems are adaptation of communication speed to the needs of the system and certain level of communication protection (using cryptographic methods).

It is concluded, proposed and recommended in this paper that, because of many advantages and benefits, the wireless communication technologies should be used as much as possible in the motor vehicles. The wired communication technologies should be used only in time critical, high processor speed demanding and for security critical systems in the automobile. There is smaller number of such systems in the vehicle. For all other motor vehicle systems it is proposed and recommended to use some type of the wireless communication technology. It is concluded that the ZigBee communication wireless technology has the greatest possibilities for application in the motor vehicles. It is proposed and recommended that the ZigBee communication be used in all systems that are not time critical, not high processor speed demanding and for security not critical systems in the automobile. There is greatest number of such non critical systems in the vehicle. Only for some specific non critical applications and systems could be and should be used other wireless communication technologies, NFC technology and Wi-Fi technology.

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