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Case study-based ZigBee network implementation for maritime on-board safety improvement

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Abstract **– This paper is dedicated to some aspects of maritime on-board safety improvement. Analyzed aspects concern the measurement and control signal transmission on marine environment. The main topic faced by the paper is concentrated on case study-based ZigBee network implementation in the area of the acquisition of data from sensors and measuring transducers connected to the terminal network. The exemplary implementation of ZigBee network, elaborated in Gdynia Maritime University is related, firstly, to the configuration of a simple wireless measurement and control channel, and secondly, to wireless communication channel supported by autonomously working microprocessor measurement and control system. Finally, some concluding remarks are formulated**.

I. INTRODUCTION

Nowadays ships are very sophisticated technical objects operating in marine environment. A modern automated cargo ship as an object of measurement and control can be described by a complex structure of four main systems: navigation, power, cargo and crew living conditions [1]. All these systems require supervision by measurement and control sensor networks for ensuring safe and effective ship operation, including its fundamental mission: transportation of cargo and people. At present, the distributed microprocessor systems are usually used for implementation of the measurement control monitoring and safety functions related to previously mentioned ship systems. Taking into account a negative impact of hostile marine environment, communication is essential for maritime safety, integrated operations and for information technology purposes. In this context, marine environment is a special area considering working conditions of people and devices installed on a ship. Many factors contribute to this state of affairs, including [2]:

- high relative humidity in presence of sea salt,
- high temperature prevailing in many rooms of the ship,
- accumulation of devices, including electrical ones, in a small space,
- relatively frequent emergency situations and the related need to work in cases requiring immediate action,
- work in conditions of limited space,
- monotony and routine in the performance of work,
- rolling, pitching and tilting the ship,
- noise and vibrations.

Therefore, safety issues of crew and ship equipment play key role in the operation of the ship. Safety also includes the exchange of measurement and control information between people and devices, as well as between the devices themselves. Analyzing the possibilities of safety improvement of aforementioned information exchange two aspects should be taken into account: connectivity of related sensor networks and technology for data transmission. A large number of cable connections on a ship is a challenge for ship designers. The cables are deployed in a complex and extensive network of cable trays. The cable connections creating communication channels must grant a whole range of requirements related to resistance of signals transmitting information against disturbances and correctness of transmission. In many applications, a special mechanical construction of cable is required for affirmation of immunity on mechanical factors (tension, vibrations, friction, etc.), particularly, when the connections are applied among movable devices. Since deploying full-scale wired sensor networks on a ship loads to complexity and high costs, in [3] a Wireless Sensor Network (WSN) solution was proposed. Fundamentals and many interesting information related to this solution namely WSN technology, can be found in [4]. In [5] authors have conducted ZigBee measurements on the passenger deck of a ship and a small WSN has been deployed between the main engine room and the control room. Next in [6], a WSN has also been tested successfully in the main engine room of a ship. Finally, in [7], a WSN on board a ferry moored in the harbor has been tested. All these measurements have been carried out when the ships were moored at port. To date of study [8] experiments during ship operation have not been carried out. To complete hitherto existing state of the art, in paper [8] authors studied the possibility of replacing the wired shipboard monitoring system by a WSN technology. Since the main engine or other equipment and the passengers' movements (metallic door closing and opening) can affect the quality of wireless communication, it is necessary to conduct measurements with a ship in operation. This environment has a specific metallic structure which makes the wireless communication more difficult than in other classical indoor and outdoor environments. Two types of experiments based on dedicated measurement setup [8] have been carried out on board a ferry-type boat during sailings and stopovers. Measurement setup is discussed in the wake of characteristics of considered environments and the technology used for the measurement campaigns. Aforementioned characteristics describe the measurement sites properties and localization and used technology based on IEEE 802.15.4 standard as well as define related frequency band. When several wireless standard have been developed for WSN with the key design requirement for low power consumption and adequately chosen frequency band. The equipment based on previously cited IEEE 802.15.4 is operating in the 2,4GHz ISM frequency band. The first experiment [8] consist of point-to-point measurements using ZigBee-based equipment and the second one consists of deploying and testing a WSN on board of ferry. Point-to-point communication tests [8], covered communication between nodes placed in the same room, communication between nodes placed in adjacent rooms, and communication between nodes placed in adjacent decks. These tests have proved that communication becomes impossible when two watertight doors between the two communicating nodes are closed. Next, wireless sensor network deployment was described and results analysis of its testing based on the packets statistics led to conclusion, that the transmission ratio of all nodes was higher than 97 % [8]. That is, the results have shown very good network reliability, documented this way, that more than 97 % of packets of each sensor node have arrived successfully to the base station. The obtained results have shown that the wireless solution may be a cost-effective alternative to the huge amount of cables used currently to connect sensors to central control units. Aforementioned experiments [8] are one of the first tests conducted on board a ferry during sailings and under realistic condition. Nevertheless, a later on, based on some different sources, the authors of the paper [9] were stated, that although feasibility of WSN technology in ship applications can be justified from next examples from the literature (among others [8] and [10]), real deployments still meet difficulties.

Interestingly, boat electrical systems break down more often from the failure of some mechanical (rather than electrical) connection issue, like a parted wire splice, a frayed wire, a loose connection, or a missing or loose screw. Each of these can interrupt electricity flow, causing equipment to not work at all or to operate at less than optimum levels.

Some considerable part from above mentioned cable connection problems is possible to solve by applying wireless technologies for data transmission. Similarly, the wireless communication seems to be reasonable application, where either the object of measurement or control device is situated in an inaccessible place or where the structure of the cable connections is expensive.

Although there are many networks functioning in industry, a lot of devices are still not connected to any network, because the cabling engineering is very costly. Additionally, wireless connection devices usually comprise the ADC converters on board, so data acquisition becomes more homogeneous. Digital data is transmitted to PC, so the problem of conversion of analog information into its digital representation on the entrance to PC disappears. It is worth adding, that in [9] was stated: "as we know that neither a wired or wireless solution of deploying sensor networks on board will function well alone to combine their strength together becomes on intuitive thought". This idea, referring in fact to hybrid sensor networks was implemented in [11] and [12].

In the last years, several techniques of wireless exchange of information have been developed (e.g. Bluetooth, Wi-Fi, WiMAX, ZigBee, GSM, UMTS, etc.). Some of them have successfully been applied to distributed measurement and control systems.

With the wireless communication technologies we can easily make so far inaccessible data visible, moreover, the next wireless applications in industrial automation are expected.

The development of wireless sensor networks (WSN) was originally motivated by military applications such as battlefield surveillance. However, wireless sensor networks are now used in many industrial and civilian application areas, including industrial process monitoring and control, machine health monitoring, environment and habitat monitoring, healthcare applications, home automation and traffic control. A wireless sensor network consists of spatially distributed autonomous devices using sensors to monitor physical or environmental conditions, such as temperature, pressure, vibration, etc. at different locations.

An added value of this paper concerns the design and carrying out of the exemplary implementation of ZigBee network elaborated in Gdynia Maritime University (GMU) consisting of two cases: firstly, as ZigBee application dedicated to valve control, and secondly, as wireless communication channel supported by autonomously working microprocessor measurement and control system cooperating with the ZigBee network. The experiments carried out were based on the authors' physical models (prototypes of the ZigBee End-device as well as microprocessor measuring and control devices were developed) and were completed by application of the LabVIEW environment.

Following the introduction, the rest of this article is structured as follows. In Section II a short information about metal compartment and partition onboard a ship is presented. Section III describes ZigBee network self-organization of communication. In Section IV exemplary peripheral devices of wireless network elaborated in Gdynia Maritime University are presented and described. Section V shortly presents the carried out research and explain obtained results. Finally concluding remarks and future works directions are formulated.

II. METAL COMPARTMENT AND PARTITION ONBOARD A SHIP

The wireless communication on board vessels is limited by several factors. Metallic structure of bulkheads and watertight doors severely decrease the power of received radio signals. Moreover, due to the metallic environments on board ships, propagation effects like the multipath can be a serious cause of received signal degradation [4].

The solution can be the installation of repeater nodes (Routers) to overcome metal obstacles. They can be installed in dedicated tunnels in the partition walls (Fig. 1).

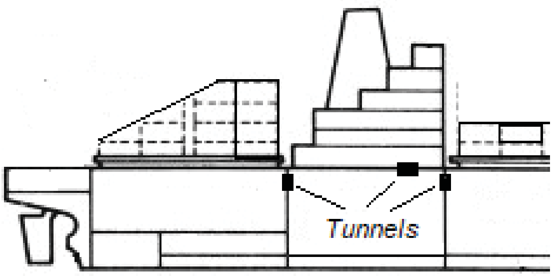

Fig. 1. Wireless communication tunnels.

These tunnels help solve the problems of the aforementioned limitations in wireless communication by metal structures on the ship.

III. ZIGBEE NETWORK SELF-ORGANIZATION OF COMMUNICATION

After around a decade of active research on wireless sensor networks, recent standards released are stimulating the development of commercial products. One of these standards is the ZigBee wireless sensor network.

The complete ZigBee mesh network equipment consists of three types of devices: Coordinator (C), Router (R) and End-device (E-d) (Fig. 2). The Coordinator is mainly responsible for organizing and maintaining the network. It is used to start and manage the network, and also provides an interface in communication with the central processing unit (PC). Routers as intermediary network nodes, responsible for data routing, provide access to End-devices. The Routers deal with the division of network into subnets and the transmission of packets between network devices (e.g. from the End-device to the Coordinator). The End-devices, connected for example with a measuring transducer, sends measurement data to the Router (or directly to the Coordinator, if accessible). It can be turned off most of the time. This way of working and low energy consumption is the advantage of the End-devices. They are only excited for a few milliseconds to read data from an external converter or to communicate with other devices in the network.

A self-organizing network is an automation technology designed to make easy the planning, configuration, management, optimization and healing of wireless mesh networks. Among others, a ZigBee mesh network can automatically and seamlessly configure connections between End-devices and Coordinator, continually seek opportunities to improve their own performance and efficiency as well as automatically detect, diagnose, and repair localized software and hardware problems.

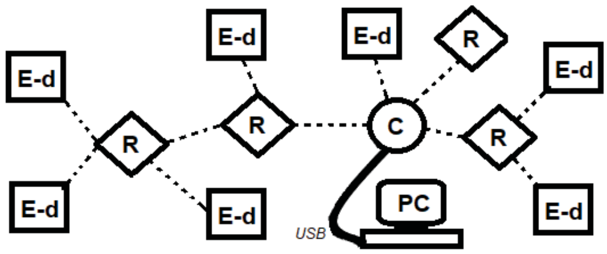

Fig. 2. A ZigBee mesh network.

In ship condition, a network self-organization property is particularly important, because of redundancy needs.

IV. EXEMPLARY PERIPHERAL DEVICES OF WIRELESS NETWORK

The typical use of ZigBee network is associated in most cases with the acquisition of data from sensors and measuring transducers connected to the terminal equipment of the network. The application supervising the exchange of data has been developed in the LabVIEW environment. The network consists of three types of devices: Coordinator, Router and End-device (Fig. 2).

In the conducted experiments, the ZigBit™ modules on the base of ATmega1281V Atmel microcontroller were used, both in the form of assembled and ready-to-use ZDK MeshBean 2 boards as well as a prototype End-device (Fig. 3), a simplyfied version of ZDK board.

Every ZDK can work as Coordinator, Router or End-device, what is to select using on-board DIP switches.

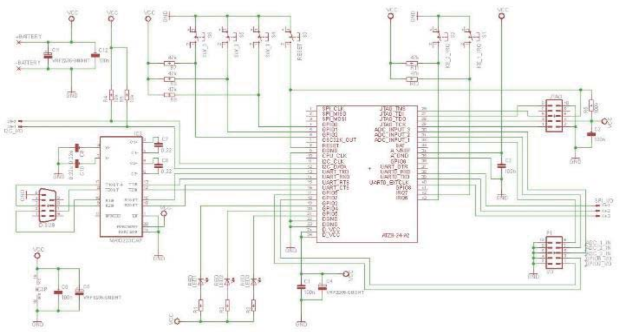

Fig. 3. A diagram of the prototype End-device.

Two examples of ZigBee network implementations have been elaborated in GMU. These applications, in addition to the standard acquisition of sensor data, enable control of any actuator.

In the first solution, the data from Executive Device (Fig. 4), through End-device and Router, is sent wirelessly to the Coordinator that manages the entire ZigBee network, e.g. network initialization, recording of active devices and receiving data from network devices. The Coordinator communicates with the PC via a USB port. The data from the Coordinator is collected and processed in the LabVIEW application.

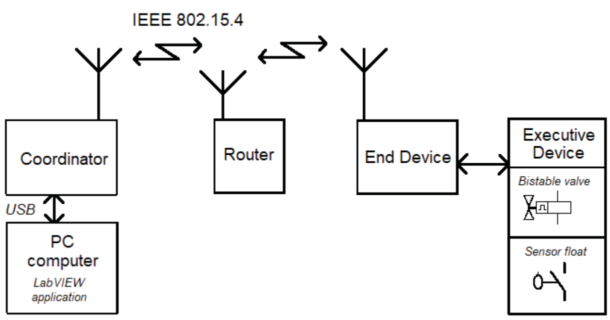

Fig. 4. Valve control in ZigBee wireless network

The firmware stack on the End-device has been modified. A set of commands has been added as a support for reading the status of level sensor and identifying the commands relating to the valve control module (Fig. 5) connected to the End-device in the ZigBee network. The actuating device in the form of a bi-stable valve is connected to the terminals of the valve control module. Such a valve is an element with two stable position states: isolating and opening the medium flow, requiring only a short voltage pulse applied to the valve coil for switching between states. The override between the valve states is realized by the appropriate pulse polarization. Figure 5 shows the electrical diagram of the valve control module.

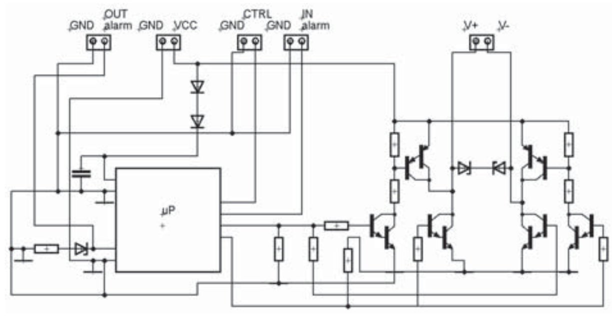

Fig. 5. Diagram of the bi-stable valve control module.

A signal is sent on the CTRL line forcing the valve state to change. The medium level sensor is connected to the IN alarm terminal. The valve coil is connected to the V + and V- terminals. Time parameters of the voltage pulse are set in the µP microcontroller system. The module in stable condition draws a current of approx. 180 µA with 6 V battery power supply, and the valve coil current is approx. 0.32 A in a pulse with a duration of 25 ms. The capacity of the set of standard batteries is enough to power the module for approx. 3 years, with the number of valve switches limited to a few during the day. The above properties of the actuating device correspond to the requirements and operating conditions of the ZigBee End-device, which can cooperate with the described actuator in an autonomous and energy-saving manner for a long period of time. A level sensor is also connected to the End-device, for identifying the alarm state in the medium circuit (Fig. 4).

Figure 6 presents the view of the main application panel designed in LabVIEW for remote, wireless valve control. Before starting the application, the port through which the application is to communicate with the terminal device has to be selected. The valve can be operated manually or automatically. In addition, the window displays the basic information sent via the network, such as IEEE address, short node address (used to identify devices in the network), short address of the parent (Coordinator), WSN channel mask and the type of terminal device. Other parameters available on the panel are the data obtained from the sensors, such as battery status, temperature or lighting. At the end of the frame, a CRC code is sent, used to check correctness of the transmitted data. The considered End-device sends this information, apart from data from temperature and light sensors, and instead information from the float sensor is provided to the Coordinator. Next to the control switch, the alarm line status is displayed, signaling that the medium has reached the critical level. In the alarm state it is not possible to open the valve, in either automatic or manual mode.

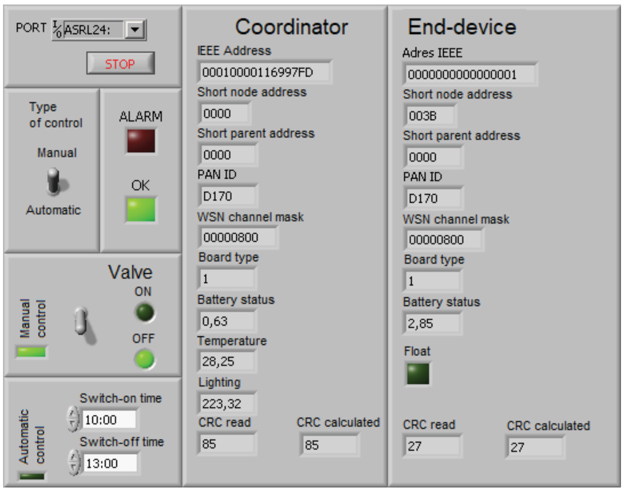

Fig. 6. The view of the main application panel in LabVIEW

First, a ZigBee frame is set up, containing start tags, user data (address and command sent to the End-device), frame delimiter and CRC code (validation of data transmitted between network elements). In the next step, the frame is sent to the Coordinator via a USB port (emulated RS232). In the Coordinator, the frame is read and checked, and then sent to the appropriate device in the ZigBee network. After sending the frame, the Coordinator awaits confirmation of delivery to the indicated device. If there is no confirmation, the sending of frame is retried after a specified time. After receiving the frame in the End-device, which is the addressee, the frame is checked and decoded. The valve is actuated according to the received message. In the next step, the End-device is completed with the float sensor data and sends the frame to the Coordinator, and further to the LabVIEW application on PC. On the basis of the information received, in case of an alarm signal from the float sensor, a command containing an emergency valve closure request is formed.

The second exemplary solution, also elaborated in GMU, consists of a wireless communication channel and is supported by autonomously working microprocessor measurement and control system (Fig. 7). This system communicates with the ZigBee End-device using the I^2C bus.

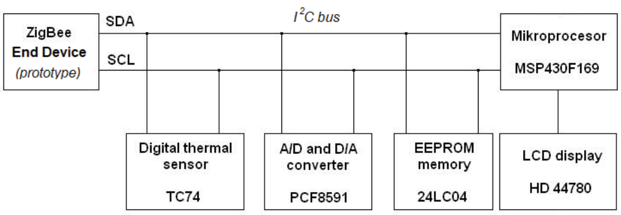

Fig. 7. The autonomous microprocessor system cooperating with the ZigBee End-device.

The prototype microprocessor system additionally contains the TC74 temperature sensor, the PCF8591 with 8-bit ADC and 8-bit DAC as well as the 24LC04 EEPROM memory connected to the I^2C bus. The microprocessor system is connected via a 4-bit interface with an LCD display (HD 44780 controller).

The elaborated peripherals can cooperate with the sensors, transducers and actuators operating as the terminals of a ship safety system.

Miniature versions of the End-devices can also serve in the properly configured ZigBee mesh network as the personal identification tags.

V. RESEARCH

As it was mentioned in Section IV, in the conducted experiments, the ZigBee devices were used, both as a redy-to-use modules as well as a prototype End-device developed in GMU. They cooperated with the dedicated mesasurement and control microprocessor devices as the terminal devices of the network.

The hermetic metal box was used to check the performance of End-device and its peripherals operations. Two experiments were carried out.

In the first experiment, the End-device was placed inside the hermetic box, and the remaining part of ZigBee network was outside. In the second test, the box was equipped with a small tunnel that houses the Router.

As you would expect, successful communication to End-device and its peripheral was possible only in the second experiment. In this case, the communication error rate did not differ from the value in open space.

Other experiments concerned the functionality of the wireless communication channel supported by autonomously working microprocessor measurement and control system, cooperating with the ZigBee End-device.

The benefits of using this system are related to the possibility of local conversion of analogue signals to digital and vice versa, and digital communication via a wireless network with a central unit. Preliminary tests have shown that this solution can be an attractive alternative to analog measuring and control tracks, still used on ships.

VI. CONCLUDING REMARKS

The research performed in laboratory conditions, simulating the ship obstacles well, shows usability of the ZigBee network for various ship applications.

In fact, wireless network devices, such as Coordinator or Router, need permanent cable power supply while End-devices can be battery powered. In practice, local power supply is easily available in all rooms on the ship.

However, building new measurement or control channels or modifying existing ones in ship conditions is much easier with the use of wireless networks. This technology allows flexible configuration of communication channels, easier modification and management. Also, the application of the principle of redundancy in the configuration of ship systems can be implemented in a much more efficient way using wireless networks.

Future works concern the integration of wireless networks, including compact communication modules working in the WiFi standard, and researching the possibilities of their use on the ship.

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