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A ZIGBEE/RFID SAFETY SYSTEM AT THE SEAPORT

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Key words: seaport, workers' safety, ZigBee/RFID.

ABSTRACT

The paper examines three potential safety solutions for the protection of port workers, which are based on a junction of Radio Frequency IDentification (RFID), as an automatic identification, data collecting and positioning system from one side, and ZigBee, as a low energy consumption communication technology from another. The considered solutions are placed in the context of the individual needs and capacities of the developing Port of Bar in Montenegro (South East Europe), which has been operating in the transitional environment for the past two decades. The transitional circumstances prevent the port from adopting advanced occupational and environmental safety systems. Therefore we are proposing models for improving the workers' safety that are at the same time cost-effective, reliable and flexible. More precisely, the on port workers' body area sub networks formed by RFID active/passive devices are treated in the paper as end nodes of the ZigBee network. On the other hand, the forklifts' RFID warning systems are treated as the moving routers of the ZigBee network. Some simulation experiments with such RFID/ZigBee hybrid system in an OPNET environment have been implemented over the Port of Bar container and general cargo terminal layout, while corresponding conclusions have been derived, along with some directions for further research work in the field.

I. INTRODUCTION

Seaports (hereafter ports) are traditionally viewed as an economic springboard for the country development, since their services and manufacturing activities create economic benefits and socio-economic wealth via labor income, business earnings, taxes, etc. (Park and Seo, 2016). Ports also have catalytic economic and social impacts on their corresponding hinterlands. Over the past years, advances in Information and Communication Technologies (ICT) have played a key role in transforming the way they function. The successful transfer and implementation of the actual ICT applications is a prerequisite for their greater business achievements. However, port innovations cannot be restricted to the adoption of new technologies, which have been mostly ICT driven in the recent years. The so-called soft innovation is currently used to refer to non-technological dimensions such as: people and organization, markets and relationships, knowledge and integration, meanings and experiences (Martino et al., 2013), etc. It seems that both technological and soft innovations can ensure a sustainable advantage to a port. The afore remarked holds true for highly developed leading class ports, but unfortunately not for the developing ones, e.g., the Port of Bar in Montenegro. It has been operating for decades in a transitional environment and it combats with the lack of investments and rigid administration structures, which permanently reproduce crises and prevent its economic development. Through several projects and research papers we have tried to at least enlighten and merely alleviate these problems (Bauk, 2014; Bauk, 2015; Bauk et al., 2015; Bauk at al., 2016). We have been focused on conceiving and developing ICT models for enhancing on port workers' safety and uprising the level of their occupational culture. This paper provides a continuation in this regard, and it is organized in the following manner: (i) it gives a short overview in terms of how working on port can be dangerous; (ii) it considers three available RFID solutions for reducing the workers' safety risks; (iii) it presents some channel analysis in an OPNET environment, while workers' body central units (BCUs) and active RFID identification (ID) badges are treated as moving end nodes of the ZigBee network; (iv) it also analyses the channel between the workers' and/or pedestrians' RFID active ID badges (tags) as end nodes, and forklift trucks' (hereafter forklifts) RFID warning systems as moving routers of the ZigBee network. Finally, the paper gives some concluding remarks based on the simulation experiments' results, as well as directions for further examinations in this domain.

II. ON PORT WORKING RISKS

Work at ports takes place throughout the day and night in all weather conditions (HSE, 2011; HSE, 2013). It involves a number of different employers and contractors carrying out various activities: harbor authorities, stevedoring firms, haulers, ship's

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masters, crews, etc. This requires a synchronized co-operation and communication between all the involved parties. There are frequent pressures to load or unload ship's cargo quickly to catch a tide or to free up a wharf for another ship; or, for example, visiting drivers want to pick up or drop off their cargo as quickly as possible and get back on the road.

Ports also tend to be associated with emerging environmental problems (Darbra and Casal, 2004): water and air pollution, soil contamination, problems related to dust and noise, generation of waste, dredging operations, warehouse storage of hazardous substances, etc. Therefore, they can be dangerous places especially for on port workers and/or pedestrians in terms of operational risks connected to un-loading operations, managing on port traffic and transportation, handling manipulative equipment, warehousing dangerous cargoes (Roberts and Gray, 2013), etc. All these make the port work challenging, but also highly risky.

Under the regulations, both employers and employees in ports must ensure the health and safety of themselves and others. In developed ports, employers have specific obligations concerning the provision and use of the Personal Protective Equipment (PPE) by the employees who are exposed to risks. This is still not the case in the Port of Bar, but it should become obligatory. In this regard, within the following section we shall refer to several PPE *intelligent* solutions proposed and/or employed in highly developed harsh working environments. PPE can include items such as safety helmets, gloves, eye protection, highly visible clothing, safety footwear, safety harnesses, etc., but it is commonly limited to the 3 Point PPE, i.e., helmet, safety vest and protective shoes. Garments equipped with passive or active RFID devices can help in identifying each protective piece, examining its functionality and proper use. By a corresponding alarm system, workers are alerted if some PPE garment is missing or is not properly worn, or if some of the RFID tags embedded-attached to the PPE do not function properly. Furthermore, using active RFID ID badges allows smart back-end software system monitoring the workers' presence at the port, their access to dangerous zones, and, in the case of emergency, the workers can be alerted to come to the appointment place which is well covered by the anchor readers. Thanks to the numerous interrogators installed at strategic points of the appointment zone, the workers can be automatically identified, located, and the inspection of using and correctness of their PPE garments can be carried out. Additionally, the RFID locating system can be used for both the workers equipped with ID cards (i.e., active RFID tags) and forklifts equipped with RFID light/audio alerting system for warning the workers and/or pedestrians and providing them with enough time to get themselves to safety. These safety solutions will be described in some more detail within the next section.

III. SOME PPE-RFID SAFETY SOLUTIONS

For the purpose of giving support to the managers of the developing Port of Bar in providing justification to their senior management and stakeholders regarding a secure buy-in and implementation of *smart* safety solution(s) for preventing and reducing occupational risks, we described within this section some of the previously mentioned *smart* PPE-RFID systems. The first one is described at large in Barro-Torres et al. (2012). However, it is still at the level of a prototype, with the intention to be implemented at construction sites. The second system, which is presented here, is implemented in the North Sea oil and gas industry (Vermesan, 2010), and the third one can be implemented at a port or at any other industrial and transportation environment of high density. In any case, there are no severe restrictions for implementing these solutions at any rough and commercially intensive port environment whatsoever. Introducing the ZigBee network for establishing communication between workers', pedestrians', and forklifts' RFID enabled devices and warning systems at the port perimeter, including port's backend info-communication system, might be considered as a novelty of this paper in comparison with the previous research works in this domain (Sole and Musu, 2013a; Sole and Musu, 2013b; Musu, 2014; Sole, 2014; Musu, 2015; Bauk et al., 2016).

1. The RFID System for Monitoring the Use of PPE

This system is composed of a body area network (BAN) that collects information from the readers located throughout the workers' clothing (Barro-Torres et al., 2012). The short range RFID readers are located at strategic points within the clothing, for checking the correctness of wearing 3 Point PPE. The detection rate clearly increases when the antennas of the reader and the tag attached to each 3 Point PPE garment are in parallel, while it decreases dramatically when the antennas are oriented orthogonally. To avoid the null spots, different alternatives have to be weighted up in order to modify the antenna radiation pattern. The central unit microcontroller (CUM) processes data from the readers and transmits them by a radio module to the ZigBee mesh network composed of the set of end nodes (workers' BANs), routers, and the coordinator. CUM contains the XBee module for ZigBee communications. This module has a transmitting power of 2 [mW] and works at 2.4 [GHz], while its range varies significantly depending on the environment (temperature, humidity, size, and material of obstacles). The coordinator collects and stores the data coming from the end nodes, configures the nodes and performs synchronization. The end nodes are the critical part of the system. The scheme of this scenario is given in Fig. 1. We do not recommend it to be implemented in the Port of Bar at the present moment, since it is complex, intrusive, and the central microcontroller is currently in the developing phase. In any case, we believe it is worth presenting to the management of the Port of Bar as a potential environmental safety solution, which might be adopted in the future.

2. Active RFID Tags and PEE

A cost effective RFID technology solution for locating and tracking personnel in case of emergency situation was deployed at oil and gas rigs in the North Sea in the first decade of 2000's. This system is conceived as an offshore emergency prepared-

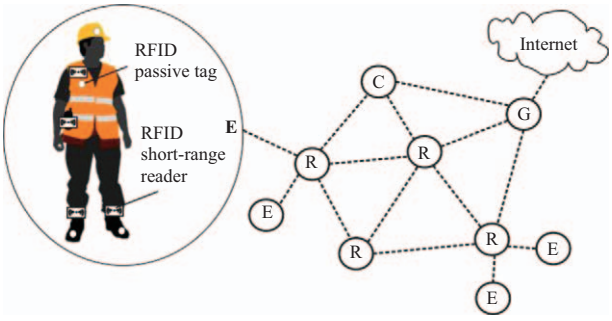


Fig. 1. Scenario 1: Worker's BAN as an end node. (Legend: E-end node; R-router; C-coordinator; G-gateway/coordinator).

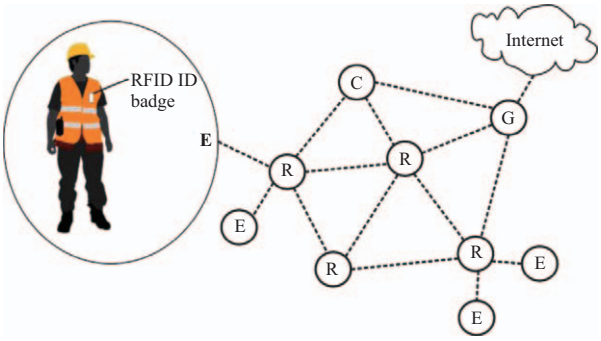


Fig. 2. Scenario 2: Worker's RFID active ID badge as an end node. (Legend: E-end node; R-router; C-coordinator; G-gateway/coordinator).

ness system, rather than a personnel surveillance one. Its two key components are RFID readers and tags. In the event of an emergency, the system determines the current and past locations, and the identities of all the personnel wearing an active RFID tag (ID badge, or card) for the purpose of tracking. Naturally, in addition to this emergency safety system, using PPE at oil and gas rigs is obligatory. The extended version of the personnel tracking system may also include the use of environmental sensors, e.g., for temperature, humidity, gas detection, etc. In some cases, the active ultra high frequency (UHF) Gen2 tags are installed onto the hard helmet of each worker. By installing RFID readers at each entry gate of the floating ship or another enclosed space, the system can track the number of persons on board. This way the fire and security officials are provided with real-time information on head count and are able to decide on the necessary escape routes (Hild, 2007).

Platforms operating in an offshore environment typically employ hundreds of people. Some of them are connected via bridges creating a center that can hold up to thousands of persons. Each person on the rig has an RFID active ID badge which can be worn around the neck, attached to the clothing or placed in the pocket. The badge has a battery powered UHF tag working at 868 [MHz] (EU standard) and transmitting the ID number at preset intervals. The tags can be read from the distance of up to 500 [m]. Back-end software stores each worker's name, shift, job, education, etc., which is linked to the unique ID number on the badge. When the reader captures the tag's ID number, it forwards that information via a wireless connection to a computer, which can then pass on that data, either to the company's back-end server or to a server on-site via Wi-Fi or the Internet connection (Swedberg, 2011).

We propose here the employment of the ZigBee mesh network as a connector to the smart back-end control system, while the end nodes would be the workers' active RFID tags. Simplified, the worker has an RFID active tag, while the router reads the tag and sends the information to the ZigBee network. At the end, the data arrive to the coordinator which is connected to a geographic information system (GIS) map (Grupo Autolog, 2010). The basic scheme of this workers' RFID safety scenario is given in Fig. 2. If there are several readers on the site, the system can determine each employee's location, while the accuracy of the position depends on the number of readers used. The system typically tracks the zone of the employee's presence, rather than the worker's specific location. The system also provides an alerting function, in case certain personnel are not allowed to enter one or more specific zones. Using active ultra-wideband RFID tags, which operate at 3.1-10.6 [GHz], should allow for the determination of the worker's position with the precision of a few inches (Roberti, 2013). However, such tags can be fairly expensive, especially if we bear in mind the specific economic and administrative working conditions of the Port of Bar. Therefore we suggest using UHF active RFID ID badges for the workers' identification and their locating within a certain zone or read field within the range of about 5-10 [m].

3. The RFID Supported Forklift Warning System

Workplace accidents involving moving vehicles (e.g., forklifts) cost ports huge amounts of money in terms of expensive downtime, investigations and increased insurance premiums (Orbitcoms, 2016). Above all are fatal injuries and loss of human lives. In 2014, e.g., the number of casualties in the transportation sector in the USA was 734, according to the Bureau of Labor Statistics (Grayson, 2015). Fortunately, the fatal accidents have not been recently recorded in the Port of Bar, but this should not be excluded as a potential danger and should be prevented anyway.

There are several ready made, commercial solutions for reducing the risk of collision between moving vehicles and workers/pedestrians at the workplace, such as: Forklift Safety RFID Solutions (SPT, 2016), BodyGuard (Orbit, 2016), Pedestrian Alert System (IcnitaSafety, 2016), EGOpro Safety Move Proximity Warning Systems (AME, 2016), etc. They all improve safety through a proximity alert system for forklifts and workers/pedestrians. The main operating features of these systems are: the detection of workers/pedestrians in frontal (0.5-6.5 [m]), back (0.5-6.5 [m]), and side area (up to 4 [m]) of the forklift in operation to warn the forklift's driver (while maximum detection range can be adjusted to smaller). They also alert the worker/pedestrian by visual and/or audible alarms and automatically reduce the speed or stop the forklift, while its maximum speed is limited to 10 [km/h] (IcnitaSafety, 2016).

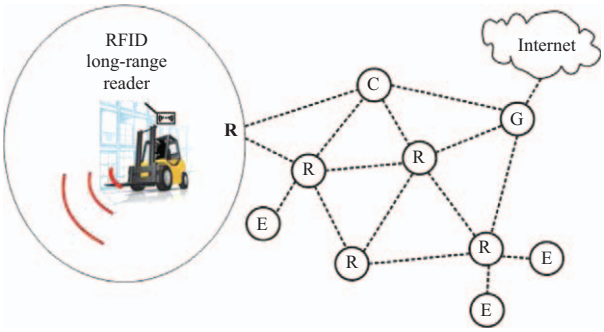


Fig. 3. Scenario 3: Forklift's RFID reader as a moving router. (Legend: E-end node; R-router; C-coordinator; G-gateway/coordinator).

The systems help in overcoming the typical risks caused by factors such as driver inattention, poor visibility (e.g., blind entry/exit, warehouse aisles, etc.), worker's non-compliance with exclusion areas around vehicles, collision between a worker and moving vehicle at a common working area, etc.

Through the simulation experiments (Section 5) we are considering the case when a forklift contains an RFID long-range reader and an alerting system and is treated as a moving router of the ZigBee network at the port area (Fig. 3).

IV. BLENDING ZIGBEE AND RFID

The ZigBee networks can collaborate with RFID devices to enhance the reduction of battery power consumption, robustness, extension of ranges, communication with applications and other network devices, etc. In other words, an integrated ZigBee/RFID system architecture has the performances of multiple applications and of more capability than stand-alone RFID products. It can deliver an extended range through multi hops and considerable savings in power consumption when all the network components are well coordinated. In the ZigBee/RFID system, a ZigBee end device like a worker's BAN, an active on port worker's ID badge and a forklift RFID warning system have the ability of returning a unique identifier to a nearby scanning reader. The ZigBee transceivers automatically form a mesh network with any ZigBee transceiver in the range of the same network ID and frequency range (Rubio, 2010; Abdula and Widad, 2011). The XBee product (Digi, 2016) is a radio frequency transmission module programmed to be used as a ZigBee end device with a transparent operation as an active RFID tag and receiving and transmitting capabilities in a wireless transmission physical layer. In the following simulation experiments we assumed that the workers' BANs composed of active/passive RFID devices (Fig. 1 and Fig. 2) are end nodes of the ZigBee network the features of which we analyzed. Also, we considered the forklifts' RFID sub network composed of a reader, warning devices, and driver's ID badge as a moving router of the analyzed ZigBee mesh network on the port parameter (Fig. 3). Some of the results of the performed experiments in OPNET (Sahraei, 2009; Saha, 2013; Kaur, 2014; Hammoodi et al., 2015) are presented and discussed in the following section. In addition to improving

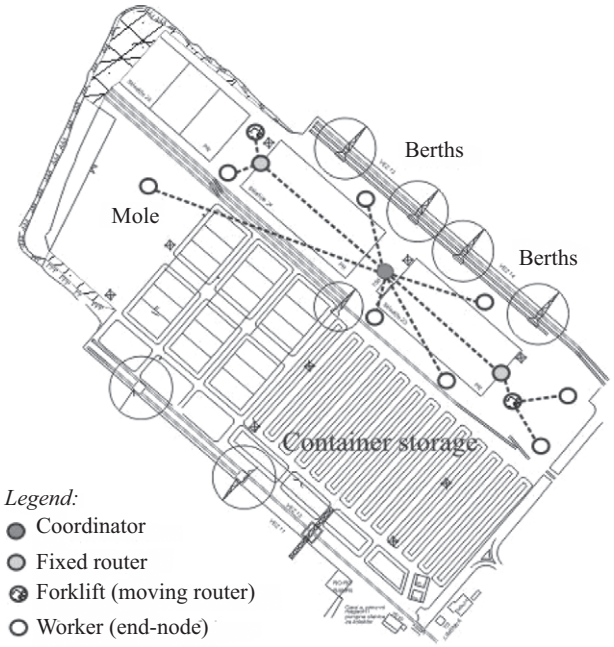


Fig. 4. Layout of the Port of Bar container and general cargo terminal.

the on port workers' and pedestrians' safety, the ZigBee/RFID systems can also be used for enhancing the building security (Infanta, 2013), traffic flow management (Chao and Chen, 2014), intelligent traffic control and patient monitoring for efficient ambulance services (Suneesh, 2015), etc.

V. SIMULATION EXPERIMENTS AND RESULTS

The simulation experiments with the ZigBee network with end nodes being the workers' RFID sub networks, and moving routers being the forklifts' RFID warning systems sub network, are performed in OPNET Modeler (Riverbed Modeler v.17.5.A) on PC (Intel-Core™ i7, 2.50 GHz, 8GB RAM) over the layout of the Port of Bar container and general cargo terminal which covers the area of 650 × 350 [m^2] (Fig. 4).

For the needs of the simulation experiments, the fixed routers and the coordinator of the ZigBee network are set on the top of the main warehouse buildings at the terminal, which are approximately 10 [m] high, in order to be higher than the container blocks at the container yard. We used a mesh topology since it generally has superior performances in comparison with star and tree topologies (Mihajlov and Bogdanovski, 2011; Vats et al., 2012; Vancin and Erdem, 2015).

Workers and forklifts are moving over the operational area between wharfs and storage (warehousing) area. We suppose that a worker's speed is 2 [km/h], and the forklift's speed is 10 [km/h]. The paths of the workers and forklifts are chosen randomly. Since the Port of Bar has about 100 on port workers who are allocated at seven terminals depending on the workload: (1) container and general cargo terminal; (2) wood terminal; (3) terminal for grains; (4) bulk cargo terminal; (5) container and general cargo terminal; (6) liquid cargo terminal, and (7) passenger

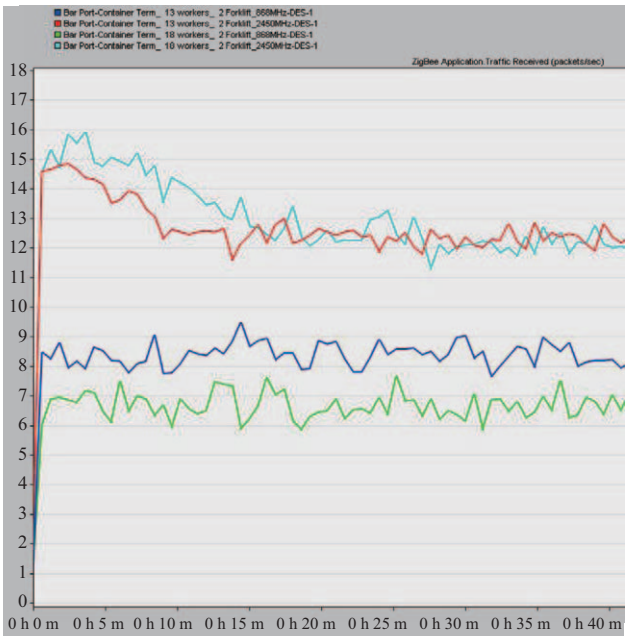


Fig. 5. Traffic received by coordinator for different on port scenarios.

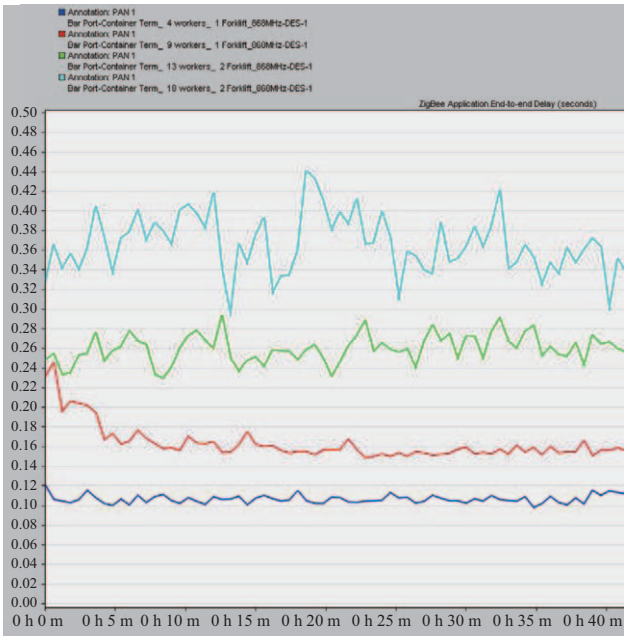


Fig. 6. End-to-end delay for 868 [MHz] carrier's frequency.

terminal, we supposed (according to the usual turnover) that mostly 18 workers might be engaged daily at the container and general cargo terminal. Also, according to some previously made consultations with port managers, we assumed that 2 forklifts are usually in operation on the terminal daily. In order to get a better insight into the simulation experiments' results, we tested the network for various combinations of the workers and forklifts, e.g., for: (a) 4 workers and 1 forklift; (b) 9 workers and 1 forklift; (c) 13 workers and 2 forklifts, and (d) 18 workers and 2 forklifts. The main settings for the network end nodes are as follows:

(1) Packet Interval Time: constant (1);
(2) Packet Size: constant (32);
(3) Start time: constant (30);
(4) Stop time: infinite; and,
(5) Transmition power: 5 [mW].

The forklifts, treated as moving routers, have the same application traffic parameters, but the transmission power is greater, i.e., it is 50 [mW]. The routers do not generate application traffic. The coordinator is responsible for the configuration of the network parameters. It sets the network topology (tree, star, or mesh; here the mesh one), the number of children that each node can have, the number of routers, the depth on the network tree, it defines PAN, etc. The coordinator does not generate any application traffic either, but will be the final destination for all the application traffic generated in the end nodes.

Fig. 5 presents the traffic received by the coordinator in the cases (c) and (d) at the frequencies 868 [MHz] and 2.45 [GHz], respectively. It is obvious that the received traffic is about 12-18 packages per second for 2.45 [GHz], and that it is considerably lower, i.e., it is between 6-9 packages per second for 868 [MHz]. This is due to the increased performances that we have in the 2.45 [GHz] band, compared to 868 [MHz], such as the data rate, the number of channels, or the use of more efficient modulation protocols. We may also remark that each end node sends the traffic each second, therefore some packet losses are acceptable, as long as not all the data from one worker is completely lost.

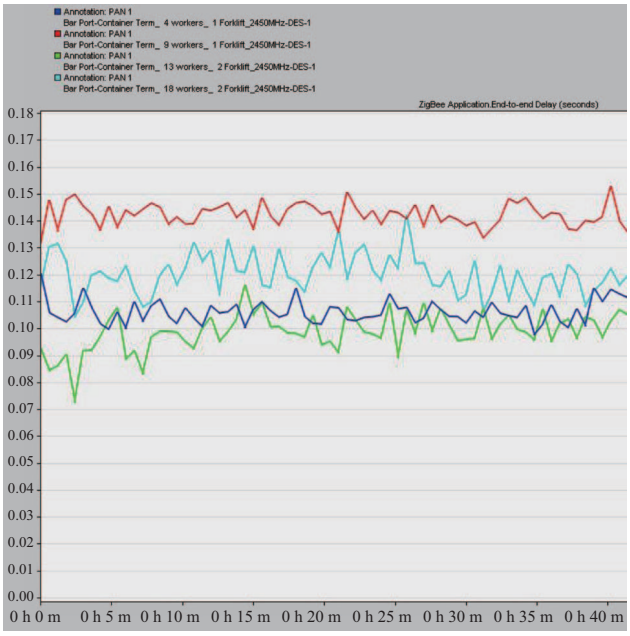


Fig. 7. End-to-end delay for 2.45 [GHz] carrier's frequency.

Figs. 6 and 7 present end-to-end delays for (a), (b), (c), and (d) scenarious, for 868 [MHz] and 2.45 [GHz] carrier frequencies.

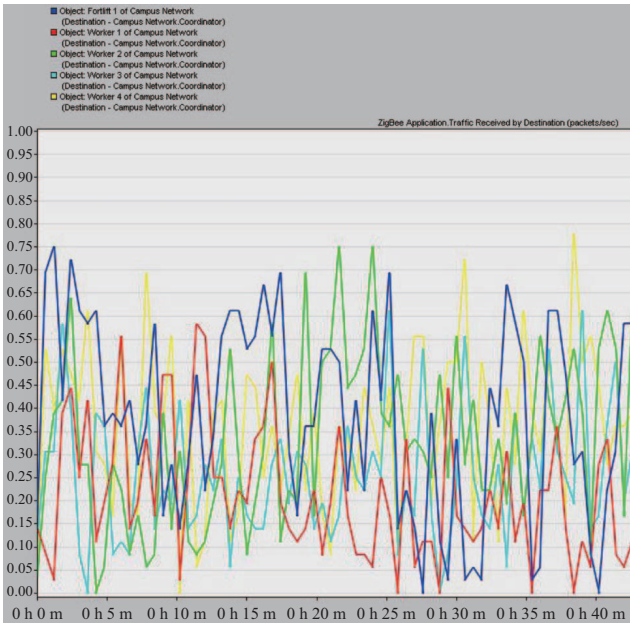


Fig. 8. Traffic received by destination from different routers and end nodes at 868 [MHz].

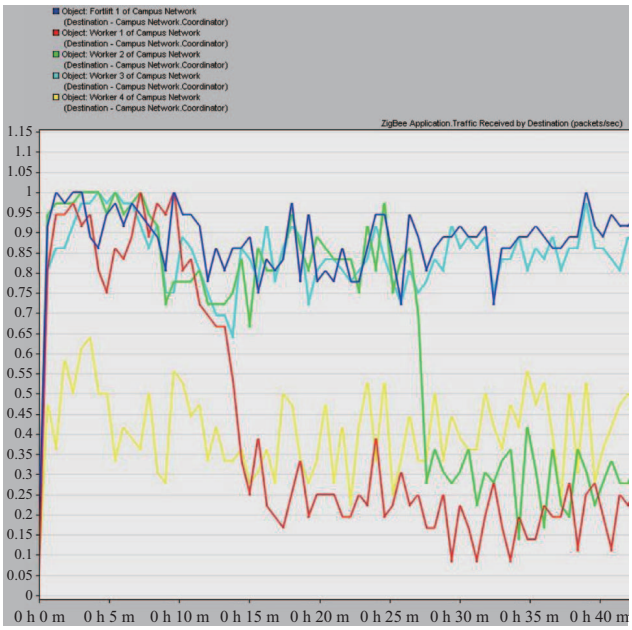


Fig. 9. Traffic received by destination from different routers and end nodes at 2.45 [GHz].

It is clear that the delay is consideralby lower for 2.45 [GHz] than for 868 [MHz]. More precisely, in the better case (at 2.45 [GHz]) it is about 0.07-0.16 seconds, while in the worse one (at 868 [MHz]) it is about 0.12-0.44 seconds. This happens because the data rate increases at 2.45 [GHz], and because of the more efficient QPSK modulation scheme used (in comparison with BPSK one).

It is also interesting to consider the traffic received by destination, i.e., network coordinator from certain end nodes (workers) or moving routers (forklifts) as it is shown in Figs. 8 and 9. The traffic received by destination reaches 1 package per second for 2.45 [GHz] and 0.75 package per second for 868 [MHz]. Although the received traffic has oscillations which mostly depend on the distance between the end nodes and/or moving routers from the destination within the time interval covered by the simulation period, there is no permanent interruption in receiving. This is of particular importance.

The simulations were performed for the actual number of workers and forklifts usually employed per shift based on the workload on the container and general cargo terminal in the Port of Bar. In the forthcoming analysis, a larger number of workers and mobile mechanization units should be involved in order to confirm the experimental ZigBee technology functionality for a greater number of network nodes, i.e., its reliability and scalability. Furthermore, the impacts of different obstacles and environmental parameters should also be analyzed. The on port workers' readiness to become constitutive parts of the proposed smart safety solutions is to be examined, as well. All these should assist the managers in making the port safer and greener at the global market of un-loading, manipulation, transportation, and various added-value services.

VI. CONCLUSION

The paper presents a continuation of the previous authors' research work (Bauk et al., 2015; Bauk et al., 2016) and attempts towards repositioning the Port of Bar at the market of safety ports. It considers the RFID based occupational safety solutions in ports and other similar harsh environments and proposes the RFID system co-work with ZigBee technology in a satisfactory and efficient way for the purpose of enhancing the on port workers/pedestrians safety. The ZigBee was analyzed as a communication technology because it provides low energy consumption, a larger range, and it works properly with quite a large number of end devices. An XBee module was proposed as a link between the workers' and forklifts' RFID sub networks and ZigBee communication channel. The simulations are focused on the ZigBee performances over the Port of Bar container and general cargo terminal. They were realized in OPNET (Riverbed Modeler v.17.5.A) environment, while the following have been obtained:

(1) As the number of end-nodes increases (from 15 to 20), the traffic received by the coordinator decreases (from about 12 to 7 packages per second), but there are no interruptions such as the coordinator not receiving any traffic at all;
(2) The experiments show that the performances of the ZigBee network are in general significantly better at 2.45 [GHz] than in the case of 868 [MHz] carrying frequency. This is due to the greater data rate at 2.45 [GHz], greater number of available channels, more efficient modulation schemes, etc.;
(3) Better performances at 2.45 [GHz] than at 868 [MHz] are noticed when it comes to the number of packages received by the coordinator per second, and when it comes to the end-to-end delay of the received signal;

(4) The number of packages received by the destination (coordinator) from different routers and end nodes varies depending on the current location of these devices. It is greater in the case of using 2.45 [GHz] than 868 [MHz]; and,
(5) Concerning the received power, it is in all the cases higher than the power reception sensibility threshold, which is the minimum reception power needed by the receiver. In all our scenarios, it was set to -85 [dBm] to all the devices.

The experiments were done for the real number of workers and forklifts being commonly in operation at the Port of Bar container and general cargo terminal. They show a completely satisfying level of the ZigBee network performances. In our simulation experiments we assumed that the ZigBee end nodes and moving routers are RFID sub networks joint to the ZigBee via XBee modules. In the forthcoming research, a larger number of end nodes and routers should be involved. Additionally, some more detailed explanations of connecting possibilities for RFID and ZigBee technologies are to be considered.

Our goal here was to familiarize the managers and stakeholders of the developing Port of Bar, operating in a transitional economy, with contemporary ICT solutions which might be adapted for improving the safety of human lives and environmental management system. Since the industrial safety systems use a whole panoply of technologies, our intention was not to offer the *best solution*, but just to open a discussion about cost and energy effective and, at the same time, reliable occupational safety measures. It is upon the port's management to develop strategies for their implementation in the future, with the ultimate goal of protecting the on port workers'/pedestrians' lives and maritime ecosystem. These should promote the Port of Bar in the future as safe and green at the maritime market and upgrade its current position at the customers' perception maps.

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