MANET vs. ZigBee: Some simulation experiments at the seaport environment

Sanja Bauk, Diego Garcia Gonzalez, Anke Schmeink, Zoran Ž. Avramović

bsanjaster@gmail.com; diego.kmp@gmail.com; anke.schmeink@rwth-aachen.de; zoran.avramovic@sf.bg.ac.rs

Critical review

DOI: **10.7251/JIT1602063B**

UDC: **539.163:504.03]:001.892**

Abstract: The paper presents the results of some OPNET simulation experiments realized with an aim to benchmark MANET and ZigBee networks' performances at the seaport environment. The MANET is formed among workers' and supervisors' personal digital assistants (PDAs). On the other side, the ZigBee is established between end-nodes or employees' body central units (BCUs), which collect signals from several active and passive devices embedded into ID badges and personal protective equipment (PPE) pieces; several moving and fixed routers; and the coordinator mounted at the appropriate seaport location. The simulation experiments are realized over the layout of the Port of Bar (Montenegro) container and general cargo terminal by taking into account the real number of workers and supervisors engaged at the terminal per each shift. This research work should give an insight to the seaport's managers and stakeholders into some advantages and disadvantages of these two considered wireless networks' schemes, and to motivate them to provide conditions for implementing these or similar on seaport and backend info-communication solutions for uprising the level of occupational safety and overall seaport's environmental management system.

Keywords: MANET, ZigBee, seaport, occupational safety.

Introduction

This paper is a kind of follow-up of several previously published papers [2-5], which consider possibilities of adopting new info-communication technologies in improving on seaport (afterwards port) workers' and supervisors' safety at the Port of Bar (Montenegro). The Port of Bar functions during the decades in transitional environment that implies permanent reproduction of different crisis and prevents the port's development. Such circumstances have, among other impacts, negative implications to the employees' and environmental safety. By proposing variety of contemporary safety monitoring and controlling info-communication models, we have in mind a need for positive and progressive transfer and adoption of new technologies from developed environments into a developing one [1]. In other words, we were trying to propose affordable, i.e., cost-effective solutions, which have to be *smart*, safety and sustainable ("3S") at the same time [19]. In this paper, firstly, we shall give a short overview of the MANET and ZigBee networks' concepts and their functionality. Then, we shall propose simple models for employing them at the above mentioned developing, invasive port environment, along with presenting some simulation experiment results obtained for both proposed networks' by using OPNET simulation modeler.

The MANET: In brief

A Mobile Ad-hoc NETwork (MANET) is a self-configuring network where nodes are connected wirelessly and move freely by changing network topology constantly and unpredictably. Ad-hoc wireless networks suffer not only the same problems of wireless and mobile communications, like power control, bandwidth allocation and optimization, transmission quality, etc., but also others due to the lack of fixed infrastructure and the multi-hops, such as configuration advertising, ad-hoc addressing, self-routing, etc. MANET nodes rely on batteries and remain in a continuous awake mode in order to be ready for either transmission or reception of packages, thus energy savings are among the relevant system design criteria [7]. Apart from these, it is to be pointed that the multi-hop paradigm characteristic for MANET extends the possibility to communicate to any couple of network nodes, without the need to develop any ubiquitous network infrastructure. Nearby users communicate directly, not only to exchange their own data, but also to relay the traffic of other network nodes that cannot directly communicate. At the beginning stage of its development, MANET was one of the most innovative and challenging network paradigm and was promising to become one of the major technologies, increasingly present in everyday life. However, after more than three decades of intense research efforts, the pure general-purpose MANET concept suffers from scarce exploitation and relatively low interest in the industry and among the users, except military and disaster recovery applications. Additionally, the number of manuscripts focused on MANET, published in top quality journals, is decreasing [6]. Since a great body of knowledge about MANET has been produced, many researchers in the field are now trying to apply it to the field of wireless sensor networks. Besides, up to the current moment, several networks concepts have emerged from the MANET field, like: mesh, opportunistic, vehicular, sensor ones, etc. MANET is usually close to humans, in the sense that most nodes in the network are devices that are meant to be used by human beings (e.g., laptops, PDAs, mobile radio terminals, etc.). We used this in exploring channel performances, at physical and MAC layers, over the set of on port workers and their supervisors equipped with their personal digital assistants (PDAs) at the port terminal.

THE ZIGBEE: IN BRIEF

The ZigBee is a global hardware and software standard designed primarily for Wireless Sensor Networks (WSNs). WSNs topology may change dynamically, not only due to the node mobility like in MANET, but because some nodes can fail [15]. Especially in some harsh and inaccessible environments, the nodes are prone to fail. Beside failures, topology may also change due to the sleep-awake circle characteristic for these networks. Through these cycles, energy savings are to be achieved. Today, ZigBee technology is used in almost every appliance. It is embedded in a wide range of products and applications across customer, commercial, industrial and government markets worldwide. Predominantly it is used for monitoring and control applications. It is easy to install and maintain (self-organizing); it is reliable (self-healing); it scales to thousands of nodes; it is low cost; it uses open standard and provides multi-vendor availability; batteries operate for several years, etc. This technology is simpler and less expensive than other W-P/L/M-ANs (Wireless- Personal /Local/Metropolitan-Area Networks) like Bluetooth, Wi-Fi, Wi-Max, etc. [20,14] In the paper, we have made some simulation experiments in OPNET with ZigBee standard at the physical and communication layers between on port workers' and supervisors' body area sub-networks composed of a set of active and passive sensors, RFID tags, ID badges, BCUs, several moving and fixed routers, and the coordinator, in order to allow permanent insight into employees' and their personal protective equipment (PPE) garment presence and functionality at the terminal.

CASE STUDY

The paper compares some MANET and ZigBee performances at the harsh and dynamic developing port environment through the simulation experiments whiles the layout of the Port of Bar container and general cargo terminal, including its real workload, mechanization and personnel capacity, is taken as an exemplar (Figure 1). It is well known that ports are dangerous places, especially for on port workers and pedestrians, in terms of operational risks connected to un-loading operations, managing on port traffic and transportation, including hard manipulative mechanization, warehousing dangerous cargoes, etc. Work at ports takes place through the day and night, in two or three shifts sometimes, in all weather conditions. It involves a number of different employees and contractors carrying out different activities. This requires highly synchronized co-operation and communication between all involved parties. Ports also tend to be associated with emerging environmental problems: water and air pollution, soil contamination, problems related to dust and noise, generation of waste, dredging operations, warehouse storage of hazardous substances, etc. Thus, a comprehensive management of these risks can help improving safety, reducing accidents and saving lives [7,11,17]. The Port of Bar suffers the lack of contemporary infra- and supra-structural capacities, including advanced info-communication solutions which could optimize working processes and reduce occupational and environmental risks. Relatively low turnover of the port saves workers of some risks, but this fact should not be *recommended* as a desired state of the port's operational and business outcomes. Working conditions at the port should be improved through effective and progressive adoption of new transportation and manipulative technologies including info-communication ones. Therefore, through the previous research works in the field [2-5] we proposed several models for enhancing on port workers safety. As a continuation of these pioneer research endeavors, a comparative analysis between potential MANET and ZigBee applications for supporting on port employees' occupational safety measures has been realized. It is very important that workers have available possibility of uninterrupted interpersonal communications and communications with their supervisors (e.g., via MANET PDAs), and also it is very important to provide continuous monitoring of workers' presence at the terminal, as well as, monitoring if required PPE is used, and if it is functional during the operational process at the terminal (e.g., via ZigBee BCUs).

Figure 1. The container and general cargo terminal at the Port of Bar (Source: web)

The container and general cargo terminal at the Port of Bar (Figure 1) has a quadrilateral form, which is approximated for our research work by a rectangle with dimensions 650 x 350 m. Workers can move with high level of freedom over the terminal, while their movements are only restricted by the physical structures present on the surface, which are in this case three industrial warehouses, moving vehicles, vertical mechanization structures, and several container blocks. The industrial warehouses are not a serious problem for the mobility freedom of the workers, since they can go inside and through the warehouses; moving vehicles is also not a big problem; but, the containers are, since they are usually located in blocks and can cause interference to the communication devices by reducing the range.

In experiments with the MANET, IEEE 802.11 standard for the physical and MAC layers is used, while some of the key network performances are analyzed for DSR, AODV, OLSR and TORA routing protocols [10]. The simulation experiments with the ZigBee are realized by using IEEE 802.15.4 standard for the physical and MAC layers, too. The analyses are done considering two ISM frequency bands allowed in the port region, i.e., 868 MHz and 2.4 GHz, along with three common topologies: star, cluster three and mesh.

For both approaches, the application traffic contains the information taken by the sensors or RFID tags attached to the workers/supervisors PPE garments, or their ID badges. That information contains important data to be analyzed, such as ID of each worker/supervisor, ID and sensors' functionality of each worker's/supervisor's PPE piece (hard helmets, safety vests or protective shoes), data on plantar pressure, ambient light, temperature, etc. All these data are collected by BCU (body central unit) attached to the employee's belt. The content of the information is not clear at the present moment and it may vary in the future, depending on the port's real needs. Therefore, it will be abstracted here and treated as a payload that the network has to transmit to a certain point where it will be analyzed. This payload in the application level for each packet transmitted by each worker/supervisor is approximated by 32 bits, which is enough to transmit the IDs of the employees and a few more data collected from the sensors attached to PPE garments [12].

SIMULATION ANALYSIS

Both MANET's and ZigBee's simulation experiments are realized in OPNET Reverbed Modeler Academic Edition 17.5 over the plot of general and cargo terminal at the Port of Bar. The Port of Bar consists in fact of seven different terminals that are used for different purposes and it has about 200 employees in total on port operations. We assumed that there are mostly 20 employees at analyzed container and general and cargo terminal per shift. We analyzed this terminal since it is exposed to the highest operational risks. Although we did experiments for 5, 10 and 15 employees, or better say networks' PDAs (MANET) and end-nodes/routers (ZigBee), the results obtained in the cases of 15 and 20 moving devices should be put in focus, since they appear more challenging in terms of evaluating the networks' usual performances.

Experiments with MANET

The analyzed scenario for 20 workers, including their supervisor(s), is shown in Figure 2. There is no fixed infrastructure in MANET. Thus, the network is formed just by PDAs of employees who can move freely around the terminal. Nevertheless, the traffic is to be centralized to a certain destination in order to be routed to an external server by using another interface. This device is PDA carried symbolically by worker_1 in our scenario. The whole traffic must be sent towards the worker_1 (market with a laptop icon in Figure 2). In fact, any PDA could play this role since this node is exactly the same as any other PDA node; it is just marked with a different icon to visualize which is the device that receives the traffic from other nodes, what will be done by using the IP direction of the node. The blue rectangle around the network (Figure 2), defines the mobility domain for the nodes within which the employees can move freely. In OPNET environment, some characteristics shared by all nodes in MANET are to be defined by using "configuration nodes" that group all common features, but they do not represent any physical node. In our scenario, it was necessary to define three different configuration nodes: mobility configuration node, IP configuration node and reception configuration node. The attributes of these nodes are shown in Figure 3. The detail description of used devices, their parameters and OPNET basic interface information are given in reference [8].

Figure 2. The MANET scenario: 20 workers and supervisor(s) at the seaport terminal (Source: own)

Frequency band is determined by the IEEE 802.11, and it is set at 2.4 GHz. Simulation time is set to one hour. After several series of simulations

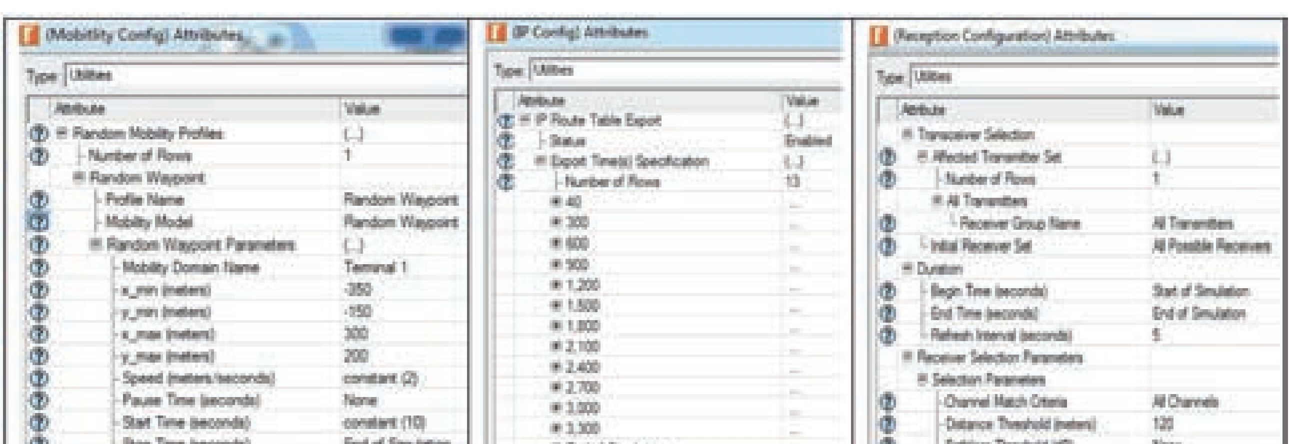

Figure 3. Some attributes of the mobility, IP and reception configuration nodes (Source: own)

for 5, 10, 15 and 20 nodes, it is observed that MANET performances are quite poor for lower number of nodes (especially for 5 and 10 nodes). The absence of fixed infrastructure for small number of nodes requires establishing longer range communications that is not always possible due to the maximum range inherent to the devices, leading to the isolation of some nodes. By increasing the number of nodes (e.g., to 15 or 20), the MANET considerably improves its performances. The simulation results are shown in Figure 4. They present the network load (i.e., amount of control, routing and traffic data being carried by the network) for different routing protocols: AODV, DSR, OLSR and TORA. In Figure 4 can be seen that TORA and AODV are the protocols with the lowest network load while OLSR and DSR mostly charge the network in the considered case. The difference is quite big if we compare DSR with AODV or TORA, e.g., DSR doubles the network load comparing it to AODV, and triplicates it when it is compared to TORA, e.g. By comparing the traffic received by the destination, it can be concluded that AODV and DSR are a bit stronger against topology changes than OLSR, and that the weakest is TORA, under the same conditions.

Additionally, by comparing the total end-to-end delay, OLSR and TORA represent a big improvement over the other two considered protocols. For networks with fewer nodes, TORA would not be that effective, but as the number of nodes increases, the delay rapidly decreases [8]. The values of the end-to-end delay for different routing protocols and different number of nodes are given in Table 1. A common trend which can be noticed on the basis of conducted simulation experiments is that end-to-end delay decreases as number of the MANET nodes increases.

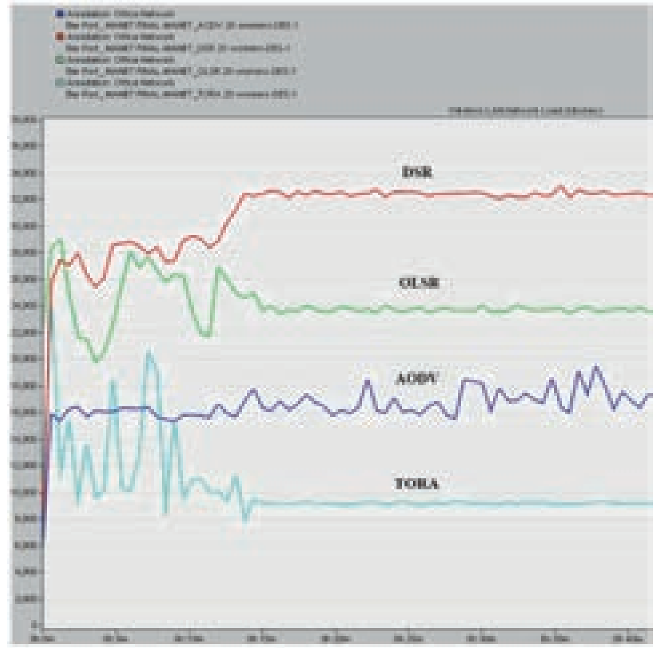

Figure 4. The MANET network load for 20 nodes in the case of AODV, DSR, OLSR and TORA routing protocols (Source: own)

Generally, total end-to-end delay is the time from the moment of generating packages at the source to its receiving at the destination. Some applications, e.g., voice transmissions, are more susceptible than others to the end-to-end delay of packages, and therefore they require its lower average value. Due to the weak signals at the nodes, frequent creation and termination of connections, as well as, the mobility of nodes, the total delay in the MANET network usually increases. It should be noted that there are in fact four different types of delays [18]:

- *transmission delay* - the time which the transmitter needs to deliver all bits of data packages;
- *propagation delay* - the time which is necessary to transfer one bit from the source to the destination;
- *processing delay* - the time which is necessary for processing package before its delivery at the source node, at any intermediate node, and at the end node for processing package before its proceeding to the application; and,
- *queuing delay* - it is the delay which occurs due to queuing at any node along the transmission path.

Table 1. The MANET end-to-end delay maximal values for different routing protocols and number of network nodes [sec/msec] (Source: own)

OLSR	TORA	AODV	DSR
5_nodes: 40 msec.	5_nodes: 1 sec.	5_nodes: 1.7 sec.	5_nodes: 2 sec.
10_nodes: 30 msec.	10_nodes: 0.3 sec.	10_nodes: 3 sec.	10_nodes: 0.5 sec.
15_nodes: 0.2 msec.	15_nodes: 0.05 sec.	15_nodes: 10 sec.	15_nodes: 0.3 sec.
20_nodes: 0.8 msec.	20_nodes: 0.00 sec.	20_nodes: 0.04 sec.	20_nodes: 0.015 sec.

Accordingly, total delay might be expressed by the following model (1):

$$T_{Total\_Delay} = N \cdot (T_{Trans\_Delay} + T_{Prop\_Delay} + T_{Process\_Delay} + T_{Queu\_Delay}) \quad (1)$$

Where,
N - is a number of nodes in the network;
T_{Total_Delay} - is the total delay;
T_{Trans_Delay} - is a transmission delay;
T_{Prop_Delay} - is a propagation delay;
$T_{Process\_Delay}$ - is a processing delay; and,
T_{Queu_Delay} - is a queuing delay.

The traffic received by destination in the cases of 5, 10, 15 and 20 nodes in the case of using DSR routing protocol is given in Figure 5. It indicates that it is necessary to increase the number of nodes (at least 15 to 20 nodes) to establish functional network, in terms that nodes can route traffic smoothly to the destination. By analyzing the number of hopes and global delay, it is also observed that they decrease, as the number of nodes increases.

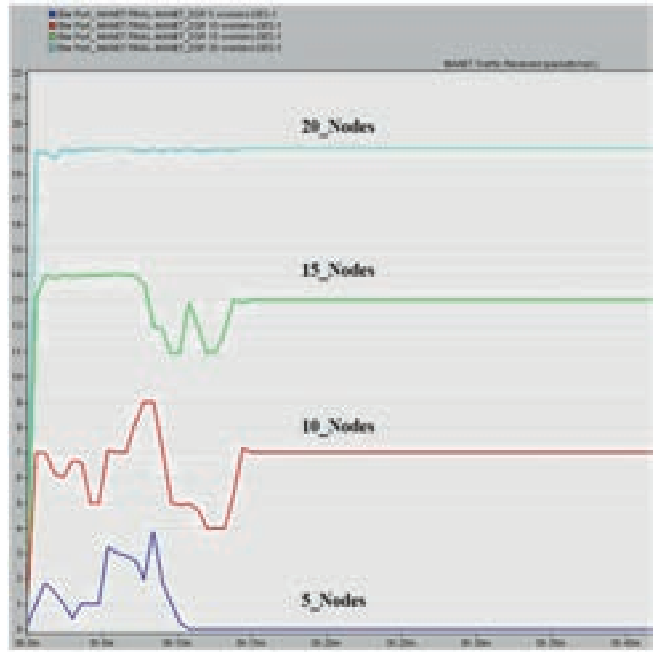

Figure 5. Traffic received by destination in the case of DSR routing protocol in MANET for the scenarios with 5, 10, 15 and 20 nodes (Source: own)

Experiments with ZigBee

Some simulation experiments with ZigBee are realized for three different topologies: star, cluster tree and mesh [13,16], and for two different frequencies 868 MHz (with max. bit rate of 22 kbps) and 2.4 GHz (with max. bit rate of 250 kbps). The scenario includes: a coordinator, three fix routers, mounted at the warehouses' roofs, one or two moving routers attached to the forklift(s) which operate(s) at the terminal, and 4(+1), 9(+1), 13(+2), and 18 workers (+1 or 2 forklifts). More or less, the location of a coordinator and fixed routers might vary depending on the eventual changes of the physical conditions at the port perimeter in the future. The detail description of network devices, physical and MAC layers parameters, packet size, packet interval time, etc., is given in [8]. The ZigBee scenario in OPNET environment with 18 workers and 2 moving routers attached to the forklifts is shown in Figure 6.

Some ZigBee network performances' analyses are done for star, tree and mesh topologies, while the following might been observed:

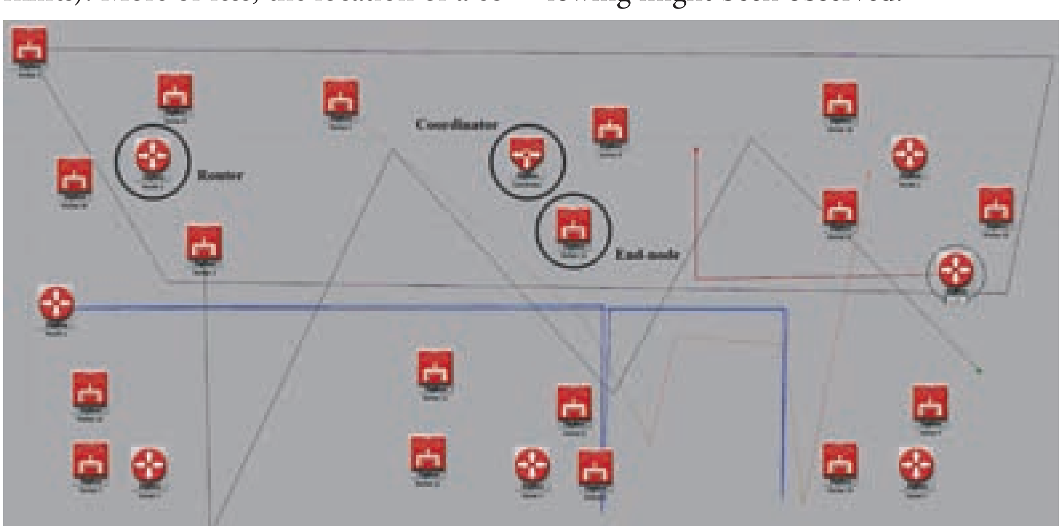

Figure 6. The ZigBee scenario: 18 on port workers and 2 moving routers mounted at the forklifts (Source: own)

- ***Star topology***: The traffic received by the coordinator is among the most important features for this application. It is not so important if some packages are lost, as long as a node is not isolated. The experiments showed that in the case of 5 nodes there are no loses; for 10 nodes there are a few; for 15 nodes the package loses are higher, but the network still works. The problem comes with 20 nodes, since loses are quite high. When we analyzed the traffic received by the destination from a single worker in the case of 20 nodes, the traffic from some workers that are far from the coordinator is completely lost and some workers became in such way isolated. These package loses are caused primarily due to the interference and the distances between some nodes and the coordinator, but also due to the star topology that forces direct communication. The global end-to-end delay increases with the number of nodes, too. In the case of 20 nodes, the traffic falls when the nodes get isolated and they are not able to communicate. It is important to note that 2.4 GHz frequency brings in general some benefits over 868 MHz to this topology.

- ***Tree topology***: The traffic received by coordinator is between 13-15 packages in the cases with 15 and 20 nodes, which represents the important improvement in comparison to star topology, due to the possibility of routing traffic through the routers. Concerning the global delay, in comparison to the global delay in the star topology, it is rather similar. It is important to emphasize that there are considerable differences in these network parameters in the case of 868 MHz and 2.4 GHz. The 2.4 GHz band provides the important performance enhancements. This means that 50% more packages is received for 15 nodes, and double the amount of packages received in the case of star topology for 20 workers. In terms of global delay, 2.4 GHz band provides more than 60% lower delay than in the star topology for the same frequency. This huge reduction is caused by multiplication of the number of packages received, which reduces the number of transmissions. Another important moment is increase in the maximum bit rate from 20 kbps (868 MHz) to 250 kbps (2.4 GHz).

- ***Mesh topology***: The traffic received by coordinator does not show a big improvement in comparison to tree topology. The global delay is slightly reduced, due to new connections between routers. It can be concluded, that there are no considerable differences in the network performances, in general, with tree and mesh topology within the considered scenarios. However, the differences between network performances in the case of 868 MHz and 2.4 GHz are to be pointed again, especially for the larger number of nodes, i.e., 15 and 20 (see Figure 7). It happens since the data rate is considerably higher at 2.45 GHz, and since more efficient modulation scheme, i.e., Quadrature Phase-Shift Keying (QPSK) is used, in comparison to Binary Phase-Shift Keying (BPSK) one, which is used in the case of 868 MHz frequency band.

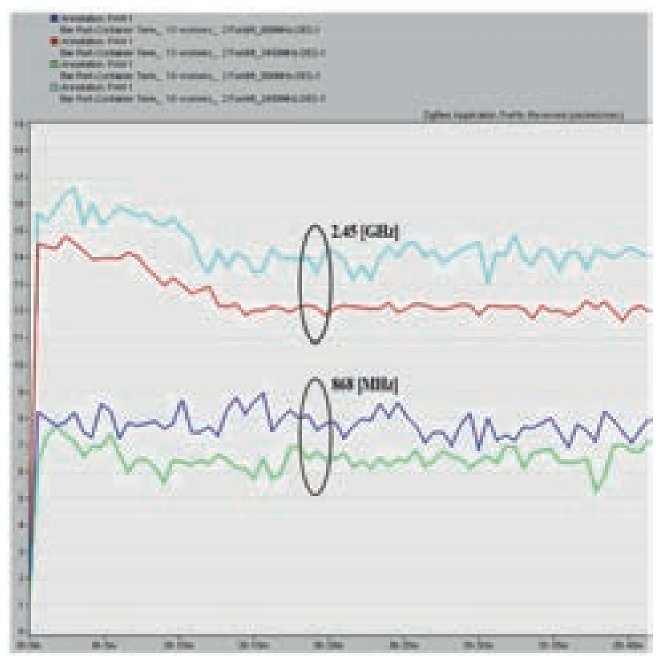

Figure 7. Traffic received by a coordinator for ZigBee mesh topology: 868 MHz vs. 2.4 GHz (Source: own)

Some experimentally obtained values of end-to-end delay for different topologies of the ZigBee network for 5, 10, 15 and 20 end nodes and 1 or 2 moving routers, depending on the scenario at the analyzed port terminal, are given in Table 2. There are some variations, but it is obvious that for each topology a negative correlation between the number of nodes and end-to-end delay exists. The main reason is that ZigBee is primarily projected for low traffic density, and this implies bigger delay for the larger number of end-nodes and routers.

Table 2. The ZigBee end-to-end delay minimal and maximal values (bold) for different topologies and number of end-nodes and moving routers [sec] (Source: own)

No. of nodes	Star		Tree		Mesh	
	868 MHz	2.4 GHz	868 MHz	2.4 GHz	868 MHz	2.4 GHz
5_nodes	**0.065**-0.085	**0.065**-0.085	**0.090**-0.120	**0.090**-0.150	**0.050**-0.100	0.100-0.110
10_nodes	0.140-0.150	0.135-0.150	0.150-0.210	0.140-0.220	0.150-0.200	0.140-**0.220**
15_nodes	0.180-0.210	0.065-0.110	0.250-0.360	0.850-**0.950**	0.250-0.350	**0.070**-0.100
20_nodes	0.130-**0.480**	0.100-**0.155**	0.350-**0.490**	0.130-0.140	0.370-**0.480**	0.120-0.140

MANET and ZigBee comparison

In the attempt to determine which of the considered wireless technologies has more capabilities under given assumptions, it is possible to compare the MANET and ZigBee by using different routing protocols, different network topologies and different number of nodes (nodes here include: workers, supervisors, i.e., their PDAs and BCUs, and moving routers at the forklifts in the case of ZigBee). It is absolutely clear that ZigBee has better performances than MANET for the lower number of nodes, i.e., 5 and 10 nodes, in the analyzed port scenarios.

The traffic received by the destination for 15 nodes scenario shows a change in the performance of the MANET and ZigBee, in comparison to the scenarios with 5 and 10 nodes, and supports the idea of better performance of the MANET. Only tree and mesh ZigBee topologies at 2.4 GHz for 15 nodes, e.g., are close to the performance of the MANET. The global end to end delay also shows a change in the performance. In general, the MANET is more suitable technology for this scenario.

The traffic received by the destination for 20 nodes again shows opposed results in comparison to the scenario with 5 and 10 nodes. In this scenario, all MANET routing protocols show better performance than the ZigBee with any topology and frequency band, while only at 2.4 GHz and by using tree and mesh topologies, the ZigBee is let us say comparable to the MANET. The values of the global end to end delay are similar to those obtained in 15 nodes scenario.

The resume of the MANET versus ZigBee performances in the considered developing port environment is given in Table 3.

Table 3. Resume of the MANET and ZigBee comparisons for 5, 10, 15 and 20 moving nodes (Source: own)

Scenario	Most suitable technology
Five nodes	ZigBee (star topology; 868 MHz and 2.4 GHz)
Ten nodes	ZigBee (mesh topology; 2.4 GHz)
Fifteen nodes	MANET (generally OLSR routing protocol)
Twenty nodes	MANET (generally AODV routing protocol)

Conclusion

The results obtained from different scenarios and by various simulation experiments within the developing port environment (the Port of Bar in Montenegro) can give some new landmarks in the process of the optimal wireless network(s) technology selection, including specific requirements as: the number and mobility of nodes, package size, package inter-arrival time, etc. On the basis of the presented simulation results, the following can be extracted:

- The ZigBee performances are better than the MANET ones for the low density of nodes (here workers, supervisors mobile devices and/or moving routers). The main reason lies in the fact that the ZigBee relies on rather fixed infrastructure, while MANET does not have it. Therefore, for the relatively small number of nodes, it becomes necessary to establish longer communication range that is not always possible due to the maximum range inherent to some MANET devices, leading to the isolation of the nodes;
- As the number of nodes increases, an opposite trend is observed, i.e., the MANET shows better performances than the ZigBee. As the number of nodes rises, it becomes easier for the MANET to establish communication between nodes and to route the traffic towards the destination. On the other side, the ZigBee finds it harder in such case to route the traffic towards the single destination. A ZigBee is conceived to be used for low traffic

applications with low requirements, and the increase of traffic is a threat to its low maximum data rate;

- The simulation results undoubtedly show that 2.4 GHz frequency band improves the efficiency compared to 868 MHz one, due to the higher bit rate and advanced modulation schemes that make 2.4 GHz more suitable to the networks with higher load. When it comes to the ZigBee topologies, tree and mesh topologies increase the range of the communications to the detriment of the delay. Besides, the mesh topology enables the connection between routers that allow the traffic in the case when one router fails. Therefore, when the complexity of the ZigBee network is increased, the best choice should be to select a mesh topology, which operates at the 2.4 GHz;
- Concerning the MANET, the choice of a routing protocol has influence on the network performances. The results show that in the case of larger number of workers, the most efficient routing protocols are AODV and OLSR. DSR is also able to route the traffic with similar delay as AODV or OLSR, but at the cost of increasing the routing traffic which leads to triplication of the network load in comparison to AODV, and its duplication in comparison to OLSR. Thus, for larger networks, where the risk that a node can become isolated is low, the protocol that might offer the best qualities is AODV, etc.

In further analysis, behavior of the larger number of network nodes should be examined. This might be achieved by connecting networks at different terminals within the port and analyzing them as a whole, within the considered-real scenario(s). Also, the experiments with larger packages' inter-arrival intervals should be done. The content of the network payload, i.e., the content of each package should be specified, as well. The managers and stakeholders at the port should be introduced in detail to the basic pros and cons of both here analyzed networks' structures and performances. Their real needs and preferences should give proper directions for further more intensive and rigorous research studies in the field. The workers'/supervisors' willingness to become part of such wireless network(s) is to be assessed, too, as a part of non-technical, or more *soft*, further examinations. Of the key importance is, in any case, top managers' and stakeholders' interest in adopting new, advanced wireless networks and back-end info-communication systems for improving both on port workers' and integral port's environmental safety measures.

References:

[1] Avgerou C. 2011. Discourses on innovation and development in information systems in developing countries research, in Galliers R.D., Currie W.L. (Eds.), The Oxford Handbook of Management Information Systems – Critical Perspectives and New Directions, published in the United States by Oxford University Press Inc., New York, Chapter 25, pp. 647-671.

[2] Bauk S., Gonzalez D.G., Schmeink A., Examining some ZigBee/RFID safety system performances at the seaport, Proc. of the 58th IEEE International Symposium Electronics in Marine (ELMAR), Zadar, Croatia, 12-14 September, 2016, pp. 133-137.

[3] Bauk S., Schmeink A., Colomer J., An RFID Model for Improving Workers' Safety at the Seaport in Transitional Environment, Transport, doi:10.3846/16484142.2016.1233512, article in press, 2016.

[4] Bauk S., Schmeink A., Džankić R., Port workers' safety monitoring by RFID technology: A review of some solutions, Proc. of the 7th International Conference on Maritime Transport (MT), Barcelona, Spain, 27-29 June, 2016, pp. 570-580.

[5] Bauk S., Schmeink A., RFID and PPE: Concerning workers' safety solutions and Cloud perspectives - A reference to the Port of Bar (Montenegro), Proc. of the 5th IEEE Mediterranean Conference on Embedded Computing (MECO), Bar, Montenegro, 12-16 June, 2016, pp. 35-40.

[6] Conti M., et al., From MANET to people-centric networking: Milestones and open research challenges, Computer Communications, 71, 2015, pp. 1-21.

[7] Ecoport 8, Project documentation: Ecoport 8 - Environmental management of transborder corridor ports, Code: SEE/A/218/2.2/x, Port of Bar (Montenegro) Final Report, 2013.

[8] Garcia Gonzales D., Wireless Sensor Networks (WSNs) vs. Mobile Ad-hoc Networks, Master thesis, Lehrsuhl für Theoretische Informationstechnick, RWTH Aachen University, Aachen, Germany, 2016.

[9] Garcia-Macias J.A., Gomez J., MANET versus WSN, in Sensor Networks and Configuration – Fundamentals, Standards, Platforms, and Applications, Ed. Mahalik N.P., Springer, 2007, pp. 367-388.

[10] Hakmat P., Ad-hoc Networks: Fundamental Properties and Network Topologies, Springer, Dordrecht, The Netherlands, 2006.

[11] HSE - Health and Safety Executive, A quick guide to health and safety in ports, London, UK, May, 2013. (Web resource; last access November, 2016)

[12] Kelm A., Laußat L., Meins-Becker A., Platz D., Khazaee M.J., Costin A.M., Helmus M., Teizer J., Mobile passive Radio Frequency Identification (RFID) portal for automated and rapid control of Personal Protective Equipment (PPE) on construction sites, Automation in Construction, 36, 2013, pp. 38-52.

[13] Manpreet J.M., Simulation Analysis of Tree and Mesh Topologies in ZigBee Network, International Journal of Grid Distribution Computing, 8(1), 2015, pp. 81-92.

[14] Mihaijlov B., Bogdanovski M., Overview and Analysis of the Performances of ZigBee-based Wireless Sensor Networks, International Journal of Computer Applications, 29(12), 2011, pp. 28-35.

[15] Pan M-S., Tseng Y-C., ZigBee and Their Applications, in Sensor Networks and Configuration – Fundamentals, Standards, Platforms, and Applications, Ed. Mahalik N.P., Springer, 2007, pp. 349-367.

[16] Saha S., ZigBee OPNET Modeler: An Efficient Performance Analyzer for Wireless Sensor Networks, International Journal of Engineering Sciences & Research Technology, 2(8), 2013, pp. 2032-2036

[17] TenEcoport, Project documentation: TenEcoport - Transnational ENhacement of Ecoport8 Network, code: SEE/D/01889/2.2/x, Port of Bar (Montenegro) Feasibility Study on Improving Environmental Management System at Container Terminal, 2014.

[18] Tepšić D., Jedno unapređenje OLSR ruting protokola u mobilnim ad noc mrežama, Doktorska disertacija, Univerzitet Singidunum, Beograd, Srbija, 2013.

[19] Trentesaux D., et al., Emerging ICT concepts for smart, safe and sustainable industrial systems, Computers in Industry, http:dx.doi.org/10.1016/j.compind.2016.05.001, article in press, 2015.

[20] Vancin S., Erdem E., Design and Simulation of Wireless Sensor Network Topologies Using the ZigBee Standard, International Journal of Computer Networks and Applications (IJCNA), 2(3), May-June, 2015, pp. 135-143.

Submitted: December 9, 2016.
Accepted: December 11, 2016.