V2P/I Communication for Increasing Occupational Safety at a Seaport

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Abstract **– This paper presents a model and some simulations of vehicle-to-pedestrian/infrastructure (V2P/I) communication channel performances at the seaport, whereas vehicles are taken as front-lifts and pedestrians as on port workers. More precisely, the aim of the paper is to study the important radio channel features between end nodes in order to optimize the network deployment and, at the same time, to display the communication limitations under realistic conditions. An ultimate goal is providing the contribution towards increasing works' and environmental safety at the invasive seaport industrial and commercial areas. Consequently, the corresponding radio channel simulation analyses are realized over the layout of the container and general cargo terminal at the Mediterranean Port of Bar (Montenegro).**

Keywords – **V2P/I; occupational safety; communication channel model.**

I. Introduction

The vehicle-to-pedestrian/infrastructure (V2P/I) communication has to improve traffic management in order to prevent traffic accidents (collisions), which are causing deaths, injuries, waste of productive hours, additional insurance costs, environmental impacts, etc. Intelligent Transportation Systems (ITS) which constitutive part, among others, is V2P/I communication have to provide safety, efficiency and comfort applications [1]. The cellular or broadband wireless interfaces provide the vehicles (here front-lifts) with connectivity to pedestrians (here on port workers) and infrastructural base stations, while dedicated short-range communication (DSRC) allows data transfers. Let us note that there is an IEEE 802.11p standard for vehicular communication in the 5.9 GHz (75 MHz RF) band as DSRC to enable vehicular communication for different safety and infotainment applications. This standard allows vehicle (front-lift) to transmit up to 1,000 m with 32 dBm power [1,2]. A vehicle (front-lift) is a source node and whenever it detects some danger, e.g., obstacle, reduced visibility, malfunctioning of braking system, road merging, potential collision situation, etc., it generates a warning message. This warning message should be broadcasted to all nodes (other front-lifts and workers) in the seaport area of relevance as quickly as possible [3].

Within this context, it is important to note that pedestrians (i.e., on port workers) safety at the invasive seaport environment is not an issue to be overlooked. For instance, front-lifts account for thousands of serious injuries and dozens of deaths each year in American workplaces. According to the National Institute for Occupational Safety and Health statistics reported to government inspectors by employers [4]:

- 20% of all front-lift accidents involve a pedestrian being struck by a front-lift, translating to almost of 19,000 people per year;
- 100 workers are killed in front-lift accidents every year;
- 20,000 workers are seriously injured in front-lift related accidents every year;
- 34,000 injuries are treated in emergency rooms every year due to the front-lift accidents.

While the above given statistics are not negligible, many pedestrians/workers and employers are still unaware of the dangers associated with operating/employing front-lifts. What is even more unfortunate is that many of these injuries could have been prevented by the simple installation of safeguards in the workplace, e.g., V2P/I devices.

When it comes to avoiding putting oneself at risk of being struck by front-lift, here are some of the common situations to watch for [5]:

- pedestrian/worker did not see the front-lift;
- pedestrian/worker did not hear the truck;
- pedestrian/worker came into too close proximity of the front-lift, etc.

The frequency of pedestrian/worker involvement in front-lift truck accidents can be controlled through better traffic management, in conjunction with safety equipment and awareness training. The traffic management can involve the demarcation of pedestrians'/workers' routes to keep mobile equipment and pedestrians/workers separate. The safety equipment on the part of pedestrians (workers) starts with wearing a high visibility vests. Additionally, front-lifts are required to have horns, and can be fitted with warning lights or other warning indicators. Curved mirrors can also be used to improve safety. As more sophisticated safety measure, an appropriate V2P/I system might be employed.

Unfortunately, there is no official statistics on above mentioned accidents in the under developed and developing countries (including Montenegro) due to the best of our knowledge. These numbers of incidents are not, most probably, so high because of the considerably lower workload in industrial and commercial areas of these countries, but anyway, stakeholders, employers and workers should be aware of the potential dangers, while the possibilities of introducing and adopting the appropriate V2P/I safety-warning systems should be taken into consideration in addition to other previously mentioned safety mechanisms. The V2P/I collision avoidance system uses energy-efficient and non-dedicated technologies [6]. This system employs existing infrastructure (if it is available) and devices like smart phones (widespread among drivers and pedestrians), cellular network and cloud. The safety mobile apps can be set to driver or pedestrian mode. These apps frequently send vehicle and pedestrian geo-location data to cloud servers. In cloud are performed threat analysis and alerts are sent to the users in risky situations.

On the basis of previously noted, the rest of the paper is organized as follows: Section 2 gives short research background with focus on the considered seaport environment; Section 3 contains the problem definition along with the description of the simulation environment; Section 4 discusses simulation results, and Section 5 gives some conclusion remarks, including potential directions for further research endeavors in the field.

II. Research Background

Within several previous research works, we have tried to show how occupational safety can be increased at the developing seaport harsh environment at the example of the Port of Bar. Accordingly, we have firstly considered a deployment of safety-warning solutions based on RFID technology. Some safety measures were proposed at logical level and tested in Opnet and Omnet++ simulation environments [7]. Then, we considered some possibilities of adopting ZigBee/RFID hybrid solutions for enhancing on port workers' safety [8]. And finally, we compared the application of ZigBee and MANET communication technologies [9]. All proposed solutions are cost-effective and energy-sparing, and they can be taken into consideration as affordable ones from the perspective of a developing seaport which is permanently facing the lack of available funds for environmental safety system improvements.

The obtained results, through the above referred research studies, should be used by the port top management team, stakeholders, and ICT experts as a kind of landmarks for increasing occupational and environmental safety, and also for repositioning (of course, in positive direction) the considered port at the global market of safe and green ports.

III. Problem Definition and simulation environment

The aim of this paper is to study the important radio channel characteristics of a V2P/I system (received power, delay and angular domain) in order to optimize the network deployment and, at the same time, display the communication limitations. In this context, the paper shows a realistic simulation using a semi-stochastic radio channel model, i.e., a combination of a ray-tracer algorithm and stochastic parameters [10].

The base stations (BS) are deployed covering the maximum area possible. The workers and their walking paths are randomly selected covering almost the entire seaport area (blue lines), while the front-lifts are simulated covering longer routes from side to side of the port working area (red lines), Fig. 1.

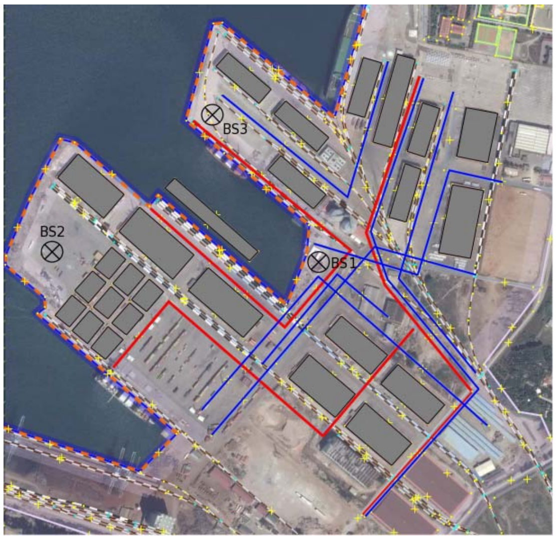

Figure 1. Layout of the container and general cargo terminal at the Port of Bar with front-lifts (red) and workers (blue) routes. (Source: Own)

The container terminal is located at the Pier I of the Port of Bar and it covers the area of 60,000 m^2. Wharf length is 330 m and the depth of the sea is 11 m. The surface of the terminal is marked by zones, and the connections for refrigerated containers are provided. The terminal has an area for disposal of 2,635 TEU in the range of the container crane. It has also 13 modular fields with capacity of 2,320 TEU per field. Additionally, the terminal has 6 modular fields for transportation and manipulation operations with 6,320 TEU per field. The containers handling is realized in direct manipulation with railway wagons or other means of transportation.

The general cargo terminal is located at the Piers I and II of the Port of Bar, and it is equipped with necessary devices for un/loading and manipulation cargo (including front-lifts). The length of the operational waterside line is 1,370 m. The average sea depth is 10 m. The terminal is equipped with 15 portal cranes with capacity of 15 t per crane.

The number of workers at the port depends on the workload and daily operational plans, and it varies from several workers to 20-25 per terminal/shift. The workers paths are simulated with a speed in the range of 1.4 m/s to 2.5 m/s (blue lines in Fig.1), while the front-lifts move at a maximum speed of 6 m/s (red lines in Fig.1). The simulation has been conducted deploying three base stations and 10 mobile users, i.e., workers and front-lifts in total.

The simulations are performed in a PIROPA environment, i.e., by using a deterministic ray-tracer algorithm [11], at a vehicular communication frequency of the 5.9 [GHz], which is envisaged for short distances 10-1,000 [m] using 2.6 GHz Intel Core i5 with 16 Gb of RAM, while the obtained results are presented within the next section.

IV. Simulation Results and Discussion

Regarding the V2P/I communication network using the ray-tracer algorithm output and adding stochastic properties, the following network features are considered:

- the Empirical Cumulative Distribution Function (ECDF) of the received power for the different workers and different speed, as well as for the front-lifts;
- the angular spread and delay spread for workers and front-lifts; and,
- the Doppler spread for all the workers (focus on max/min) and the front-lifts.

The first analyzed parameter is the received power at each position using the Empirical Cumulative Distributed Function (ECDF), which shows the distribution function associated to the empirical measure of the received power. As shown in Fig. 2, the received power for the workers and front-lifts is within the range of -140 dBm to -65 dBm, and around 40% of the receiver positions are above the -100 dBm threshold, which fits in the range of our previous study [12]. The simulated curves for Base Station 2 and Base Station 3, show the same behavior where the received power by the front-lifts is slightly higher due to the higher elevation, i.e., the front-lift has the receiver located at 10 m. Using Fig. 2, it is possible to plan the required number of base stations in order to fulfill certain power requirements for all users with different communication systems.

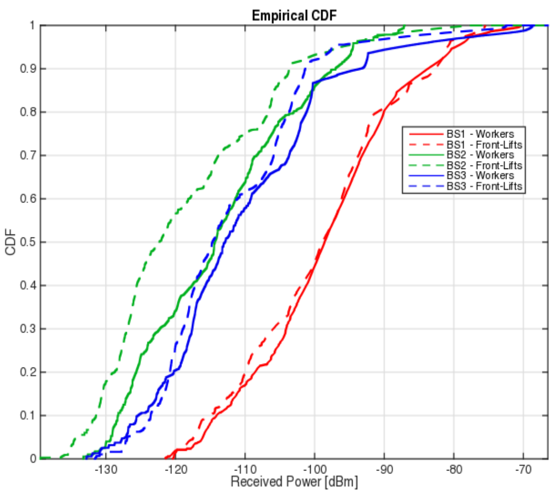

Figure 2. ECDF vs. received power [dBm]. (Source: Own)

In Fig. 3, the angular directions for all the users are displayed. The optimal antenna pattern has to be designed depending on the communication requirements and it also required fulfilling the technical limitations, i.e., antenna design. The last studied parameters are at the receiver side, Doppler shift and delay, which are useful in order to design the receiver devices for workers and front-lifts. Table 1 shows the maximum Doppler shift for the communication between the workers and front-lifts, i.e., for both sides of the communication channel, which are movable. Due to low speeds in the port area, the Doppler shift can be neglected in the base station-worker scheme and easily reduced in the case of worker to worker communication.

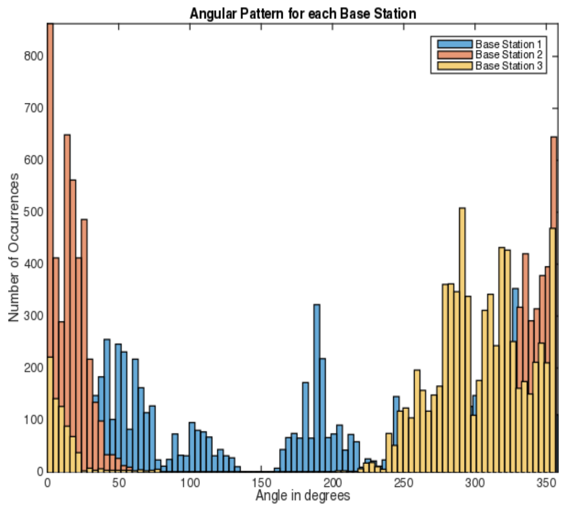

Figure 3. Angular patterns for deployed base stations. (Source: Own)

Regarding the delay values, the results show a higher delay in the base station-worker communication, which is to be taken into consideration in the safety measurements design. However, in the worker to worker communication scheme, the delay is in the range of a few microseconds which does not impact the communication scheme at the receiver side.

TABLE I. Some Doppler shift and delay analysis

Features vs. Interplays	Max DS	Min DS	Max Delay	Min Dilay
BS/FL-W	negligible	negligible	13.941 µs	0.202 µs
W/FL-W/FL	3.969 Hz	-3.455 Hz	1.652 µs	35.967 µs

Legend: DS – Doppler Shift; BS – Base Station; W – Worker; FL – Front-lift (Source: Own)

From the view point of the developing Port of Bar, which is here used as example, it is very important to consider expected costs of deploying such safety system. On the basis of secondary literature resources in the field, the figure of 50,000 $ can be used as a total potential average costs per site [13,14]. This cost should be affordable for the Port of Bar, despite the fact that it functions during almost three decades in transitional economy, which causes permanent reproduction of crises and prevents its economic development and growth.

V. Conclusions

The paper presents an idea of adopting V2P/I communication pattern for enhancing occupational safety over the seaport operational area. An appropriate communication channel model is conceived for the needs of the developing Port of Bar, while some corresponding simulation experiments are realized using a semi-stochastic channel model in a PIROPA environment. Accordingly, it has been shown that:

- three arbitrary placed base stations can cover the entire container and general cargo terminals at the considered seaport perimeter and provide smooth communications between a certain number of moving on port workers and front-lifts in order to improve pedestrian (worker) detection and on port road safety by avoiding collisions;
- for the proposed arrangement and elevation angles of the base stations antennas, the received power is at the satisfying level in the range of each base station; and,
- the Doppler shifts and delays at the receiver's side are negligible for different workers and front-lift interplays in relation to the fixed base stations.

Since the idea of deploying V2P/I communications in the developing seaport environment is proposed, it is necessary to mention the costs of deployment under such conditions. Due to the data given in Section IV, it becomes obvious that such safety system might be affordable in the considered case. However, it is up to the port's top managers and stakeholders to provide funds for such safety-warning system, and also to engage ICT experts in its implementation.

Further experiments in the field should be realized over the whole Port of Bar, i.e., over its all seven available cargo and passenger terminals and for greater number of pedestrians (workers), front-lifts and/or other transportation devices. Also, more extensive simulation experiments should be realized for different numbers and arrangements of base stations including different obstacles that might appear at the seaport terminal(s) and cause communication channel disruptions.

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