Enhancing on Port Safety by Vehicular Communication Approach

Port of Bar (Montenegro) Case Study

Sanja Bauk
Maritime Faculty
University of Montenegro
Kotor, Montenegro
bsanjaster@gmail.com

Jose Angel Leon Calvo, Anke Schmeink and Rudolf Mathar
Institute for Theoretical Information Technology
RWTH Aachen University, Germany
{leon, anke.schmeink, mathar}@ti.rwth-aachen.de

Abstract—**The paper proposes vehicular communication principles in order to increase workers and pedestrians cross-roads safety at the seaport. A hybrid environment-based approach for modeling the vehicular communication channel is used. It is based on a combination of a deterministic ray-launching algorithm (PIROPA) to model large-scale parameters, and a stochastic model to obtain small-scale ones. Simulation analysis of some power-delay profiles for different workers or pedestrians and front forklifts seaport cross-roads interplays are done over the selected container and general cargo terminal area of the Port of Bar (Montenegro). The results provide good understanding of the communication requirements in order to obtain a feasible on-post safety system.**

Keywords-seaport; safety; vehicular communications; channel modeling

I. Introduction

Increasing safety at seaports (afterwards ports) is among the main tasks of the environmental management system, while safety of on-port workers and pedestrians is at the forefront. Among the most dangerous places are cross-roads at the port operational area and quay side, where unexpected collisions of workers and/or pedestrians and transportation/manipulation vehicles are to be avoided. Therefore, the appropriate safety-warning systems are to be conceived, designed, adapted and implemented at the cross-roads.

In the previous research attempts in the field, different types of communication channels between workers/pedestrians and transportation/manipulation heavy mechanization structures are analyzed, like: RFID [1], ZigBee/RFID and MANET [2]. Keeping in mind that Port of Bar operates since decades in transitional environment, an intention to propose affordable, reliable and flexible *smart* safety solutions was present. Therefore our main intention through the previous research experiments was to introduce the research community, but also the managers and stakeholders in the port with contemporary safety systems, which might be used at the port and promote it as safety and green one.

This paper presents a pioneer attempt to involve vehicular communication propagation principles into a real on-port scenario over the layout of the Port of Bar container and general cargo terminal, which has the greatest turnover at the port, and consequently the highest potential risks. This approach is reasonable since the on-port safety is the main goal and vehicular communications focus on this aspect. Moreover, the workers/pedestrians and the transportation vehicles form an ad-hoc network in order to share their location in the same way as vehicles use beacon messages [3].

II. On Radio Channel Modelling

The term channel is generally used to describe the models, theory, and experimental data, which include one's knowledge of a wireless channel in a specific type of environment. Typically, it is a function of bandwidth and center frequency. The channel can be described as the complete set of parameters for all paths that transmitted electromagnetic waves in the frequency band of interest take from transmitter to receiver over the spatial region of interest [4]. The vehicular communication propagation channel has strong impact on the coverage, reliability, and real-time capabilities of the networks. Wrong assumptions about fading, e.g., can lead to wrong conclusions on the dependability of pedestrians'/vehicles' warning systems at the cross-roads. On the contrary, sound and reliable knowledge of the propagation channel and its realistic corresponding model can be used as a core one for flexible and practical design and testing of vehicular communication systems [5].

In this research work, a combination of ray-launching algorithm (PIROPA - Parallel Implemented Ray Optical Propagation Algorithm) to model large scale parameters (pathloss, delay, angle of arrival/departure and number of rays per cluster) and stochastic model to obtain small scale parameters (Doppler shift, inter-cluster phases and fast-fading) [6] has been used.

A. Large scale parameters

The impulse response obtained by applying PIROPA is based on the double-direction radio channel [7] described by (Eq.1):

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$$h(t,\tau,\theta,\varphi)=\sum_{n=1}^{N}A_n\delta[(\tau-\tau_n)(\theta-\theta_n)(\varphi-\varphi_n)]. \quad (1)$$

Where, A_n is the complex amplitude of the received ray, τ is the delay of each signal path, θ is the angle of arrival, φ is the angle of departure, and δ is Dirac delta function. By Eq.1 the received power can be calculated as (Eq. 2):

$$P(t,\tau,\theta,\varphi)=\int_0^\infty |h(t,\tau,\theta,\varphi)|^2 dt\,. \quad (2)$$

Where, h is the channel impulse response calculated using the long-scale parameters. These parameters involved in the calculation of the received power are deterministic and they are calculated by ray-launching algorithm. This is acceptable due to the fact that θ,φ, and A_n of each cluster are not changing rapidly. On the other side, the phase of the inter-cluster rays fluctuates fast and needs to be determined stochastically, along with Doppler shift and fast-fading phenomenon.

B. Small scale parameters

Small-scale stochastic parameters are used for final adjustment of the channel model to its random nature. Parameters too fine grained for modeling in the previously shortly described deterministic approach, e.g., workers and/or pedestrians, and transportation and/or manipulation vehicles signs at the analyzed on-port scenario, are considered by adding stochastic components, as: Doppler shift, inter-cluster phases and fast-fading.

Doppler shift is influenced by relative motion of the communication network end nodes and its behavior can be summarized as follows: the bigger the relative speed between both end nodes of the channel and the higher the mobility of the environment elements, the higher the Doppler shift will be. It is worth to mention that speeds of moving end nodes and environment objects in concrete port scenario are relatively low, and consequently Doppler shift is small.

Inter-cluster phases is caused by the movements of the surrounding network elements (e.g., ship, container cranes and railway wagons at the port scenario), which produce a change in the indirect phase of the ray. It is calculated as a function of the inter-cluster phases obtained by PIROPA, scaled by coefficient $K\in(-1,1)$ and uniformly distributed values in the range $(0,2\pi)$ [6].

Fast-fading is the fluctuation suffered by the transmitted signal due to the multipath components. It is modeled as Racing fading and the scaling factor of the distribution biased by the environment [8]. In a Line of Sight (LoS) situation, fast-fading have smaller impact on the channel than in a Non-Line of Sight (NLoS) case, where the multipath propagation has a bigger impact. Both situations are present in the considered port area.

III. THE PORT ENVIRONMENT SCENARIO

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 protects workers of some occupational risks, but this fact should not be recommended as a model of the port's desirable operational and business state. Working conditions should be improved through effective and progressive adoption of new transportation and manipulative technologies, along with corresponding info-communication systems.

Therefore, through the previous research works in the field [1,2], several models for enhancing on-port workers safety have been proposed at logical and simulation levels. As a follow-up of these pioneer research endeavors, this paper considers theoretically, with rather high level of abstraction, the possibility of deploying vehicular communication propagation patterns over the port container and general cargo terminal. In focus are cross-roads between the quay and storage area, and between container blocks at the storage area itself.

End nodes of the communication network are on-port workers/pedestrians and front forklifts which are hypothetically equipped with sensing and vehicular communication platforms, which include warning system in the case when workers/pedestrians and front forklifts are in the vicinity of the cross-road. Front forklifts are chosen as manipulative and transportation devices which suffer of both NLoS and LoS visibility problems, black spots, death angels, etc., since the container is always in front of the driver. There is no records on accidents at the cross-roads at the Port of Bar, mostly because of its relatively low turnover, but in the future this situation can be changed and here proposed safety communication model might be useful.

IV. SIMULATION EXPERIMENTS AND RESULTS

The container and general cargo terminal at the Port of Bar has a quadrilateral form, which can be approximated by a rectangle with dimensions 650 x 350 [m] (Fig. 1).

Workers/pedestrians can move with high level of freedom over the terminal, while their movements are restricted by the physical structures present on the surface, which are in this case industrial warehouses, moving vehicles, moving railway wagons, vertical and horizontal mechanization structures, and several container blocks.

Workers'/pedestrians' moving speed is approximately 2-3 [km/h]. Front forklifts are moving along the roads and free spaces at the terminal. They are moving by the speed of about 15-20 [km/h]. Our idea is to simulate the communicational channel between these moving end nodes in order to trigger warning system when workers/pedestrians and front forklifts are in the vicinity of their paths cross.

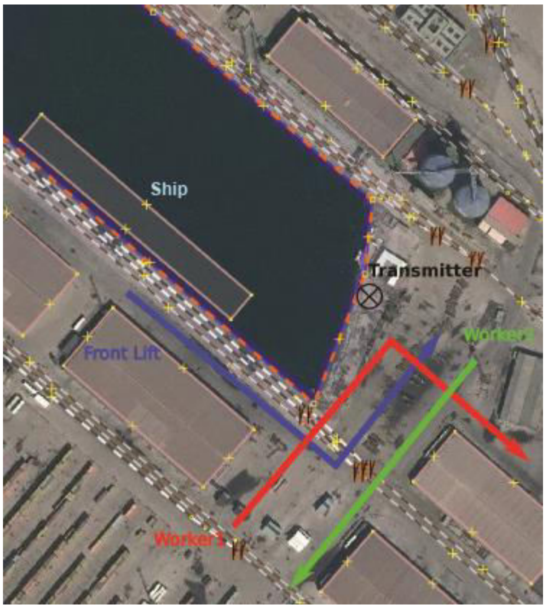

Figure 1. Layout of the container and general cargo terminal at the Port of Bar. (Source: Adapted OpenStreetMaps view)

The berth is about 330 [m] long and it can allow sailing in of a container ship which depth gauge is maximally 11.5 [m] and which carries 800-1200 [TEU]. Ship's speed while sailing into the port is only a few knocks. There is a container crane and railway line along the coast which length is approximately 500 [m] and there are 24 railway wagons which operates during ship's (un)loading operations. The speed of these railway wagons is 5-10 [km/h]. These are the main elements of the dynamic port environment [9,10] in which vehicular communication channel is simulated by the combination of previously described deterministic and stochastic approaches over OpenStreetMaps background.

Simulation experiments are realized over several different scenarios which consider interplays between two workers (Worker 1 in red, and Worker 2 in green) and one front forklift (Front Lift in blue), while transmitter (in black) is placed at the strategic location at the terminal perimeter (Fig.1). The lower and upper bounds of the received power by end nodes are given in Table 1, and they are all in-between the thresholds. Delays are also negligible.

TABLE I. POWER-DELAY BOUNDARY VALUES FOR DIFFERENT ON-PORT DYNAMIC SCENARIOS

	Power [dBm]		**Delay [10^{-6} s]**	
Scenario	min	max	min	max
1. Front Forklift-Worker 2	-75	-33	0.2	2.8
2. Transmitter-Front Forklift	-105	-72	2.2	10
3. Transmitter-Worker 1	-108	-75	0.2	1.2
4. Transmitter-Worker 2	-103	-84	4.2	9.4
5. Worker 1-Worker2	-110	-30	0.01	0.12

(Source: Own)

The shapes of power-delay curves vary depending on the mutual positions of the network end nodes within the dynamic port environment. In Fig. 2, power-delay profile for Front Lift – Worker 2 interplay is shown. Blue-green dots represents direct signal, while yellow-green dots represent its multipath components. Direct signal is obviously more compact than multipath rays which show large scattering trend.

Fig. 3 shows the power-delay profile in the case of Transmitter-Front Lift interplay in the considered dynamic environment, which has "W" shape, following the moving pattern of the Front Lift. It has a sense if one takes into account relative movement of these end nodes. Multipath components are not so emphasized in this case, due to the higher altitude of the Front Lift which provides a predominance of LoS situations.

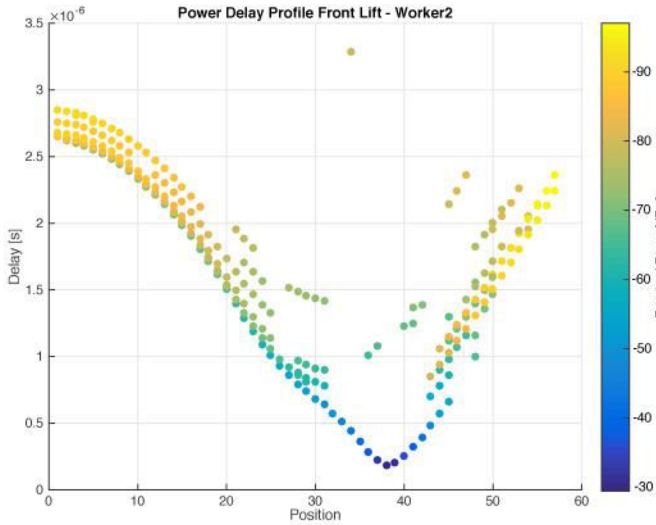

Figure 2. Front forklift-Worker 2 power-delay profile. (Source: Own)

Fig. 4 presents rather parabolic power-delay curve in the case of Worker 1 - Worker 2 communicational channel. Received power is closed to the threshold, but one must have in mind the distance between them, which should be considerably reduced, e.g., in the need of triggering alarm at the cross-road. There are also some multipath components which are arranged as extensions of direct signal.

Simulations are done in PIROPA environment, at the vehicular communication frequency 5.9 [GHz], which is envisaged for short distances 10-1000 [m] using 2.6 GHz Intel Core i5 with 16 Gb of RAM. The simulation time is almost negligible due to the reduced number of receiver points. Since the density of moving objects is not so high, as well as their speeds in comparison to general vehicular communication environments [11,12], stochastic components are not predominant like in the cases of high density of end nodes and surrounding objects movements. In addition, the Port of Bar has modest infra- and supra-structure objects and it can not be treated as a real "urban canyon" scenario. However, it was worth to analyze its dynamics from the perspective of actual vehicle communication channel modeling principles. This can stimulate further research endeavors in this domain.

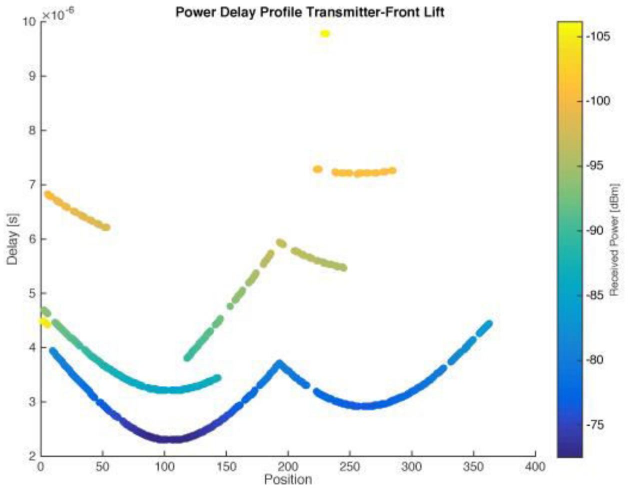

Figure 3. Transmitter-Front forklift power-delay profile. (Source: Own)

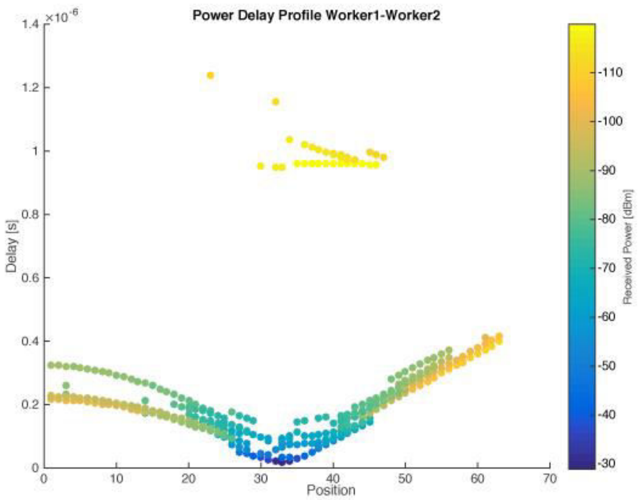

Figure 4. Worker 1-Worker 2 power-delay profile. (Source: Own)

V. CONCLUSIONS

Vehicular communications are increasingly gaining importance in research and industry as a viable communication technology, which makes cost-efficient, reliable and flexible deployment strategies [13]. In this paper, a port industrial environment-based strategy is used in simulation analysis of the communication channel power-delay profiles for different transmitter, workers and front forklift interplay scenarios. Our main motive was increasing on-port workers/pedestrians safety at the cross-roads at the port perimeter. It is shown that the strengths of the received signals is in all considered cases are within the boundaries of upper and down received power thresholds, while delays are negligible. There is no connectivity interruption when it comes to the direct signal. This works for each considered on-port scenario. The main drawback of the considered port environment-based model is low density and speed of end nodes (two workers and one front forklift), as well as, low density and speed of surrounding objects (container ship, quay crane, railway wagons, and two straddle-carriers, which also operate at the terminal). Further research should be oriented towards exploring vehicle communication channel performances in larger ports, which have higher level of commercial and industrial activities. Exploring such environments will require more detail analysis of both deterministic and stochastic features of the channel. In addition, end nodes sensor-communication platforms and corresponding warning system features are to be considered, since it is an important segment of proposing affordable, reliable and scalable safety solutions. Also, the in-situ experiments might be planed and realized in the future, with an aim to make comparison with here presented simulation results.

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