Abstract

of the Habilitation Thesis

Optimization of detection, communication, and safety processes in transportation automation systems

by Marius Minea

The habilitation thesis with the title "Optimization of detection, communication, and safety processes in automation systems for transport" synthetically presents the results of the own research activity, showing the most important developments and milestones of the professional career, participation in research and development projects at the national level or international, as well as part of the publishing activity in the scientific field in the period from obtaining the title of Doctor of Engineering to the present.

During the professional activity, I got to know multiple facets of automation systems and their challenges, especially for rail, road and naval modes of transport, initially working as a interlocking engineer within the Regional C.F. Bucharest, Section CT2, respectively the Regional Laboratory, then as a researcher within the Institute of Technological Research and Design in Transport (ICPTT), and from 1991 until now, teaching staff at the Polytechnic University of Bucharest.

In the first stage of my professional activity, my knowledge grew regarding elements and technical solutions of railway automation, as District Head of Railway Train Yard Automation at the triage in the town of Videle, at that time called the "cybernetic railway island", where I made my contribution to the organization of technological processes, as well as proposing new solutions of the technological flow.

Later, I worked as a scientific researcher within the Institute of Technological Research and Design in Transports (I.C.P.T.T.), where I participated in numerous automation projects in the railway, naval, communications and other fields, having the opportunity to work with the first types of data processors of 1 bit for the construction of an automated ship hull cleaning robot, as well as an automatic mapping system of port seabed, based on ultrasonic localization and radio remote control, field testing for railway remote-controlled locomotives and other automation projects.

During my work as a teacher at the University, I have developed a range of research activities in the field of road transportation as well, by participating in numerous projects at national and international level.

I obtained my doctorate in 1997, and my doctoral thesis, with the title "Behavior of railway systems with high functional reliability under intense disturbances " was confirmed by the Ministry of Education by Order no. 4268/23. 07. 1997, based on the CNADTCU opinion of 10-11.07.1997.

The structure of the habilitation thesis is compliant with the methodological regulations approved by the Order of the Minister of National Education - OM No. 3121 of January 25, 2015 - published in the Official Monitor of Romania, part I, no. 107/10. II. 2015 and by Order No. 5225 / 2020 of August 17, 2020 – published in Official Monitor No. 783 of August 27, 2020.

The choice of the topic for this habilitation thesis was in close relationship to my professional and scientific concerns and preoccupations. I strongly believe that automation processes in transports can be improved in

terms of energy efficiency, safety, and security of information exchange. Currently, these are based on complex infrastructures, which exhibit higher consumption of materials and energy, with a major impact on the environment, also having high costs. In the context of the current economic recession, the increasing risk factors, or the nature of cyber and energy security issues, I was concerned with finding solutions to mitigate these risks, through research-design measures, appropriate to the functionality of the components in the transport infrastructures. Thus, I turned my attention to the area of information collection, where, in the case of road transportation, the solution of gathering very accurate information from many sensors installed in the infrastructure, although accurate, proves to be expensive and sometimes not fully justified. I considered that the use of an information input obtained from data of a statistical nature, properly processed and filtered, could compensate for these shortcomings. Thus, the idea of replacing the classic concept of remote-powered transport infrastructure, based on fixed sensors, with an autonomous micro-grid structure, which could use a combination of fixed sensors with "mobile" sensors, installed even on the vehicles moves on these transport routes. Thus, I proposed some innovative solutions such as:

- To increase the efficiency of inter-vehicular communications, based on hybrid technologies, opportunistic methods, and algorithms for better clustering vehicles that communicate data to each other.

- Development of non-intrusive data collection solutions through mobile sensors, for public passenger transport, designed for urban areas and multi-modal transportation.

- To change from the concept of developing infrastructures with fixed physical sensors to that of infrastructures based on the capturing information of a statistical nature and hybrid sensors (both fixed and mobile).

- Development of solutions for indoor localization of travelers and guidance in the public transport system.

- Innovative energy harvesting solutions to achieve a reduced carbon footprint for urban highways.

To conclude, the unified concepts underlying these research activities were: Increased autonomy and resilience, based on modularity, economy of materials, reduced carbon footprint and maximized informational efficiency.

The main results obtained based on these research activities, after 1997, may be resumed as follows:

- Publication of a total number of more than 60 papers indexed in international databases, with more than 50 ISI Web of Science papers, of which 8 in high impact factor journals: MDPI Sensors IF 3.847 (Q1/2022), MDPI Energies IF 3.252 (Q1/2022), in most cases being first author, or even sole author.

- 19 papers and articles in the volumes of recognized international scientific events, organized in the country and internationally.

- Two invention patents, one of which as the first author and the submission of another patent application (currently under evaluation).

- 7 specialized books published in recognized publishing houses.

- Obtaining 25 awards at international invention salons.

In 2020, I won the gold medal at the International Invention Show in Zagreb, Croatia, the same prize being awarded in 2021 at the International Competitive Invention Show in Toronto, Canada, organized by the International Society of Innovation and Advanced Skills (TISIAS), for the solution "Method and system

for the anonymous collection of position and mobility information in public passenger transport, based on Bluetooth and artificial intelligence".

My university career began in 1990 by supplementing some hours at the disciplines Electronic Devices and Circuits and Train Trial Yards Automation, specialization in Telematics and Electronics in Transport. Later, starting in 1991, I filled the position of assistant professor at the department with the same name, in 1997 that of lecturer, and in 2002 I obtained the position of associate professor. Throughout the teaching activity, as the educational plans evolved, I wrote the following new university courses, for all of which I have published several textbooks and laboratory manuals, in several editions:

- Railway traffic management systems (C, L, P) – course developed based on the experience in railway automation operations, during the three years of work as an engineer in the field, timely updated based on a successful cooperation with Thales Romania and Alstom.

- Watrerway traffic management systems (C, L, P) – course developed on the basis of a good and long collaboration with the River Administration of the Lower Danube, SCN Giurgiu, as well as with *viadonau* (Austria).

- Telematics for navigation (C, L), also developed based on the experience of collaboration with Austriatech (Austria), within international projects.

- Quality, reliability, and security in Transports (C).

- Modeling and simulation methods (C, P).

- Technologies for autonomous vehicles (C).

- Connected Vehicles and Mobility (C – Engl., I.T.S. master's program).

- Navigation Dynamic Guidance and Autonomous Driving (C, L, P – Engl., I.T.S. master's program).

I developed successful cooperation with several private companies, and from the position of specialist consultant of the Bucharest City Hall for the Bucharest Traffic Management System (BTMS) I managed to sponsor the faculty laboratories with signaling, control and traffic management equipment: road signaling system SUCCESSOR (Romania), SWARCO ITC-2 detection, signaling and control system, together with the UTOPIA-SPOT adaptive road signaling software suite, which currently equips the centralized traffic management systems of Bucharest and other cities in the country and around the world. These labs serve students to develop their technological skills and knowledge, but also as research tools. Also, I have been involved in Nea Holland's cooperation with Romanian authorities for the elaboration of Masterplan for Transports in Bucharest, Ploiești, and Sibiu cities.

Other successful cooperation with foreign companies to mention are in the field of River Information Services, Ship Tracking and Tracing and Notices to Skippers – viadonau (Austria) and Plovput (Republic of Serbia) – here I have participated in several projects for the elaboration of terms of reference for River Information Services (Serbia) and COMPRIS demonstrator program for Europe.

The habilitation thesis, drawn up in accordance with the legal provisions, is structured as follows:

- Abstract (in Romanian and English)

- Part I - Achievements in the professional, didactic and research fields

- Part II – Plans for the evolution and development in the professional, scientific and academic careers.

Part I - Achievements in the professional, didactic and research fields

1. Optimization of vehicle and passenger detection through non-intrusive methods with low energy impact.

This section proposes an integrated solution for collecting traffic and travel information using public transport vehicles, running on fixed routes in urban environments. A specific configuration of BT and/or Wi-Fi sensors located on the vehicle is used, and through trilateration methods, respectively Voronoi diagrams, the detected BT devices are radio mapped. Then, through a specific algorithm, the density of nodes in radio bounded areas, as well as other parameters, is determined, using elements of artificial intelligence and unsupervised learning. Figure 1 below shows the configuration of the sensors on the vehicle.

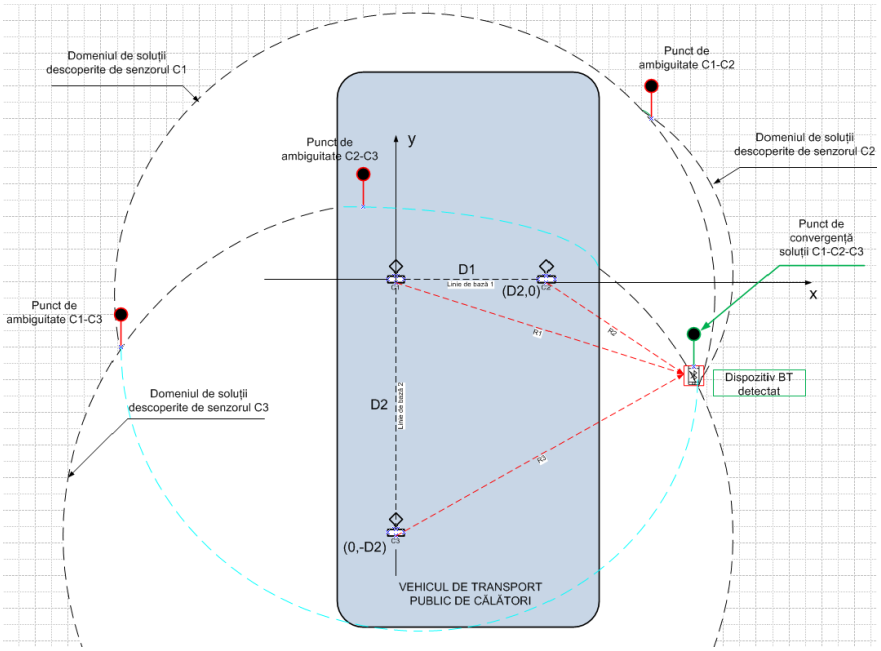

Figure 1 Structure and placement of sensors onboard the vehicle

A number of experimental results were presented, field measurements to determine the representativeness of the number of detectable BT devices in relation to the actual number of physical elements (vehicles and passengers), to determine correction factors and error compensation methods, limiting the RSS (Received Signal Strength) for establishing the limits of the radio zoning polygon, etc.

Considering an access point (AP), the distance has been computed taking into account the following formula:

$$D_{AP} = 10^{\frac{P_M - RSSI}{10 \cdot N}} \quad (1),$$

where P_M stands for the power level at the transmission point, and N represents a coefficient which describes the environment from the propagation point of view. N has to be adjusted at the initial calibration tests, in order to optimize the results. A comparison has been made between Wi-Fi and Bluetooth communication technologies, employing the Weka tool (Waikato Environment for Knowledge Analysis, classifier: Linea Regression), Figures 2 and 3:

Correlation coefficient	0.9992
Mean absolute error	0.0058
Root mean squared error	0.0067
Relative absolute error	4.3379 %
Root relative squared error	3.8848 %
Total Number of Instances	98

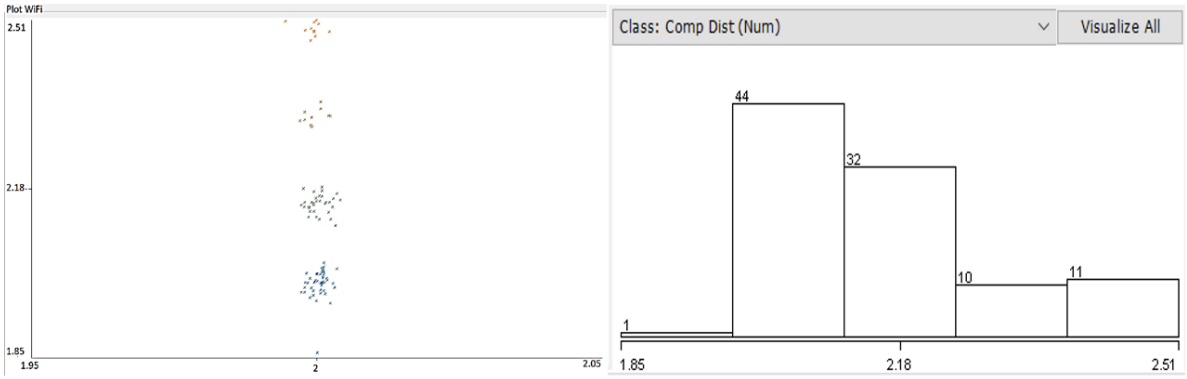

Figure 2 Distance to WiFi AP computed from measured RSSI, versus actual distance distribution, plotted in Weka. The colors represent the membership of the data in the different clusters, classified by the LR algorithm in Weka

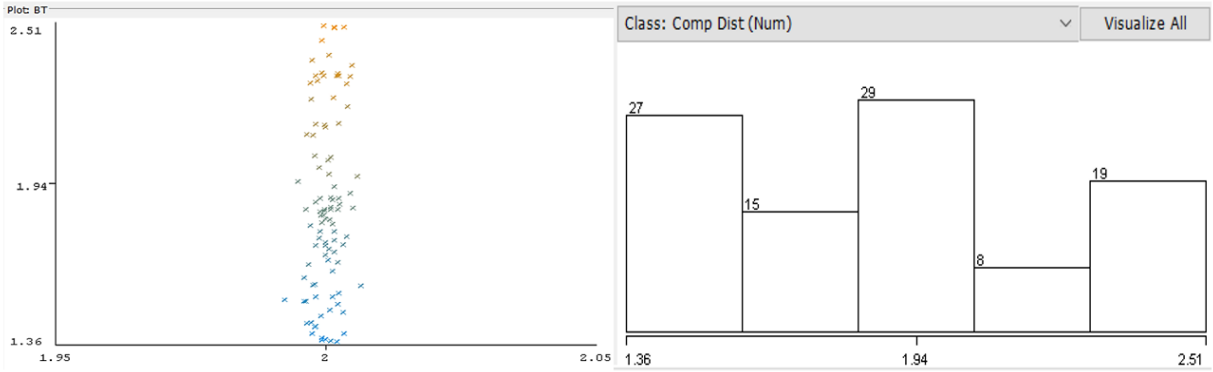

Figure 3 Distance to BT transmitter computed from measured RSSI, versus actual distance distribution, plotted in Weka. The colors represent the membership of the data in the different clusters, classified by the LR algorithm in Weka

Also, several algorithms for grouping (clustering) targets are analyzed to determine the secondary quantities: passenger and vehicle density, traffic flow, etc. Finally, the solution is completed with the algorithm for clustering information in three zones: passengers in the vehicle, travelers waiting in public transport stops, and traffic density.

Non-intrusive vehicle-in-traffic detection of targets of interest involves equipping public transport vehicles with detection systems capable of collecting a significant amount of traffic information. The proposed solution aims to collect information on:

- Estimated number of passengers on board, with origin-destination patterns (dependent on the randomization feature in Android devices).

- Estimated density of private, collateral, vehicle traffic.

- The estimated number of passengers from public transport stations and the estimated density of passengers in the station, in the radio delimited area, for the assessment of transport demand and allocation of vehicles on the route.

- Public transport vehicle secondary location technique by memorizing the position of fixed BT devices, detected at several crossings (e.g., TV sets, smart home appliances, with BT) – usable as a backup in the situation when the main solutions do not work.

The solution is based on a specific configuration of BT sensors, on trilateration, and collects information that is subsequently filtered with unsupervised AI algorithms, from the k family (k-means, k-medians or k-medoids), respectively Voronoi diagrams for density estimation in area of interest. As a future development, it is possible to use this solution in a V2I environment as well. The solution has been patented: RO134415-B1 / RO134415-A0, DIIDW:2020857359, patent obtained in 2022.

2. Solutions to optimize indoor location methods for guiding travelers in multi-modal transport terminals. This section studies different methods of collecting location and timestamp information for people inside buildings and transport terminals, also using BT and Wi-Fi technologies. The different indoor location solutions (based on RSSI, RTT, TOF, TDOF, DOA, TDOA, etc.) are presented synthetically with their advantages and disadvantages. A proprietary dual solution is proposed, based on the use of the RSS and RTT indicator and the application of corrective measures, followed by clustering techniques based on unsupervised learning (k-means algorithm, respectively EM-GMM). Also, the influences of the equipment on the accuracy of RSSI determination, the position of their antennas, as well as the influence of the number of people in the radio field between the transmitter and the receiver are analyzed, in order to determine some coefficients and algorithms for correcting the measurement results. Figure 4 shows how the RSS indicator is influenced by the number of people between the transmitter and the receiver. As a solution, a dual variant is proposed: i) uncontrolled/asynchronous, in which radio mapping techniques are used for localization followed by position recognition algorithms, based exclusively on RSSI information and association methods with known positions (e.g. k-NN), respectively ii) controlled/synchronous localization, in which, in addition to the previously presented method, RTT techniques are also used to improve the localization accuracy.

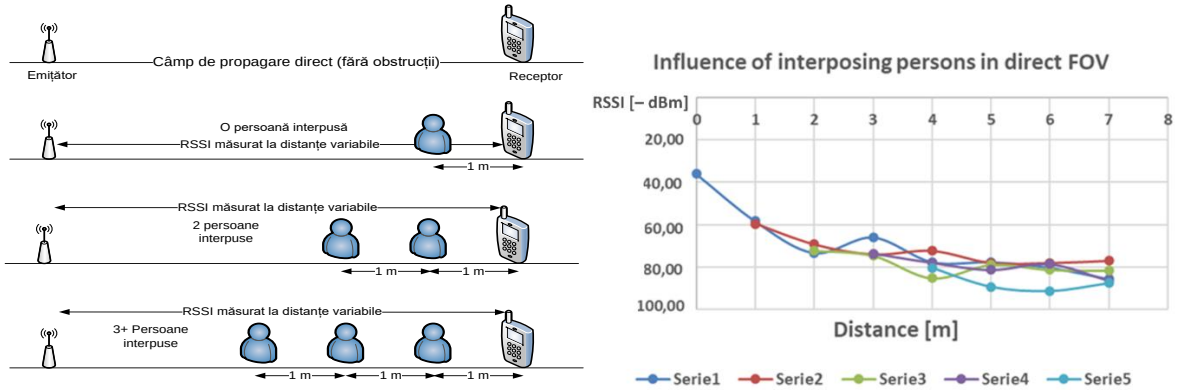

Figure 4 The effect of the interposition of people between the transmitter and the receiver, in the case of BT technology

3. Contributions to increasing the functional safety of the communications component of cooperative transport systems, to improve resilience and environmental protection. This section of the thesis addresses a related subfield, namely that of connected vehicles, in the context of the transition from non-autonomous to autonomous vehicles, with a transition period in which non-properly equipped vehicles, partially equipped vehicles, as well as fully equipped vehicles for connectivity. Three scenarios are covered, namely:

- a) Solutions to increase the availability of V2V and V2X communications through opportunistic methods - VANET-Cellular, in which the connectivity of vehicles on extra-urban highways is analyzed.

- b) Solutions to increase the availability of V2V and V2X communications through opportunistic methods - VANET - CB Radio.

- c) Improving traffic safety through cooperative driving control strategies, based on VANET. In this case, the pro-active strategy (recommended safe speed and clearance information) ensures an acceptable level of traffic safety. The Figure 5 below shows the network connectivity versus flow density plot.

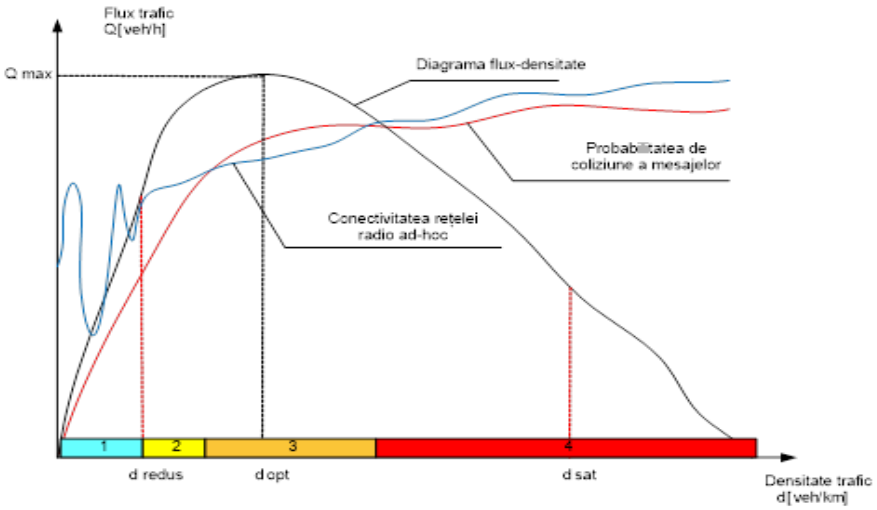

Figure 5 Connectivity and Message Collision Probability in Traffic-related VANET Performance Evaluation (Extraurban Environment)

In each section, different scenarios are analyzed, and practical field measurements are carried out, then different working algorithms are proposed for vehicle communication compatibility, safety enhancement and opportunistic use of multiple communication media so that vehicles poorly equipped with communication systems can benefit from the advantages of DSRC / VANET and other similar warning/safety solutions.

4. Contributions to the development of modular automation systems, with low energy dependence, for non-polluting (green) highways. This section proposes a modular highway model, with high energy recovery capacity and/or high level of energy autonomy, having a low impact on the environment. Several energy recovery technologies (solar, thermal, electrokinetic, wind, etc.) are comparatively analyzed and the most convenient options are chosen. It is also proposed to segment the highway into modular automation sections, with radio communications, forming autonomous, local energy microgrids. For their management, specific algorithms are proposed, based on Markov chain prediction of solar energy and optimized genetic algorithm management of the energy micro-grid, having four operating regimes. Also, several experimental tests are carried out for: the efficiency of solar panels in relation to the angle of incidence of light, the variability of daily sunlight, the variability of wind, the efficiency of LoRA and nRF24 communication technologies for transmitting data from sensors. Figure 6 shows the Genetic Algorithm proposed for a highway automation segment and Figure 7 the experimental result for LoRA.

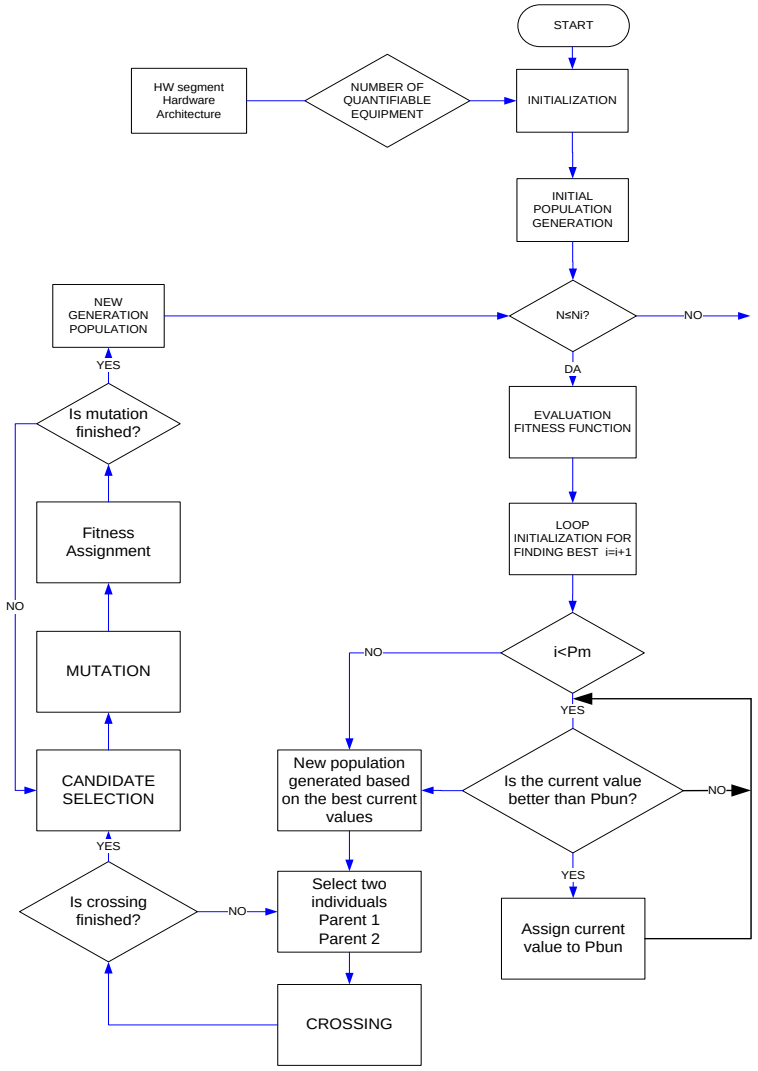

Figure 6 Flow chart of operations in the genetic algorithm for optimizing energy consumption in the highway sector micro-network

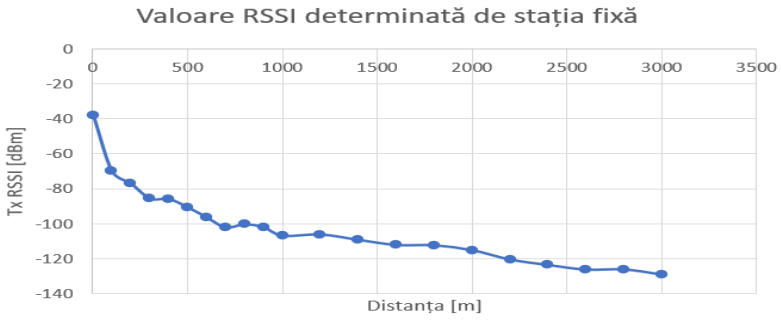

Figure 7 Mean RSSI values recorded by the fixed station as a function of the distance between them (FOV scenario)

Section II - Plans for evolution and development in professional, scientific and academic careers

On a professional level, I propose myself to obtain the accreditation of PhD supervisor in the field of Electronics, Telecommunications and Information Technologies, in order to contribute to the professional and scientific development of young researchers with an orientation towards transport applications in particular, by promoting attractive, innovative research themes, with the conviction that in this way I will also give my contribution to the development of the field, not only at the national level, where this development is so necessary, but also at the international level.

With a permanent concern for fundamental research, the topics I want to tackle in the future will fall into the following categories:

- Intelligent, non-intrusive sensing and data collection solutions, with highly energetic autonomy.
- Efficient communication and information systems - for autonomous and connected vehicles.
- Autonomous, modular, and low-carbon emission transport infrastructures.

I want these ambitious goals to become possible, to diversify, considering my career of 3 years in production, 3 years in research and over 30 years of teaching activity, obtaining a score more than twice the minimum standards, publications Q1 also achieved participation in international conferences, mostly in the ISI category, as well as my involvement in the management of the study programs for the Telematics and Electronics for Transports dept., and the master's program Telematic Systems for Transport. I am convinced that these ambitious development directions will be feasible, because combining university didactic aspects with those of research and dissemination will contribute to their successful realization. Moreover, a good part of the results of personal research and various collaborations have already been introduced as updates of some profile subjects taught at the faculty.

Regarding the management of PhD students, I propose to further develop on the one hand the concepts presented in this paper, and on the other hand to support and encourage young researchers, their own ideas and talents. Depending on their performance, I will encourage them to continue their research activities through post-doctoral fellowships. Throughout my professional career, I have developed communication and student support skills that are highly valued by students – proven by evaluation surveys, and I believe that ongoing dialogue contributes the most to fruitful collaboration. Also, I have always encouraged individual study, public presentation of results, participation in scientific communication sessions, or even the publication by students of some articles. These are materialized by the good results obtained by the students guided in the undergraduate and dissertation projects (more than 200), throughout my work as a university teacher. I have had numerous students who wanted to continue their professional career development under my guidance, as well as graduates with whom I still have fruitful collaborations for student training and tutoring for undergraduate or dissertation projects. I also participated as a co-supervising professor for several PhD students, some of whom completed their theses.

I also propose to intensify collaboration with prestigious Q1-Q2 journals (which I frequently recommend to students as high-level bibliographic materials) in the field of sensors and data communications - both by reviewing papers or participating as a member of editorial boards, as well as by publishing as many research results as possible, to strengthen the prestige of the university and the department where I work and increase their international visibility.

For the future, I wish to strengthen the national and international university prestige, based on new scientific and professional achievements, to constantly respond to the level of academic demands, through collaboration with colleagues, professors, and students from all levels of studies.