Bi2Bi ZigBee-Based Communication Assessment for Smart Campus Mobility

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***Abstract*- In this study, we analyze and experimentally evaluate Bike-to-Bike (Bi2Bi) wireless communication within a university campus, taking into account the complete topographical and morphological features of campus settings through deterministic 3D Ray Launching hybrid simulations. The focus is on sustainable urban mobility, highlighting cycling as a sustainable transport option due to its adaptability, affordability, minimal carbon footprint, and the ability to enhance city traffic and mobility. With the advent of Vehicle-to-Vehicle (V2V) and Vehicle-To-Everything (V2X) networking, non-motorized vehicles like bicycles are anticipated to engage in these networks, despite receiving less attention. Finally, since communication and data exchange between bikes relies on the IEEE 802.15.4 standard, we assess the performance of ZigBee-based Bi2Bi communication in the presented campus scenario.**

I. INTRODUCTION

The escalating concerns around sustainable transport systems stem from the significant impact of energy consumption and air pollution on global health and climate. Reports from the Intergovernmental Panel on Climate Change (IPCC) highlight that urban traffic is a primary source of CO2 emissions, contributing to approximately 13% of the global total. Besides carbon emissions, cities face the challenge of noise pollution, which has been increasingly recognized for its adverse long-term health implications. Addressing these issues, cycling has gained prominence as a sustainable mode of urban transport, offering solutions to the environmental and health challenges posed by motorized vehicles [1].

Cycling not only reduces the emission of harmful gases and noise pollution but also contributes to the alleviation of traffic congestion, presenting a practical solution for short to medium-distance urban travel. The potential of cycling to foster sustainable urban environments has led to the exploration of how bicycles, integrated with Internet of Things (IoT) technologies, can serve as mobile data collection and communication platforms. Equipping bicycles with sensors and internet connectivity allows for the dynamic collection and transmission of environmental and traffic data, facilitating the development of new mobility services and the improvement of urban living conditions [2].

However, the implementation of such IoT-enabled bicycles faces challenges in terms of communication technology. Current solutions like Long-Term Evolution (LTE), LoRa, and Narrow Band-IoT, though widely used, are hampered by high operational costs, power consumption, and the need for continuous network coverage [3]. The exploration of alternative communication infrastructures, such as ad hoc networks and Wireless Personal Area Networks (WPANs), offers a glimpse into more efficient and cost-effective means of enabling bike-to-bike and bike-to-infrastructure communication [4].

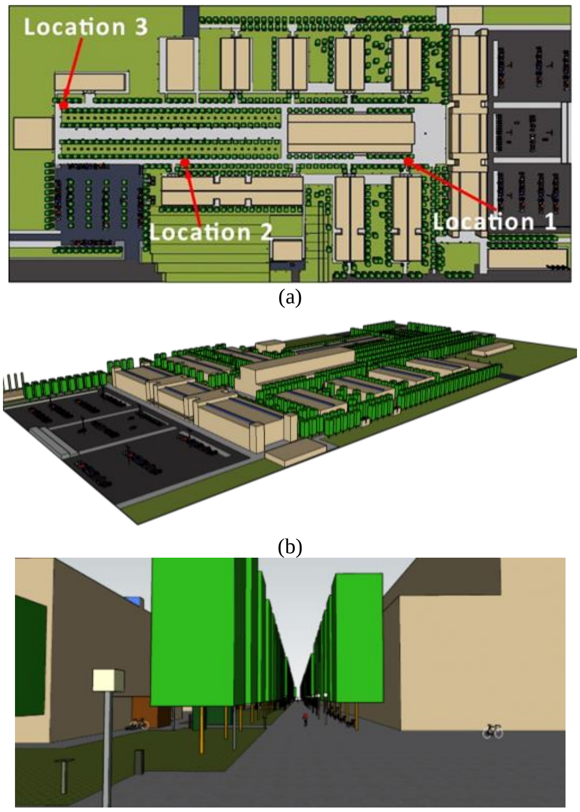
Nowadays, many students and academic staff use bikes to go to the university. Thus, a Bi2Bi radio link estimation at a university campus is important. In this context, a 3D Ray Launching scenario replicating the campus of the Public University of Navarre in Spain has been created to study the feasibility of the proposed Bi2Bi communication system in university campus environment. Moreover, this paper delves into the practicalities and performance of bike-to-bike (Bi2Bi) communication in university campus settings, considering the unique challenges posed by the campus landscape. It aims to evaluate the communication efficacy between bicycles, using advanced simulation tools to provide a comprehensive analysis of the network's performance in a sub-urban scenario.

II. 3D RAY LAUNCHING BASED BI2BI COMMUNICATION IN UNIVERSITY CAMPUS ENVIRONMENT

Unlike empirical and stochastic models, deterministic models provide an accurate modeling of all the elements within the specific scenario under analysis [5], making them the most accurate option for radio planning tasks of urban and sub-urban environments. In the literature, many V2V propagation models and channel simulators can be found [6], [7], but further investigations are needed regarding the Bi2Bi wireless communications.

With the aim of analyzing the Bi2Bi channel in urban scenarios, an in-house developed deterministic 3D-RL simulation tool has been employed in this work. The detailed operating mode of this deterministic algorithm can be accessed in [8], and it is based on the creation of complete 3D scenarios, where the complete volume is meshed into a fixed number of cuboids. The transmitter antennas and their characteristics are the input parameters of the algorithm. Then, rays are launched form the transmitter following a combination of electromagnetic theory and equations based on Geometrical Optics (GO) and Geometrical Theory of Diffraction (GTD). The propagation parameters are calculated along the path of each ray, which interacts with all the elements within the scenario, creating radio propagation phenomena such as reflection, refraction, and diffraction. These characteristics, added to the implementation of the material properties of all the elements within the scenario (conductivity and permittivity) lead to an efficient and robust technique already employed and validated in many different environments, including large urban environments [9], [10].

The created scenario of the campus is illustrated in Figure. 1. The dimensions of the scenario are 590 meters of length, 290 meters of width and 30 meters of height, resulting in a volume of 5.1 million m^3. The existing elements and materials at the campus such as trees, foliage, grass, streetlights, baskets, benches and buildings were all taken into account while simulating the presented scenario. Moreover, since the dielectric properties of any material depend on the radio frequency, temperature and humidity levels, the dielectric properties of the materials used in the presented scenario were taken from [11] for a considered humidity level of 20% and a Temperature of 20 C.



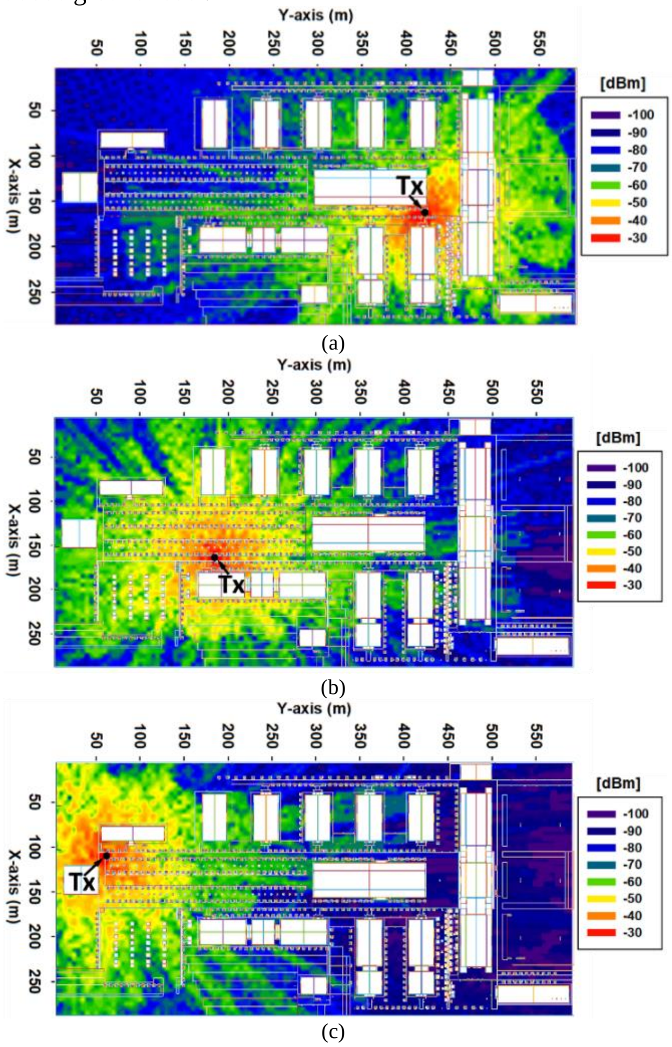
(a)

(b)

(c)

Fig. 1. (a) Top view, (b) 3D view, (c) transmitter at location 1 within the created university campus scenario.

In the simulations, the transmitter was placed on the front part of the bicycle at three different locations, as depicted in Figure. 1a. These locations were chosen to assess radio coverage in both Line-of-Sight (LoS) and Non-Line-of-Sight (NLoS) Bike-to-Bike (Bi2Bi) links. A significant benefit of the 3D-Ray Launching (3D-RL) code is its capability to analyze any point within the three-dimensional space of the scenario. Figure. 2 presents the estimated RF power distribution at 2.41 GHz, with the transmitter at these three locations, positioned 1.15 meters above ground level.



(a)

(b)

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Fig. 2. (a) The estimated RF power distribution planes for transmitters placed at (a) location 1; (b) location 2; (c) location 3.

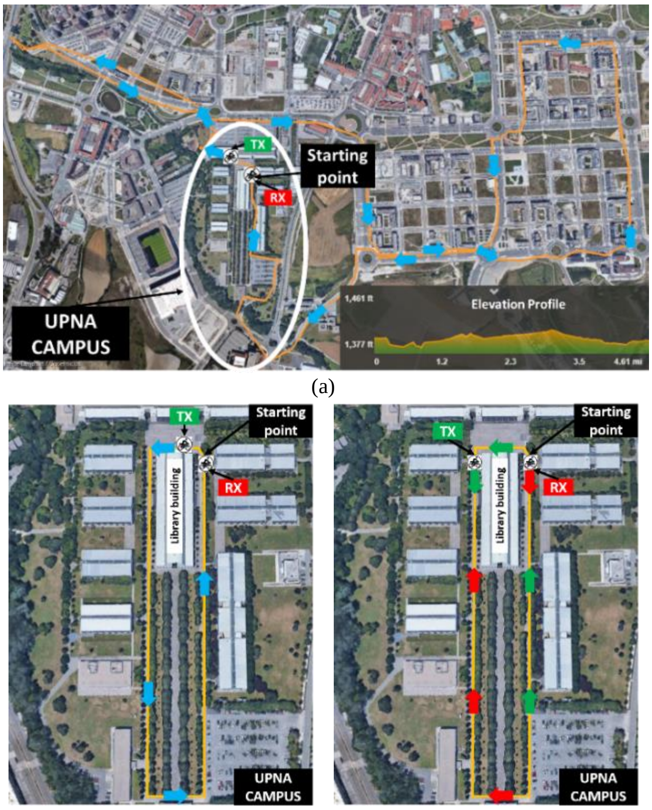
Figure. 2 reveals that a single bicycle can cover half of the campus area. It also indicates that bikes positioned at locations 2 and 3 provide greater radio coverage, attributed to the lower density of buildings in these areas. Conversely, the bicycle at location 1 experiences signal attenuation due to the surrounding buildings. According to Figure. 2a, reliable Bi2Bi communication extends to a 150-meter radius from the transmitter at location 1. Figure. 2b shows that a transmitter at location 2 maintains high link quality up to a 180-meter radius. Finally, Figure. 2c demonstrates that Bi2Bi communication from a transmitter at location 3 can achieve a range of 200 meters.

III. Bi2Bi Communication Assessment

This subsection details experiments conducted with ZigBee modules mounted on bicycles to evaluate the wireless communication performance between two moving bikes, specifically focusing on packet loss. Two distinct scenarios were examined: firstly, a route through a varied sub-urban environment featuring different building types and urban structures, along with notable elevation changes, is illustrated in

Figure. 3a. Secondly, a specific scenario on a university campus is explored, shown in Figure. 3b and Figure. 3c, which aligns with the simulated environment in Figure. 1 using 3D-Ray Launching techniques.

ureure. 3 illustrates the Bi2Bi communication tests using IEEE 802.15.4 modules along path 1, as presented in Figure. 3a, in the sub-urban area, and paths 2 (Figure. 3b) and 3 (Figure. 3c) at the UPNA university campus. In Figure. 3a and Figure. 3b, the first bicycle (transmitter) is positioned 10 meters ahead of the second bicycle (receiver). In Figure. 3c, the bicycles (transmitter and receiver) travel in opposite directions around the UPNA Library building. In all scenarios, a packet was sent every 5 seconds, a timing chosen to test the ZigBee-based dynamic wireless link between bicycles under challenging conditions, given that ZigBee technology is primarily designed for low data rate Wireless Sensor Networks.



(a)

(b) (c)

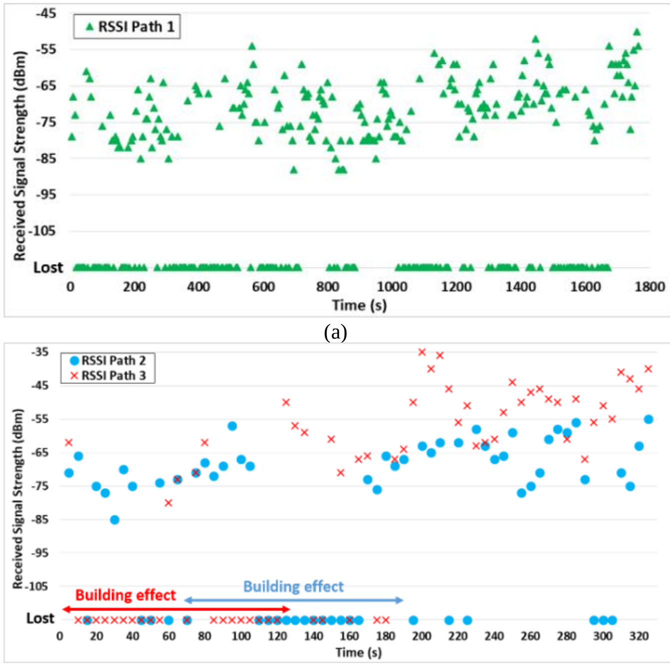
Fig. 3. (a) Path 1; (b) Path 2; (c) Path3.

Figure. 4 presents the Packet Error Rate (PER) for each path, highlighting that path 1 experiences the highest rate of packet loss, attributable to the obstacles and elevation profile in the suburban environment. Conversely, paths 2 and 3 exhibit similar Packet Error Rates.

(a) (b) (c)

Fig. 4. Packet Error rate per path.

Figure. 5 displays the RSSI for each received packet across three paths, where lost packets are marked with a level below the sensitivity threshold of the devices, at -100 dBm (shown in Figure. 5a and Figure. 5b). The results, as outlined in Figure. 4, indicate a significant packet loss rate of 30 to 40%. It is crucial to understand that these measurements pertain to a dynamic wireless link, with both bicycles moving through a variable environment, which primarily contributes to the packet losses. For instance, the Library Building in the campus scenario (Figure. 3b and Figure. 3c) is a major cause of packet loss due to the shadowing effect when the bicycles are in a NLoS situation. This phenomenon is evident in Figure. 5b, where the losses attributed to the building are highlighted. Similarly, the chart illustrates minimal packet loss in LoS situations, where no building obstructs the path between the bicycles. Figure. 5a also shows this variance, with areas of high and negligible packet losses.



(a)

(b)

Fig. 5. Received Signal Strength for (a) Path 1; (b) Path2 and 3.

In this study, the received power levels calculated using 3D-Ray Launching algorithms are not directly compared with the RSSI of commercial ZigBee nodes for several reasons. Primarily, RSSI measures the amount of radio signal power and serves as an indicator of the radio frequency (RF) energy detected at the antenna port. However, RSSI values may encompass energy from both background noise and interferences, leading to potentially misleading high signal strength readings. In complex environments, high RSSI values can occur even when communication errors are present. Therefore, RSSI should be considered an approximate measure of signal strength at the antenna rather than a reliable indicator of link quality. To achieve a more precise RF analysis, the study estimates received power levels in the proposed scenarios. Additionally, RSSI measurements are generally less precise than received power level estimations, with potential errors ranging from 1 dB to 10 dB or more, depending on the hardware utilized.

IV. CONCLUSIONS

In conclusion, this study explored Bi2Bi communication on a university campus, using 3D Ray Launching simulations to understand the impact of the environment on signal propagation. We highlighted the potential of bicycles in sustainable urban mobility and networked transportation systems. Despite challenges like signal attenuation in complex terrains, the experiments demonstrated the feasibility of effective Bi2Bi communication. The research emphasizes the importance of accurate power level estimations over RSSI values for reliable communication assessment. This work contributes to the integration of non-motorized vehicles into smart urban networks, supporting the development of more sustainable and efficient urban transportation solutions.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Y. Zhang and Z. Mi, ''Environmental benefits of bike sharing: A big databased analysis,'' Appl. Energy, vol. 220, pp. 296–301, Jun. 2018.

[2] M.-D. González-Zamar, E. Abad-Segura, E. Vázquez-Cano, and E. López-Meneses, ''IoT technology applications-based smart cities: Research analysis,'' Electronics, vol. 9, no. 8, p. 1246, Aug. 2020.

[3] W. Ouyang, C. W. Yu, K.-M. Yu, K.-J. Lin, J.-H. Yu, H.-W. Chang, L.-L. Tai, and C.-H. Lin, ''Station decision problem in bicycle ad hoc networks,'' in Proc. 9th Int. Conf. Ubiquitous Intell. Comput. 9th Int. Conf. Autonomic Trusted Comput., Sep. 2012, pp. 876–881.

[4] J. P. Shanmuga Sundaram, W. Du, and Z. Zhao, ''A survey on Lora networking: Research problems, current solutions, and open issues,'' IEEE Commun. Surveys Tuts., vol. 22, no. 1, pp. 371–388, 1st Quart., 2020.

[5] J. Gozalvez, M. Sepulcre, and R. Bauza, ''IEEE 802.11p vehicle to infrastructure communications in urban environments,'' IEEE Commun. Mag., vol. 50, no. 5, pp. 176–183, May 2012.

[6] M. Boban, J. Barros, and O. K. Tonguz, ''Geometry-based vehicle-tovehicle channel modeling for large-scale simulation,'' IEEE Trans. Veh. Technol., vol. 63, no. 9, pp. 4146–4164, Nov. 2014.

[7] D. W. Matolak, ''Modeling the vehicle-to-vehicle propagation channel: A review,'' Radio Sci., vol. 49, no. 9, pp. 721–736, Sep. 2014.

[8] L. Azpilicueta, M. Rawat, K. Rawat, F. Ghannouchi, and F. Falcone, ''Convergence analysis in deterministic 3D ray launching radio channel estimation in complex environments,'' Appl. Comput. Electromagn. Soc. J., vol. 29, no. 4, pp. 256–271, 2014.

[9] M. Celaya-Echarri, I. Froiz-Miguez, L. Azpilicueta, P. Fraga-Lamas, P. Lopez-Iturri, F. Falcone, and T. M. Fernandez-Carames, ''Building decentralized fog computing-based smart parking systems: From deterministic propagation modeling to practical deployment,'' IEEE Access, vol. 8, pp. 117666–117688, 2020.

[10] F. Granda, L. Azpilicueta, M. Celaya-Echarri, P. Lopez-Iturri, C. Vargas-Rosales, and F. Falcone, ''Spatial V2X traffic density channel characterization for urban environments,'' IEEE Trans. Intell. Transp. Syst., vol. 22, no. 5, pp. 2761–2774, May 2021.

[11] V. V. Komarov, Dielectric and Thermal Properties of Microwaveable Materials: Parameters, Measuring Techniques, and Some Theoretical Aspects. Norwood, MA, USA: Artech House, 2012.