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*International Journal of Combinatorial Optimization Problems and Informatics, 15(5), Dec 2024, 64-74. ISSN: 2007-1558.*
*https://doi.org/10.61467/2007.1558.2024.v15i5.558*

# VANET Network Simulation for Greenhouse Monitoring Utilizing Two Mobile Differential Robot Nodes

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**Abstract.** Monitoring the greenhouse environment is crucial for regulating physical variables such as temperature, humidity, CO2 concentration and luminosity. VANET (Vehicular Ad-hoc Network) represents a particular case of multi-hop wireless network, characterized by rapid topology changes due to the high mobility of nodes. With an increasing number of vehicles equipped with computer technologies and wireless communication devices, vehicular communication emerges as a promising domain for research, standardization, and development. In the forthcoming era, VANET is positioned to become an integral part of smart cities, offering diverse applications. This article presents the outcomes of simulating a VANET network comprising two mobile nodes within a greenhouse, alongside the design and Lyapunov analysis of mobile node control within that network.

**Keywords:** Vanet Network, Mobile Node, Lyapunov Analysis, Differential Robot and Wireless Sensor Network.

Article Info
*Received May 10,2024.*
*Accepted Nov 20, 2024.*

## 1 Introduction

The increase in world population will have a significant impact on the food supply. The World Population Prospect is an estimate and future projection prepared by the Department of Economic and Social Affairs (DESA) of the United Nations. since 1951. In its last update in 2019, a population of 7.7 billion was estimated and it has been projected that by the year 2059 there will be an increase in the population of about 9.7 billion inhabitants [1]. For this reason, it is important to have good quality food and abundant harvests throughout the year, regardless of the change in climate in the different seasons. The greenhouse is a protected agriculture (PA) technique that maintains a controlled environment in a closed place, and is a good solution for supplying food throughout the year. To obtain good quality in the crops, the environment in the greenhouse must be monitored with a network of sensors, for this reason the objective of this work is to apply the VANET concept in two mobile nodes located on a differential robot, each one to measure different variables. physics such as: temperature, humidity, CO2 and luminosity. The purpose of using a VANET network for greenhouse monitoring is that mobile devices have a greater coverage capacity than static nodes without movements due to the fact that they have the ability to tour the greenhouse, in addition to the fact that mobile robots can adapt to another type of tasks other than monitoring. This work is limited only to the part of the control and analysis of communications with respect to the mobility of the sensor nodes, therefore it consists of two main parts: control of the VANET nodes for their movement in the greenhouse and the analysis of the Indicator received signal power (RSSI) in the communication network through which the information will be transmitted, therefore a simulation environment of the received signal power is designed and the control simulation and implementation of the control will be presented by the control part.

## 2. Related Work

Numerous studies in the literature address the management of wireless sensor networks in greenhouses [2-10]. The deployment of static nodes in space has been managed in many ways, either randomly distributed in space or in a grid-ded manner to obtain a more balanced range in the sensor nodes [2], but regarding the deployment of mobile sensors, there is no established methodology for physical deployment, since mobility in sensors has been worked on in few proposals.

Other methodologies exist for sampling and transmitting physical variables. For instance, some studies advocate for sampling and transmission at constant time intervals [3], despite the high energy consumption associated with frequent transmissions. To mitigate this, other works suggest longer time intervals between transmissions, with sample averaging to maintain data precision [4]. Additionally, certain methodologies, such as the one described in [5], propose increased sampling frequency beyond a specified threshold δ, indicating significant changes in measurements.

In terms of wireless communication technologies, Zigbee is commonly used due to its low energy consumption and suitability for ad hoc topologies [6,8]. Other technologies, like Xtream, offer long-range communication capabilities spanning 5-16 km [7]. Bluetooth and Wi-Fi are also viable alternatives. LoRa (Long Range) is a recent addition, designed for the Internet of Things and widely used in greenhouse monitoring. However, due to its novelty, cloud management of LoRa data remains limited [9]. Data collected by sensor networks are typically fed into a computer database, either remotely or near the greenhouse, where the greenhouse's status can be monitored and controlled [9-12].

In this work, we have evaluated two Zigbee mobile nodes, including channel losses in communication, by comparing practical measurements against four propagation models to better approximate the behavior of losses within a greenhouse [8]. This comparison helps in understanding the unique environmental factors that affect signal propagation and aids in improving the accuracy of network design and deployment strategies.

## 3 Wireless Sensor Networks in Greenhouses

A wireless sensor network (WSN) is deployed in specific spaces to measure environmental conditions and finds diverse applications including military, healthcare, forest fire monitoring, and agriculture [10]. These networks consist of a few to thousands of nodes, each equipped with hardware for measuring, processing, and transmitting data wirelessly. Typically, there's a central node or base station for receiving information. In greenhouse applications, nodes are usually equipped with sensors for temperature, humidity, CO2, and luminosity measurement. A microcontroller processes the data, and a wireless transceiver device transmits it across the network [11].

Vehicular Ad-hoc Network (VANET) is a specialized type of multi-hop wireless network characterized by rapid topology changes due to high node mobility. With the increasing adoption of wireless communication devices in vehicles, research and development in vehicle-to-vehicle communication have surged. VANETs offer various applications such as collision avoidance, security, dynamic route planning, and real-time traffic monitoring. Another significant application is providing Internet connectivity to vehicles [12]. This work combines the concept of VANET networks with mobile nodes and the methodology of traditional static wireless sensor networks to create a mobile data monitoring network.

## 3.1. Calculation of the Received Signal Power to Evaluate Data Transmission

In wireless communications is crucial to evaluate de data transmission quality through the intensity of the received signal across different environments. Typically, information propagation is more efficient in open spaces compared to closed areas. Thus, a Monte Carlo simulation of the environment is developed in MATLAB to analyze the propagation conditions within a greenhouse. To achieve this, a propagation models based on the free space, log-normal and two-rays equations has been evaluated [13-14]. The free space propagation model is given by

$$P_{rx}(d) = \frac{P_{tx}}{\left(\frac{4\pi d}{\lambda}\right)^2} \tag{1}$$

where $P_{rx}$is the received power signal at a distance $d$ and $\lambda$ is the wave length of the transmitted signal. $P_{tx}$is the transmitted power signal.
The log-normal equation is regulated by [14]

$$P_{rx}(d) = \frac{P_{tx}G_{tx}G_{rx}}{d^{\mu}} 10^{\zeta/10}\xi \tag{2}$$

where $P_{rx}$is the received power signal at a distance $d$, $\mu$ is the exponent of lost path. It takes different values depending on the environment, in free space it is 2 but in urban areas it has values between 2.7 and 3.5, and indoors it is 4 [14]. $P_{tx}$is the transmitted power signal. $G_{tx}$ $and$ $G_{rx}$are the transmitted and received antenna gains respectively. The log-normal random variable $10^{\zeta/10}$, models the shadowing effects. Finally, the Rayleigh $\xi$ random variable, models the fast fading effects.
Finally, the two ray model is given by [14]

$$P_{rx}(d_0, d_1) = P_{tx}\left[\frac{\lambda}{4\pi}\right]^2 \left[\frac{\sqrt{G_0}}{d_0} + \frac{R\sqrt{G_1}e^{j\Delta\phi}}{d_1}\right] \tag{3}$$

where $G_0$ $and$ $G_1$ are the antenna field radiation patterns in the LOS direction coresponding to the rays, $R$ is the ground reflection coefficient and $\Delta\phi$ is the phase difference between the two received signal components.
Another model that is applied is the Close-In. It is a generic model to analyze propagation signals that describe the loss in a given environment considering the received signal and the losses given by

$$Pr_{CI} = \frac{P_{tx}}{PL_{CI}} \tag{4}$$

To carry out the simulation it is necessary to obtain the different distances between the mobile nodes and the base station due to their mobility. Therefore, it is necessary to study the control strategy and define the space in the greenhouse where the mobile nodes move.

## 4 Design and Control Analysis of the Differential Type Robot

In order to complete the communications simulation environment, it is necessary to simulate and implement the movement of the mobile nodes in the greenhouse through a control strategy. Mobile nodes in the wireless sensor network require specific hardware to move around the greenhouse, not only a sensor, a microcontroller and a transceiver, it also needs a robot with mobility. In this work, a differential robot has been selected. The movement of the robot has been analyzed through a kinematic model [15]. Kinematics is the study of motion without addressing its fundamental causes. The kinematic equation of the differential drive robot relative to a point "a" (as it shows Figure 1) is described below

$$\dot{h} = \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} Cos(\theta) & -a\,Sen(\theta) \\ Sen(\theta) & aCos(\theta) \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V \\ \omega \end{bmatrix} \tag{5}$$

The inputs to the system are the angular velocity (ω) and the linear velocity (V), and the outputs are the x, y, θ positions.

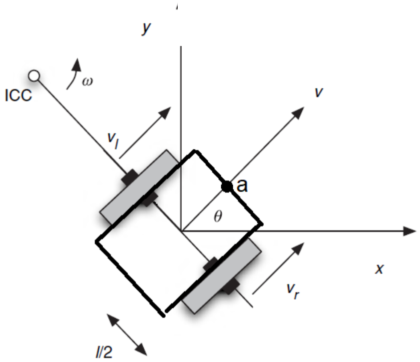


Figure 1. Kinematic model of the differential robot with 3 degrees of freedom.

It is desired to have position control so that the mobile robot reaches the points (x y) given by the user. Therefore, to obtain the control equation, the characteristic Jacobian matrix of the system given by the following equation is taken into account.

$$RJ = \begin{bmatrix} Cos(\theta) & -a\,Sen(\theta) \\ Sen(\theta) & aCos(\theta) \end{bmatrix} \tag{6}$$

Since the control will be implemented in a microcontroller in discrete time, the error must be taken into account. So

$$\dot{h}_e = \dot{h}_d - \dot{h}$$

Where $\dot{h}_d$ d is the desired speed at which the robot should move and $\dot{h}_e$ e is the error between the current position ($\dot{h}$) and the desired trajectory. To obtain the control law, the Jacobian $J$ is solved and obtained. To carry out a correct control, the convergence of the error to 0 must be analyzed to guarantee the stability of the system through the Lyapunov method.

$$q = \begin{bmatrix} V \\ \omega \end{bmatrix} = J^{-1}\left(\dot{h}_d - \dot{h}_e\right) \tag{7}$$

## 4.1. Lyapunov Stability Analysis

Stability analysis by finding the poles and zeros of the transfer function is limited to linear dynamical systems, and there are a large number of mathematical models for real systems that do not have this linearity. Thanks to Lyapunov's stability theory it is possible to study the stability of nonlinear systems [16,17].

Lyapunov's direct method: Let x = 0 be an equilibrium point of the system x=f(x) and let $V: D \rightarrow \Re$ a continuously differentiable scalar field defined on a domain $D \supset \Re^n$ which contains the origin, then

- If $V\ (x)$ is positive definite ($V(x) > 0$) and $\dot{V}(x)$ is negative semi-definite $\dot{V}$ (x) ≤ 0, the origin is a stable equilibrium point.
- If V (x) is positive definite and $\dot{V}$ (x) is negative definite ($\dot{V}$(x)<0), the origin is an asymptotically stable equilibrium point.

A function V (x) that meets the conditions imposed by the theorem is called a Lyapunov function and is a great analysis tool. However, it has two disadvantages.

1. There is no systematic method to find the Lyapunov function and test whether it meets the stability criteria.

2. The theorem only provides sufficient conditions so failure to find a candidate Lyapunov function that satisfies the stability or asymptotic stability conditions does not mean that the origin is unstable or asymptotically stable.

## 4.2. Control Design and Lyapunov Analysis

The mobile robot is required to move at a constant speed $\dot{p}d$ through the greenhouse following an established path. Then substituting into (5), the control law is described by the following expression

$$q = J^{-1}\left(\dot{p}_d + K\dot{h}_e\right) \tag{8}$$

$$\dot{p}_d = \begin{bmatrix} \dot{p}_x \\ \dot{p}_y \end{bmatrix} = \begin{bmatrix} V_d Cos(\beta) \\ V_d Sin(\beta) \end{bmatrix} \tag{9}$$

$$\beta = tan^{-1}\frac{P_{yd} - h_y}{P_{xd} - h_x} \tag{10}$$

where:
$V_d$ is the desired Speed at which the robot will move.
$P_{xd}$ and $P_{yd}$ are the desired x and y points of the path to travel.
$h_x$ and $h_y$ are the current points of the robot.
Taking into account that the speed error is$\dot{\delta}_e = \dot{h}_d - \dot{p}_d$ and the position one is $\dot{h}_e = \dot{h}_d - \dot{h}$.
A Lyapunov stability analysis is performed proposing the following candidate equation,

$$V(h_e) = \frac{h_e^T h_e}{2} \tag{11}$$

$$\dot{V}(h_e) = h_e^T \dot{\delta}_e - h_e^T K h_e \tag{12}$$

To ensure stability($\dot{V} < 0$) the following condition must be achieved

$$K > \frac{|\dot{\delta}_e|}{|h_e|} \tag{13}$$

## 5 Simulation of the Mobile Greenhouse Environment

The greenhouse area for the MATLAB MonteCarlo simulation is set to be 8m x 4m, where mobile nodes are deployed to measure the environment. Within this zone, the mobile nodes will move symmetrically, with initial positions at (1,0.5) for node 1 and (5,0.5) for node 2. The base station is configured at (7.75,2) and remains static throughout the simulation. Only the robots move around the greenhouse. Table 1 illustrates the trajectory of the nodes, and the route they follow is depicted in Figure 2.

**Table 1**. Trajectory of the mobile nodes.

| Node 1 | | Node 2 | |
|---|---|---|---|
| **X** | **Y** | **X** | **Y** |
| 1 | 0.5 | 5 | 0.5 |
| 3 | 0.5 | 7 | 0.5 |
| 3.5 | 1 | 7.5 | 1 |
| 3.5 | 3 | 7.5 | 3 |
| 3 | 3.5 | 7 | 3.5 |
| 1 | 3.5 | 5 | 3.5 |
| 0.5 | 3 | 4.5 | 3 |
| 0.5 | 1 | 4.5 | 1 |
| 1 | 0.5 | 5 | 0.5 |

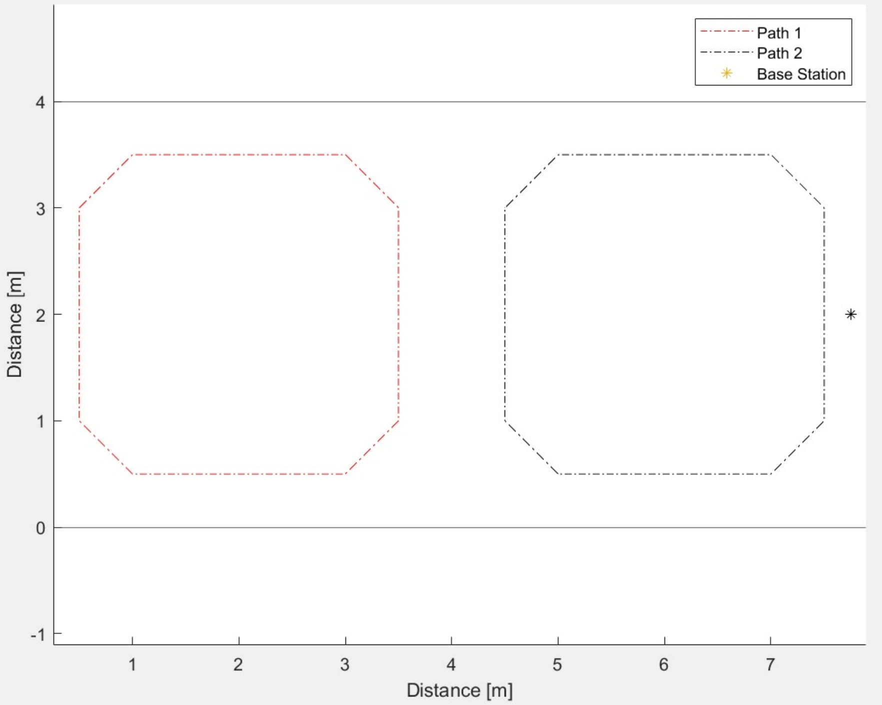


Figure 2. Route of the mobile nodes.

## 5.1. Simulation of Power Received from Node 1 and Node 2

Table 2 list the main simulation parameters included in the MonteCarlo environment considering the mathematical models of equations (1), (2), (3) and (4). The evaluations are shown in Figure 3 to 6.

**Table 2**. Simulation parameters.

| Parameter | Value |
|---|---|
| Base station height | .90 m |
| Vehicle height | .25 m |
| Frequency | 2.4 GHz |
| Path loss exponents | 2, 4 |
| Tx Power | 1 W |
| $m_\zeta, \sigma_\zeta$ | 0, 8 dB |
| $\Gamma_\xi$ | 0.001 |

Figures 3 to 6 illustrate the received power at node 1 and node 2 for different propagation models in comparison with the measurements. It is observed that the further the mobile nodes move from the base station, the received power decreases. It is important to estimate the received power to ensure good data reception. The model proposed here for simulation shows that at a distance between 0.5 and 8 meters, the reception sensitivity specified by the IEEE 802.15.4 standard is ensured even in environments with many obstacles. Additionally, the 2-ray model is the closest to the measurements in comparison to the log-normal, close-in and free space propagation models.

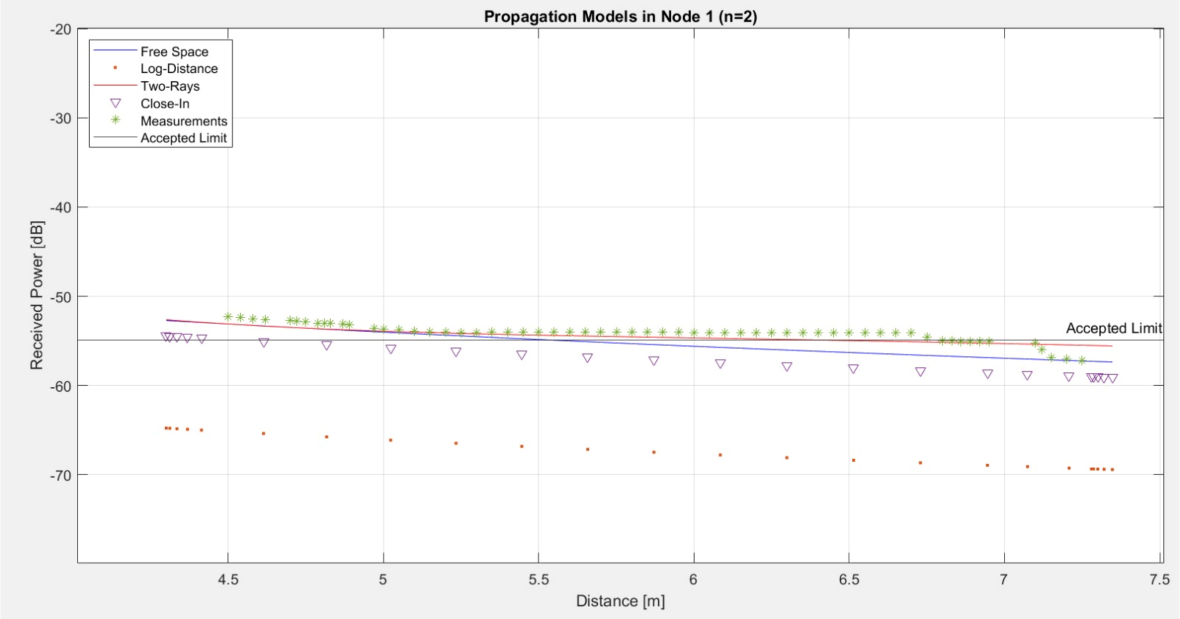


Figure 3. Power received from node 1 (n = 2).

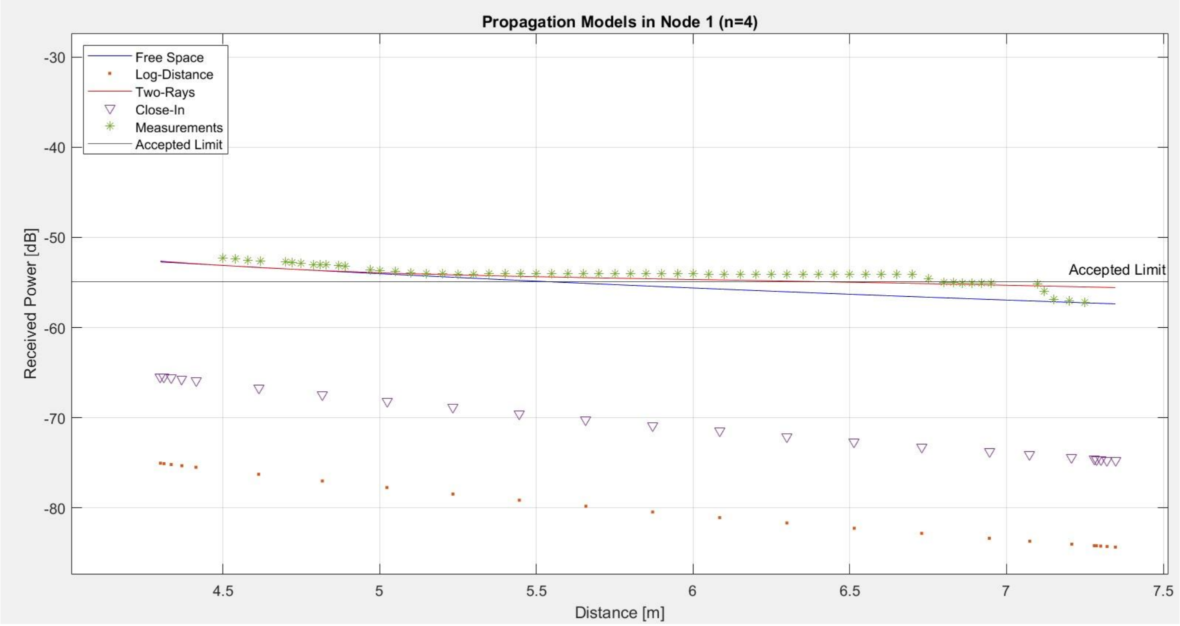


Figure 4. Power received from node 1 (n = 4).

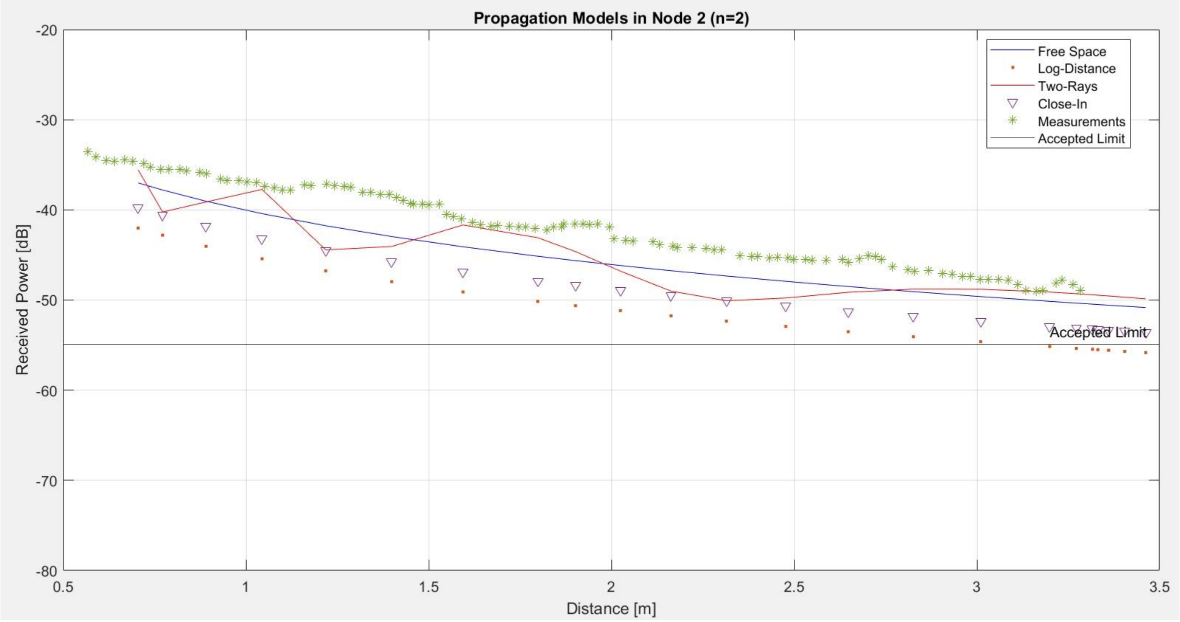


Figure 5. Power received from node 2 (n = 2).

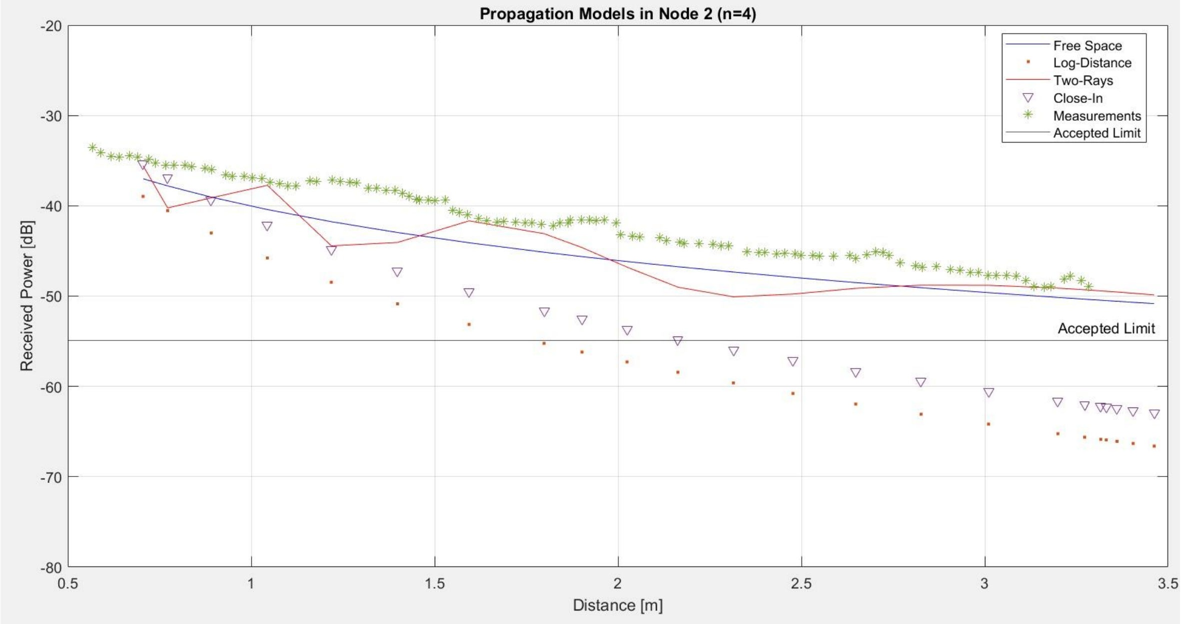


Figure 6. Power received from node 2 (n = 4).

## 5.2. Simulation and Implementation of Control at a Constant Speed

For the control simulation, it is specified that the mobile robot moves at a velocity of 0.1 m/s, as denoted by Equation 5. The simulation results are compared with the actual measurements obtained using the encoders of the differential robot, as illustrated in Figure 7.

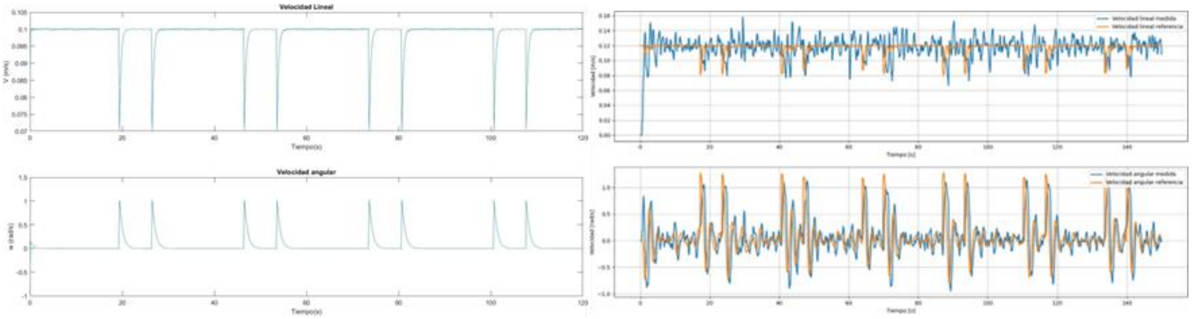


Figure 7. Simulated and real robot motion control.

The results of the real test show the interference of the environment on the measurements, the control operates correctly as it shows Figure 8. In the path followed by the robot, it is observed that there are small ridges when the robot turns, but it stabilizes after a while.

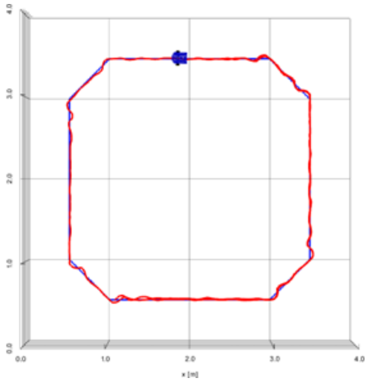
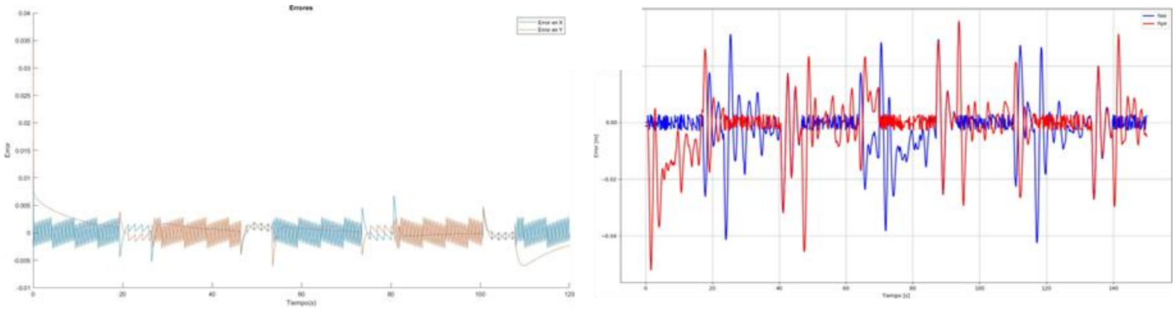


Figure 8. Movement of the robot through the greenhouse.

As depicted in Figure 9 a), there is an illustration of the instability of the error for very small values, observed both in the x-axis and the y-axis relative to the traveled path. This instability aligns with the stability analysis conducted in equation (13). In the real implementation, a similar pattern is observed, with differences emerging during the rotation of the robot, leading to a slight increase in error. Nonetheless, the convergence remains close to zero. While there are discrepancies between the real implementation and the simulation, the behavior closely resembles each other, as shown in Figure 9 b).



a) Measurements.   b) Simulation and Implementation.

Figure 9. Error behavior over time.

## 6 Conclusions and Directions for Further Research

To ensure effective data communication, it is crucial to analyze the propagation environment. Simulation results provide insights into these effects, revealing a decrease in received power as mobile nodes move farther away. A physical implementation and measurements are necessary to verify if real-world data align with simulation results and obtain the path loss exponent $\mu$ in a greenhouse. The model proposed here for simulation shows that at a distance between two and three meters, the reception sensitivity specified by the IEEE 802.15.4 standard is ensured even in environments with many obstacles. Additionally, the 2-ray model is the closest to the measurements in comparison to the log-normal (typically used in the literature), close-in and free space propagation models. However, due to its complexity, it is used less frequently.

Future work will involve the use of XBee or LORA modules, designed by digimesh, capable of establishing networks of thousands of nodes and measuring received signal power between nodes. In addition, future communication systems are expected to transition to higher spectral bands, where the 2-ray equation remains applicable to model these changes. Information collected by mobile nodes, including temperature, humidity, CO2, luminosity, and received signal power, will be displayed on a base station.

Simulation of control strategies is also vital, offering theoretical data on system behavior over time and aiding in making necessary adjustments to bring simulations closer to reality. Physical implementation of robot movement reveals variations compared to simulations due to the non-ideal environment. However, achieved results thus far enable adequate physical implementation of the differential mobile robot movement. Further observation of its behavior in the greenhouse and adjustments, if needed, are essential. Having two mobile robots collecting data inside the greenhouse will enhance environmental control.

## 7 Acknowledgements

To CONAHCYT, BUAP Puebla and PUCV Chile.

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