On the Applicability of the Walfisch–Bertoni Urban Propagation Model for Path Loss Estimation in Citrus Plantations at 3.5 GHz

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Key Words :	Propagation measurements, Agriculture, Radio propagation

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What is the problem being addressed by the manuscript and why is it important to the Antennas & Propagation community? (limited to 100 words).

The planning of these radio communication systems is carried out using computer tools that incorporate propagation models. Most of the propagation models incorporated into these tools can be applied in rural, urban, suburban and indoor environments, due to the massive deployment of systems such as GSM, UMTS or LTE. The massive use of sensors and actuators expected in Agriculture 4.0 will require a large deployment of wireless systems in other environments. In this sense, it is necessary to propose propagation models for specific agricultural environments according to the type of plantation (citrus, vineyards, cereals, vegetables, etc.).

What is the novelty of your work over the existing work? (limited to 100 words).

A lot of work has been done since the 1960s to propose both empirical and theoretical models for forest or vegetated environments. However, more recent are the works for specific agricultural environments such as potato fields, vineyards, apple orchards, etc. Citrus plantations also have a special relevance. In 2019, the world's total citrus fruit area harvested, and production quantity were estimated at 9.92 million hectares and 158 million tonnes, respectively. The applicability of the theoretical propagation model proposed by Walfisch–Bertoni in this type of environment is of great interest since this model is already incorporated into radio planning tools.

Provide up to three references, published or under review, (journal papers, conference papers, technical reports, etc.) done by the authors/coauthors that are closest to the present work. Upload them as supporting documents if they are under review or not available in the public domain. Enter “N.A.” if it is not applicable.

- José-Víctor Rodríguez, María-Teresa Martínez Inglés, José-María Molina-García-Pardo, Leandro Juan-Llácer, Takeo Fujii, and Ignacio Rodríguez-Rodríguez, UTD-PO Formulation for the Analysis of Multiple-Plateau Diffraction when considering Illumination from a Low Source, IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, 18/12/2020. DOI: 10.1109/TAP.2020.3044377

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- J. Walfisch, and H.L. Bertoni, “A theoretical model of UHF propagation in urban environments,” IEEE Trans. Antennas Propag., vol. 36, no. 12, pp. 1788-1796, Dec. 1988.

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***Abstract*— Agriculture 4.0 represents a considerable increase in the number of sensors, as well as the appearance of new wireless technologies, which will mean the need to efficiently plan radio communication systems in agricultural environments. In this work, the applicability of the Walfisch–Bertoni theoretical urban propagation model for path loss estimation in citrus plantations has been studied. Such hypothesis has been undertaken by considering that, when the frequency is above 1GHz and the transmitter is in clearing, the main propagation mechanism is multiple diffraction over the obstacles – that is, buildings, in an urban environment, and trees, in a citrus plantation. In this way, the propagation losses estimated by the mentioned theoretical model have been compared with measurements carried out at 3.5 GHz (one of the 5G bands) in a lemon plantation before and after the fruit was collected. It has been observed that the slope of the regression line of the measurements yields values of 3.6 (with fruit) and 3.7 (without fruit), which are close to the value estimated by the Walfisch–Bertoni model (3.8). The standard deviation of the prediction error given by the difference of the observed and estimated values, is 4.5 dB (with fruit) and 3.2 (without fruit).**

***Index Terms*—Radiowave propagation, precision agriculture, radio planning**

I. Introduction

Wireless technologies have undergone great development in recent years for short-distance communications, such as Bluetooth technology; mid-range, like ZigBee; and long distance, such as WiFi, GSM/GPRS (2G), UMTS (3G) or LTE (4G) [1]. In agriculture, medium and long-distance wireless technologies have been combined to remotely send parameters captured in localized areas. Agriculture 4.0 [2] will mean a considerable increase in the number of sensors, as well as the appearance of new wireless technologies that will facilitate, for example, the automatic guidance of tractors, the monitoring of the state of the fruit over time before harvesting, the automation of the fertilizer or the harvesting of fruits, etc., which will mean the need to efficiently plan the radio communication systems in these environments.

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Fig. 1. Lemon tree plantation, location of the transmitter and measurement routes.

The planning of these radio communication systems is carried out using computer tools [3] that incorporate propagation models [4]. Most of the propagation models incorporated into these tools can be applied in rural, urban, suburban and indoor environments, due to the massive deployment of systems such as GSM, UMTS or LTE. The massive use of sensors and actuators expected in Agriculture 4.0 will require a large deployment of wireless systems in other environments. In this sense, it is necessary to propose propagation models for specific agricultural environments according to the type of plantation (citrus, vineyards, cereals, vegetables, etc.).

A lot of work has been done since the 1960s to propose both empirical [5-9] and theoretical [10] [11] models for forest or vegetated environments. However, more recent are the works for specific agricultural environments such as potato fields [12], vineyards [13], apple orchards [14], date palm orchards [15] or tomato plantations [16].

In the agricultural sector, citrus plantations also have a special relevance. In 2019, the world's total citrus fruit area harvested, and production quantity were estimated at 9.92 million hectares and 158 million tonnes, respectively [17] [18]. With these numbers, the significant increase in radio communication systems in these plantations to be at the level of what Agriculture 4.0 assumes, increasingly requires the efficient planning of these systems.

Citrus plantations (lemon, orange, mandarin and grapefruit) follow a plantation framework that is defined by the distance between rows and the distance between the trees in the same row (see Fig. 1). This planting is usually done so that the distance between rows is greater than the distance between trees, resulting in the branches of consecutive trees touching, leaving a path (street) between rows that is used mainly for fumigation, tree trimming and to collect the fruit. In this context, if a frequency above 1 GHz is considered and the transmitter antenna is assumed to be in a clearing, the main propagation mechanism of such scenario would be diffraction over the trees, due to the increased opacity of the latter [5]. Therefore, such environment could be modeled as in the urban scenario proposed in [19], where a series of equally-spaced buildings with the same height with respect to the transmitter height (Fig. 2(a)) are modeled as a series of knife-edges (Fig. 3).

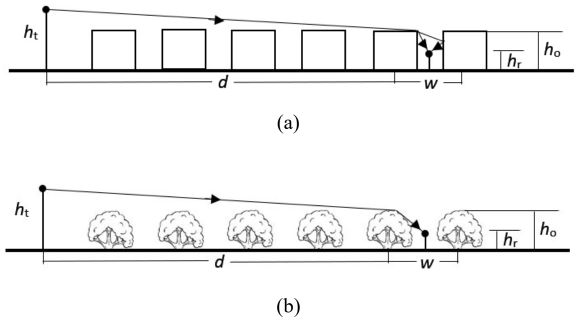


Fig. 2. Vertical profile with equally spaced (a) buildings and (b) trees

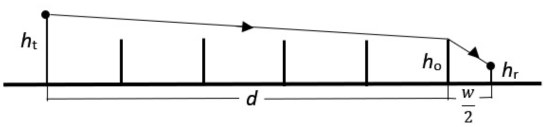


Fig. 3. Idealized vertical profile with equally space edges and horizontal plane.

In the work presented here, the profile of Fig. 2 (b) for citrus plantations has been considered and the applicability of the theoretical propagation model proposed by Walfisch–Bertoni [19] in this type of environment has been studied, which is of great interest since this model is already incorporated into radio planning tools.

In this letter, we first describe the propagation measurements carried out in a lemon plantation (before and after harvesting) at 3.5 GHz, one of the 5G bands [20]. Then, we present the expressions that estimate the propagation losses of the studied models and some considerations are made to apply these models in citrus plantations. Finally, the results obtained with the theoretical model are analyzed and compared with measurements and we sum up with the conclusion.

I. Propagation Measurements

A. Propagation environment

The measurements were made in a 200x300 m area of a lemon grove belonging to the FRUCA company located in the Carrascoy valley in the Region of Murcia, Spain (see Fig. 1). The planting frame is 7.5x5 m, that is, 7.5 m between rows and 5 m between lemon trees in the same row. Lemon trees are very leafy, their average height and width are 2.5 m and 2.5 m, respectively, so the width of each path (street) between rows is around 2 m.

B. Measurement system

The measurement system used is based on the Rhode & Schwarz VNA ZVK (10MHz–40GHz) network analyzer used as the transmitter and the Anritsu MS2090A (9kHz–26.5GHz) handheld spectrum analyzer used as the receiver. In addition, the ZVE-8G+ (2-8GHz) amplifier in transmission, 2 STEATITE Q-PAR ultra-wideband antennas (0.8–40GHz), a GPS, cables and connectors have been used. A MATLAB program has also been developed to automate the measurement process.

In transmission, the network analyzer generates a tone at the frequency of 3.5 GHz that is amplified and transmitted with vertical polarization by an antenna located on a mast at a height h_t = 4.2 m.

(a) (b)

Fig. 4. One of the path of the measurement campaings without fruit in the trees (a) and with fruit (b)

The receiving system is mounted on a vehicle with the receiving antenna at a height h_r = 1.8 m. The developed program allows selection of the frequency to be measured, the bandwidth, the time between samples, etc. of the portable spectrum analyzer and stores a set of samples for each route. For each sample, the geographical position, the received power and the time (hour, minutes and seconds) are also available.

To consider the effect of all the equipment on the measurement, a calibration process was carried out with a set of measurements in direct vision paths between the transmitter and receiver.

Two measurement campaigns were carried out, the first one with fruit in the trees (before harvesting, see Fig. 4(a)) and the second one without fruit (after harvesting, see Fig. 4(b)). Fig. 1 shows the location of the transmitter and the 21 runs, each one of them on a path (street) with a length of 200 m. The number of samples per route was 116 on average per street, with the total number of samples being 2448.

II. The Walfisch–Bertoni Model for Urban Environments

This model assumes the profile of Fig. 3 and the path loss is estimated by the sum in dB of three contributions [19]: the path loss between antennas in free space, the multiple diffraction over rooftops term and the final diffraction from the rooftop to the street.

The free space path loss is calculated by:

$$L_o(dB) = 32.44 + 20log10(d) + 20log10(f) \tag{1}$$

where d is expressed in km and f is the frequency expressed in MHz.

The multiple diffraction contribution is calculated with the following expression:

$$L_{msd}(dB) = 68.87 - 9log10(f) - 18log10(h_t - h_o) + 18log10(d) \tag{2}$$

where f is expressed in MHz and d in km.

The final diffraction loss is estimated with:

$$L_{rts}(dB) = -11.8 + 10log10(f) + 5log10\left[\left(\frac{w}{2}\right)^2 + (h_o - h_r)^2\right] + 20log10\left[\frac{2(h_o - h_r)}{w}\right] \tag{3}$$

where f is expressed in MHz, w is the width of the street, h_b the average height of the buildings, and h_r the height of the receiver.

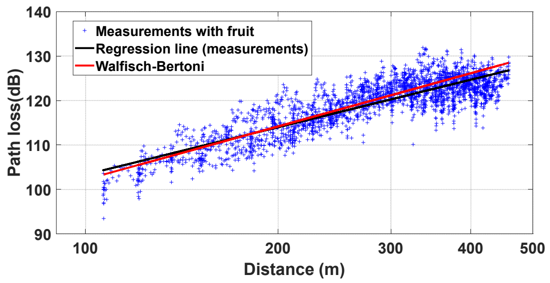
III. Application of the Walfisch–Bertoni Model in Citrus Plantations

In the propagation environment of Fig. 2 (b) for the case of multiple trees, with the transmitting antenna above the trees, we assume the same dominant propagation contributions as for the urban scenario of Fig. 2 (a), that is, multiple diffraction over trees and final diffraction from treetop to street.

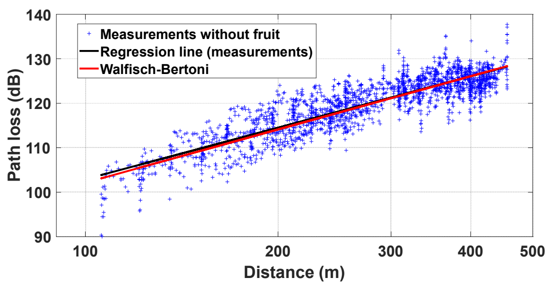
For multiple diffraction over trees, if we replace each tree by a knife-edge, then the losses can be estimated with (2).

In the final diffraction, the expressions of the Walfisch–Bertoni model consider the effect of the reflection of the building on the other side of the street (see Fig. 2 (a)), which will not occur in the environment of trees since the diffracted signal at the edge is going to scatter into the trees on the other side of the path. Therefore, we propose to correct (3) by the addition of a factor of 3 dB.

In the next section, the results shown take these considerations into account.



(a)



(b)

Fig. 5. Path losses versus distance (a) with fruit (b) without fruit.

IV. Results

In Fig. 5 the measured losses (in dB) are represented as a function of distance. The regression lines of the measured losses and the losses estimated by the Walfisch–Bertoni model have also been represented. These regressions have been obtained using the FI (Floating Intercept) adjustment method.

$$L_{FI}(dB) = \alpha + \beta 10log10(d) + \chi_\sigma \tag{5}$$

where α (in dB) and β (slope) are adjustment parameters, d the distance between the transmitter and receiver in meters, and χ_σ a Gaussian random variable with zero mean and standard deviation σ in dB.

TABLE I
Parameters for the Calculations

f (GHz)	3.5
h_t (m)	4.2
h_r (m)	1.8
h_o (m)	2.5
w (m)	7.5

TABLE II
FI Parameters and Standard Deviation

	With fruit			Without fruit		
	α	β	σ (dB)	α	β	σ (dB)
Meaurements	32.3	3.6	3.2	29.0	3.7	3.2
Walfisch-Bertoni	22.7	3.8	0.9	22.5	3.8	1.0

TABLE III
Mean Error and Standard Deviation

	With fruit		Without fruit	
	Error (dB)	σ_{error} (dB)	Error (dB)	σ_{error} (dB)
Walfisch–Bertoni	0.7	4.5	-0.2	3.2

Table I shows the parameters used in the calculations.

Table II shows the slopes and standard deviations in every case. From the results, it is observed that the slope of the regression line of the measurements is 3.6 (with fruit) and 3.7 (without fruit), close to the value of 3.8 estimated by the Walfisch–Bertoni model.

Table III shows the mean and the standard deviation of the prediction errors of the models from the observed values, where the prediction error is given by the difference of the observed and predicted values. Practically no differences are observed in the mean error in both cases, 'with fruit' and 'without fruit'. The standard deviation of this error is 4.5 dB in the case 'with fruit' and 3.2 'without fruit'.

V. Conclusion

In this work, the possible application of the Walfisch–Bertoni theoretical urban propagation model for path-loss estimation in citrus plantation environments has been studied. To do this, a measurement campaign has been carried out at a frequency of 3.5 GHz in a lemon plantation in two situations: with lemons in the trees and without lemons once they have been harvested. The height of the transmitter is above the height of the trees and the receiver height is below the height of the trees. In these conditions, it has been observed that the slope of the regression line of the measurements has a value of 3.6 (with fruit) and 3.7 (without fruit), which are close to the value estimated by the Walfisch–Bertoni model (3.8). Furthermore, practically no differences have been observed in the mean error in both cases with fruit and without fruit. The standard deviation of the prediction error of the model from the observed values in both cases is 4.5 dB (with fruit) and 3.2 dB (without fruit). Therefore, the results shown in this work point to the possibility of considering the Walfish–Bertoni theoretical urban model for path loss estimation in citrus plantations, with such fact entailing barely any loss of accuracy.

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