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WIRELESS NETWORKS INTERFERENCE AND SECURITY PROTECTION BY MEANS OF VEGETATION BARRIERS

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Abstract—The success of wireless technologies could paradoxically leads to a collapse in their performance: the interference between adjacent networks and the attacks done by users from outside the expected coverage limits are two important enemies to the well function of the networks. The proposal of this paper is simple but efficient: the use of vegetation barriers to create shadowing areas with excess attenuations in the edge of the service area, in order to reduce the coverage distance of each wireless node, reducing the possible interference to other networks as well as improving security aspects by minimizing the signal strength outside the service area.

1. INTRODUCTION

The wireless paradigm has become one of the technological successes of last years. The different standards [1, 2] allow high speed connectivity, which in the past was the main disadvantage of wireless networks compared to wired ones. At this point, the corporative and domestic computing networks, which were traditionally projected following a wired scheme, are rapidly migrating to wireless. This fact full fits the people requirements in terms of mobility and connectivity, but it also suffers some important problems as interference between adjacent or neighbor networks and undesired access to the network facilities by unknown users from outside the service area.

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These problems could appear in domestic networks, but it is in trade buildings where the situation becomes worse: various neighbor networks (corresponding to different companies or departments within the same company) could interfere one among the others, overloading the network facilities with retransmission events, and then degrading its performance. Besides, the number of unauthorized accesses could grow: both for using services (people surfing the Internet "for free", occupying resources paid by the company) and for damaging purposes (done by hackers).

There is several propagation research done in the area of wireless networks, from general works to more specific ones. Typically, deterministic methods have been proposed to model static elements, both constructive and natural obstacles [3]. However, there are other kinds of obstacles in the radio links that must be modeled by stochastic procedures [4]. Such obstacles may be persons [5], furniture [6], vegetation [7], or in general non-polygonal structures [8]. All these obstructions can mitigate the received power in a radio link, or even they could break the connection.

The thesis of this paper is to propose the use of vegetation barriers to mitigate such problems. The induction of attenuation in the radio waves propagating across vegetation media is a well-known effect, but its consequences, mechanics and applications have not been completely explored. This paper presents a possible application of that attenuation effect. The vegetation obstructing the radio channel could provide attenuation enough in the edge of the service area to: a) reduce the distance at which elements of different networks can be installed without generating and receiving interference; and b) shorten the distance at which an external user could access the network servers or facilities. Thus, a correct decision in the location of indoor or outdoor plants could benefit the performance of the wireless network to be protected against interference and/or external attacks.

A large measurement campaign involving seven different species have been performed to support the proposal. Both indoor and outdoor shrubs have been used to construct different barriers, as indicated in Section 2. The measured attenuations, shown in Section 3, could be used to compute the improvement in terms of interference and security provided by the vegetation barrier, as commented in Section 4. Finally, Section 5 summarizes the conclusions.

2. MEASUREMENT CAMPAIGN

The measurement campaign was performed in an open area, with separate transmitter and receiver. The transmitter was based on a

Rohde&Schwarz radio signal generator SMR-40, whereas the receiver was constructed around a Rohde&Schwarz spectrum analyzer FSP-40. The narrow-band measurements were performed at 2.4 and 5.8 GHz, which are frequencies in bands used by wireless standards. Although the actual wireless world is dominated by omnidirectional antennas, which pick up all scattering energy around the receiver, the measurements were performed with directional antennas. This decision was adopted as the objective was to isolate the effect of the vegetation barrier from the environment scatterers. The use of omnidirectional antennas would probably lead to lower attenuations but the measurement results would also include many environment effects which would be difficult to extract to define the attenuation induced by the vegetation. Then, both ends of the measurement setup were installed with log-periodic antennas Electrometrics EM6952, which gain is 4.72 dBi at 2.4 GHz and 4.62 dBi at 5.8 GHz, placed at 1.25 meters height.

The measurement setup was completed by a linear positioner that supports the receiving antenna and allows its movement parallel to a vegetation barrier. The positioning platform is driven by a stepper motor, connected to an indexer. The scheme can be observed at Figure 1.

At the transmission end, the signal generator feds the antenna with a 10 dBm amplitude tone. The receiver was moving along this 2.5 meter long linear table, stopping at 126 and 150 locations for 2.4 and 5.8 GHz measurements, respectively, and getting 8000 received power samples at each stop. The data were caught following a sequence move-stop-measure-move-. This measurement procedure was deeply explained in [9], where a campaign at mobile phone frequencies is presented. That paper was focused on reducing the electromagnetic pollution at cellular systems bands, whereas the present paper is

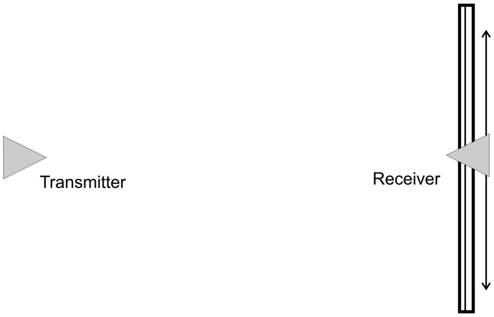

Figure 1. Vegetation barrier configuration $C0$.

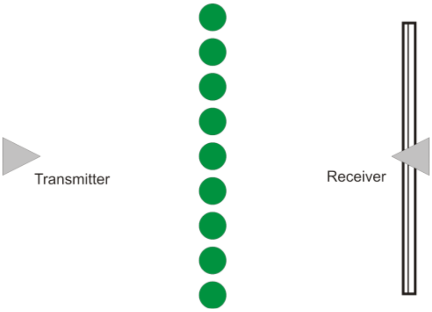

Figure 2. Vegetation barrier configuration $C1$.

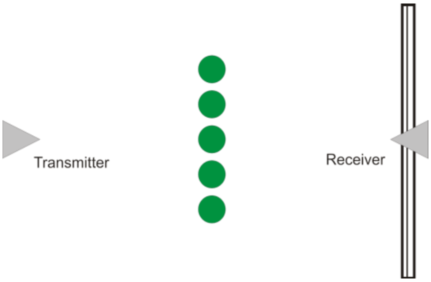

Figure 3. Vegetation barrier configuration $C2$.

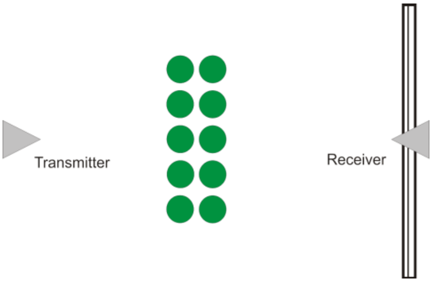

Figure 4. Vegetation barrier configuration $C3$.

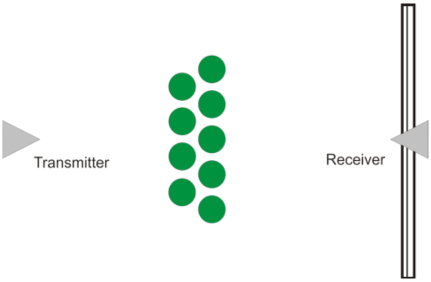

Figure 5. Vegetation barrier configuration $C4$.

centered in different frequency bands (those for wireless LANs), and also oriented to different applications. So, the procedure for getting the data is the same, at different frequencies of operation, but the presented results and the application are completely different.

The distance between transmitter and receiver antennas was 6 meter and the vegetation barrier were installed just in the middle, following the six configurations defined in Figures 1 to 6, and denoted as $C0$ (configuration 0) to $C5$ (configuration 5), respectively. $C0$ represents the setup for a reference measurement, in line of sight conditions between transmitting and receiving antennas. The distances from transmitting antenna to barrier and from barrier to receiving antenna are enough to consider that both the obstacle and the receiver are at far field distance from the radiating element. Seven different species were considered separately to build the vegetation barrier, which was constructed with up to ten individuals of the same species. The characteristics of the seven species are summarized in Table 1.

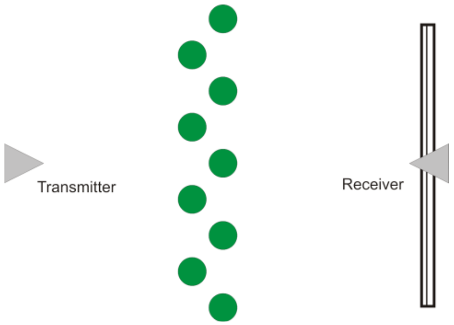

Figure 6. Vegetation barrier configuration $C5$.

Table 1. Dimensions of the shrubs, in cm.

Specie	shrub		leaf	
	height	diameter	length	width
areca	150	70	25	1
schefflera	160	60	10	4.5
ficus	170	55	7	3
callistemon	150	80	7	4
camellia	165	90	8	6
Irish juniper	205	55	2	0.5
thuja	165	45	0.5	0.2

3. MEASUREMENT RESULTS

The outcomes of the measurement campaign represent almost 160 million received power samples, which obviously need a processing to analyze the performance of the proposal. The most interesting parameter to be extracted from the measurements is the attenuation induced by the different barriers at each receiving point. These attenuation values were computed by comparing the median measured power at each measuring point (the median among the 8000 power samples at this point) with the median power measured in line of sight (LoS) conditions (i.e., at configuration 0). Thus, the computation of the attenuation includes a normalization of the effects of the antenna frequency response. Each measurement contains the effect of transmitting and receiving antennas, the propagation path between them, and, depending on the barrier configuration, the effect of the vegetation (when this is within the radio channel). The measurements were done taking the LoS reference ($C0$) at exactly the same environment where the obstructed LoS (OLoS) data ($C1$–$C5$) was gotten. So, the path loss exponent would be assumed to be the same in both scenarios and the only difference between them would be the vegetation barrier induced attenuation between transmitter and receiver. When comparing the results related to the reference configuration, $C0$, with those related to any other configuration, the antennas and the propagation path contributions are canceled and only the influence of the vegetation barrier is then considered.

At that point, we have a collection of vectors composed by attenuation values at different locations within the shadow area behind the barrier. The median of each of these vectors is a good representation of the median attenuation provided by each barrier in

Table 2. Median attenuation (dB) at 2.4 GHz, with horizontal polarization.

Specie	barrier configuration				
	$C1$	$C2$	$C3$	$C4$	$C5$
areca	0.1	0.2	0.4	2.9	0.1
schefflera	0.4	0.8	1.6	1.9	0.7
ficus	2.2	2.8	4.3	4.7	2.7
callistemon	2.1	2.5	3.5	3.3	1.5
camellia	3.1	3.2	3.9	5.9	2.9
Irish juniper	5.2	5.2	8.9	6.2	4.5
thuja	1.6	1.5	1.8	2.1	1.4

Table 3. Median attenuation (dB) at 2.4 GHz, with vertical polarization.

Specie	barrier configuration				
	$C1$	$C2$	$C3$	$C4$	$C5$
areca	3.2	3.5	2.5	2.1	3.2
schefflera	0.1	0.9	1.5	1.0	0.4
ficus	2.1	4.1	5.1	5.9	2.0
callistemon	3.3	3.0	6.9	5.4	3.0
camellia	5.4	5.5	6.9	8.2	5.2
Irish juniper	9.6	9.8	10.7	10.1	8.0
thuja	3.5	3.8	5.6	6.2	3.5

its shadow area. These results, obtained at 2.4 GHz, are presented in Tables 2 and 3, for horizontal and vertical polarization respectively, whereas Tables 4 and 5 are related to 5.8 GHz experiences. It must be observed that the attenuation appears to be larger for vertical polarization than for horizontal, as it occurs in most of the measurement results related in the literature. The explanation must be the own geometry of the vegetation, which is vertically organized: the trunks are clearly vertical; the disposition of leaves is also dominantly vertical, whereas the orientation of branches appears to be more random.

These results could be compared to those provided at [9], obtained at lower frequencies (900, 1800 and 2100 MHz), when lower attenuations were detected. The attenuation induced by vegetation

Table 4. Median attenuation (dB) at 5.8 GHz, with horizontal polarization.

Specie	barrier configuration				
	$C1$	$C2$	$C3$	$C4$	$C5$
areca	0.1	0.1	0.9	4.1	0.1
schefflera	0.1	0.2	5.6	6.7	1.0
ficus	6.2	5.4	9.3	11.3	5.3
callistemon	1.1	4.0	6.5	7.7	2.4
camellia	10.1	12.4	12.1	13.2	10.7
Irish juniper	6.8	5.9	13.2	10.6	8.1
thuja	3.9	5.1	6.3	6.8	4.7

Table 5. Median attenuation (dB) at 5.8 GHz, with vertical polarization.

Specie	barrier configuration				
	$C1$	$C2$	$C3$	$C4$	$C5$
areca	2.0	2.4	5.1	3.8	2.6
schefflera	2.5	2.9	6.1	6.4	2.4
ficus	7.1	8.4	10.7	9.9	7.1
callistemon	10.5	13.0	14.5	14.6	11.1
camellia	10.4	11.3	14.2	13.5	10.5
Irish juniper	15.7	13.7	21.2	19.8	15.4
thuja	5.2	7.2	12.0	8.8	4.4

appears to grow with the frequency, following approximately the same trend observed at that paper: this indicates that the proposal of electromagnetically shielding locations by using vegetation barriers seems to be more efficient at higher frequencies. Besides, there are some species with wooden trunks and very dense canopies (camellia trees, Irish junipers and white cedars) that appear to be the most suitable to perform vegetation barriers.

4. COVERAGE ANALYSIS

An analysis of the coverage reduction provided by the vegetation hurdles is also presented. The attenuation induced by the vegetation barriers would be the input data for the different formulation, which will give the coverage distances in various scenarios. These results will be used to obtain the reduction in terms of coverage distance provided by the shrubs.

We will assume that a location is within the coverage area when there the received power is larger than the Sensitivity, S, of the receiver for a given BER. The maximum distance from a transmitter with coverage depends on many factors and it can be calculated using the Equation (1).

$$P_{rx} = P_{tx} + G_{tx} + G_{rx} - L(d) \geq S \tag{1}$$

where P_{rx} is the reception power, P_{tx} is the transmission power, G_{tx} is the transmission antenna gain, G_{rx} is the reception antenna gain, and $L(d)$ represents the losses as a function of the distance d. So, the maximum distance with coverage, $d_{\max}$ could be calculated from the Equation (2).

$$L(d_{\max}) = P_{tx} + G_{tx} + G_{rx} - S \tag{2}$$

Three propagation models have been chosen to calculate the losses from the transmitter to the receiver, and the distance that limits the coverage, $d_{\max}$. Two of them are full indoor models and the other has part of the path indoor and part of the path outdoor. The considered propagation models are going to be identified as the empirical indoor-to-outdoor [10], International Telecommunications Union (ITU) indoor [11], and the statistical indoor [12]. This selection of models covers the different situations mentioned in the introduction section: the possible interference between adjacent wireless networks within the same building (the full indoor models), and the hacker attack from the surroundings of the building hosting the network (the indoor to outdoor model). The following paragraphs describe the three considered propagation models: empirical indoor-to-outdoor, ITU-R, and statistical path loss.

4.1. Empirical Indoor-to-outdoor Model

The empirical indoor-to-outdoor model [10] is formulated as in Equation (3). It is an outdoor-indoor model, so it considers a wall between the transmitter and the receiver.

$$\begin{aligned} L(d) &= L_i + L_o = -1.8f^2 + 10.6f + 5.8N_w - 5.5 + 62.3 \\ &\quad +10\left(3.3 \cdot 10^{-4} f^6 + 3.2\right)\log(d/5) \end{aligned} \tag{3}$$

At the equation, L is the total path loss, in dB; f is the frequency of transmission, in GHz; d is the distance between transmitter and receiver, in m; and N_w is the number of walls between the transmitter and the outdoor receiver.

4.2. ITU-R Model (Indoor)

The ITU model [11] is defined by Equation (4). The model has been proposed for a frequency range from 900 MHz to 5.2 GHz, and it considers 1 to 3 floors.

$$L(d) = 20\log f + N\log d + P_f(n) - 28 \tag{4}$$

where the different parameters are: f, the frequency in MHz; N, the distance power loss coefficient ($N = 30.5$ at 2.4 GHz); n, number of floors between the transmitter and receiver; and $P_f(n)$, the floor loss penetration factor (one floor — 15 dB).

The distance power loss coefficient, N, is the quantity that expresses the loss of signal power with distance. This coefficient is empirical. The floor penetration loss factor is another empirical constant which depends on the number of floors the waves need to penetrate. Some values for both parameters are proposed in [11].

4.3. Statistical Path Loss Model (Indoor)

The statistical path loss model [12] is described by the Equation (5).

$$P_{rx} = \frac{P_{tx}}{d^n}\left(\frac{\lambda}{4\pi}\right)^2 \tag{5}$$

where n is the mean path loss exponent, and its proposed values depends on the environment: Classroom LoS $n = 1.8$, corridors LoS $n = 1$, one wall OLoS $n = 3.4$ and multiple walls OLoS $n = 3.46$.

5. COVERAGE RESULTS

The effect of the vegetation barriers must be translated into excess attenuations to the models results: the attenuation induced by the barriers has to be added to that attenuation computed by the proposed models. These excess attenuations correspond to the values presented in Tables 2 to 5. So, the three models have been used to analyze the coverage distances with and without vegetation barriers, being the propagation path losses in presence of vegetation barriers as indicated by Equation (6), which modifies Equation (2). L_{barrier} represents the contribution of the vegetation barrier to the total attenuation.

$$L(d_{\max}) = P_{tx} + G_{tx} + G_{rx} - S - L_{\text{barrier}} \tag{6}$$

Some parameters were chosen to do this calculus, which are common to the three models: $P_{tx} = 20\,\text{dBm}$, $S = -78\,\text{dBm}$, $G_{tx} = 6\,\text{dBi}$, $G_{rx} = 2\,\text{dBi}$.

The results presented in this section has been computed by using two standard excess attenuation (L_{barrier}) of 5 and 10 dB, representing two of the possible attenuations due to the vegetation barrier. This has been done in order to reduce the number of considered scenarios, which in other case would be as many as 140: four times (two frequencies, two polarizations) the 35 measured barriers (five configurations with seven vegetation species). In fact, the use of measured results led to more exact computations in terms of distances. However, we decided to present results corresponding to 5 and 10 dB attenuation to illustrate the performance of the proposal, because of the large amount of data available. The results related to both attenuation levels appear to be significant to demonstrate the validity of the proposal; whereas provided attenuation values are useful to compute the exact coverage distances at each situation. Thus, these results can show an illustration of the performance of the proposal by using a reduced amount of data. So, we computed $d_{\max}$ in line of sight conditions, and also when L_{barrier} equals 5 and 10 dB, by means of the three proposed propagation models. Table 6 contains the computed values of coverage distance, provided at 2.4 GHz, a common frequency band for wireless networks (WiFi).

Table 6. Coverage distances (m), with different barrier attenuations and propagation models.

Vegetation barrier	Excess attenuation (dB)	Coverage distance (m)		
		Empirical indoor-to-outdoor	indoor	
			ITU-R	Statistical
No barrier	0	37	81	87
Standard 1	5	26	55	62
Standard 2	10	18	37	44

The first row at Table 6 (no barrier) gives the maximum distances calculated using the three models previously mentioned without vegetation barrier. This represents a reference for the other results. The second and third rows show the new distances with 5 and 10 dB of excess attenuation due to the standard vegetation barriers, defined as a good representative of the actual performance.

The difference between these rows and the first one in indoor models (ITU-R [11] and statistical [12]) columns indicates how close nodes from two adjacent networks could be installed, avoiding interference events, when vegetation barriers providing attenuations of 5 or 10 dB are installed. The selection of the indoor model could lead to different results, but both provide values in similar magnitude order: maximum coverage distances of 81 and 87 meter in open conditions, for ITU-R and statistical respectively; and coverage from 55 to 62 meter when the barriers induce attenuation of 5 dB and from 37 to 44 meter when the induced attenuation is 10 dB. So, in general terms, in such indoor environments the distance appears to be reduced to the 70% with the 5 dB standard barrier and to the 50% with that inducing attenuation of 10 dB. This indicates that the prevention of interference between wireless networks is possible by installing vegetation barriers.

The analysis made by the empirical indoor-to-outdoor model [10] is related to the hacker capability to illegally connect to the network from a place out of the company domains. It can be seen that with a 5 dB barrier this distance is reduced to 70% percent and with 10 dB to the 50% approximately. In many cases these reduction made impossible to be connected from the street or from a car, as the network coverage could be limited to the company building and gardens: thus, the task of the possible hacker would be more difficult than in non vegetation surrounded networks.

Another scenario could be defined when many access points have to be deployed in adjacent areas. In such situations, it is very important to install all access points as close as possible. The relation between the distance among nodes, D and the coverage radius R, represents a measure on how close they can be installed. This relation is enunciated in Equation (7).

$$\frac{D}{R} = 1 + \left(\frac{N_{\text{interf}}}{at_{\text{barr}}}\frac{c}{i}\right)^{1/n} \tag{7}$$

At this equation, N_{interf} is the number of adjacent nodes, at_{barr} is the attenuation of the barrier, c is the power of the carrier signal, and i is the power transmitted by the adjacent nodes that could produce interference. Considering c/i to be approximately 100 and $n = 3.4$, Table 7 shows D/R without barrier, and with both previously defined standard barriers (inducing attenuations of 5 and 10 dB).

Table 7. Relation between distance among nodes and coverage radius.

Vegetation barrier	Excess attenuation (dB)	D/R
No barrier	0	4.9
Standard 1	5	3.8
Standard 2	10	3.0

The first row at the Table 7 (No barrier) is included as a reference to the other two rows, to compare the computed ratios. A reduction can be observed in the parameter D/R: from near 5 without barrier to 3.8 with standard 1 barrier or to 3.0 with standard 2. This reduction in D/R leads to a more efficient application of WiFi technology in intensive use environments, as office buildings are. This reduction is directly related to the decrease in frequency re-usage distance, which indicates an improvement in the capacity of the network. For example, if the access points cover areas with radius of around 20 meters, the neighbors could be located at 98, 76 or 60 meters (interference free distances) depending on the attenuation induced by the vegetation barrier: 0, 5 or 10 dB respectively.

6. CONCLUSIONS

A large measurement campaign has been developed in order to analyze the attenuation induced by vegetation barriers, with different configurations. The measurements were done taking a LoS reference at exactly the same environment where we get the OLoS data. So, the path loss exponent would be assumed to be the same in both scenarios and the only difference between them would be the vegetation barrier induced attenuation between transmitter and receiver. Thus, the LoS path loss would be canceled by comparing the LoS reference and each measurement series, and only attenuation due to the barrier is the result of the comparison. Attenuations up to 21 dB at 5.8 GHz and up to 10 dB at 2.4 GHz have been detected. These shadowing capabilities of the vegetation lines are then translating into coverage distance reduction, which is proposed to be used in the ambit of wireless networks, in two directions: the reduction of the free interference distance between nodes from adjacent networks, and the protection against hacker attacks that wirelessly connects to the network from streets or parking areas.

The results are encouraging because the barriers seem to produce attenuation enough to reach interesting reductions in the distance to the adjacent nodes, avoiding interference, and also in the distance at which a hacker must be installed to access a network.

The coverage distances were computed by using three different models, both indoor and indoor-to-outdoor, and these results indicate that this reduction is more important the larger the attenuation is. As an example, for 5 dB and 10 dB excess attenuations due to the vegetation barriers, reductions of distance from 30 to 50% could be achieved, compared to scenarios with no barriers.

The relation between the distance among nodes D and the coverage radius R has been also analyzed as a measure on how close nodes from two adjacent networks could be installed when a line of shrubs is used to separate the coverage areas. The improvement of network efficiency in presence of vegetation barriers, in terms of the reduction in frequency re-usage distance has been then computed.

As these barriers are not expensive, environment friendly and well accepted by the people, the success of the proposal is expected.

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