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Impact of Weather and Climate on Internet Connection

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ABSTRACT

It is believed that meteorological factors such as rain, wind or temperature do not affect significantly to wireless systems operating at radio frequencies below 10 GHz. However, using an appropriate statistical analysis to the measurements taken from an outdoor IEEE 802.11b/g WLAN, we show that this is not true. Although these networks operate at 2.4 GHz, we have been able to prove a significant relationship between some meteorological factors and the behavior of several control frames in these networks.

Index Terms—Frame behavior, Meteorological factors, Non- parametric statistics, Spearman's correlation coefficient, WirelessLAN.

INTRODUCTION

ELECTROMAGNETIC radio waves are affected by several external sources during their propagation which cause, among others, diffraction, refraction, reflection and attenuation effects. These phenomena alter the wave propagation path and reduce the signal strength. Therefore, studying the way and the degree of their influence on radio systems is very important in telecommunication networks [1]. Meteorological factors are the usual sources causing these effects on radio waves, but according to several previous studies [1, 2], they do not have influence or it is negligible in wireless systems working at frequencies below 10 GHz. Because nobody has been able to demonstrate any relationship between the weather and radio wave below 10 GHz, it is considered that the weather does not affect significantly to WLANs based on IEEE 802.11 b/g standards (they they work at 2.4 GHz). However, based on our experience as end-users, a degradation in the performance of an outdoor WLAN is experienced (i.e. the number of disconnections increases and lower speeds or higher time delays) when the meteorological conditions are bad or suffer strong variations. Therefore, we believe that the weather really impacts on the performance of an outdoor WLAN but it is not perceived at physical layer. So, we analyzed such influence in an upper layer, that is, at data link layer.

Up to date outdoor WLANs are usually designed without considering the influence of weather effects. As commented before, this is the consequence of a very limited number of previous studies which consider an insignificant influence of meteorological factors at low frequencies (< 10 GHz). As an example, the attenuation due to rain was studied in [3, 4], and rain in forest areas or vegetation-shadowed environments [5- 7]. Indeed these studies are more related to effects caused by vegetation than isolated meteorological effects. Moreover, in[4] the authors conclude that rain is still an unclear factor for signal propagation at low frequencies.

In order to study how the meteorological factors affect radio waves, several parameters from the physical layer such as the signal strength or the signal-to-noise ratio are measured. However, because in this layer nothing has been demonstrated and our study is focused on the performance of WLANs, we consider more convenient to analyze the reception of control and management frames from the data link layer. We want to find out if frames are affected by different meteorological factors. Prior to this study, we already published two papers about this issue. In the first work [8], we analyzed how humidity, wind speed and temperature affect the following management frames: request to associations, disassociations and maximum retries. We showed a weak relation, even insignificant in some cases, but after all, we found out a relationship. For this reason, the aim of this paper is to improve and extend these previous results to analyze how the weather affects both control and management frames. Unlike management frames which mostly depend on the users, control frames are more related with the data link layer working order. In this sense, it is more accurate to find out this relationship from control frames rather than from management frames. Besides, we increased the gathering period and considered new meteorological factors and frames. Then, in the second study [9] we checked that the weather did not influence parameters of upper layers such as delays, jitters or numbers of lost packets. This is due to two main causes: on the one hand, because the effect of the atmospheric parameters is attenuated by the lower layers, and on the other hand, because mechanisms of protection against errors in the upper layers are more powerful and minimize the influence of undesired meteorological effects. Accordingly, we did not include any of these parameters in this paper. In short, the goal of this paper is to find which meteorological factors have a greater impact on the number of control and management frames generated in an outdoor IEEE 802.11b/g WLAN operating at 2.4 GHz. These frames were chosen as an indicator of WLAN performance.The remainder of the paper is organized as follows. The test bench is detailed in section II, as well as the data preprocessing required before applying the statisticalanalysis.In section III, the results obtained are discussed. Finally, the main conclusions are summarized in section IV.

II. MEASUREMENTS AND DATAPREPROCESSING

In order to find out if the weather affects WLAN data link layer frames, a set of measurements has been taken and preprocessed for its subsequent analysis. Therefore, this section is divided into three subsections. Firstly, the test bench used to obtain the data is described, then we explain how data has been gathered and the period of data gathering, and finally we describe the steps followed to preprocess thedata.

A. *TestBench*

The study shown in this paper has been carried out in the outdoor WLAN located in the Vera campus at the Universitat Politècnica de València (UPV). This campus is composed of fifty buildings spread over approximately two square kilometers. In order to offer WLAN service to more than 40,000 users, among professors, researchers, students and staff, there are more than 500 access points (APs) installed all around this campus and providing a coverage of approximately 99%. However, as the weather affects outdoor connections, only the 26 outdoor APs providing wireless connection in gardens and surroundings of the campus were considered. These APs are Cisco Aironet 1130AG Series; they use the standard IEEE 802.11b/g and provide transmission speeds of up to 54Mbps.

B. *Gathering data*

For our study we required the log file of all outdoor APs. This file records the following events in the WLAN: a station attempts to be identified in an AP but it is not allowed (failed authentication), the maximum number of connection attempts is reached in an AP (maximum retries), a station joins an AP (association), a station leaves an AP (disassociation), or a station leaves an AP to join another one with better coverage (roaming). All these data are referred as management frames of the data link layer of aWLAN.

On the other hand, we also collected the control frames of the WLAN via SNMP (Simple Network Management Protocol) [10]. In our case, the following cumulative counters were stored periodically during two months: *dot11FailedCount.1*, *dot11RTSSuccessCount.1*, *dot11RTSFailureCount.1*, *dot11ACKFailureCount.1* and *dot11FCSErrorCount.1*. These counters increment their value in the following situations: when a frame is not transmitted successfully due to the number of transmission attempts exceeding the limit, when a CTS is received in response to an RTS, when a CTS is not received in response to an RTS, when an ACK is not received when expected, or when an FCS error is detected in a received frame. The data collection period was two months: April and May 2011. Therefore, data from all outdoor APs were collected from both the log file and the SNMP counters. The counters values were sent every hour in the 40th minute, while the log file recorded for each event at the same moment theyoccurred.

Finally, the Spanish Agency of Meteorology (AEMET)provided us the rainfall, temperature, humidity and solar radiation (direct, diffuse and global) from the weather station installed at the center of the campus. These variables were collected every 10 minutes for the same period.

C. *Preprocessing data*

As we described in the previous section, meteorological factors and the number of frames obtained from the WLAN have been gathered with different frequency. In this section, we explain how data have been processed to analyze them together. Our objective is to obtain one sample per hour because the weather changes significantly, at least, with this frequency.

First, the log of each AP has been obtained as a raw file where the MAC addresses were obfuscated to prevent problems with the Spanish Organic Law of Data Protection (LOPD). In order to obtain the number of associations, disassociations, failed authentications, maximum retries and roamings, two scripts were generated to count these frames per hour in all outdoor APs.

On the other hand, the control frames counters were programmed to be sent in the 40th minute of every hour per AP and since these counters are cumulative, two tasks were required in this case: first, to average them to obtain one sample per all AP in the 40th minute of every hour and second, to calculate the difference between the 40th minutes of each hour to obtain the real number of each control frame. In this way, we could eliminate the accumulation of counters and obtain the exact number of frames generated from the 40th minute of one hour to the same minute of the following hour.

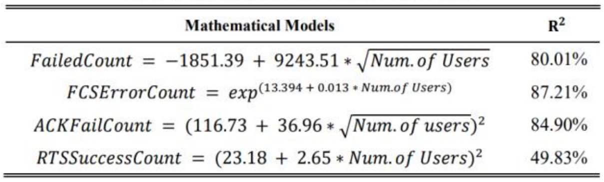
The last requirement involves isolating the human behavior from collected data to avoid results that may cause misunderstandings. Indeed, the human behavior is closely related to the number of users in the outdoor WLAN. This undesirable variation affects the data in two ways: on the one hand, the number of users varies with the weather in a non- periodic way. For instance, when it is a very windy day, surely there will be less outdoor users than when it is a sunny and quiet day. As a consequence, in these days there will be also less frames in outdoor APs, not due to more or less problems in the connections, but because there will be lessusers.

The number of users varies with the weather according the following mathematical model:

$$UUUUUUUUUU=-84.862+8,141*TT^{aa}+10.432*WWWW \qquad (1)$$

This model indicates that TT^{aa}(temperature) and WS (Wind Speed) are the most influential meteorological variables on the human behavior. These variables explain 30% of the variability in the number of users.

TABLE I MATHEMATICAL ESTIMATION MODELS



Mathematical Models	R^2
$FailedCount = -1851.39 + 9243.51 * \sqrt{Num.of\ Users}$	80.01%
$FCSErrorCount = exp^{(13.394 + 0.013 * Num.of\ Users)}$	87.21%
$ACKFailCount = (116.73 + 36.96 * \sqrt{Num.of\ users})^2$	84.90%
$RTSSuccessCount = (23.18 + 2.65 * Num.of\ Users)^2$	49.83%

On the other hand, the human behavior also varies with the daily evolution in an almost periodic way, that is, there will be more users connected during working hours than at lunchtime or during the weekends. Therefore, in the same way as before, there will be less or more frames according to the number of users connected to the outdoor WLAN, not because of the presence or absence of connection problems. The following mathematical models shown in Table I, relate each type of frame with the number of users:

In the above tableI, the parameter RR^2 indicates the percentage of variability of each type of frame which is explained from the number of users by these models. All these percentages are significant enough to eliminate the number of users of the frames and thus avoid wrong correlations between the frames and the weather. Results from frames independent and depend of the number of users are shown in tableII.

Finally, figure 1 shows the relationships that can be observed over time. We can see that the number of users is closely related to the number of each frame type and to temperature.

To summarize, the goal is to eliminate the human behavior as much as possible to guarantee accurate results. For this reason, we calculated the number of frames per user. So, as we can see in figure 2, the human behavior has been effectively minimized.

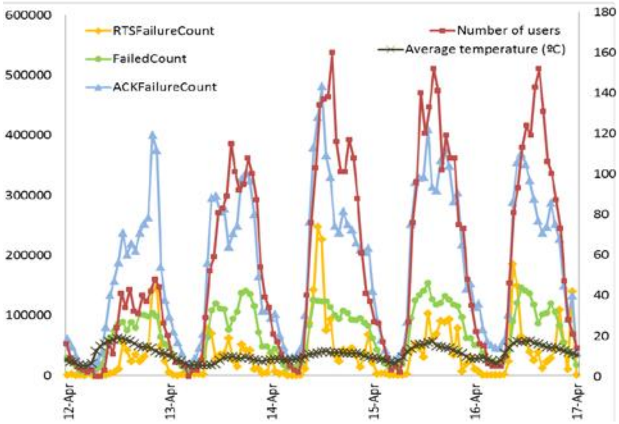


Fig. 1. Daily evolution of frames and the number of users.

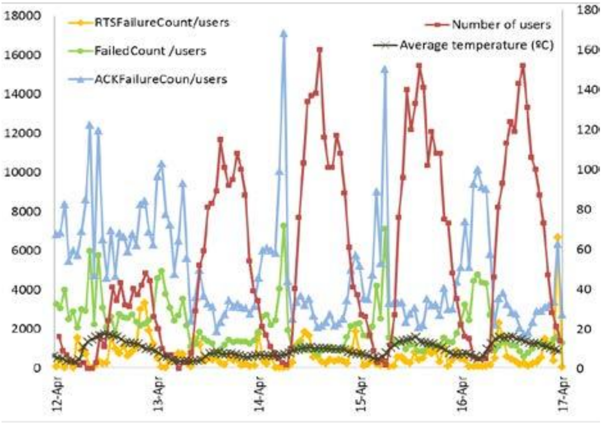


Fig. 2. Daily evolution of frames independent from the number of users.

In figure 1 and 2, control frames evolution is displayed for five working days, from the 12th until the 17th of April. Besides, the average temperature and the number of users at each instant are also shown.

In both figures, we can see the same peaks all days in the peak working hours. There are more users and so, more traffic and more control frames. In the case of temperature, it follows a similar evolution every day with the highest values at noon and lowest at night.

Finally, meteorological variables were processed to obtain a sample per hour, averaged as they were collected every 10 minutes). In this way, they can be analyzed together with all the above frames.

III STATISTICALANALYSIS

The first step in any statistical analysis is to explore the nature of the data. The exploratory analysis of the variables is crucial since further analysis will depend on the nature of the data. In our case, since data do not follow a normal distribution at all, non-parametric tests must be used. We chose the Spearman's rank correlation in order to determine whether there is any relation between pairs of data: each meteorological factor vs. each networkframe.

The Spearman's rank correlation is used when the data do not meet the assumptions about normality, homoscedasticity and linearity [11]. The Spearman's correlation is based on ranks, that is, each item of each variable is replaced by the rank to which it belongs according to its ordinal position. Using ranks rather than data values produces two new variables (the ranks). Spearman's correlation can be thought of as the regular Pearson product moment correlation coefficient, that is, in terms of proportion of variability accounted for, except that Spearman is computed from ranks. From these ranks calculated from original variables, the Spearman's rank correlation coefficient ρ is calculated by the traditional equation [12]. From this coefficient and taking into account the level of significance, we can conclude whether two variables are related or not and the strength of theassociation.

We chose the SPSS software package, owned by IBM, in order to analyze the data. Table II shows Spearman's correlation coefficient, significance value, and the number of cases with non-missing values (N). The correlation coefficient range varies from -1 to 1. The sign of the correlation coefficient indicates the direction of the relationship (positive or negative). On the other hand, its absolute value indicates the strength, with larger absolute values indicating stronger relationships.

Table II shows results for data independent on the number of users and dependent on. It shows that number of users increases the correlation coefficient in a wrong way.

Once the correlation coefficient is computed, then SPSS should determine the probability to occur the observed correlation by chance. Thus, it conducts a significance test. The significance testing parameter goal is to determine that correlation probability is the real one and not a chance occurrence. There are two hypotheses:

Null hypothesis: it is assumed that there is no correlation between the two variables.

Alternative hypothesis: it is assumed that there is a correlation between variables.

Table Ii The Spearman's Rank-Order Correlation Coefficients

		Temperature		**Wind Speed**		**Humidity**		**Direct Radiation**		**Diffuse Radiation**		**Global Radiation**	
		Ind.	Depend.	Ind.	Depend.	Ind.	Depend.	Ind.	Depend.	Ind.	Depend.	Ind.	Depend.
Number of Failed	Coefficient	**-,360****	,494**	-,276**	,414**	,197**	-,252**	-,181**	,389**	-,294**	,524**	-,272**	,512**
	Sig. (2-tailed)	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000
	N	1254	1254	1254	1254	1254	1254	1254	1254	1254	1254	1254	1254
Number of RTS Success	Coefficient	-,303**	,419**	-,253**	,336**	,129**	-,195**	-,207**	,289**	**-,315****	,422**	-,285**	,394**
	Sig. (2-tailed)	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000
	N	1254	1254	1254	1254	1254	1254	1254	1254	1254	1254	1254	1254
Number of ACK Failure	Coefficient	**-,333****	,501**	-,255**	,410**	,192**	-,251**	-,167**	,379**	-,269**	,516**	-,252**	,501**
	Sig. (2-tailed)	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000
	N	1254	1254	1254	1254	1254	1254	1254	1254	1254	1254	1254	1254
Number of FCS Error	Coefficient	**-,358****	,441**	-,198**	,416**	,109**	-,277**	-,121**	,334**	-,232**	,455**	-,203**	,444**
	Sig. (2-tailed)	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000
	N	1254	1254	1254	1254	1254	1254	1254	1254	1254	1254	1254	1254

Before testing the hypothesis, the significance level should be concreted. In most cases, it is assumed as 0.05 or 0.01. When the significance is 1%, we are conducting a test where the correlation is a chance occurrence with no more than 1 out of 100. If the significance level is very small (less than 0.01) then the correlation is significant and the two variables are related.Otherwise, if the significance level is relatively large, then the correlation is not significant and the two variables are not related.From all these processed data we performed a Spearman's correlations analysis, by obtaining a Spearman's rank correlation coefficient between each management and control frame vs. each meteorological factor. The most interesting results are highlighted in bold in table II. According to that, we can conclude that the number of frames which are not transmitted successfully, due to the number of transmission attempts exceeding the limit (*FailedCount*), is significantly related to temperature with a correlation coefficient of 0.36. In the same way, the number of received frames in which an FCS error is detected is significantly related to temperature with almost the same value of the correlation coefficient. Finally, the number of ACK frames not received when expected is also significantly related to the temperature with a correlation coefficient of 0.333. We also observed the diffuse solar radiation is significantly related to the number of CTS frames received in response to an RTS with a correlation coefficient of 0.315. Note that all these values represent weak negative associations.

III CONCLUSION AND FUTURE WORK

In this paper, we analyzed in detail the correlation between several weather variables and the behavior of several management and control frames in an outdoor WLAN. The data collection period was two months and we obtained 1254 samples for the analysis. After performing the statistical analysis, we concluded that the behavior of control frames has a significant relationship with temperature and solar radiation. The remaining relations, according to this analysis, are negligible. We consider that the results of this paper may help network designers and researchers to create new protocols potentially able to adapt to climate characteristics, providing better performance and operation of WLANs in outdoor environments. In future works we will compare these results with controlled links at 2.4 GHz. This controlled environment will let us study the WLAN, but without being affected by the users while the weather changes. Moreover we are seeking for an analytical model to provide the relationship between some atmospheric variables and some data link later parameters. Some published works use traffic analysis to provide new model in order to optimize the network [13]. Our aim is to use this model to develop a new dynamic protocol that will be able to adapt to the meteorological conditions.

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