Model fitting to account for the weather's impact on wireless propagation at 2.4 GHz

Abstract.- Usually, users of outdoor wireless local area networks have a good quality of experience and they do not have any complaint about its performance. However, under certain weather conditions, their performance is decreased due to influence of meteorological variables on wireless signal propagation and users notice this deterioration through disconnections, delays, data loss, etc. This paper presents the research carried out in order to approach by mathematic models the unsuccessful transmission of different frames at MAC layer from the weather conditions at run time.

Keywords: IEEE 802.11b/g; Meteorological variables; Outdoor Link; Symbolic Regression; MAC Frames.

Quality of wireless propagation is affected by natural and man-made terrestrial sources [1]. Therefore, the knowledge of the environment is of particular interest in planning and setting up wireless systems. Moreover of wireless channel external noise, wireless signals are also attenuated as a function of radio link distance and frequency by atmospheric gases [2] and rain conditions [3]. Obviously these disruptions are perceived on signal to noise ratio (SNR), and so on bit error rate (BER). ITU (International Telecommunications Union) recommendations do not highlight these impartments as significant at the 2.4 GHz frequency range, since SNR is decreased very few dBs. However, it has been shown that despite of so low impact on physical layer, it is really perceived in upper layers as a higher number of lost control frames [4] [5]. Moreover, it is clearly noticed as end-users when we are connected to an outdoor access point under adverse weather conditions. Since previous outcomes are derived from non-parametric correlation studies, we want to go beyond with another statistical method like symbolic regression. It allows analysing which weather conditions jointly impact greatly with the wireless link quality. Our goal has been to model such impact over an outdoor link IEEE 802.11 b/g.

Analysing how the weather impacts on outdoor wireless networks can be carried out from experimental data obtained by an accurate setup [6]. Once performance data and weather data are gathered by minute, they can be statically analysed in order to find precise correlations [7]. It has been shown that both groups of data (meteorological and wireless link quality) are significantly correlated [8], but this type of statistical analysis presents some limitations. It only assesses one by one variable, and it is not possible to estimate the correlation level from a group of meteorological variables as happens in reality. Secondly, it is necessary to pay attention to the concept CINAC (correlation is not a cause). It means that it is not possible to infer that certain weather conditions cause better or worse network performance directly without going deeper in this issue. Other works analyse how some weather conditions affect links, but only under simulations [9] without considering real scenarios. Therefore, we consider essential to perform another type of analysis that overcomes these constraints. The chosen solution is the symbolic regression because it is based on approaching mathematical models to fit an experimental dataset. Its objective is to distil raw data into non-linear mathematical equations [10]. This method allows to model wireless propagation quality from weather conditions jointly as these phenomena undoubtedly interfere as a whole. We have performed this analysis with Eureqa software [11] since it is one of the most powerful tools today to carry out this type of statistical analysis.

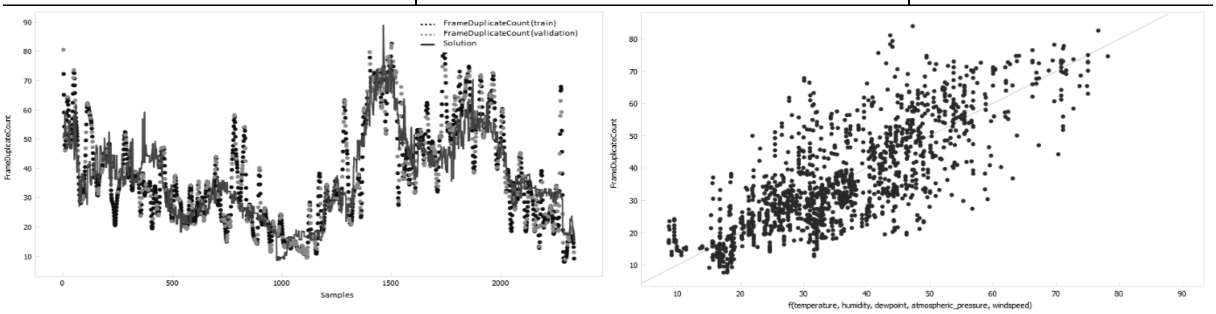
Collecting an accurate experimental dataset is essential to achieve reliable results. Our setup consisted of an outdoor point-to-point link IEEE 802.11b/g [12]. We transmitted constantly ICMP packets of the same size (200 bytes), so a stable and constant traffic was provided. The goal was to avoid congestion and problems due to changeable traffic. Moreover, it was encrypted and so any external user could not connect. Its length was 100 meters and it was as isolated as possible from external interferences. It was monitored for one month by the protocol SNMPv2 (Simple Network Management Protocol) that queried the IEEE802dot11-MIB (Management Information Base file) of access points to gather MAC (Medium Access Control) counters. They are considered as wireless quality parameters of this research since they are referred to frames that have suffered some mishap during wireless transmission. Failed counter is referred to frames not transmitted successfully due to the number of transmit attempts is exceeded. Frame duplicate counter is incremented when a frame is received as a duplicate and ACK failure counter increases when an ACK (Acknowledgement) is not received when expected. All data was collected by minute since this period is considered enough to perceive weather changes and network problems. Weather data was collected from a close weather station. Both weather data and wireless quality parameters were gathered in April 2013 since weather is quite changeable for this month. As data were collected by minute, it was essential to select a subgroup continuous of samples in which weather data do not present repeated patterns and counters do not reach their maximum value. Therefore, the selected subgroup of 2300 samples was chosen after an accurate data analysis in order to fulfil such conditions.

Fig. 1, 2, and 3 present the fitting models extracted for abovementioned counters and table 1 shows their corresponding sensitivity study. Sensitivity is referred to the relative impact within this model that a variable has on the target variable. The likelihood that increasing this variable will increase the target variable corresponds to the positive percentage. Such positive percentage indicates the % of the time in which this variable is increasing and it leads to increases in the target variable (but the remaining of the time it either decreases it or has no impact). In the same way, positive magnitude indicates how big the positive impact is. The negative percentage and magnitude have the same meaning but just in the opposite way. Increases in the variable suppose decreases in the target variable. Solution fit plot depicts how the model (continuous line) fits actual observed values. Clear data points are used for validation and dark data points for training. Moreover, observed vs. predicted plot outlines actual observed values against the values predicted by the selected model. Constant values in models are represented by lower case letters. Fig. 1 depicts the number of duplicated frames since temperature, humidity, dew point and atmospheric pressure conditions. Humidity and dew point present greater influence within the model in a slight negative way. However, the influence of temperature and atmospheric pressure is mainly positive. Counter of frames not transmitted successfully (fig. 2) is fitted mainly by dew point and atmospheric pressure in a positive way and humidity in a negative way. Finally, the model for lost acknowledgments (fig. 3) is based on temperature, humidity and atmospheric pressure. Temperature and atmospheric pressure have an impact mainly positive and humidity totally negative. Wind speed has not been included in any model because it was not really strong during the period of gathering data. Humidity, dew point and temperature are three indicators of the amount of moisture in air. Humidity is mainly related positively with network parameters, so it entails that worse performance is noticed when the environment is wet. Atmospheric pressure indicates the force per unit area exerted against a surface by the weight of air. Its main positive influence shows that generally as the atmospheric mass increases, more transmission problems are noticed.

$$\text{FrameDuplicateCount} = a * sin(b * \mathbf{AP}) + \frac{c}{(d*\mathbf{H}^2 - e*sin(f*\mathbf{T}) - g*\cos(h*\mathbf{DP}*\mathbf{H^2}))}$$

where a=100, $b=49.69*10^{-2}$, $c= 1.002*10^{4}$, d=0.01, e=6.37, f=2.05, g=2.92, $h=8.66*10^{-4}$

R^2 Goodness of Fit: 0.66	Correlation Coefficient: 0.81	Mean Absolute Error: 7.48



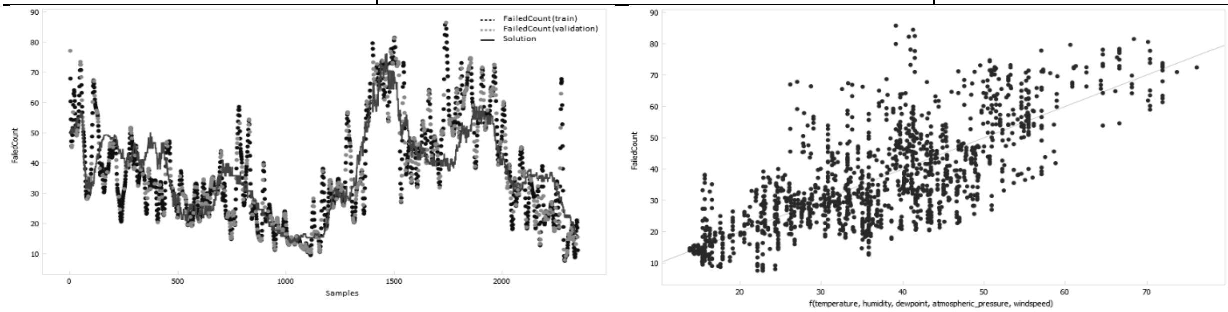
Solution Fit Plot | Observed vs Predicted Plot

Fig. 1. Model fitting to account for the number of duplicated frames.

$$\text{FailedCount} = a + b * cos(c * \mathbf{H} - \mathbf{DP}) - d * sin(e * \mathbf{AP})$$

where a=1993; b=17.92; c=0.3138; d=1962; e= 0.1

R^2 Goodness of Fit: 0.64	Correlation Coefficient: 0.80	Mean Absolute Error: 7.96



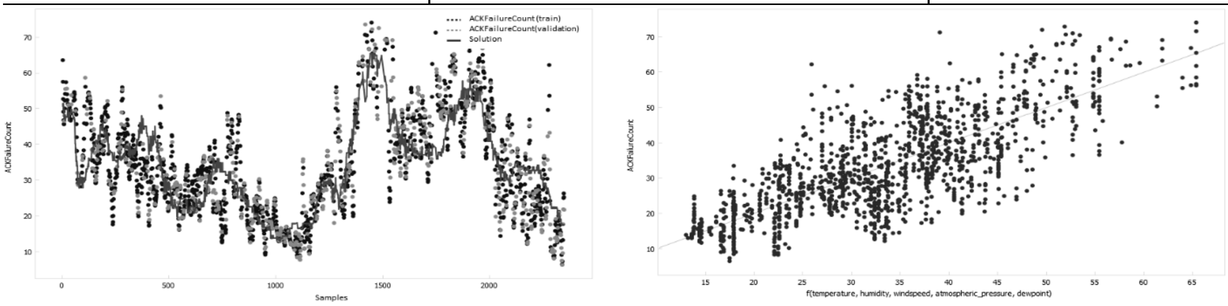
Solution Fit Plot　　Observed vs Predicted Plot

Fig. 2. Model fitting to account for the number of frames not transmitted successfully.

$$\text{ACKFailureCount} = a + b * \sin(c * \mathbf{T} - d * \mathbf{AP}) - e * \mathbf{H} - f * \sin(g * \mathbf{AP})$$

where a= 2142; b=9.324; c=1.584; d=0.5592; e=1.931; f=1943; g=0.1

R^2 Goodness of Fit: 0.63	Correlation Coefficient: 0.79	Mean Absolute Error: 7.04



Solution Fit Plot　　Observed vs Predicted Plot

Fig. 3. Model fitting to account for the number of ACKs failed.

Table 1. Sensitivity Results.

Model fitting	Variable	Sensitivity	% Positive	Positive Magnitude	% Negative	Negative Magnitude
FrameDuplicate	T	1.0023	75%	0.99181	25%	1.0344
	H	4.1492	36%	3.3451	64%	4.6099
	DP	2.8571	49%	2.9874	51%	2.7315
	AP	1.4427	68%	1.4688	32%	1.3858
Failed	H	0.6865	84%	0.73382	16%	0.44368
	DP	0.8701	84%	0.93008	16%	0.56234
	AP	1.1203	69%	1.1934	31%	0.96101
ACKFailure	T	0.74744	72%	0.7832	28%	0.65742
	H	1.5563	100%	1.5563	0%	0
	AP	1.4147	65%	1.4788	35%	1.2955

ITU-R highlights that attenuation due to weather conditions on frequencies of few GHz is around 1-2 dB. Therefore, the weather's impact over outdoor IEEE 802.11b/g networks is considered relatively low. However, it is really noticed a worse function when we are connected to an outdoor access point under adverse weather conditions. Therefore, the motivation to perform this research is to study in depth if despite of low attenuation, upper layers such as MAC layer really notice it as a deterioration of wireless link quality.

This research points out the impact of the weather conditions on the wireless link quality. Mathematical models extracted fit different transmission problems over a link IEEE 802.11b/g as a function of different meteorological variables. As goodness of fit (R^2) of these models is between 0.64 and 0.66, and correlation coefficients are around 0.80, we consider that such weather's impact is really significant and it should be taken into account to deploy future outdoor links. This research has been carried out by symbolic regressions since it is a powerful and reliable method to analyse difficult hidden relations among variables. Results show that grouping weather conditions entails a significant increment in the correlation coefficients in comparison with previous studies. Symbolic regressions have allowed concluding which group of weather conditions jointly has a greater influence on links at 2.4 GHz.

Nowadays, there are some proposals to adapt wireless protocols to the environment in order to improve the network performance [13]. Therefore, as future work, we will propose some improvements to the Standard IEEE 802.11b/g to overcome the weather's impact on wireless links.

References

[1] C. Bianchi, A. Meloni (2007) Natural and man-made terrestrial electromagnetic noise: an outlook. Annals of Geophysics, 50: 435-445.

[2] International Telecommunications Union (2013) Recommendation ITU-R P.676-10: Attenuation by atmospheric gases.

[3] International Telecommunications Union (2013) Recommendation ITU-R P.530-15: Propagation data and prediction methods required for the design of terrestrial line-of-sight systems.

[4] D. Bri, M. Fernández-Diego, M. Garcia, F. Ramos, J. Lloret (2012) How the Weather Impacts on the Performance of an Outdoor WLAN. IEEE Communications Letters, 6: 1184-1187.

[5] D. Bri, F. Ramos, J. Lloret, M. Garcia (2012) The influence of meteorological variables on the performance of outdoor wireless local area networks, IEEE International Conference on Communications, Ottawa.

[6] D. Bri, S. Sendra, H. Coll and J. Lloret (2010) How the Atmospheric Variables Affect to the WLAN Datalink Layer Parameters. Advanced International Conference on Telecommunications, Barcelona.

[7] C.-H. Chu, Y.-M. Chen, Y.-T. Huang, R. Carvalho, C.-C. Hsu and L.-J. Chen (2014) Measurement of long-distance Wi-Fi connections: An empirical study. IEEE International Conference on Communications, Sydney.

[8] K. Ohshima, H. Hara, Y. Hagiwara, M. Terada (2012) Field investigation of the radio transmission performance and distance in an environmental wireless sensor network. International Conference on Information Networking, Bali.

[9] F. Nadeem, E. Leitgeb, O. Koudelka, T. Javornic and G. Kandus (2008) Comparing the rain effects on hybrid network using optical wireless and GHz links. International Conference on Emerging Technologies, Rawalpindi.

[10] M. Schmidt, H. Lipson (2009) Distilling Free-Form Natural Laws from Experimental Data. Science, 324: 81-85.

[11] M. Schmidt, H. Lipson (2013) Eureqa (Version 0.98 beta) [Software] Available: www.nutonian.com

[12] D. Bri, M. Garcia, J. Lloret, J. Misic (2015) Measuring the weather's impact on MAC layer over 2.4 GHz outdoor radio links. Measurement, 61: 221-233.

[13] F. Yu, S. Biswas (2012) MAC Protocol Switching: A Novel Tool for Performance Adaptation in Wireless Sensor Networks. Network Protocols and Algorithms, 4: 69-85.