# Prediction Metrics for QoE/QoS in Wireless Video Networks for Indoor Environmental Planning: A Bayesian Approach

André Augusto Pacheco de Carvalho
Laboratory of Computation and Telecommunications
Federal University of Pará, UFPA,
Belém, Brasil
e-mail: andrepcarvalho@gmail.com

João Victor Costa Carmona
Laboratory of Computation and Telecommunications
Technology Institute, Federal University of Pará, UFPA,
Belém, Brasil
e-mail: victorjvcc@gmail.com

Jasmine Priscyla Leite de Araujo
Laboratory of Computation and Telecommunications,
Technology Institute, Federal University of Pará
Belém, Brasil, Bolsista CNPq-Brasil
e-mail: jasmine.araujo@gmail.com

Simone da Graça de Castro Fraiha
Laboratory of Computation and Telecommunications,
Institute of Exact and Natural Sciences, Federal University
of Pará Belém, Brasil
e-mail: fraiha@ufpa.br

Hermínio Simões Gomes
Laboratory of Computation and Telecommunications,
Institute of Exact and Natural Sciences, Federal University
of Pará Belém, Brasil
e-mail: herminio@ufpa.br

Gervásio Protásio dos Santos Cavalcante
Computer and Telecommunication Engineer Faculty
Federal University of Pará, UFPA,
Belém, Brasil
e-mail: gervasio@ufpa.br

***Abstract*—The evolution of applications on wireless networks has grown in recent years due to the growth in the number of users of mobile phones, tablets, and other. The availability of demanding services, such as video transmission affect the Quality of Experience (QoE) and Quality of service (QoS) provided domestic and commercial users, it has stimulated the study of new techniques of management of network resources, always having as objective to provide high quality services to an increasingly demanding customer. This paper presents a methodology of Artificial Intelligence, using the technique of Bayesian networks, as a hybrid evaluation strategy by analyzing the behavior of QoE and QoS metrics, in designing wireless LAN. So, by manipulating the basis of Bayesian networks, it was possible to find satisfactory results for the proposed solution helps the planning of wireless networks in indoor environments, which does not exclude the possibility of using this approach for other situations**.

***Keywords-QoE/QoS; measurements; simulation; Bayesian networks; wireless networks.***

## I. INTRODUCTION

Currently, there is an increasing need for bandwidth services due to the demand for greater high-speed mobility and available services, any time, any place, anywhere. It should be noted that there is a widespread access to wireless networks and the use of multimedia applications such as Voice over IP (VoIP), and online video games (data and video).

The International Telecommunication Union (ITU) report [1] indicates that this increase includes network bandwidth usage. This has involved observation and improved planning in Wireless Local Area Networks (WLAN), so that bottlenecks and/or overloading can be avoided.

Studies based on measurements can provide more precise results than studies based on simulations or modeling [2].

In [3], there is a visualization tool for wireless network parameters; in this case, physical layers for the network, where the data are also collected through measurements in an indoor environment. In [4], a study was carried out on wireless and digital television transmissions in networks. Metric data of the physical layer and application were gathered with the aim of creating a cross-layer approach to model quality loss through empirical equations.

In this study, a combination of measuring and simulation (through the use of Matlab® software [5]) is proposed. This is carried out by means of modeling with the aid of Bayesian networks to represent wireless network and predict the behavior of Quality of Experience or services offered to the user that differ from [3], where the QoS was only evaluated for a VoIP application.

An evaluation will be conducted of several Quality of Experience (QoE) and Quality of Service (QoS) metrics [6], some taken from the measuring process and others originating from the data handling.

The study is structured in the following way: Section II presents the related work. In Section III, the environment where the measurements were carried out is examined. Section IV describes the methodology employed and Section V shows the results obtained. Section VI discusses the conclusions of the study.

ISBN: 978-1-61208-398-8

## II. RELATED WORK

This work has as a differential of other article published, consideration of the parameters of QoS and QoE to assist in planning design of wireless networks for indoor environments.

As we can see from Wu et al. [7], the beginning of the form study in this area of planning mainly uses techniques of neural networks and genetic algorithm to perform the forecast/prediction with some QoS/QoE metrics, never both.

Dimitriou et al. [8] makes use of physical layer parameters such as average power, signal error and signal, interference noise (SINR).

Fraiha [9] proposed a methodology for projects in wireless local area networks optimized by using a model of loses of signal power and measures considered QoS parameters, always aiming to maximize coverage with the least number of Access Point (PA) to be installed in a given indoor environment by using a technique of optimization of multi-objective genetic algorithms, proposing a propagation model that allows simulating the likelihood of receiving the signal in the environment studied.

This paper presents a new approach in designing indoor networks; prediction considering the QoE and QoS parameters to assist in the planning of wireless networks for indoor environment.

## III. THE MEASUREMENT SETTING

The classroom building of the Federal University of Pará (UFPA) was used as the setting for carrying out the measurement campaign, as illustrated in Figure 1. It is built of bricks and concrete and has glass windows on the side and a corridor. The chairs and tables inside the rooms are made of plastic and metal.

The measurements were conducted on the second floor. The size of the building is 40x11 meters. This floor has six rooms, each measuring 6x8 meters.

Figure 2 shows a diagram of the classrooms where the measurements took place. The transmitter location is shows together with the points that were analyzed (in red).

Figure 1. The classroom building: classrooms and side corridor

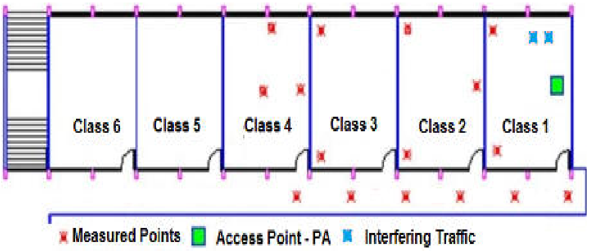


Figure 2. Model of the setting and location of the points analyzed (red) and transmitter location (PA).

## IV. METHODOLOGY

The methodology employed for this study followed a number of stages: collection of the results of the experiment - these results are used to gain entry to the Bayesian networks [3], so that probability maps can be generated. After this, these maps are converted into information to allow an analysis of the behavior of the QoE/QoS metrics in wireless networks and to assist in the planning of the indoor networks. Figure 3 shows a flowchart of the methodology employed in this study.

In planning wireless networks there is a mathematical formula that proves of installation exact PA, so in the methodology of this article was carried out measurements for the construction of measures to generate Bayesian network, to conduct training and validation.

Several tools were used in order to control the traffic characterization, mapping the wireless network created, and can perform the analysis while the transmitter sent the video to the recipient.

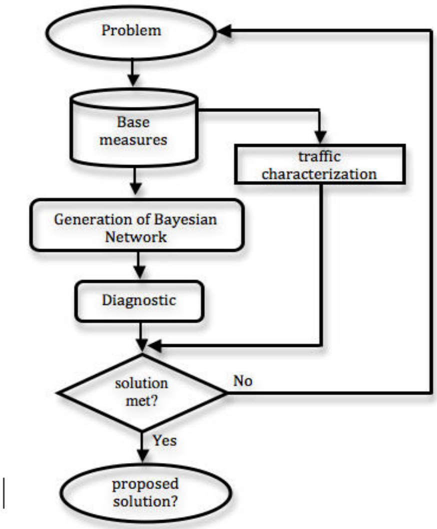


Figure 3. Flowchart of the Methodology

### A. *Materials Used*

The components of the interconnected network were as follows: four notebooks, two being used for the video transmission and reception respectively, and the remaining two to generate competing traffic in the network by using the Windows 7 operating system.

The configurations of the computers and PA that were employed, were as follows:

- Two computers with a processor: core I5 2.4 GHz; 4 GB RAM memory, HD of 500 GB; on-board video card with up to 512 MB of shared RAM memory and Windows 7 64 bit operating system;
- Two computers with AMD A6 3410mx processor; video radeon HD graphics 1.6 GHz card; 4 GB RAM memory; HD of 500 GB; and Windows 7 64 bit operating system;
- An Evo-W301AR (SIROCO) Router Model, Channel 3 (2422 MHz) - mode: 802.11g – channel width 20 MHz, maximum transmission rate 54 Mbps and Transmission power 20 dBm.

Figure 4 below shows the layout of the computers in class 1, where some of the devices used were installed.

### B. Measurements

A WLAN network was assembled to evaluate the communication and video transmission. Evalvid [10] software was employed for the video transmission and reception; this consists of a set of tools that allow the network to be evaluated by obtaining performance metrics such as jitter, end-to-end delay, Peak Signal-to-Noise Ratio (PSNR) and Structural Similarity (SSIM).

These were obtained by making a comparison between the video frames received and the video reference frames. Figure 4 shows the two frames - the frames degraded by the effects of transmission (left part) and the original frame without degradation, (right part).

In the case of the SSIM metrics, the index varies from 0 to 1, where the closest to 1, means a greater quality and indices closest to 0, means a lowering of quality. By analogy, the PSNR, is in a scale that ranges from 0 to 50, where the higher the value, the greater the inability of the user to detect failures in the video.

Some metrics like PSNR and SSIM are calculated through a set of frames. Other metrics like jitter and end-to-end delay are calculated through the time needed for the consecutive frames to reach the receptor. As well as these metrics, at each reception point, the Receiver Signal Strength Indicator (RSSI) was measured by means of the WirelessMon tool [11].

Traffic simulation (T-Iperf and R-Iperf) constant [12] was generated in the network with the aim of creating competition for bandwidth between the traffic caused by Iperf and the transmission of video traffic. This made it possible to characterize the network that was the nearest possible to a real network where competitive services are made available by the band.

The videos were transmitted in the MPEG-4 Widescreen 16:9 format with a resolution of 1920x1080p so that they complied with the digital TV coding Standards.

During the measurement procedure, a methodology was employed to ensure there was no divergence in the way the data were collected. It can be described as follows: the PA was installed in the first room together with both the computers which carried out the video transmission and the computers that generated the network traffic constant with the T-Iperf e R-Iperf measurement tools. Only the video receptor that remained moved around between the points and this meant that the video could be received and reconstructed and it was thus possible to evaluate the quality of the transmission.

Figure 4. Example of frame reception failures (above) and the original video frame (below).

The sending of the video and the measurement of the signal strength generated by the PA was carried out for each point shown in Figure 2. After the dispatch, a receptor file was made which enabled the video to be reconstructed by checking the quality of the data transmitted to determine if there had been any packet losses during the transmission.

### C. Computational Modeling and Simulation (Bayesian Networks)

At the end of the measuring, several files were compiled and on the basis of this data, the modeling was carried out to enable us to create a Bayesian network.

Bayesian networks are probabilistic graphical models for the representation of knowledge in areas where there is uncertainty. These models can be represented in two way:

- **Qualitative**: representing the dependencies between the nodes;
- **Quantitative:** represented by conditional probability tables.

As a result, the evaluation can be carried out in terms of the probability of these dependencies [13][14]. These components form an efficient representation of the joint probability distribution of the X variables in a given domain [15].

Since a network is generated, it is possible to predict its future behavior through the choice of an interval for a given attribute. When this interval is selected, the values are propagated to the nodes, which is called the Bayesian inference [14].

After the measurements, numerous files were generated; these files contain data that generated the basis of measures. However, due to signal coverage, we could not obtain all the necessary measures for the entry of Bayesian network.

However, with the use of Matlab®, it has been possible to perform the database extension measures. Dealing with a real existing base, we could create a Bayesian network.

Despite having generated multiple files, scientifically measured points were to be based on an analysis of a methodology. However, due to coverage area of PA and the size of the building, we could not do more measurements; so, as a solution to extend the base, Matlab® has been used.

A program was created that uses the feature of Matlab® of a micro type artificial neural network Radial Basis Function (RBF), the function *newgrrnn*, which implements the generalized recurrence, where a Gaussian function [2] with crests near the points measured is simulated. So, the points obtained from regression [9] has underestimated values and values well estimated to close points measured, making the gradual expansion of the points so that there was a sufficient database for Bayesian network was applied.

Furthermore, in the program, there was the need of a softening in the generation of items, by using the parameter in the Matlab ® called *spread*, for which the creation of new point was approximately, so the regression cited would point creation by simulating the real scenario, where points close to the measured point stay good and far from the worst gets worse.

Figure 5 shows the network generated with the QoS and QoE metrics and the metrics for physical layer, distance and RSSI. Figure 6 shows the inference of best distance. The probability values of the other nodes are altered, which confirms the propagation.

This was exemplified by analyzing the RSSI metric when it was observed that there is a 81% probability of being between -60.0 and -49.0 dBm when the inference for the distance metric is at its best value, with points close to the access point of 5.36 to 6.06 meters. The PSNR value for the same inference has 65% of probability of being between 24.55 and 36.24dB. The delay has almost 100% of probability of being between 151 and 591 ms. Jitter has a 99.0% probability of being between entre 0.08 and 1.83s. Finally, the SSIM has a probability of 65% of being between 0.75 and 0.868.

Figure 7 gives an example of another inference that can be made with regard to the worst distance. When the RSSI metric is analyzed, it can be seen that it has an 86% probability of being between -64.0 and -79.8 when the inference of the metric distance is at its worst value, if the worst value is considered to be the points most distant from the access point of 12.55 to 24.13 meters. The PSNR value for the same inference has a 62.1% probability of being between 13.33 dB to 19.89 dB.

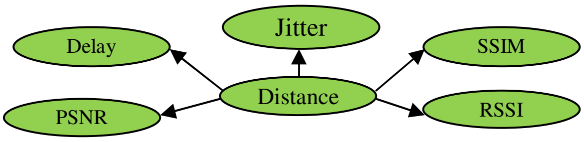
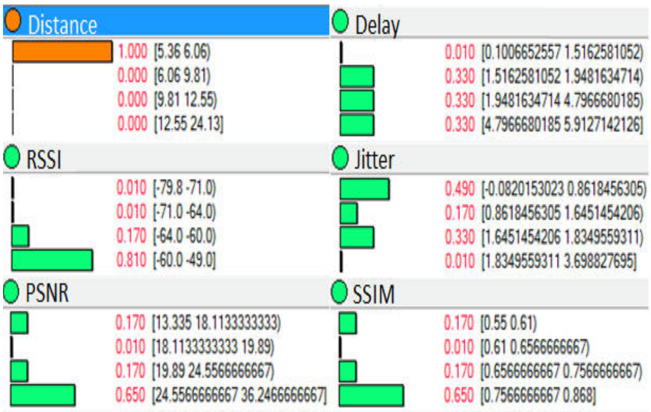


Figure 5. Bayesian Network

The Delay has more than 50% of probability of being greater than 194 ms. Jitter has a 61.3% probability of being between 1.834 and 3.69 seconds. Finally, the SSIM has a probability of 62.1% of being below 0.65. Figure 8 and Figure 9 can be analyzed for a visual inspection of the inferences carried out.



Distance
1.000 [5.36 6.06)
0.000 [6.06 9.81)
0.000 [9.81 12.55)
0.000 [12.55 24.13]

Delay
0.010 [0.1006652557 1.5162581052)
0.330 [1.5162581052 1.9481634714)
0.330 [1.9481634714 4.7966680185)
0.330 [4.7966680185 5.9127142126]

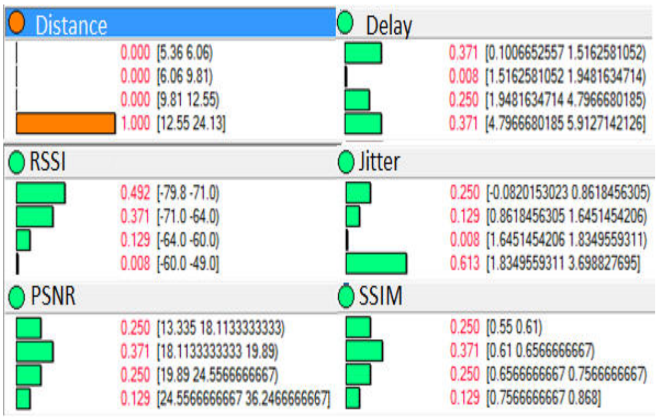
RSSI
0.010 [-79.8 -71.0)
0.010 [-71.0 -64.0)
0.170 [-64.0 -60.0)
0.810 [-60.0 -49.0]

Jitter
0.490 [-0.0820153023 0.8618456305)
0.170 [0.8618456305 1.6451454206)
0.330 [1.6451454206 1.8349559311)
0.010 [1.8349559311 3.698827695]

PSNR
0.170 [13.335 18.1133333333)
0.010 [18.1133333333 19.89)
0.170 [19.89 24.5566666667)
0.650 [24.5566666667 36.2466666667]

SSIM
0.170 [0.55 0.61)
0.010 [0.61 0.6566666667)
0.170 [0.6566666667 0.7566666667)
0.650 [0.7566666667 0.868]

Figure 6. Inference of best distance



Distance
0.000 [5.36 6.06)
0.000 [6.06 9.81)
0.000 [9.81 12.55)
1.000 [12.55 24.13]

Delay
0.371 [0.1006652557 1.5162581052)
0.008 [1.5162581052 1.9481634714)
0.250 [1.9481634714 4.7966680185)
0.371 [4.7966680185 5.9127142126]

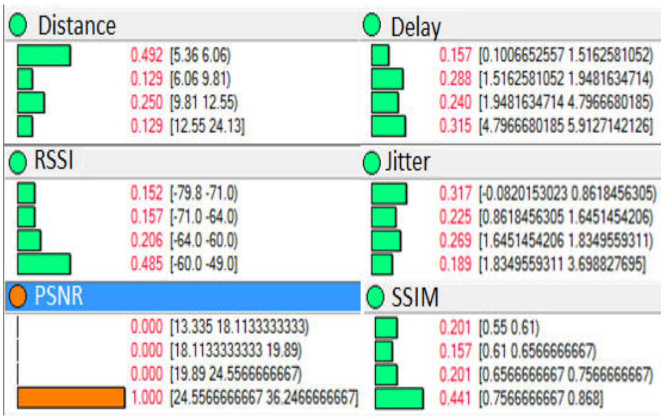
RSSI
0.492 [-79.8 -71.0)
0.371 [-71.0 -64.0)
0.129 [-64.0 -60.0)
0.008 [-60.0 -49.0]

Jitter
0.250 [-0.0820153023 0.8618456305)
0.129 [0.8618456305 1.6451454206)
0.008 [1.6451454206 1.8349559311)
0.613 [1.8349559311 3.698827695]

PSNR
0.250 [13.335 18.1133333333)
0.371 [18.1133333333 19.89)
0.250 [19.89 24.5566666667)
0.129 [24.5566666667 36.2466666667]

SSIM
0.250 [0.55 0.61)
0.371 [0.61 0.6566666667)
0.250 [0.6566666667 0.7566666667)
0.129 [0.7566666667 0.868]

Figure 7. Inference of worst distance



Distance
0.492 [5.36 6.06)
0.129 [6.06 9.81)
0.250 [9.81 12.55)
0.129 [12.55 24.13]

Delay
0.157 [0.1006652557 1.5162581052)
0.288 [1.5162581052 1.9481634714)
0.240 [1.9481634714 4.7966680185)
0.315 [4.7966680185 5.9127142126]

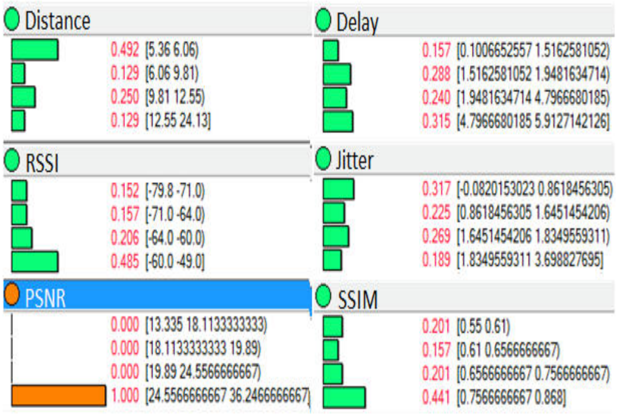
RSSI
0.152 [-79.8 -71.0)
0.157 [-71.0 -64.0)
0.206 [-64.0 -60.0)
0.485 [-60.0 -49.0]

Jitter
0.317 [-0.0820153023 0.8618456305)
0.225 [0.8618456305 1.6451454206)
0.269 [1.6451454206 1.8349559311)
0.189 [1.8349559311 3.698827695]

PSNR
0.000 [13.335 18.1133333333)
0.000 [18.1133333333 19.89)
0.000 [19.89 24.5566666667)
1.000 [24.5566666667 36.2466666667]

SSIM
0.201 [0.55 0.61)
0.157 [0.61 0.6566666667)
0.201 [0.6566666667 0.7566666667)
0.441 [0.7566666667 0.868]

Figure 8. Inference of best PSNR


Distance
0.492 [5.36 6.06)
0.129 [6.06 9.81)
0.250 [9.81 12.55)
0.129 [12.55 24.13]

Delay
0.157 [0.1006652557 1.5162581052)
0.288 [1.5162581052 1.9481634714)
0.240 [1.9481634714 4.7966680185)
0.315 [4.7966680185 5.9127142126]

RSSI
0.152 [-79.8 -71.0)
0.157 [-71.0 -64.0)
0.206 [-64.0 -60.0)
0.485 [-60.0 -49.0]

Jitter
0.317 [-0.0820153023 0.8618456305)
0.225 [0.8618456305 1.6451454206)
0.269 [1.6451454206 1.8349559311)
0.189 [1.8349559311 3.698827695]

PSNR
0.000 [13.335 18.1133333333)
0.000 [18.1133333333 19.89)
0.000 [19.89 24.5566666667)
1.000 [24.5566666667 36.2466666667]

SSIM
0.201 [0.55 0.61)
0.157 [0.61 0.6566666667)
0.201 [0.6566666667 0.7566666667)
0.441 [0.7566666667 0.868]

Figure 9. Inference of worst PSNR

With the aid of the conditional probability tables obtained from the Bayesian network and variance tables, a simulation was conducted on the basis of this mathematical modeling and adapted to QoE metrics by means of Matlab. Finally, the values of the distance metrics can be visualized to analyze/predict the behavior of the video streaming network.

## V. RESULTS

The heat maps presented follow the same reasoning of the measured building plan; for this reason, from Figure 10 to Figure 14, the X axis represents the distance in meters and the simulation also represents the layout of the ¨pavilion¨ (inner part of the building) described in Section II. The Y axis represents the width of the classroom and the colors represent the degree of probability of the metric. The reference-point can be considered to be at the beginning of the X axis at a distance of 40 meters, that is it passes through the pavilion in an opposite direction to that shows in the diagrams. All the distance values shows in this section follow this reference-point.

With regard to the SSIM metric, the greater it is, the better according to Figure 10, and a Bayesian simulation with measurement data shows a behavior above 0.7, even up to 10 meters from class 1.

In the case of the delay metric, Figure 11 shows a reasonable value that corresponds to less than 250 ms at a distance of approximately 10 meters too. In Figure 12, jitter follows the previous metrics and shows reasonable values in up to 10 meters with values less than 0.8 second.

PSNR is most often used to measure the quality of reconstruction of loss compression codec (example: for image compression). The sign, in this case, are the original data, and the noise is the error introduced by compression. When comparing compression codec, PSNR is an approach to the human perception of quality reconstruction.

In Figure 13, PSNR also has satisfactory values up to 10 meters with values that are approximately 28 or more. In Figure 14, the RSSI also has values higher than 10 meters, above 60 dB.

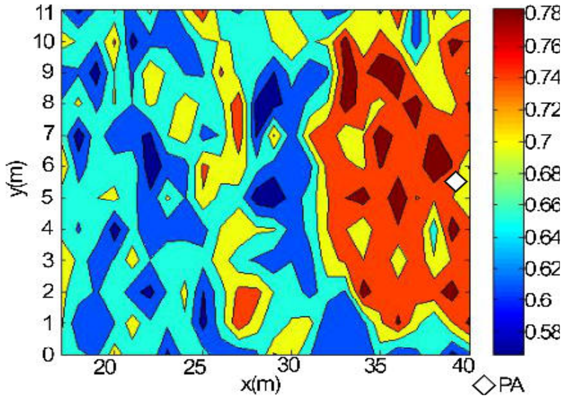


Figure 10. Maps showing Probability of SSIM

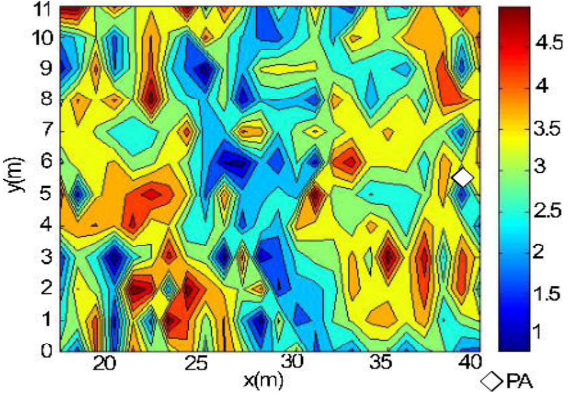


Figure 11. Maps showing probability of delay

As in visual terms, the metrics had a suitable performance at a distance of up to 10 meters from the Access point; in this case, it is suggested that in the planning stage, other PAs are installed from this point, so that the other classrooms can be provided with a satisfactory number of applications that use video.

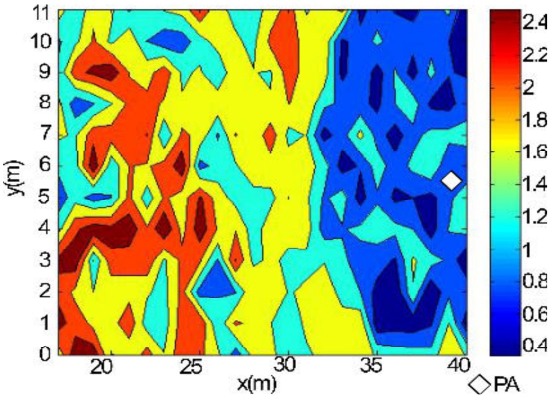


Figure 12. Maps showing the probability of jitter

This decision-making is based on the use of video to meet the needs of metrics that measure performance within a specified standard. Thus, the behavior of metrics can be predicted and access points installed, to make improvements when complying with the requirements of the QoS/QoE parameters.

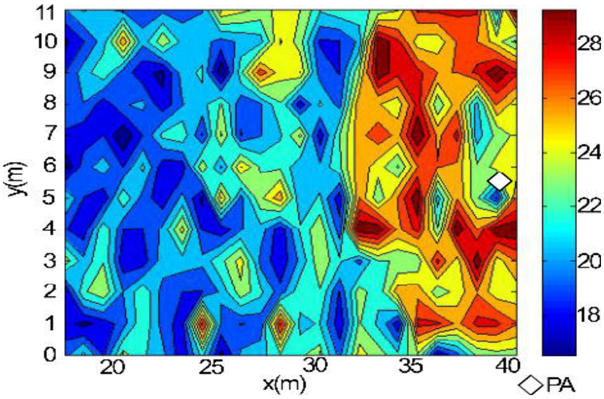


Figure 13. Maps showing the probability of PSNR

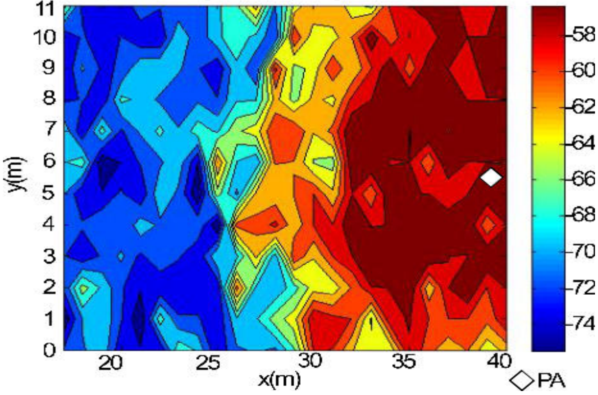


Figure 14. Maps showing the probability of RSSI.

Finally, these probabilistic maps show the use of the hybrid technique: measurements and the Bayesian approach. They can be used to analyze the behavior of wireless networks and assist in the analysis of the performance of these networks by taking account of both QoE/QoS bandwidth applications in the growth of indoor wireless networks.

## VI. CONCLUSION AND FUTURE WORK

This article has outlined an empirical approach and simulation for assisting the planning of wireless networks based on video measurements in the inside environment of the facilities of UFPA.

The results suggest that the use of the proposed tool is feasible. The measured data allow the Bayesian network to make estimates in a consistent and reliable way for environments similar to those measured in this study.

In future studies, it is intended to perform more measurements campaigns, however these measurements shall be directed in other buildings, with totally different internal architecture of the architectures present in the building chosen for this dissertation.

Perform simulations with other types of network traffic, such as audio. Expand the methodology of this study for the outdoor environment, and tests with other emerging technologies, such as the 4G and 5G.

At the time of the confrontation of environments, would be inevitable, as a consequence the achievement also approach in the frequency range that used, as used in the frequencies of 2.4 GHz to 5 GHz, based on the IEEE 802.11 wireless networks while the 4G is used in the 700MHz frequency in Brazil.

## ACKNOWLEDGMENT

This work was done with the support of CNPq - National Council for Scientific and Technological Development – Brazil. The authors also would like to thank to UFPA, and the National Institute of Science and Technology – Wireless Communications (INCT-CSF) and their research staff for their support of this study.

## REFERENCES

[1] ITU-T, “Measuring the Information Society Report 2014” in http://www.itu.int/en/ITU-D/Statistics/Pages/publications/mis2014.aspx [retrieved: 03/2015].

[2] R. Jain. The Art of Computer Systems Performance Analysis: Techniques for Experimental Design, Measurement, Simulation and Modeling, Publisher Wiley, 1991, pp. 418-425.

[3] J. Araujo, J. Rodrigues, S. Fraiha, H. Gomes, N. L. Vijaykumar, G. Cavalcante, and C. Frances, “A Visualization Tool for Analyzing the Design of Physical and Network Layers Parameters of a Wireless Network”, Proceedings of the Second International Conference on Advances in Computing and Information Technology, vol. 3, July 2012, pp. 291-305.

[4] B. S. L. Castro, “CrossLayer Modeling of Quality of Experience for Video Transmission in OFDM Wireless Systems”, Doctoral Thesis, UFPA,Feb. 2014, pp. 20-24 in http://repositorio.ufpa.br/jspui/handle/2011/5593 [retrieved: 03/2015].

[5] J. B. Klaue, B. Rathke, and A. Wolisz, “EvalVid - A Framework for Video Transmission and Quality Evaluation”, 13th International Conference on Modeling Techniques and Tools for Computer Evaluation, Urbana, Illinois, USA, Sept. 2003, pp. 255-272.

[6] H. Chaari, K. Mnif, and L. Kamoun, “An Overview of Quality Assessment Methods of Video Transmission over Wireless Networks”, Electrotechnical Conference (MELECON), 16th IEEE Mediterranean, vol. 1, March 2012, pp. 741-744.

[7] R. Wu, Y. Lee, and S. Chen, “Planning System for Indoor Wireless Network”, Consumer Electronics, IEEE Transactions on, IEEE Consumer Electronics Society, vol. 47, Feb. 2002, pp. 73-79.

[8] A. G. Dimitriou, S. Siachalou, A. Bletsas, and J. N. Sahalos, “An efficient propagation model for automatic planning of indoor wireless networks”. Antennas and Propagation (EuCAP), 2010 Proceedings of the Fourth European Conference on. Barcelona, April 2010, pp. 1-5.

[9] S. G. C. Fraiha, “Location of Access Points in Indoor Environments in Wireless System Projects”, Doctoral Thesis, UFPA, May 2009, pp. 6-104.

[10] Matlab, Matlab version 7.0. In Technical Documentation, 2012.

[11] WirelessMon, PassMark Software, 2010.

[12] Y. Byun, S. Narayanan, S. Mott, K. Biba, J. Schwenkler, R. Osborn, and M. Morris, “Wireless Broaband Measurement in California”. 10th International Conference on Information Technology: New Generations, vol. 1, April 2013, pp. 505-509.

[13] Z. Chen, Data Mining and Uncerta in Reasoning: An Integrated Approach,Wiley-Interscience, Aug. 2001, pp. 285-289.

[14] K. B. Korb and A. E. Nicholson, Bayesian Artificial Intelligence, Crc Press, 2004, pp. 74-89.

[15] J. Pearl, Probabilistic Reasoning in Intelligent System, Morgan Kaufmann Publishers, Sep. 1988, pp. 223-232.