2013 IEEE 27th International Conference on Advanced Information Networking and Applications

EDCA 802.11e performance under different scenarios

Quantitative analysis

Santiago Perez, Higinio Facchini, Gustavo Mercado, Luis Bisaro
Center of Research and Development GRID TICs
National Technological University
Mendoza, Argentine
santiagocp@frm.utn.edu.ar, higiniofac@frm.utn.edu.ar, gmercado@frm.utn.edu.ar, lbisaro@frm.utn.edu.ar

Javier Campos*
Department of Informatics and Systems Engineering
Zaragoza University
Zaragoza, Spain
jcampos@unizar.es

Abstract—**The global throughput of an 802.11e WLAN is determined by EDCA (Enhanced Distributed Channel Access) parameters, among other aspects, that are usually configured with predetermined and static values. This study carefully evaluates the Quality of Service (QoS) of Wi-Fi with EDCA in several realistic scenarios with noise and a blend of wireless traffic (e.g., voice, video, and best effort, with Pareto distribution). The metrics of the benefits obtained in each case are compared, and the differentiated impact of network dynamics on each case is quantified. This study proposes a new experimental scenario based on the relative proportion of traffic present in the network. Stations have been implemented using HSANs (Hierarchical Stochastic Activity Networks) and simulated using the Möbius tool.**

Keywords QoS; WLAN; EDCA; MAC Parameters; Analysis

I. INTRODUCTION

Providing Quality of Service (QoS) in Wi-Fi networks is a considerable challenge for data networks, due to the high levels of burst-like packet loss, latency, and jitter. Several ways to characterise QoS through strict requirements expressed using quantitative values include data velocity, throughput loss thresholds, packet loss rates, and maximum limits on delay and jitter.

The family of IEEE 802.11 protocols is the most promising framework for Wireless LAN (WLAN) networks; there is also hope that it can become the standard in industrial and personal environments [1]. The protocol includes the 802.11e standard that proposes a new function for the MAC layer, known as the Hybrid Coordination Function (HCF). This function uses a channel access method based on EDCA contention. EDCA is designed to provide prioritised QoS and improve the Distributed Coordination Function (DCF) belonging to the original 802.11 standard.

This paper presents a detailed analysis that verifies the success of priority-based traffic differentiation and eventually QoS specifications in Wi-Fi network communications. Specifically, the principal focus is analysing the quantitative behaviour of the EDCA IEEE 802.11e protocol in supporting QoS while in a shared communications setting with diverse traffic used by wireless networks.

The results may be compared to and complement those obtained by studies, as in the literature relating to Wi-Fi network behaviour. These studies propose creating a behavioural model for nodes in particular and the network in general based on the analysed or simulated trace collection.
Trace collection is a necessary first step in creating realistic models crucial to designing, simulating, and evaluating network protocols [2-4]. Unfortunately, a portion of authors tend to define a model as interpreting trace collections, although only conclusions can be drawn from traces while searching for the behavioural characteristics of the traffic in question.

The other method of analysing the performance of IEEE 802.11communication networks has been to develop evaluation models based on two different perspectives: analytical and simulation. Analytical models [5] have the advantage of providing expressions/formalisms that help analyse the influence of different parameters. To develop realistic scenarios like those anticipated in this study, we assume that using analytical models would not be an adequate approximation for the following reasons: a) simplifications usually used in these models cannot appropriately capture important aspects to evaluate, including various metrics obtained through simulation, b) most models assume Poisson traffic sources, thus making exactly modelling other traffics difficult, c) greater flexibility in configuring and comparing different evaluation scenarios is possible with appropriate simulators.
For more realistic scenarios, several simulation analyses have been made using tools like Network Simulator (NS-2) [6], OPNET [7], or IP TRAFFIC [8]. All of these tools are especially appropriate for analysing the performance of communication networks. However, in some of them it is not practical for use in the sort of tests that are intended to make, and difficult to implement any type of light modification to protocols or the network's timing characteristics.

Few papers are available in the literature or research studies that use Stochastic Petri Nets (SPNs) [9] as a modelling formalism for analysing IEEE 802.11

* The work of J. Campos has been supported by the project TIN2011-24932 of the Spanish Ministry of Economy and Competitivity.

1550-445X/13 $26.00 © 2013 IEEE
DOI 10.1109/AINA.2013.20

communication protocols. Although early models have made important contributions from a modelling standpoint, their implementation in most SPN tools either suffers from limitations or entails overcoming significant difficulties in characterising more complex simulation scenarios. The replication is essential in evaluating scenarios comprising similar stations with a mix of different traffic types or when varying the proportional relationships of traffic in the presence of noise.

A base model [10] is thus adopted using HSANs [11], which closely follows the EDCA IEEE 802.11e standard and is executed on the Möbius simulator [12]. To the best knowledge of the authors, this report describes the first EDCA implementation using SPNs. These resources rectify the observations discussed above and facilitate a precise study of QoS in Wi-Fi networks.

The principal contributions of this article are i) to specify a new research methodology that simulates Wi-Fi dynamics using different experimental scenarios with conclusive quantitative results concerning its impact over a WLAN 802.11e network with QoS configured using default static parameters, ii) to specify and experiment on variants of known scenarios, as well a new scenario offering metrics evaluation while maintaining a relative proportion for network traffic, iii) to demonstrate that the standard EDCA IEEE 802.11e mechanism using default static parameters provides traffic differentiation but does not on its own assure the desired QoS for supporting multimedia data traffic dynamics in real time and automatic control in next-generation administrative and industrial environments, and iv) the contributions and conclusions made using an EDCA model with either SPNs that complement, enrich, and facilitate comparison with precedents within Wi-Fi network knowledge obtained from pure trace collection or other types of analytical studies and modelling using mathematical tools for different real and hypothetical contexts.

The rest of this document is structured as follows. Section II provides a general view of the EDCA 802.11e standard. Section III presents the wireless station model built with HSANs and simulation scenarios defined for experimental evaluation. Section IV presents the configuration values for experiment scenarios and gives the results for EDCA behaviour on these values. Section V summarizes the most significant conclusions and directions for future work.

II. Brief Description of EDCA 802.11e

Wherever DCF (802.11 Distributed Coordination Function) provides only a best effort type of service [1]. Time-limited multimedia applications (e.g., voice over IP, video conferences) require certain guarantees for bandwidth, delay, and jitter. With DCF, all stations compete for a channel with the same priority; there is no differentiation mechanism to provide better service for real-time multimedia traffic than for data applications.

The QoS limitations in DCF have inspired many research efforts to improve MAC performance. For 802.11e, a new function has been proposed for MAC layer, known as Hybrid Coordination Function (HCF) (Figure 1). HCF uses a contention-based channel access method, also known as Enhanced Distributed Channel Access (EDCA), which operates concurrently with a polling-based, HCF-controlled channel access method (HCCA). The access point (AP) and the stations (STAs) using QoS facilities are called QoS-enhanced AP (QAP) and QoS-enhanced STAs (QSTAs), respectively.

The optimization process of QoS of EDCA is based on a generalization of contention-based DCF. Initially heterogeneous traffic reaches the MAC layer including voice, video, best effort, background and they are mapped to the corresponding Access Categories (ACs). In the MAC layer there are 4 queues, one for each AC, which receive the packets according to a specific priority of upper layer. Each AC acts as a separate DCF entity competing according to its own contention parameters (CWmin[AC], CWmax[AC], AIFS[AC] and TXOPLimit[AC]). Each AC maintains a contention window size variable (CW), which is initialized to CWmin. The CW is incremented after transmission failures until it reaches CWmax, and is reset to CWmin after a successful transmission. The maximum allowed duration for each acquired transmission opportunity is determined by TXOP limit. Once a station acquires a transmission opportunity, it may transmit multiple frames within the assigned TXOP limit. Assigning different TXOP values to ACs, therefore, achieves differential airtime allocations. To achieve differentiation in EDCA, instead of using fixed DIFS (Distributed Interframe Space) as in the DCF, an AIFS (arbitrary IFS) is applied (Figure 2), where the AIFS for a given AC is determined by the following equation:

$$AIFS[AC] = SIFS + AIFSN[AC] * SlotTime$$

where AIFSN is AIFS number and determined by the AC and physical settings, and SlotTime is the duration of a time slot [1], and SIFS is the Short Inter-Frame Space of DCF. The highest priority will be given to the AC with the smallest AIFS.

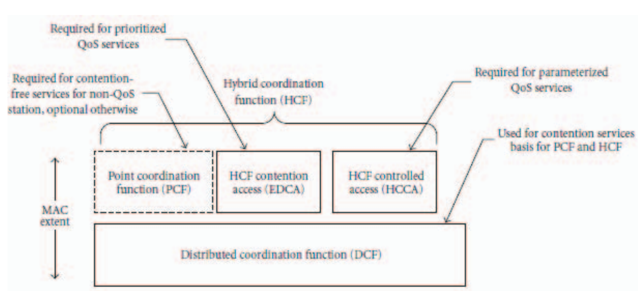

Figura 1. MAC architecture of 802.11e (IEEE Std 802.11 2007).

In general, smaller values of CWmin[AC], CWmax[AC], AIFS[AC], shorter delays of channel access to the corresponding AC, and the higher the priority for access to the medium. And to larger values of TXOP[AC], more time to retain the channel corresponding to the AC.

A contention-based mechanism for admission control is also suggested for 802.11e, which calls for both QAP and QSTA support.

III. Model and Simulation Scenarios

To experimentally evaluate the function of the EDCA 802.11e mechanism, a simulation model is adopted that uses Hierarchical Stochastic Activity Networks (HSAN) executed on a Möbius simulator. HSANs are a variety of Stochastic Petri Nets (SPNs). This model comprises a precise and detailed EDCA implementation function associated with QoS stations, considering both functional and temporal perspectives. Several international authors have sufficiently validated the model in the literature [10,13-16].

The adopted model represents a simple QoS-supporting station. This model is replicated to obtain the required simulation scenario. The user parameterises the number of replications, which the Möbius modelling tool completely automates. This tool provides significant flexibility in the evaluation process, including a faster analysis of different network scenarios.

Moreover, the station model includes an error submodel, which is a variation of the Gilbert-Elliot error model [17]. An average bit error rate (BER) of 10^{-4} was used as was the steady state probability of encountering the channel in interference at 13.3%.

Two simulation scenarios are proposed. These scenarios consider the behaviour of the highest access categories (voice and video) in the EDCA mechanism when these categories interact with each other in the presence or absence of best effort traffic sources or when the relative proportion of stations belonging to different types of network traffic changes.

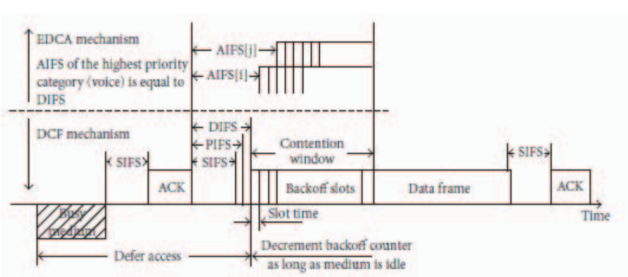

Figura 2. IFS in DCF and EDCA (IEEE Std 802.11 2007)

Scenario 1 considers traffic generated by stations operating on the same frequency bands while varying the load by increasing the number of active stations from 1 to 20, as in Figure 3.

Different situations are established in this scenario, according to the type of traffic injected by stations: a) Stations with all traffic flows present (voice, video, and best effort), b) Stations without voice traffic, c) Stations without video traffic, and d) Stations without best effort traffic.

Scenario 2 considers only one type of traffic generated by each station, varying the load by increasing the number of active stations from 5 to 45 but maintaining their relative proportion, as in Figure 4. This scenario is novel (to the best of our knowledge, it has not yet been analysed), and it amounts to a view that is closer to a realistic situation.

Different situations are posed within this scenario according to the proportion of traffic injected by stations: a) 60% voice stations, 20% video, and 20% best effort, b) 20% voice stations, 60% video, and 20% best effort, and c) 20% voice stations, 20% video, and 60% best effort.

All experimental simulations are obtained using the previously described EDCA model with a confidence interval of 95% and a precision of 5%.

Measured performance metrics are absolute throughput relative throughput, packet loss, average delay of queue, and average queue size. For brevity will be discussed only the results of relative throughput of traffic.

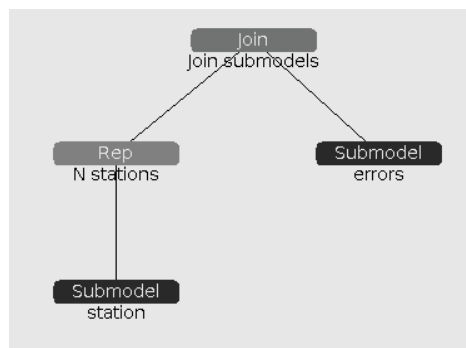

Figure 3. Representation of Scenario 1 using the Möbius tool.

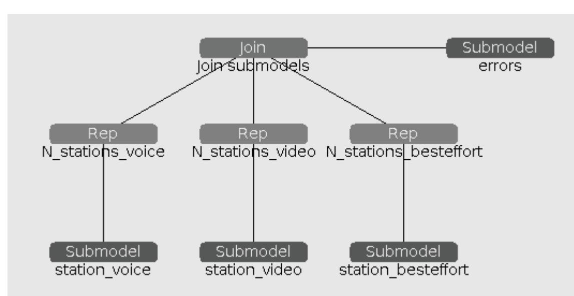

Figure 4. Representation of Scenario 2 using the Möbius tool.

IV. CONFIGURING AND EXPERIMENTING ON SIMULATION SCENARIOS

Our analysis used general 802.11a parameters at 36 Mbps and default EDCA configuration [18]. Stations were configured according to the scenario for the transmission of one, two, or three different traffic types: an isochronic voice steam with fixed periods of 20 ms, a video stream with Poisson distribution, and a best effort stream with Pareto distribution [19] and 1.9 shape parameter (with average throughput equivalent to the Poisson distribution). Tables 1 and 2 show all parameters and configuration values.

A. Experimental scenario 1

To analyze the Scenario 1, graphics for the average values obtained for direct and relative throughput for each traffic type are shown, superimposing the cases where all traffic types are present or when one is absent.

The Figure 5 show the voice traffic cases. Relative throughput stands out with a loss of 11.48% at 20 stations with no video traffic, but it falls to 28.06% and 27.39% when all traffic types are present or when there is no best effort traffic, respectively.

Video response cases have been superimposed in the Figures 6. This Figure shows relative throughput with a loss of 0.41% with 20 stations when there is no voice traffic, but it falls to 19.01% and 17.38% when all traffic types are present or when there is no best effort traffic, respectively.

TABLE I
CONJUNTO DE PARÁMETROS DCF Y EDCA POR DEFECTO

Parameters		CWmin	CWmax	DIFS/AIFSN
DCF		aCWmin	aCWmax	2
EDCA	AC_BK	aCWmin	aCWmax	7
	AC_BE	aCWmin	aCWmax	3
	AC_VI	(aCWmin+1)/2-1	aCWmin	2
	AC_VO	(aCWmin+1)/4-1	(aCWmin+1)/2-1	2

TABLE II
PARÁMETROS 802.11 A EN 36 MBS Y EDCA POR DEFECTO UTILIZADOS EN LA EXPERIMENTACIÓN

	Voice	Video	Best Effort
AIFSN	2	2	3
CW min	3	7	15
CW max	7	15	1023
TXOP	1504 ms	3008 ms	--
Paquet	160 bytes	1280 bytes	1500 bytes
Rate	64 Kbps	640 Kbps	1024 Kbps
Rate 803.11a		36 Mbps	
aSIFSTime		16 µs	
aSlotTime		9 µs	
ACCATime		4 µs	
aAirPropagationTime		1 µs	
aRxTxTuranroundTime		2 µs	
aPreambleLenght		16 µs	
aPLCPHeaderLenght		4 µs	
Maximum size of queue		50	
Nº max retries		7	
BERaverage		1.10^{-4}	

Finally, response cases for best effort traffic have been superimposed in the Figures 7. It highlights that the relative throughput of best effort has a loss of 33.75 % on the station 20, when there is no video traffic, but drops 99% and a 68.70 % when are all traffic present or there is no voice traffic, respectively.

Simulation analysis for this scenario shows the following facts: i) the growing number of stations in the network domain strongly influences traffic behaviour; ii) an undesired effect is observed for voice and video throughput in applications with strict requirements; iii) lower-priority best effort traffic is noticeably affected after 10 stations, to the benefit of other traffic types. The drastic fall in best effort performance occurs at approximately the same point, which is common for all traffic types, similar to what would be observed if the scenario ran on DCF.

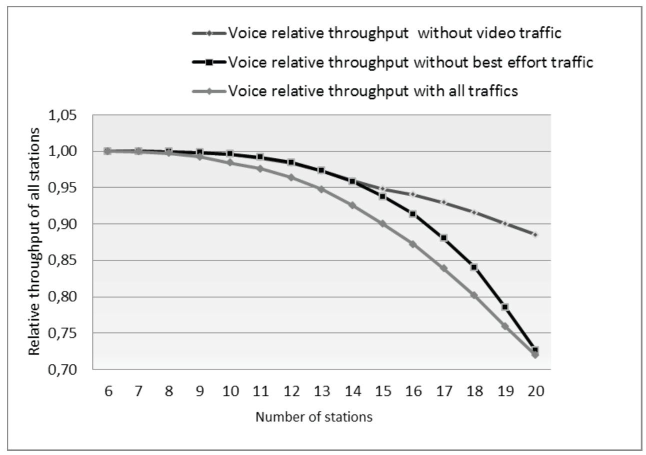

Figure 5. Relative throughput of voice traffic

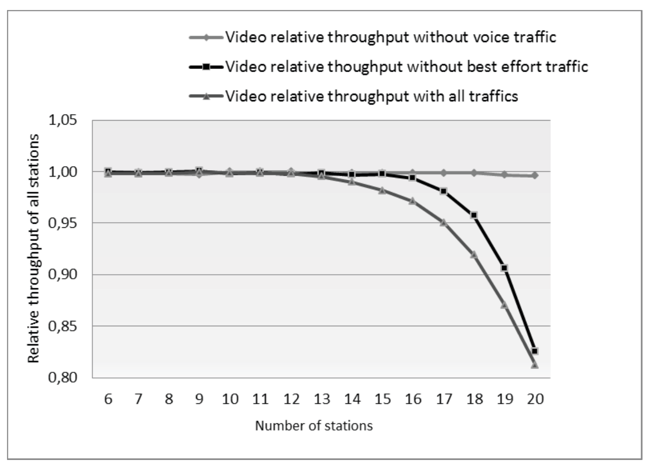

Figure 6. Relative throughput of video traffic

Can be summarized that the variation in the loss of relative throughput to 20 stations of the traffics of voice and video is of the order of 20 %, and for best effort traffic of the order of 65 %, depending on the scenario that is concerned.

B. Experimental scenario 2

The Figure 8 shows the average values obtained for relative voice traffic throughput while varying the load from 5 to 45 stations. Different situations have been superimposed on comparative analysis effects, according to the proportion of traffic injected by stations. These are a) 60% voice stations, 20% video, and 20% best effort, b) 20% voice stations, 60% video, and 20% best effort, and c) 20% voice stations, 20% video, and 60% best effort.

The Figure shows that relative throughput has a loss of 26.31% with 45 stations when there is a higher proportion of voice stations. The loss is 24.45% and only 1.76% when there is a greater proportion of video or best effort stations, respectively.

The Figure 9 shows the average values obtained for relative video traffic throughput. In the Figure, the relative video throughput drops to 15.15% at 45 stations when there is a greater proportion of video stations. The loss is 1.21% and only 0.38% when there is a greater proportion of voice or best effort stations, respectively.

Average values obtained for relative throughput of best effort traffic, varying the load from 5 to 45 stations, are shown in Figures 10 for a comparative analysis according to the type of traffic injected by stations. This Figure shows that the relative throughput for best effort has a near-100% loss at 45 stations when there is a higher proportion of video stations. The loss drops to 62.45% and 27.72% when there is a greater proportion of best effort or voice stations, respectively.

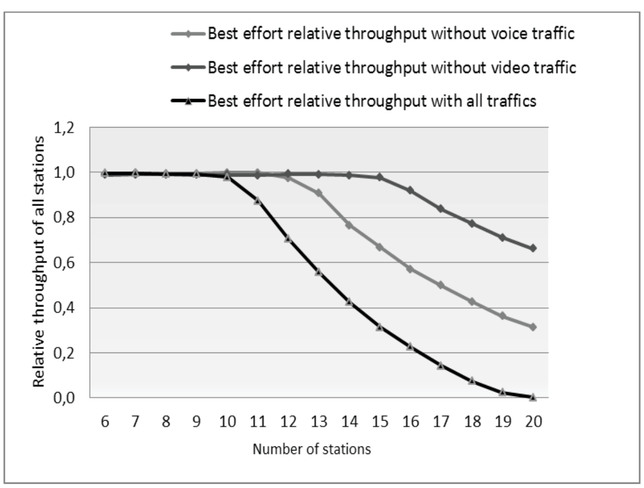

Figure 7. Relative throughput of best effort traffic

In this scenario, EDCA provides the desired service differentiation between different traffic types, favouring higher-priority traffics. As in Scenario 1, show the impacts of different relative traffic proportions. In this case the variation in the loss of relative throughput to 20 stations of the voice traffic is of the order of 25 %, and for best effort traffic of the order of 65 %, depending on the scenario that is concerned. The lower variation of relative troughput is for video traffic with 15 %.

V. CONCLUSION AND FUTURE DIRECTIONS

This study used simulation model variants built with HSANs to evaluate EDCA 802.11e protocol conditions for supporting QoS in 802.11a scenarios at 36 Mbps.

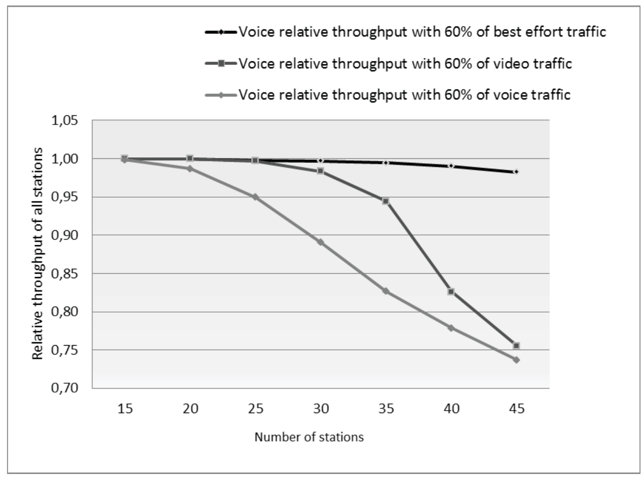

Figure 8. Relative througput of voice traffic

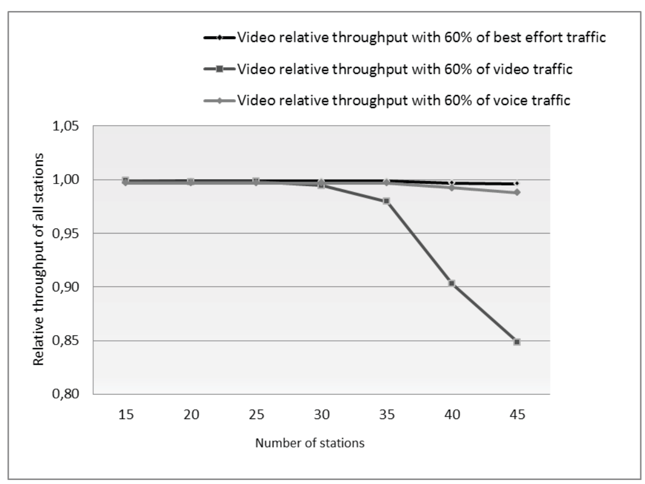

Figure 9. Relative throughput of video traffic

Scenarios included diverse traffic, electromagnetic interferences, and static default parameters for AIFSN, CWmin, CWmax, and TXOP. Simulation scenarios considered traffic interactions with different priorities.

In this context and for all proposed scenarios (including the novel experience of modifying traffic proportions), the relative throughput was exhaustively analysed.

We presented a detailed quantitative study, where the variation in relative proportion of different traffic types in wireless nodes with QoS had a differential effect on the WLAN network behaviour and general state. The state of the Wi-Fi network with QoS was essentially a dynamic one, where the values of different metrics for each traffic type and the network as a whole depended on the characteristics of existing traffic types.

New approaches must therefore be proposed that help the EDCA 802.11e mechanism support these multimedia and real-time communications while satisfying QoS restrictions for such high-priority traffic. These proposals should consider searching for parameters that optimise default configuration metrics while dynamically assuring the desired QoS conditions for current high-priority traffics, even under near-saturation conditions.

We foresee future studies offering a quantitative EDCA behaviour evaluation at different 802.11 physical layers. S tudies would precisely determine the best general network behaviour for higher Wi-Fi velocities. These study aspects could be linked to a proposal for a self-tuning algorithm and selecting appropriate analytical models for the station-admission process. Finally, a new line of study could be developed regarding the impact of queue length on maximum throughput for each context.

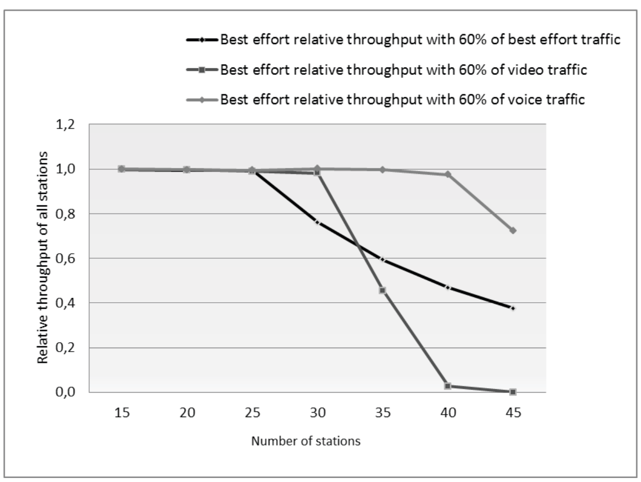

Figure 10. Relative throughput of best effort traffic

REFERENCES

[1] ANSI/IEEE Std 802.11, 1999 Edition (R2007), 2007.

[2] W. Hsu, A.Helmy, On nodal encounter patterns in Wireless LAN traces, Second International Workshop On Wireless Network Measurement, 2006.

[3] M. Papadopouli, H. Shen, M. Spankis, Characterizing the duration and association patterns of Wireless access in a campus, 11º European Wireless Conferences 2005, Nicosia, Cyprus, 2005.

[4] CRAWDAD project (Community Resource for Archiving Wireless Data At Dartmouth), <http://au.crawdad.org/>, (Accessed June 26th, 2012).

[5] N. Chendeb Taher, Yacine Ghamri-Doudane, Bachar El Hassan y Nazim Agoulmine, “An Accurate Analytical Model for 802.11e EDCA under Different Traffic Conditions with Contention-Free Bursting”, Hindawi Publishing Corporation, Journal of Computer Networks and Communications, Volume 2011, Article ID 136585, 24 page, March 2011.

[6] NS-2 network simulator - version 2.35, Available at <http://nsnam.isi.edu/nsnam/index.php/User_Information>, 2012, (Accessed June 26th, 2012).

[7] O. Tech. OPNET, Available at: <http://www.opnet.com>, 2012, (Accessed June 26th, 2012).

[8] IP Traffic, ZTI, Available at <http://www.zti-telecom.com>,2012, (Accessed June 26th, 2012).

[9] M. Ajmone Marsan, G. Balbo, G. Conte, S. Donatelli, G. Franceschinis. Modelling with generalized stochastic Petri Nets. J. Wiley, 1995.

[10] R. Moraes, P. Portugal and F. Vasques, A stochastic Petri net model for the simulation analysis of the IEEE 802.11e EDCA Communication Protocol, In Proceedings of the 11th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA), Prague, Czech Republic, pp. 38-45, September 20-22, 2006 - <http://paginas.fe.up.pt/~vasques/ieee80211e/>, (Accessed June 26th, 2012).

[11] M. Abdollahi Azgomi, A. Movaghar 2004, A modelling tool for hierarchical stochastic activity networks, Proc. of 11th Int. Conf. on Analytical and Stochastic Modelling Tech. and App. (ASMTA04), Magdeburg, Germany (2004) Pp141-146.

[12] W. H. Sanders et al., Model-based environment for validation of system reliability, availability, security, and performance, <https://www.mobius.illinois.edu/>, May 5th, 2012 (Accessed June 26th, 2012).

[13] S. Mangold, C. Sunghyun, O. Klein, G. Hiertz, L. Stibor, IEEE 802.11 wireless LAN for quality of service, European Wireless 2002, vol. 1, pp. 32–39, 2002.

[14] S. Wiethoelter, C. Hoene, Design and verification of an IEEE 802.11e EDCF simulation model in NS-2.26 (TKN-03-19), Technical University Berlin - Telecommunication Networks Group, Tech. Rep., 2003.

[15] S. Wiethoelter, M. Emmelmann, C. Hoene, A. Wolisz, TKN EDCA model for NS-2 (TKN-06-003),Technical University of Berlin - Telecommunication Networks Group, Tech. Rep., 2006.

[16] S. Pérez, Tuning mechanism of EDCA parameters: Algorithm MTDA, Thesis PhD Engineering, Universidad de Mendoza, Mendoza, Argentina, <http://www.um.edu.ar>, (Accessed June 26th, 2012), “unpublished”, 2012,

[17] A. Willig, A. Wolisz, Ring stability of the PROFIBUS tokenpassing protocol over error-prone links, IEEE Transactions on Industrial Electronics, vol. 48, no. 5, pp. 1025 – 1033, 2001.

[18] Q. Ni, Performance analysis and enhancements for IEEE 802.11e wireless networks, IEEE Network 19 (4) (2005) 21–27.

[19] S. Pérez, H. Facchini, G. Mercado, L. Bisaro, Estudio sobre la Distribución de Tráfico Autosimilar en Redes Wi-Fi, XVIII CACIC 2012, Congreso Argentino de la Computación 2012, <http://cs.uns.edu.ar/cacic2012>, <http:/latys.griditics.frm.utn.edu.ar>, (Accessed June 26th, 2012).