An - Najah Univ. J. Res. (N. Sc.) Vol. 28, 2014

Comparative Analysis to Evaluate FQ-EDCA in Wireless Ad-Hoc Networks

تقييم وتحليل (FQ-EDCA) في الشبكات اللاسلكية

Hanal Abuzant

هنال أبو زنط

Department of Computer Engineering, An-Najah National University, Nablus, Palestine

Email: hhanal@najah.edu

Recived: (7/4/2013), Accepted: (26/1/2014)

Abstract

The QoS in wireless ad-hoc networks as defined by the standard IEEE802.11e (EDCA): functions so as to guarantee the high priority traffic (i.e. Multimedia and Real-time traffics). The QoS is managed in each station by differentiating the packets into categories depending on their priorities. These packets will access the channel with varying waiting times. However, EDCA cannot control traffic when there is a congestion to guarantee the QoS required by real-time and multimedia applications, specially when the problem of the hidden nodes exists. Thereby, the ill-behaved sources consume the majority of the available bandwidth. This leads some of the source nodes (i.e. Out of range nodes) to suffer from the lack of bandwidth and unfairness. So, without a proper control mechanism, this leads to degrading the QoS guarantees. To address this issue, we have proposed (FQ-EDCA): a Fairness Queuing model for EDCA. This paper aims to evaluate the scalability of FQ-EDCA and its network performance to have more end-to-end QoS guarantees.

Keywords: ad-hoc; QoS; Fairness; Hierarchical; Scheduling.

ملخص

البروتوكول القياسي الذي يشير الى جودة الخدمة المخصصة في الشبكات اللاسلكية هو (EDCA) IEEE802.11e. هذا البروتوكول يستخدم لضمان حركة مرور البيانات ذات الأولوية العالية (أي بيانات الوقت الحقيقي والوسائط المتعددة مثل الصوت والفيديو). علاوة على ذلك، تتم إدارة جودة الخدمة في كل محطة ارسال من تمييز الحزم المرسلة الى فئات تبعا لأولوياتها. بعد ذلك، هذه الحزم ستوزع اثناء ارسالها إلى قنوات مختلفة حسب وقت انتظارها ليتم ارسالها. ومع ذلك، لايمكن ل EDCA مراقبة حركة البيانات عندما يكون هناك ازدحام وضغط على الشبكة اللاسلكية. مما سيؤثرعلى ضمان جودة الخدمة المطلوبة من قبل تطبيقات الوقت الحقيقي والوسائط المتعددة، وخاصة عندما تكون مشكلة المحطات المخفية (البعيدة) موجودة. وبالتالي، فإن سوء تصرف حجز الشبكة واستهلاك عرض النطاق الترددي المسموح به يؤدي إلى بعض المحطات سيعانون من عدم وجود عرض النطاق الترددي لارسال البيانات. لذلك، من دون آلية الرقابة السليمة يؤدي إلى تدهور ضمانات جودة الخدمة .لذا، اقترحنا (FQ-EDCA). وهو نموذج جديد لتعديل قوائم الانتظار للبروتوكول المعلن بطريقة منصفة. يهدف هذا البحث إلى تقييم قابلية FQ-EDCA لحل المشاكل المعلنة و ضبط ضمان جودة الخدمة.

Introduction

The term Wireless Networks appeared in the last decades. It refers to the interconnection between the nodes (hosts) without wires using unlicensed radio waves, which makes wireless networks widely deployed.

This changing of networks from wires to wireless contributes many advantages such as: facilitating the construction of the networks and making them flexible, minimizing the budget of wiring and installations and interconnecting the mobile nodes.

As a consequence, the popularity of wireless local area networks (WLANs) based on the standard IEEE 802.11 [11] has increased, because the needs for wireless devices (e.g. Computer tablets, smart mobile phones, Sensors, Wireless stations, etc.) are rapidly increasing, while their prices are decreasing. Generally, this standard is applied for two modes; the infrastructure mode and the ad-hoc mode.

The infrastructure mode is a centralized wireless network that relies on access points (AP) or base stations. The AP is responsible for associating the wireless devices (i.e. stations or nodes) and administrating them. So, the communication between any two nodes must be coordinated through the AP.

On the other hand, Ad-hoc is a distributed and an autonomous wireless network that can be formed without the need of any infrastructure, centralized administration or centralized coordinator. This means that it does not need an AP. It is composed of identical wireless stations or nodes. Nodes communicate with each other in a peer-to-peer fashion through single-hop or multi-hop paths. Therefore, a node can route and forward the packets of others nodes. Nodes can cooperate among them to achieve the best connection between the sender and receiver.

However, some applications (e.g. Multimedia, real-time, etc.) need to transfer critical (time-sensitive) data in wireless networks. So, the Quality of Service (QoS) guarantees support communicating this type of data, because such data sometimes require strict services, which could not be provided by the legacy IEEE802.11 standard [11]. So, an extension of this standard is needed to support QoS.

As a consequence, an enhancement of that standard (IEEE802.11e) is developed to support QoS in both the infrastructure and ad-hoc modes [9]. So, this extension supports QoS for ad-hoc networks by introducing the Enhanced Distributed Channel Access (EDCA) that manages QoS in each node. Therefore, EDCA is implemented and applied to support services for multimedia and real-time traffic. EDCA differentiates and classifies the packets in Access Categories (AC) depending on their priorities.

It is important to note that QoS could be satisfied by the standard IEEE802.11e, specially in the infrastructure mode. Although the distributed EDCA is an important enhancement for the legacy IEEE 802.11 in ad-hoc networks, it is not enough to provide strict QoS guarantees and cannot control traffic when there is a congestion to guarantee QoS required by real-time and multimedia services. There are crucial problems (i.e. hidden and exposed terminals) that need solutions, as explained in [18]. Therefore, the ill-behaved source nodes consume the majority of the allowed bandwidth. This leads some of source nodes to suffer from the lack of bandwidth and unfairness. As a result, a bottleneck or a state of starvation occurs for these nodes that degrades the QoS guarantee. So, if the traffic is properly regulated, the IEEE802.11e is capable of supporting QoS requirements for the real-time and multimedia traffic. Therefore, IEEE802.11e needs proper network control mechanisms. This is further explained in [6].

Moreover, the EDCA does not have any distributed admission control algorithm to distribute the bandwidth fairly. An enhancement of the EDCA can be used to provide fairness of resource allocation for source nodes by regulating their traffic and controlling their ill-behaved transmission. Which will optimize the QoS guarantees.

In this paper, we will first describe the QoS in ad-hoc wireless networks and notably the EDCA model (standard IEEE802.11e). After that, we will present FQ-EDCA network performance. Following that we present simulation results for the two models: EDCA and the proposed model FQ-EDCA. Comparative simulations of the two models will enable us to evaluate the real benefits of FQ-EDCA. These simulations will be performed with various scale topologies.

QoS in Wireless Network

The QoS term was first introduced within the development of wired networks. Many approaches and protocols are developed to optimize QoS in wired networks. Thereby, it is highly desirable to provide a level of services in wireless networks similar to those available from the conventional wired networks, because the market of wireless networks is growing rapidly and many applications applied in wireless networks require a level of services similar to those in wired networks.

The legacy IEEE 802.11 (DCF) [11] used in ad-hoc mode does not support real-time or multimedia application. Since, it is designed for equal priorities. There is no notion of high or low priority traffic and no differentiation. Also, a station node may keep the medium for as long as it needs. So, an enhancement of DCF (EDCA) [9] is implemented to support QoS.

However, EDCA still has the problems of transmission and access channel such as hidden and exposed terminals problems [12]. In [18], many proposals are presented to solve the last problems, but these solutions lead to new problems such as wasting bandwidth and channel utilization (spatial reuse).

Indeed, a great enhancement is achieved by the IEEE 802.11n [10], the recent IEEE 802.11aa [7] and the IEEE 802.11ac [8] standards. In general, the last standards enhance both the physical and the MAC layers in the infrastructure mode.

Many proposals for QoS enhancement in ad-hoc wireless networks mainly focus on station-based DCF enhancement scheme such as [1, 14, 5] or queue-based enhancement scheme such as [13, 16, 17, 19].

In [1] we have proposed F-EDCA (Fairness EDCA) to obtain a fairness solution by differentiating between routing nodes and non-routing nodes in EDCA. Also, In [3, 4, 2] we have proposed FQ-EDCA (Fairness Queuing EDCA) to obtain a fairness solution by queuing each source node's flows to its Access Category (AC). Thereby, supporting fairness leads to enhancing QoS guarantees in wireless networks.

The challenge for WLAN and notably ad-hoc network is to be able to apply a FQ-EDCA like techniques at the MAC layer that gives an end-to-end QoS.

So, comparative analysis is needed to evaluate FQ-EDCA and its network performance, as we will see in the next sections.

FQ-EDCA, definitions and problematic

FQ-EDCA [2] aims to develop and optimize the Quality of Service (QoS) with fairness in multi-hop wireless ad-hoc networks. The development of the wireless networks is crucial to transfer critical traffic (e.g. Multimedia, real-time, etc.). In the presence of congestion, the traffic sometimes could not obtain the required services.

In addition, another problem could appear frequently that an ill-behaved transmission of a source node lead to a lack of resource distribution and unfairness, because it could consume the majority of bandwidth and affect the performance of many other nodes.

FQ-EDCA is evaluated and analyzed by experimental simulations for many topologies [2][3]. It has been shown in this evaluation that when utilizing FQ-EDCA, the bandwidth is distributed fairly between all the source nodes. As a consequence, these nodes can access the channel fairly to transmit their flows with respect to EDCA specifications of Access Categories (AC) priorities. And also, the flow delay of the same priorities is minimized and nearly fixed for all the source nodes. This leads to minimize the Jitter as well. Therefore, the service guarantees of QoS are enhanced.

Now we will present the FQ-EDCA evaluation in real network topologies and its network performance, in the following sections.

Network Performance of FQ-EDCA

The FQ-EDCA model has been developed and implemented using the network simulator (ns-2)[15] to study the throughput, average delay and fairness performance, and to compare them with the recent standards of wireless networks (i.e. the IEEE802.11e (EDCA)).

Before evaluating the network performance of our model, we will define the performance metrics.

Performance Metrics

Several metrics can be defined to grade the performance of our model (FQ-EDCA) against the recent standards (IEEE802.11e) in ad-hoc wireless networking for QoS (EDCA). Therefore, some of these metrics have been carefully chosen to give an idea of the behavior and the reliability of FQ-EDCA in ad-hoc wireless networks.

However, these metrics measure the data transmission's features with respect to data packets. As a consequence, the analysis focuses on the benefits obtained by FQ-EDCA compared with other models. An explanation of these metrics follows:

Network Throughput

It is a measure of the amount of data (Bytes) transmitted from the source to the destination in a unit period of time (seconds). Considering the data rates and throughputs supported by IEEE802.11 standard, the throughput is measured in total bits received per second. Also to be noted is that this metric only measures the total data throughput over the network.

The throughput of a node is measured by first counting the total number of data packets successfully received at the node, and computing the number of bits received, which is finally divided by the total simulation runtime.

The throughput of the network is finally defined as the average of the throughput of all nodes. Therefore, throughput can be stated as (1):

$$Throughput = \frac{Total\ Received\ Data}{Simulation\ time} \quad (1)$$

Similarly, the network throughput can be described as (2):

$$Network\ Throughput = \frac{\sum Throughput}{Nodes} \quad (2)$$

End-to-End Delay

The end-to-end delay is the time taken for a data packet to reach the destination node. The term "End-to-End" means from an end-point sender to an end-point receiver.

When the simulations are performed with a random topology, the destination, that has the maximum number of hops from the sender, receives data packet with maximum delay. Therefore, the delay can be stated as (3):

$$Delay = \underbrace{Received\ Time}_{atDestination} - \underbrace{Transmitted\ Time}_{atSource} \quad (3)$$

Moreover, the delay for a packet is the time taken for it to reach the destination. And the average delay is calculated by taking the average of delays for every data packet transmitted successfully. Thus, the average delay of the network can be stated as (4):

$$AvgDelay = \frac{\sum Delay}{Received\ Packets} \quad (4)$$

The delivery Ratio refers to the percentage of the transmitted data packets that are successfully received over all sent packets. However, it is an important metric, which can be used as an indicator to a congested network.

Another metric of the network performance is the energy consumption. However, in our studies this metric is neglected, because we focus our studies on the network performance for data transmission.

Now, we will analyze the performance of FQ-EDCA.

The performed simulations

To evaluate the performance of FQ-EDCA, we implement it in a real topology with different number of nodes and different data transmission rates. Thus, random topologies are applied for this evaluation.

Multiple topologies are applied for different number of nodes distributed randomly to achieve real benefits and make FQ-EDCA applicable in the real world. Also, these topologies are applied for two purpose. The first is for network performance measurements, and the second is for end-to-end performance measurements.

The simulations are performed for topologies (from 5 to 100 nodes). These nodes are enumerated from 0 to ($N-1$), where N is the number of nodes for each topology. Thereby, the number of source nodes equals ($N-1$) for each topology. Every source node sends its packets to a random destination with a constant baud-rate. Also, the simulations are repeated for different baud-rates, see Table 1. High baud-rates make the network overloaded which leads to a congestion in the network. Also, this leads to increasing the ill-behaved sources which consume most of the network resources.

All the nodes are distributed randomly except 2 nodes, which are enumerated with 0 and $(N-1)$. These nodes are considered as the end-points, marked as receiving end-point and sending end-point, as an example of 100 nodes distributed randomly, see Figure 4.2. This distribution is made intentionally to obtain the end-to-end measurements. These measurements are essential for end-to-end QoS comparison.

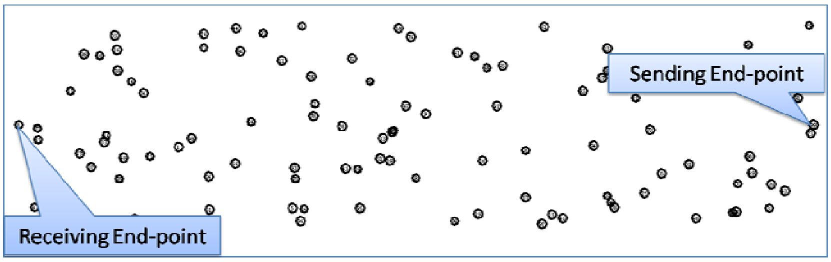

Figure (4.2): A random topology of 100 nodes.

The parameters of the performed simulations are stated in Table 1. These simulations are applied with the same parameters for both EDCA and FQ-EDCA, to compare their results.

Table (1): The parameters of performed simulations.

Standards	IEEE802.11b/e
QoS	EDCA & FQ-EDCA
Topology mode	ad-hoc
Routing protocol	DSDV
Source nodes	$5-100$
Type of flows	CBR/UDP
Transmission range	$250m$
Carrier sense range	$550m$
Packet size	$512bytes$
Packet baud-rate	$10-100kbps$
Bandwidth	$1Mbps$

The Results

After the simulations, many measurements are obtained to analyze the performance of FQ-EDCA and compare it with EDCA. the results are obtained as follows:

Network Throughput

As seen in Figure 4.3.1,which describes the general state of the network traffic. The Network throughput is increased when increasing the baud-rate until the source nodes consume most of the resource network. It is also clear that when the number of nodes is high the network throughput is minimized, because the number of collisions and retransmissions are increased. Thus, for large number of source nodes with heavy load, this degrades the network throughput.

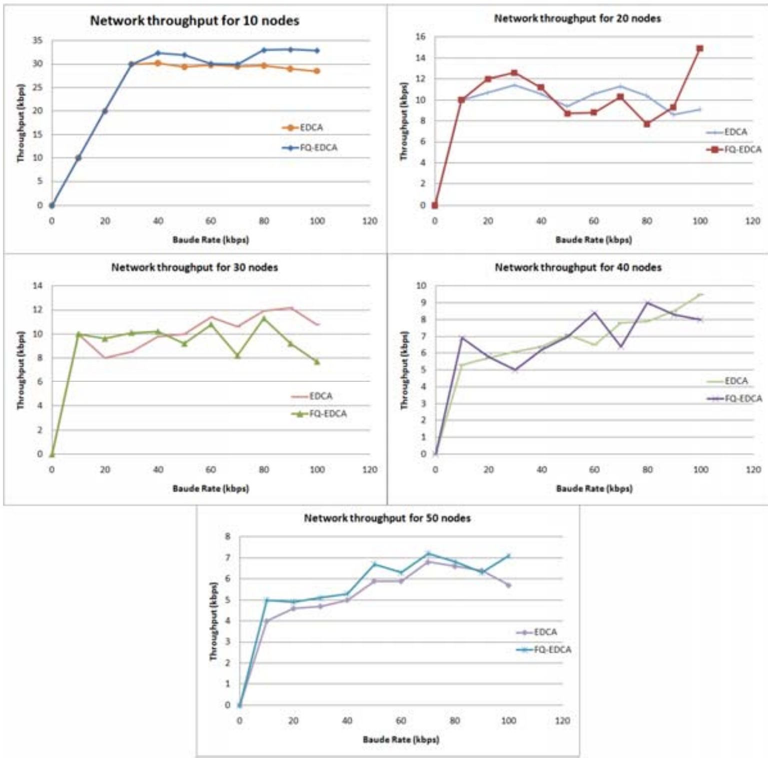

Figure (4.3.1): The network throughput of EDCA and FQ-EDCA.

On the other hand, as seen in Figure 4.3.1, we remark that, in FQ-EDCA, the Network throughput is increased when increasing the baud-rate until the source nodes consume most of the resource network. It is also clear that FQ-EDCA enhances the network throughput of EDCA specially for small number of source nodes. Also, this enhancement is minimized for increasing the number of source nodes, because the number of collisions and retransmissions is still high.

Moreover, in network throughput calculations, it does not take into account differentiating between the routing and owned packets, and the fairness. Therefrom, the main enhancement of FQ-EDCA is to apply fairness.

In addition, in FQ-EDCA, almost all the source node have the chance to send their packets while $(30-50\%)$ of source nodes are dead nodes in EDCA, specially for large number of source nodes and high baud-rate. Thus, the source nodes of one-hop destinations have the most of resource allocations than the source nodes of multi-hop.

Indeed, in general for both FQ-EDCA and EDCA, they have the same phenomenon. That means, the complexity of FQ-EDCA is still like EDCA with taking into account the enhancement that we will obtain.

Now we us present the End-to-end network performance.

End-to-end Throughput

The end-to-end throughput is an important metric of the network performance and QoS, which can describe the end-to-end throughput for the longest path traffic.

Thus, as seen in Figure 4.4, we remark that in EDCA the end-to-end throughput is increased when increasing the baud-rate until the source nodes consume most of the resources of the network. Then, the end-to-end throughput is decreased, because of the lack of resources. It is also clear that when the number of nodes is high, the end-to-end throughput is minimized, because the number of collisions and retransmissions increases. Thus, for large number of source nodes with heavy load, the number of ill-behaved sources is increased. Therefore, this degrades the end-to-end throughput and results in fully depleting the throughput.

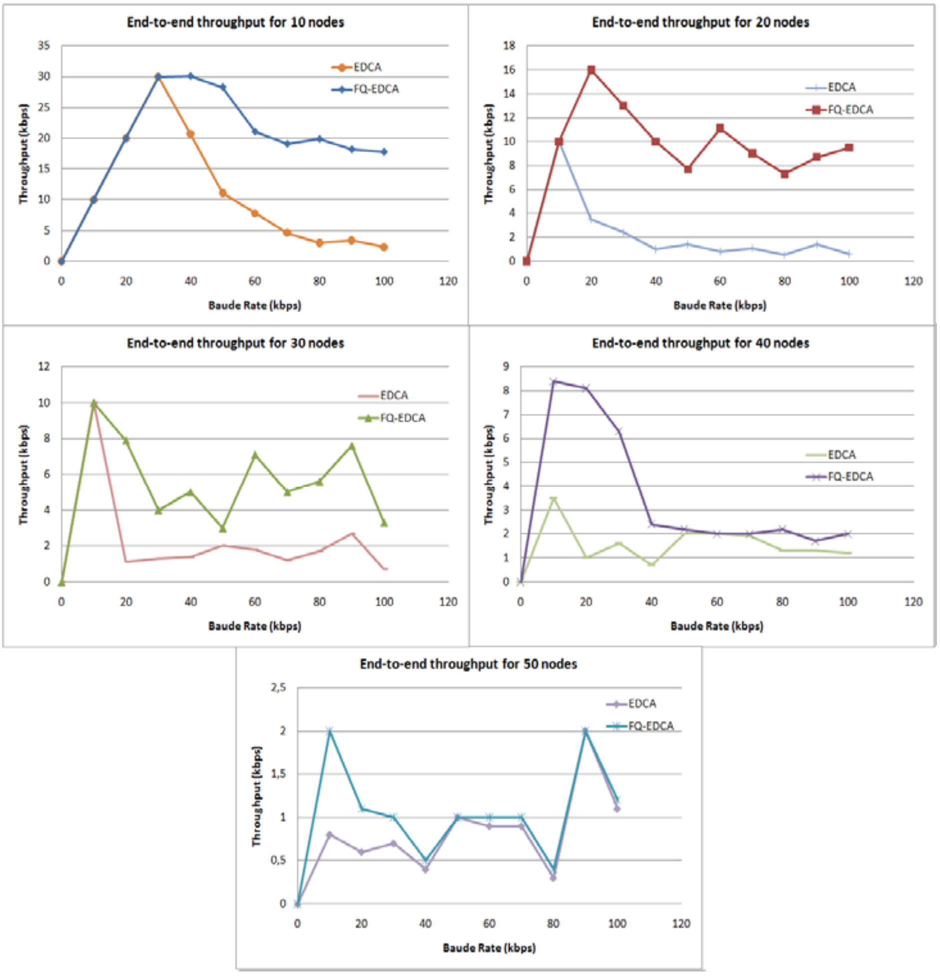

Figure (4.4): The end-to-end throughput in EDCA and FQ-EDCA.

While, in FQ-EDCA as seen in Figure 4.4, we remark that the end-to-end throughput is more stable and robust. This results in increasing QoS guarantee.

From the previous results, it is clear that FQ-EDCA enhances EDCA and the end-to-end throughput.

End-to-end Delay

The End-to-end delay is an important metric of the network performance and QoS, which can describe the worst case path delay.

Thus, as seen in Figure 4.5, as expected, we remark clearly that FQ-EDCA minimizes the end-to-end delay and enhances the QoS guarantee.

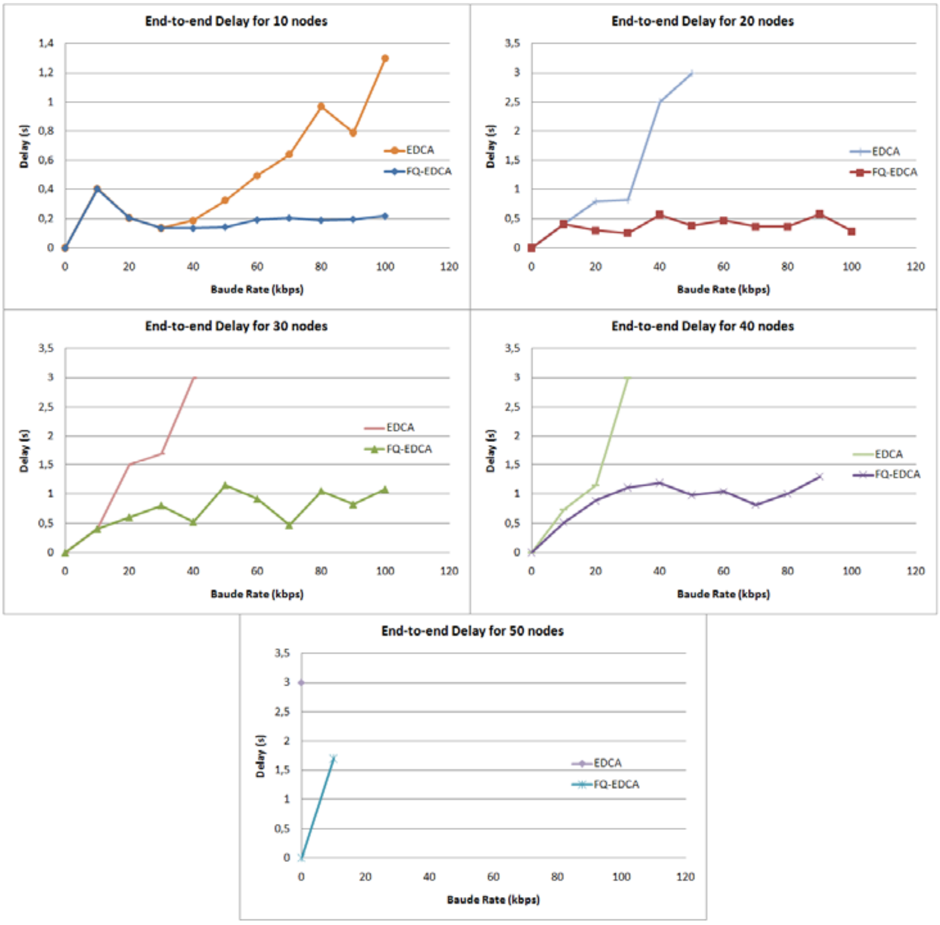

Figure (4.5): The end-to-end delay in EDCA and FQ-EDCA.

Also, it is clear that FQ-EDCA increases the end-to-end delivery ratio, which enhances the QoS guarantee.

Conclusion

We have shown that FQ-EDCA can guarantee the QoS better than EDCA, taking into account that it is as complex as EDCA. Thereby, FQ-EDCA solves most of the problems of EDCA, such as: Fairness of resource allocations, separating the ill-behaved sources, giving the multi-hop sources the chance to access the channel, etc.

FQ-EDCA is verified for simple, large and random topologies. FQ-EDCA is evaluated by comparing it with EDCA. As a result, FQ-EDCA is a robust, fair and controllable model, which has the ability for enhancing and optimizing the QoS in wireless networks.

Further more, analyzing the network performance, FQ-EDCA achieves more performance than EDCA, for Throughput, Delay and Delivery ratio. It is also a powerful model for end-to-end QoS.

Moreover, the end-to-end delay of packets that has the same priorities is bounded (i.e. for out-ranged source nodes). Therefore, the service guarantees of QoS is enhanced by FQ-EDCA, which has been proved by experimental simulations for large scale topologies.

It is imperative to note that EDCA has no control management applied to control the ill-behavior of source nodes (i.e. In-ranged). So, the Out-ranged sources suffer from the unfairness of resource allocations. on the other hand, FQ-EDCA has a robust and scalable treatment of the congestion.

Acknowledgment

A great thanks to my professor Armand Toguyeni, Dr. Benoit Trouillet and Dr. Samer Arandi.

References

[1] Abuzanat, H. Trouillet, B. & Toguyeni, A. (2008). "Routing Fairness Model for QoS Optimization in Wireless Network". Sensor Technologies and Applications. International Conference on. 0: 776–781.

[2] Abuzanat, H. Trouillet, B. & Toguyeni, A. (2009). "Fair Queuing Model for EDCA to Optimize QoS in Ad-Hoc Wireless Network". International Conference on Networking (ICN'09). 0:306–311.

[3] Abuzanat, H. Trouillet, B. & Toguyeni, A. (2009). FQ-EDCA: An Extension of EDCA to improve Fairness in Ad-hoc Wireless Network. International Conference on Computers & Industrial Engineering. Cie39. pages 1617–1622.

[4] Abuzanat, H. Trouillet, B. & Toguyeni, A. (2009). "Routage et équité pour améliorer la qualité de service des réseaux adhoc". e-STA. 6(3). 15–19.

[5] Bharghavan, V. Demers, A. Shenker, S. & Zhang, L. (1994). MACAW: A Media Access Protocol for Wireless LANs. ACM SIGCOMM. August.

[6] Chen, X. Zhai, H. Tian, X. & Fang, Y. (2006). Supporting QoS in IEEE 802.11e wireless LANs. IEEE Transactions on Wireless Communications. 5(8). 2217–2227. August

[7] IEEE802. 11aa. IEEE Standard for Information technology–Telecommunications and information exchange between systems Local and metropolitan area networks–Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 2: MAC Enhancements for Robust Audio Video Streaming. 2012.

[8] IEEE802. 11ac. IEEE Draft Standard for IT - Telecommunications and Information Exchange Between Systems - LAN/MAN - Specific Requirements - Part 11: Wireless LAN Medium Access Control and Physical Layer Specifications - Amd 4: Enhancements for Very High

Throughput for operation in bands below 6GHz. 2012.

[9] IEEE802. 11e. IEEE Standard for Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements. Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications. Amendment 8: Medium Access Control (MAC) Quality of Service Enhancements.

http://standards.ieee.org/getieee802/download/802.11e-2005.pdf. 2005.

[10] IEEE802. 11n-2009. IEEE Standard for Information technology– Local and metropolitan area networks– Specific requirements– Part 11: Wireless LAN Medium Access Control (MAC)and Physical Layer (PHY) Specifications Amendment 5: Enhancements for Higher Throughput. October 2009.

[11] IEEE802.11. IEEE Standard for Information Technology-telecommunications And Information exchange Between Systems-Local And Metropolitan Area Networks-specific Requirements-part 11: Wireless Lan Medium Access Control (MAC) And Physical Layer (PHY) Specifications. 1997.

[12] Kosek, K. Natkaniec, M. Vollero, L. & Pach, A. (2008). Performance Analysis of 802.11e Networks with Hidden Nodes in a Star Topology. Consumer Communications and Networking Conference. CCNC 2008. 5th IEEE. pages 440–441. Jan.

[13] Mangold, S. Choi, S. May, P. Klein, O. Hiertz, G. & Stibor, L. (2002). IEEE 802.11e Wireless LAN for Quality of Service. In European Wireless '02. February.

[14] Nait-Abdesselam, F. & Koubaa, H. (2003). RAMAC: Routing-aware Adaptive MAC in IEEE 802.11 Wireless Ad-Hoc Networks. In 8th International Conference on Cellular and Intelligent Communications. CIC'03. Seoul. Korea. Oct.

[15] NS2. Network Simulator 2. http://www.isi.edu/nsnam/ns/.

[16] Romdhani, L. Qiang, N. & Turletti, T. (2003). Adaptive EDCF: enhanced service differentiation for IEEE 802.11 wireless ad-hoc networks. Wireless Communications and Networking. 2003. WCNC 2003. 2003 IEEE. 2:1373–1378. March.

[17] Wiethölter, S. & Hoene, C. An IEEE 802.11e EDCA and CFB Simulation Model for ns-2. Telecommunication Networks Group (TKN). http://www.tkn.tu-berlin.de.

[18] Zhai, H. & Fang, Y. (2005). Medium access control protocols in mobile ad hoc networks: problems and solutions. In: Handbook on Theoretical and Algorithmic Aspects of Sensor. Ad Hoc Wireless and Peer-to-Peer Networks. edited by J. Wu. CRC Press. pages 231–250..

[19] Lei Zhang & Xuehui Wang. (2011). DCF Fairness Enhancement Algorithm for Multi-Hop Wireless Ad Hoc Networks. In International Conference on Wireless Communications. Networking and Mobile Computing. pages 1–4..