A Game Theory Based Dynamic Transmission Opportunity Adjustment in WLANs

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Abstract

IEEE 802.11e is standardized to enhance real-time multimedia applications' Quality of Service. This standard introduces four access categories for different types of applications. Each access category has four adjustable parameters: Arbitrary Inter-Frame Space Number, minimum Size of Contention Window, maximum size of Contention Window, and a Transmission Opportunity limit. A Transmission Opportunity limit is the time interval, in which a wireless station can transmit a number of frames consecutively, without releasing the channel and any further contention with other wireless stations. Transmission Opportunity improves network throughput as well as service differentiation. Proper Transmission Opportunity adjustment can lead to better bandwidth utilization and Quality of Service provisioning. This paper studies the dynamic adjustment of Transmission Opportunity in IEEE 802.11e using a game-theory based approach called Game Theory Based Dynamic Transmission Opportunity. Based on the proposed method, each wireless node chooses its appropriate Transmission Opportunity according to its queue length and media access delay. Simulation results indicate that the proposed approach improves channel utilization, while preserving efficiency in WLANs and minimizing selfishness behaviors of stations in a distributed environment.

Keywords: Transmission Opportunity (TXOP); Game Theory; WLAN, IEEE 802.11e; EDCA.

1. Introduction

The IEEE 802.11 standard supports only the best effort service, providing the same access probability to wireless media for all applications [1]. In practice, however, delay-sensitive traffic applications such as voice and video need to experience limited delays; therefore, IEEE 802.11e is standardized to improve Quality of Service (QoS) of real-time multimedia applications. This standard defines a medium access method called Hybrid Coordination Function (HCF) with two access mechanisms called Enhanced distributed channel access (EDCA) and HCF Controlled Channel Access (HCCA) [2]. The HCCA and EDCA are contention-free and contention-based channel access mechanisms, respectively. Each mechanism has four Access Categories (ACs) for different types of traffic. These ACs are known as voice (AC_VO), video (AC_VI), best-effort (AC_BE) and background (AC_BK). AC_VO and AC_VI have queues with the highest priorities, AC_BE has medium priority and AC_BK is the one with the lowest priority. Each AC in the EDCA mode which uses Carrier Sense Multiple Access (CSMA), has four adjustable parameters: Arbitrary Inter-Frame Space Number(AIFSN), the minimum Size of Contention Window(CWmin), the maximum size of Contention Window (CWmax), and TXOP_limit [3].

AIFS determines the time interval a wireless station should wait before the start of channel-access negotiation. Different AIFSs are assigned to each AC based on the AC to improve QoS differentiation. In case of unsuccessful access, a backoff procedure starts and the wireless station chooses a random value called backoff time, in the range of zero and CWmin. The CWmin is doubled each time a collision occurs until it achieves the CWmax. The AC with higher priority has a shorter CWmin. A short CW decreases the channel access delay but increases the collision probability. Eventually, TXOP_limit (TXOP) describes the maximum duration a wireless station can transmit and it is assigned per AC. The ACs can be prioritized by adjusting these four parameters. The major challenge is how to adjust these parameters dynamically in order to support the QoS of multimedia applications. Researches show that proper TXOP adjustment may significantly improve channel utilization and media access delay [4].

The main contribution of this paper is presenting a heuristic non-cooperative game to dynamic adjustment of TXOP. On the one hand, Game theory is a mathematical tool exploited to analyse the circumstances in which multiple participants (players) interact or affect each other. In other words, in game theory, a player's payoff is depended on not its decisions but also others' decisions.

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Besides, Game theory is a tool to investigate systems' behaviors as well as to optimize their performance in multi-agent environments. Although optimization theory cannot consider interactions between different players, game theory is a useful tool to study and analyse these interactions. Because of the competing nature of such an interaction, in order to make a decision, each player should analyse the effect of others' reactions and decide how to behave to gain the most benefit.

On the other hand, choosing a long TXOP by a station has negative effects on the neighbouring stations and the repetition of this action by the other stations may lead to violation of QoS requirements of the stations. Therefore, each station should consider the effect of its TXOP adjustment on the other stations and the overall network performance. Therefore, every long-sighted and rational station should consider the possibility of retaliation from the other stations in order to improve channel utilization along with providing proportional fairness [5] without any need to solve a global optimization problem.

Table 1. List of Acronyms and Abbreviations

AC	Access Category
AIFSN	Arbitrary Inter-Frame Space Number
ATXOP	Adaptive TXOP
CSMA/CA	Carrier Sense Multiple Access/Collision Avoidance
CW	Contention Window
CW_{max}	Maximum Contention Window
CW_{min}	Minimum Contention Window
DCF	Distributed Coordination Function
DIFS	Distributed Inter-Frame Space
EDCA	Enhanced Distributed Channel Access
GDTXOP	Game Theoretic Dynamic TXOP
GTXOP	Game Theoretic TXOP
HCCA	HCF Controlled Channel Access
HCF	Hybrid Coordination Function
MAC	Media Access Control
PCF	Point Coordination Function
QoS	Quality of Service
TXOP	Transmission Opportunity
WLANs	Wireless Local Area Networks

Although, TXOP tuning in terms of the number of stations using game theory is presented in [6], different types of traffic, including voice, video, and best effort as well as network load, mean data rate, maximum burst size, user priorities, delay bound, channel conditions, etc. have not been considered in that study. In our proposed game model, TXOP will be determined according to the station's traffic types, stations' load, and different delay bounds. The payoff function of [6] is defined based on analytical models. It includes some equations with complex solutions in order to achieve suitable TXOP for each transmission. Howeve, in the current study the payoff function is simple and requires little computing as well as no need to know the number of active stations. A list of abbreviations and acronyms used throughout the paper is given in Table 1.

Investigation of related work is given in Section 2. The proposed method and its evaluation are included in Section 3 and Section 4, respectively. Finally, the paper is concluded in Section 5.

2. Related Work

Studies show that TXOP adjustment may improve the channel utilization, performance and media access delay in IEEE 802.11e based WLANs, significantly [4]. The studies on dynamic TXOP can be divided into two main categories. The first category is dynamic TXOP determination in multiple-rate networks. Since there are different transmission rates, some approaches have been proposed to establish fairness. In the second category, by considering different characteristics of stations, such as arrival rate and type of traffic, some solutions have been proposed to improve the channel utilization.

In the first category, it is supposed that stations support multi-rate transmission, and the amount of transmitted frames in a specific period of time for a multi-rate network depends on the data transfer rate in that specific time period. Hence, in an IEEE 802.11e based multi-rate WLAN, a constant TXOP causes unfairness. In other words, in case of constant TXOP, the stations with higher data rates transmit more data than those with lower data rates. To fix this problem, some mechanisms are proposed to generate adaptive TXOPs, according to network conditions. For example, to ensure temporal fairness in multi-rate WLAN he studies in [6] have shown that equalization of channel access time results in granting an adapting throughput according to the data transmission rate of stations. Guo in [7] proposed Dynamic TXOP Assignment for Fairness, (DTAF) in order to keep fairness in multi-rate 802.11e networks. In DTAF, prior to transmission and based on the amount of collision, network traffic conditions are estimated, then the TXOP parameter is adjusted according to the load condition of the network. In [7], it is assumed that the network is in saturation condition and there are only three stations with various rates.

In [8] Adaptive TXOP (ATXOP) is proposed, in which longer TXOPs are allocated to those stations with lower data rates and vice versa. As a result, initially, the average transmission rate for each wireless station is calculated, and then the current transmission rate of each station is compared to the current rate. If the current rate is lower or higher than the average rate, the TXOP will be changed according to the ratio of the current rate to the average rate. Although the unfairness due to modification to the transmission rate is investigated in [8], TXOP allocation for different multimedia and data traffics is not analysed correctly. In addition, simulations indicate that this solution works well merely for small-sized packets and does not always lead to a better solution than the standard. Additionally, since this algorithm does not take into account the number of stations and the amount of contention in case of proliferation of stations and collisions, the efficiency of this method declines. Authors of [8], in [9], also entailed packet size in the calculation of new TXOPs and by doing so, have improved their former work in terms of fairness.

Nevertheless, with an increase in the number of stations and consequently in collisions, the performance degrades. In order to cope with the problem of performance decline due to channel faults. In [10] dynamic allocation of TXOP is proposed based on accurate predictions of channel conditions and allocating different TXOPs to different traffic. To cope with the unfairness problem due to different data rates, Yazdani et al. [11] proposed a mechanism for TXOP determination, which considers data rate, channel error rate, and data packet size to calculate adaptive TXOPs.

The main characteristic of multimedia traffic is that they are bursting and self-similar which indicates a frequent massive burst of frames. Hence, TXOPs must be adjusted according to traffic characteristics dynamically [12], so in the second group of studies, this issue is considered. In [12] each station adjusts its TXOP according to the state of its transmission queue. According to his approach, if a queue s not long enough and set to a limit, its TXOP is set to default values. In the case of the queue length exceeding the limit, the TXOP is reinforced by a new value, which is bigger than the default value (double of the default value). Simulations and numerical analysis indicate that the value of TXOP must be chosen according to buffer size [13-19]. Fang et al [20] have adjusted the value of TXOP through a Random Early Detection (RED) mechanism. They used queue length, which reflects the network load at the moment. The RED algorithm is a buffer management method in which the probability of packet loss increases in relation to the average queue size in a linear manner. Through this solution, traffic load conditions in QAP and stations are monitored. In the case of queue size, being less than the lower threshold (Tl) a smaller value is set for TXOP and if queue length exceeds this threshold, TXOP increases according to queue length in a linear manner. If queue length exceeds the high threshold level (Th), the maximum value for TXOP is used. This algorithm relies on improving QoS of video streams similar to [21].

In ETXOP [10], assuming that input traffic follows Poisson distribution, TXOP values is calculated based on the priority of ACs and its stream data rate whenever an AC wins the contention. Whenever a stream gets access to the channel, ETXOP algorithm reviews MAC queue and estimates the queue length and frame average size. Then, it calculates the most appropriate TXOP, which satisfies QoS requirements. In fact, the TXOP limit is determined based on the existing frames in the queues of AC2 and AC3. For AC0 and AC1, however, the default values of EDCA are used. ETXOP provides more flexibility by adapting network streams' QoS requirements, regardless of their individual bit rate.

In case of heavy traffic, by assigning long TXOPs to high priority ACs, low-priority traffics will suffer from starvation. Liu and Zhao [22], have allocated TXOP values in variable bit rate conditions. Their solution tunes TXOPs according to the size of incoming frames, variable-rate video prediction algorithms, and current queue length. TXOP is predicted as the total required time to transmit the next incoming frame and all the existing frames in the transmission queue as well as their ACKs. The main drawback of this solution is the comp0075tational complexity due to using a wavelet estimator for dynamic estimation of TXOP. Another dynamic TXOP allocation scheme [23] assigns the variable length of TXOP to different traffics based on the number of Service Data Units (SDUs) to be transmitted. It is claimed that this approach improves the packet delivery ratio, throughput, and end-to-end delay [23]. Al-Maqri et al [24] used piggybacked information about the size of the subsequent video frames of the uplink traffic to assign the TXOP according to the fast changes in the VBR profile. In [26], the TXOP dependency on the maximum number of VOIP calls in 802.11 networks is studied. In this approach, the highest priority is given to QAP by assigning longer TXOPs to it. However, this increase in TXOP causes a bottleneck to shift from QAP to stations, long waiting to access the channel and consequently causes long delays for stations. In addition, it has been shown that there is an optimum value for TXOP and voice capacity in WLANs. It will not be improved if values greater than TXOP higher band are used.

The impact of TXOP on video streams has been studied, and it is acknowledged that TXOP mechanism is not suitable for audio streams with a constant bit rate [25]. In [26], a QoS-capable mechanism is proposed to guarantee both inter-AC and intra-AC differentiations. In [26], each traffic class monitors the MAC queue and then based on the queue length, it calculates TXOP at runtime. An admission control function is also proposed to maintain accepted streams and network scalability. This method does not consider the frames, which are received during transmission. In [27], a distributed policy is presented in which each station measures its throughput in a temporal window and then compares its value to the target throughput and finally determines the TXOP based on the result of that comparison. In [28] the dynamic TXOP allocation scheme (DTAS) is presented. DTAS includes link lifetime estimation and dynamic TXOP allocation tasks, which dynamically allocate TXOPs to vehicles to enhance the efficiency of non-safety applications. It assigns TXOPs based on the number of competing providers, the number of packets to be transmitted and link lifetime between providers and their users. In addition, in order to improve the performance of TXOP scheduling and channel resource utilization, a game-theory-based optimization framework is proposed [29]. For every station according to the current channel capacity and transmission requirements of the stations, the optimal TXOP is determined. In another study [4], the authors proposed the Enhanced QoS with Q-Learning(EQQ) based on users' channel state estimations in order to enhance the QoS of multimedia services by adjusting TXOP and service interval(SI).

In IEEE 802.11 based Wireless mesh networks (WMNs), the fairness problem makes users in different locations of the WMN experience a different QoE and QoS [30]. Authors of [31] presented an approach to mitigate the unfairness problem in WMNs by tunning the TXOP at each intermediate node according to the number of flows served. A dynamic TXOP allocation approach based on a weighted fair queuing solution and average traffic rate of the ACs in WMNs is proposed in [32]. The approach improves fairness in wireless multi-hop networks.

Based on our knowledge, although a lot of researches from different points of view has been done to adjust TXOP dynamically, the impacts of choosing TXOP by a station on the other stations have been taken into account in only two works [6, 29]. At first, In [6] according to the number of stations in a network, a game-theoretic approach called GTXOP is proposed to determine TXOP dynamically. GTXOP is defined based on analytical models of EDCA. In GTXOP, each station can adjust its TXOP dynamically by taking the interaction between stations and impact of them on one another into account[6]. In addition, in order to improve the performance of TXOP scheduling and channel resource utilization, A game theory based optimization framework is proposed [29] where, for every station according to the current channel capacity and transmission requirements of the stations, the optimal TXOP is determined.

3. The proposed method for dynamic TXOP Adjustment

Ad hoc networks rely on the cooperation of stations. As such, they are susceptible to selfish attacks that abuse network mechanisms [33]. In all situations with two or more players that involve known payouts or quantifiable consequences, game theory can be used to help determine the most likely outcomes. WLANs are an example of such environments. In fact, game theory is a common tool for examining and analysing the problems of wireless networks. It is able to model the characteristics or limitations of wireless networks; such as lack of coordination. The theory of non-cooperative games can model conflict situations between individual players, where the payoffs of each player depend not only on its own actions but also on the actions of the other player. Non-cooperative game theory studies the optimum behaviour of rational players when cost(s) and utility(s) of each rational player depending on its own choice as well as the others. IEEE 802.11 based wireless networks are typical examples of such systems, in which communicating nodes access the channel through the CSMA method influencing the other neighbouring nodes' access. There are several parameters, which have significant effects on the performance of WLANs such as contention window, transmission power, transmission rate, transmission opportunity, etc. Game theory is widely used in CSMA based wireless networks, for different objectives such as contention window adjustment, media access control, transmission power, and rate tuning, TXOP control and etc. [6, 34-36].

In EDCA mode of 802.11e, which uses CSMA, it is seen that when an AC takes over the channel, its transmission time (TXOP) affects the other ACs' queue delay as well as the other stations. In the case of numerous active stations, this can cause frame starvation. Transmission with long TXOP reduces contention chances for channel and consequently, other stations will have little chance to transmit their frames. Hence, TXOP parameter must be set carefully and rigorously. In fact, choosing a long TXOP by a station has a negative effect on neighbouring stations, and if other stations imitate and repeat this action, it may lead to violating QoS requirements of those stations. Therefore, each station must consider the effect of its action on the others prior to adjusting it. However, in the methods that have been proposed so far for dynamic determination of TXOP, the effects of stations on one another have not been taken into account.

Therefore, to incorporate the effects of other stations, it would be helpful to model this problem within game theory framework. Game theory examines decision making in a shared environment for multiple rational decision makers with different goals. In other words, this theory plays an important role in cooperation and contention analysis among diverse rational agents. Rationality is one of the most common assumptions made in game theory. It means that every player always maximizes his utility, thus being able to perfectly calculate the probabilistic result of every action. Therefore, a rational player is goal-oriented, reflective and consistent.

The main characteristic of making a decision in game conditions is analyzing the others' reactions prior to choosing an action by an agent. After this analysis, it must take an action, which is the best one for it and gains the highest amount of payoff by taking other opponents' reactions into account. The environment in which there is such an effect and mutual reaction among decision makers is called a strategic environment and each decision maker in this environment is called a player. A game is comprised of a set of players, existing actions for the players and a set of payoff functions. Usually, a payoff function is defined in each game, which is the subtraction between a utility function and a cost function for players. The payoff function is a mapping from the action space of players to a set of real numbers. Its definition plays an important role in a game. The solution to a game is displayed by an array of a user's strategies in the game. Generally, in game theory, the goal is to find equilibrium in a game, where each player employs a strategy, which is the best response to the other players' strategies. Nash equilibrium is a solution to a game in which none of the players gains by changing their strategy in a one-way manner [2-8]. Hence, the idea of the game is to form a decision set (for each player) in which a user's strategy is the best response for her/ him and the other players choose their best strategy as well. In other words, each player chooses the best reaction to what the others have done, and each player should obtain a fair share of payoff at equilibrium.

Additionally, resistance against selfish behavior is another characteristic, which has to be taken into account in order to maintain security. In fact, in autonomous wireless networks, instead of a cooperative behavior, players may implement a strategy to maximize their own interest and utility through a selfish action regardless of the harms they will cause to the others. Therefore, it cannot be implicitly assumed that players will follow designed protocols. To do so, suitable and efficient protocols are required that are able to lead players to an equilibrium even in such conditions. In other words, the proposed method should incorporate a strategy in which none of the selfish stations has any intention to disobey the protocol. In this paper, the TXOP dynamic determination is modeled as a non-cooperative game called GDTXOP. In this game, each player implements its own strategy, including TXOP period, in order to maximize its own payoff function. A distributed and dynamic mechanism to improve TXOP, based on delay and the number of stations and the existing frames in queues, is proposed.

3.1 System Model and Problem Statement

The problem of controlling TXOP in multiple-access contention-based networks deals with the determination of the period to take over the media after winning the contention. Within the Game theory, each active station is considered as a network agent that must decide on adjusting its TXOP each time it accesses the channel. Each station makes decisions based on maximizing a payoff function that is defined in the station's decision space and indicates the amount of utility by a station in the environment.

The goal is to reach an efficient equilibrium point for the whole network when the stations maximize their payoff functions locally. It is obvious that the utilization of environment by a station is maximized when the mentioned station does its transmission in all time slots. Such selfishness behaviour causes unfairness for the adjacent stations and decreases the network throughput dramatically. Thus, the payoff function has to be defined in a way that each player makes decisions in order to maximize the whole network utilization. Therefore, in order to achieve this, the payoff function is, to use the resources of the shared environment including time and frequency, each station must pay some costs. It is clear that in a shared channel network; only one station is able to transmit its frames in TXOP period after winning the contention. Therefore, if a station increases its TXOP period selfishly, regardless of the other stations, it will increase channel access delays of the other stations. This increment causes the number of the existing frames to increase in the station's buffers and ultimately buffer-overflow. Therefore, the other stations, through a countermeasure to prevent buffer overflow, increase their own TXOPs. In the case of repeating this action by all stations, all the stations will be harmed and consequently the overall network throughput decline. Thus, choosing long intervals for TXOP by some stations causes violation of QoS and unfairness for the others. Therefore, for adjusting TXOP, each station must consider its effect on the others and chooses it is suitable TXOP regarding the arrival traffic, transmission rate and also the feedback of its former behaviours. Media access delay can be a suitable criterion to evaluate the others' behaviours and also the amount of network traffic. In other words, each station can evaluate its former behaviours' feedback by calculating its own media access delay. Thus, media access delay, which can be calculated easily for each station, can help stations to choose a suitable TXOP.

On the one hand, each station is different in terms of incoming traffic rate and must incorporate queue length in determining TXOP. Therefore, each station attempts to increase its TXOP whenever it notices an increase in its buffer queue length. A station can increase its throughput by increasing its TXOP and consequently transmitting more frames without involving further in the contention process. Thus, in this case, TXOP results in throughput improvement. On the other hand, media access delay for each station can be considered as a kind of cost in media access. This cost, informs each station about traffic volume and network load. By observing an undesirable increase in media access delay, each station notices that there has been an increase in either traffic volume or the number of active stations. Since the goal of all stations is to cooperate with one another and improve network performance, on the observation of delay increase, they tune their TXOP proportional to the observed delay and their former TXOP in order to prevent their QoS requirements violation. As a result, each station attempts to establish an appropriate trade-off between queue length and arrival traffic.

3.2 GDTXOP Game Definition

Let us assume that $G = [N, \{TXOP_i\}, \{u_i(\cdot)\}]$ indicates the GDTXOP game where $N = \{1, 2, \ldots, n\}$ is the set of active stations in the network and $TX_i = [TXOP_{min}, TXOP_{max}]$ is the strategy space of the station i. The payoff function of the MAC layer for the station i is shown as $u_i(TXOP_i, TXOP_{-i})$. This function indicates satisfaction level of station i when choosing $TXOP_i$ to transmit its frames. The TXOP vector of the other network stations other than station i is shown as $TXOP_{-i}$. The mathematical definition of GDTXOP game is as follows:

$$GDTXOP \quad \max_{TXOP_i \in TX_i} u_i\,(TXOP_i) \quad \forall j \in N \qquad (1)$$

Various payoff functions can be defined for this game, but the defined function must be a continuous, strictly increasing and concave function. To guarantee proportional fairness, a logarithmic function is used in defining the payoff function. The goal is to maximize the throughput of each station so that media access delay decreases and fairness of media access will be achieved. According to the analysis of EDCA, average media access time can be expressed as follows [15, 37-40]:

$$E[A_i] = T_{ci}\varphi_i + \overline{\sigma_i}\delta_i \qquad (2)$$

Where, T_{ci} is the average collision time and $\overline{\sigma_i}$ indicates the average time interval observed by each station. φ_i and δ_i variables show the number of collisions before a successful transmission and the average number of time intervals that station i was deferred in back off, respectively[15, 37-40].

$$\varphi_i = \sum_{l=0}^{m} \frac{l{pc_i}^{l}(1 - pc_i)}{(1 - {pc_i}^{m+1})} \qquad (3)$$

$$\delta_i = \sum_{l=0}^{m}\sum_{h=0}^{l} \frac{\min(2^h CW_{min}.CW_{max}) - 1}{2} \frac{{pc_i}^{l}(1 - pc_i)}{1 - {pc_i}^{m+1}} \qquad (4)$$

Where, pc_i is collision probability and CW_{min}, CW_{max} are the minimum and maximum size of contention window, respectively. The reasonable time interval would be [15, 37-40]:

$$\overline{\sigma_i} = (1 - pb_i)\sigma + \sum_{r=1}^{N} ps_i^r T_s^r + pc_i T_c \qquad (5)$$

Where σ is the length of a physical time interval and T_s^r shows the average amount of time for a successful burst transmission for a station in class r. In addition, pb_i and ps_i^r indicate the probability of the channel being busy and the probability of successful access for class r. Given that only the logical time interval is a function of $TXOP_i$, the average media access time can be expressed as follows [15, 37-40]:

$$\begin{aligned} E[A_i] &= T_c\varphi_i + \overline{\sigma_i}\delta_i \\ &= T_c\varphi_i + \delta_i\left[(1 - pb_i)\sigma + \sum_{r=1}^{N} ps_i^r T_s^r + pc_i T_c\right] \\ &= T_c\varphi_i\delta_i\left[(1 - pb_i)\sigma + ps_i\ T_s + \sum_{r=1}^{N-1} ps_i^r T_s^r + pc_i T_c\right] \\ &= T_c\varphi_i + \delta_i\left[(1 - pb_i)\sigma + pc_i T_c + ps_i\ TXOP_i + \sum_{r=1}^{N-1} ps_i^r TXOP_r\right] \end{aligned} \qquad (6)$$

Therefore, the average media access delay can be as:

$$E[A_i] = \Psi_i + f_i(TXOP_i, TXOP_{-i}) \qquad (7)$$

Where,

$$\Psi_i = T_c\varphi_i + \delta_i[(1 - pb_i)\sigma + pc_i T_c] \qquad (8)$$

And,

$$f_i(TXOP_i, TXOP_{-i}) = \delta_i\left[ps_i\ TXOP_i + \sum_{r=1}^{N-1} ps_i^r TXOP_{-i}^r\right] \qquad (9)$$

According to these definitions, $u_i(.)$, the payoff function for station i can be defined as follows:

$$u_i(TXOP_i, TXOP_{-i}) = \alpha_i Q_i \log(TXOP_i) + \beta_i(\mu_i - [\Psi_i + f_i(TXOP_i, TXOP_{-i})])^2 \qquad (10)$$

Where, μ_i and Q_i show the most tolerable delay (delay threshold) and queue length of the station, respectively. In addition, $\alpha_i > 0$ and $0 < \beta_i$ are constant weights to normalize the payoff function. Choosing a logarithmic function in the payoff function ensures the efficient solution to fairness [41]. GDTXOP game with the payoff function defined in (10) is a heuristic game. The first statement in equation (10) indicates that the higher the value of TXOP and the queue length of a station, the higher the media utilization by that station will be. The second statement shows the effect of controlling TXOP on the payoff function, which guarantees the maximum amount of media access delay that is μ, for station i as a barrier function. In additions, β_i is the weight of the barrier function. Therefore, each link attempts to maximize its TXOP while adjusting its MAC delay to experience the minimum delay. This term somehow shows the cost function in the payoff function. It can be seen that the payoff function is a function of each station's TXOP, the other station's TXOP and also the number of network stations. The cost function considered in the payoff function is used to coordinate selfish decisions of stations in order to use network resources, efficiently.

It is assumed that it is not possible to transmit fake frames. Stations' utilization is reduced in proportional to the delay it experiences. That is, each station decreases its utilization by the amount of difference between its delay and the delay threshold. Thus, the stations, which experience higher delay, reduce their utilization by a lower amount factor and as a result achieve longer TXOPs. However, the stations, which tolerate longer delays, set shorter TXOPs. In addition, increasing queue length has positive effects on increasing TXOPs.

3.3 Analysis of GDTXOP Game

There is Nash equilibrium in GDTXOP game if $\alpha_i > 0$ and $0 < \beta_i$. It should be proved that the strategy space of each user is a convex and compact subset and $u_j(TXOP_j)$ is continuous and concave. As that the strategy space of each user is an infinite subset of R, it is compact and convex. In addition, the payoff function in TXOP is continuous. The Hessian of this payoff function is as follows:

$$\nabla^2{}_{TXOP_i} \mathrm{u_i}(.) = -\alpha_i \frac{Q_i}{{TXOP_i}^2} + 2\beta_i\,(ps_i \;\; \delta_i)^2 < 0 \;\;, \quad (0 < \alpha_i, \beta_i \ll 1) \tag{11}$$

On the one hand $0 < \mathrm{TXOP_i} \ll 1$ and $1 < \mathrm{Q_i}$, and on the other hand $0 < \mathrm{ps_i} \ll 1)$ and $(0 < \alpha_i . \beta_i)$. Thus, assuming $\beta_i \to 0$, the Hessian function will be negative. If Hessian function is negative, the mentioned payoff function will be a concave function. The best solution from the viewpoint of the station i is obtained by local optimization of Equation (10). With respect to faster convergence of the Gradient method, each station, according to the Gradient method, updates its TXOP as follows:

$$TXOP_i(t+1) = TXOP_i(t) + \gamma_i \frac{du_i(TXOP_i, TXOP_{-i})}{dTXOP_i} \tag{12}$$

$$TXOP_i(t+1) = TXOP_i(t) + \gamma_i \left(\alpha_i \frac{Q_i}{TXOP_i(t)} - 2\beta_i ps_i \delta_i (\mu - [\Psi_i + f_i(TXOP_i, TXOP_{-i})]) \right) \tag{13}$$

Suppose we identify the delay by $\mathrm{MD_i}(t)$[1]. Thus, by substituting this delay in (13), the TXOP scheme turns into a following access latency problem then TXOP is calculated as follows:

$$TXOP_i(t+1) = TXOP_i(t) + \gamma_i \left(\alpha_i \frac{Q_i}{TXOP_i(t)} - 2\beta_i ps_i \delta_i \big(\mu - MD_i(t)\big) \right) \tag{14}$$

3.4 Distributed GDTXOP Algorithm

According to GDTXOP game, each station in every media access (probably successful) measures its current queue length and the maximum amount of MAC delay. Then based on them, it sets its TXOP. The GDTXOP algorithm proposed for dynamic TXOP determination is shown in Table 2. In addition to the existence and uniqueness of the solution, the efficiency of the proposed method is also important. The GDTXOP can be analysed from efficiency point of view by comparing the proposed method with other former methods and also the standard method. In the next section, the proposed approach is simulated and compered with exiting solutions.

4. Evaluation of the Proposed Method

Since the goal of this research is to increase throughput and maintain delay threshold and fairness within different traffic categories, the most relevant work to the current research is the one by Min et al(called TBD-TXOP) [12]. Hence, the proposed method is compared with TBD-TXOP and also with original EDCA. To do so, several scenarios with different number of stations and three kinds of different traffic type; voice, video and best effort are used.

Table 2. GDTXOP Algorithm

1. Initialization:
For each station $j \in N$, the initial TXOP value is the same as the specified value in the 802.11e standard i.e. $TXOP_j(t_0) \in TXOP_i$.
2. Measuring:
2. A. Measuring the maximum media access delay of the station *j*
2. B. Measuring the queue length of the station *j*
3. Updating TXOP:
Each station updates its TXOP using (14)
4. Transmission.

In order to obtain more clarity and do a better comparison, it is assumed that each station supports only one type of traffic. In the first scenario, three stations are used and each one supports one type of traffic. In real environments, voice traffic and video traffic have a bursting nature, so these two traffic types are defined in a self-similar manner (ON-OFF type with Pareto distribution and exponential arrival rate). Best effort traffic, however, is transmitted with a constant bit rate service. The arrival rate of the stations is random and the scenario is simulated with 3, 6, 9, 12, 15 stations. The network capacity is assumed to be 5.5 Mbps. The number of stations for each traffic type in all scenarios is the same but the traffic flow is different.

The desired delay for voice, video, and best effort traffic were set to 200, 300, 500 milliseconds respectively. In addition, to increase reliability, the simulations for each scenario are repeated several times using different seeds and finally, the average is calculated from the result of different iterations. The results are compared in terms of throughput, delay and drop rate.

4.1 Throughput Comparisons

Throughput is evaluated from the viewpoint of different ACs and in terms of overall throughput. Throughput for each ACs, is equal to the amount of payload received by the physical layer and delivered to the higher level for that ACs by the MAC sublayer of each station. Of course, it is noteworthy that repeated and incomplete frames are not considered in throughput. Fig.1 illustrates the comparison of voice, video and best effort traffic in different scenarios (different number of stations).

In TBD-TXOP and EDCA methods, the network has become saturated for BE traffic in the scenario with 12 stations and consequently, the throughput declined in these two methods. GDTXOP, however, provides good

[1] MAC Delay

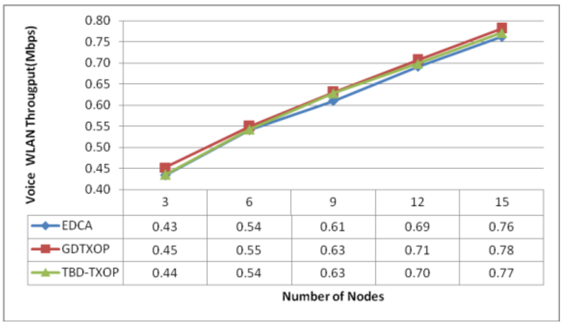
conditions in terms of throughput ceaselessly for the stations. The network stability area in GDTXOP has increased and the saturation boundary is postponed. In GDTXOP, upon entering the saturated region, this method attempts to maintain the throughput of low-priority traffics within acceptable limits in order to establish higher fairness by applying a little delay. The overall throughput (Fig.1(d)) is equal to the total number of bits transmitted from the MAC layer of every station in network to higher layers regardless of their ACs. Clearly, by setting TXOP appropriately and dynamically, the GDTXOP improves the throughput of each traffic type especially the traffic with low priority.

The GDTXOP is more flexible than TBD-TXOP, in turn; it is more compatible with network conditions. In addition, in TBD-TXOP, similar to EDCA, TXOP is used for high-priority ACs. In GDTXOP, however, TXOP mechanism is used for every ACs, by choosing different delay thresholds.

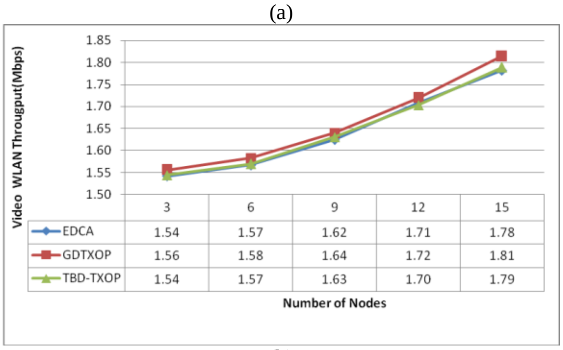
4.2 Delay Comparisons

End-to-end delay includes queuing delay, media access delay and packet transmission and receiving delay. In other words, this delay is equal to the average delay of all packets received and submitted to higher layers, by the MAC layer of all the network stations. Fig.2.(a) illustrates the comparison of voice traffic delay, which shows the result of the simulation of the three methods.

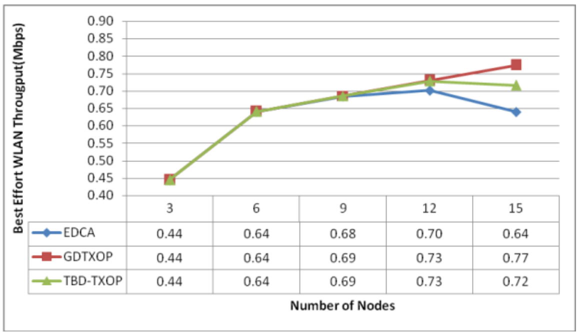
It is clear that TBD-TXOP and GDTXOP impose less delay on the stations carrying voice traffic than EDCA. The delay in GDTXOP, however, is a little higher than TBD-TXOP method. This increase in delay is the cost that GDTXOP imposes on stations with audio applications in order to improve traffics with low priority. Since voice traffic's delay tolerability is about 400 milliseconds, this slight delay will not be troublesome.



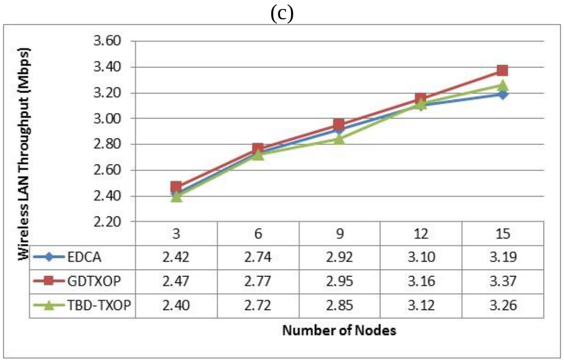
(a)



(b)



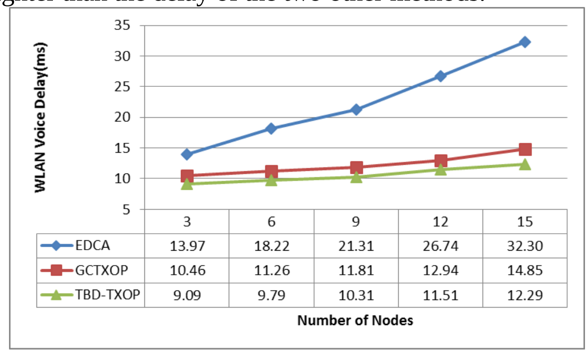
(c)



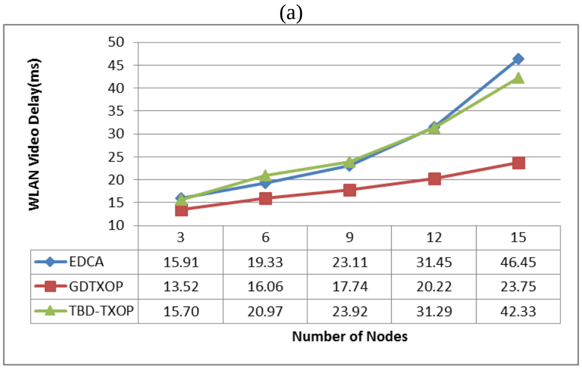
(d)

Fig.1. Throughput comparison of (a). Voice traffic (b). Video traffic (c). Best effort traffic (d). Network throughput

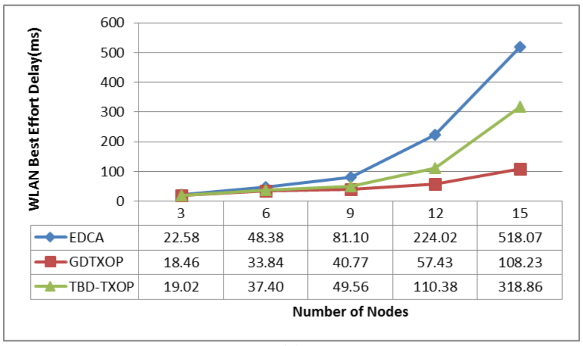
However, in comparison to the voice traffic which has the highest priority and gets access to the channel ahead of all other traffics, the delay of GDTXOP for video traffic (Fig.2.(b)) and best effort traffic (Fig.2.(c)) is much slighter than the delay of the two other methods.



(a)



(b)



	3	6	9	12	15
EDCA	22.58	48.38	81.10	224.02	518.07
GDTXOP	18.46	33.84	40.77	57.43	108.23
TBD-TXOP	19.02	37.40	49.56	110.38	318.86

(c)

Fig.2. Delay comparison (a). Voice traffic (b). Video traffic (c). Best effort traffic

4.3 Drop Comparisons

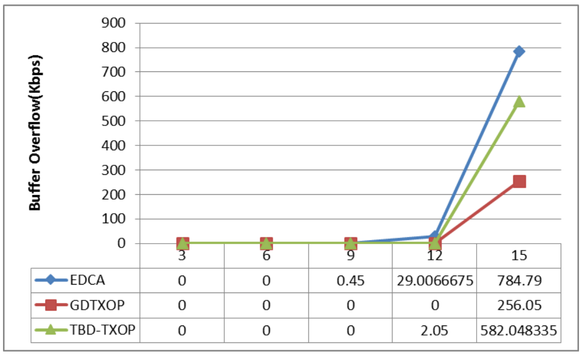
The amount of packet drop caused by buffer overflow is illustrated in Fig.3.(a). In the simulation, the size of MAC layer buffer is considered to be finite (256000 bits, approximately 32 KB). Therefore, overflow occurs when a packet is received from the higher layers and a full buffer is encountered. In bursting traffics in which several packets arrive frequently form higher layers, buffer overflow is more probable. Hence, the approach to prevent this problem is burst transmission that is proportional to the length of the buffer. Since, the number of existing packets in a queue is taken into account in both TBD-TXOP and GDTXOP when determining TXOP, in these two methods, the stations experience much fewer buffer overflows than EDCA.

In addition, GDTXOP causes fewer overflows than TBD-TXOP due to the more flexibility it features in determining TXOP. Moreover, a considerable amount of the overflow is concerned with low-priority traffics. These traffic types, in TBD-TXOP and EDCA, do not get the chance to access the channel, transmit their frames, and as a result suffer from overflow.

However, another reason for packet loss is packet drop due to exceeding the retry limit. In case an ACK frame is not received by the transmitter, it is assumed that the transmission encountered a problem and has to be retransmitted.

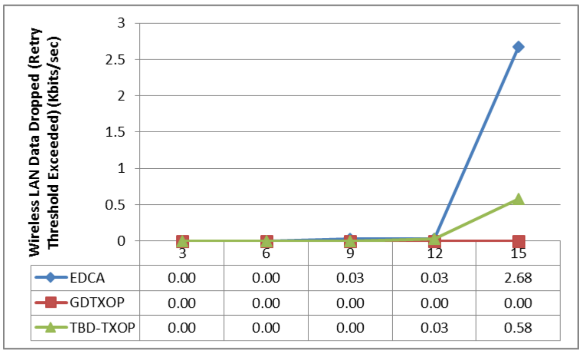
The retransmission is repeated until the packet is transmitted successfully or the number of retrials exceeds the allowed retry limit, which is usually 7 times, in which case the frame is disposed. The comparison of packet drop due to exceeding the retry limit is illustrated in Fig.3.(b). The important factor, which affects the amount of packet loss due to re-transmission, is the size of contention window. In case of saturation, in which each station always has a packet to transmit in its queue, the size of contention window is so important and plays a determining role in the probability of packet loss.

The size of contention window must increase according to the number of stations, and re-transmissions should repeat with longer periods to decrease the probability of packet loss due to successive collisions, significantly. Since the appropriate determination of TXOP results in increasing the network stability area, and consequently postponing the saturation region, it reduces the number of transmissions and decreases the collision probability.



	3	6	9	12	15
EDCA	0	0	0.45	29.0066675	784.79
GDTXOP	0	0	0	0	256.05
TBD-TXOP	0	0	0	2.05	582.048335

(a)



	3	6	9	12	15
EDCA	0.00	0.00	0.03	0.03	2.68
GDTXOP	0.00	0.00	0.00	0.00	0.00
TBD-TXOP	0.00	0.00	0.00	0.03	0.58

(b)

Fig.3. Drop Comparison (a). Packet drop due to buffer overflow (b). Packet drop due to exceeding retry limit

Therefore, in the simulation, packet drop has not occurred in GDTXOP due to exceeding the re-transmission limit. In addition, in TBD-TXOP fewer drops are observed than EDCA, again due to postponing the saturation region up to 12 stations.

5. Conclusion

In this paper, Transmission Opportunity (TXOP) was allocated using game theory. TXOP is a limited period of time allocated to each station in which the station can transmit any possible number of frames without contention with the other stations. TXOP improves network throughput as well as service differentiation. Choosing long TXOP by some stations causes unfairness and QoS violations for the others. Thus, in the proposed non-cooperative game, GDTXOP, the payoff function is defined in a way that each station chooses its appropriate TXOP according to its queue length and media access delay. Using the results of the game, an algorithm was obtained to control and determine TXOP dynamically. The resulting algorithm was simulated and its accuracy was evaluated and verified. The results of the simulation indicate that tuning TXOP appropriately improves both channel utilization for all levels of traffic priority and fairness. This improvement does not impair the QoS of high-priority applications.

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