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Bio-inspired rate control scheme for IEEE 802.11e WLANs

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***Abstract*—The uncontrolled use of limited resources in conjunction with unpredictable nature of traffic load injection in Wireless Local Area Networks (WLANs) may lead to congestion, and cannot guarantee strict Quality of Service (QoS) required by real-time service. Rate control is an important mechanism for the provisioning of QoS in the IEEE 802.11e WLANs. In this paper, a bio-inspired rate control scheme is proposed based on the extended Lotka-Volterra model, which considers the effects of arrival traffic on the system stability according to the limited network resources and competitions with others traffic flows, and ensures that the network works in unsaturated case and rapidly converge to a global stable equilibrium point (EP). Moreover, all traffic flows are of peaceful coexistence and QoS differentiation. Extensive simulations are conducted to illustrate the performance of the proposed rate control scheme.**

***Index Terms*—Rate control, QoS Differentiation, Bio-inspired model, 802.11e EDCA**

I. INTRODUCTION

WLANs based on the IEEE 802.11 Distributed Coordination Function (DCF) have been widely used in recent years due to their simple deployment and low cost. Since the current DCF can only support best effort traffic, whilst the growing popularity of real-time services and multimedia based applications, it has recently become more critical to tailor IEEE 802.11 Medium Access Control (MAC) protocol to meet the stringent requirements of such services. The IEEE 802.11e Enhanced Distributed Channel Access (EDCA) is proposed to support prioritized QoS[1]. It provides priority-based medium access mechanism with different Arbitration Inter Frame Space (AIFS), initial and maximum Contention Window (CW) size, and the limit of consecutive Transmission Opportunity (TXOP).

Meanwhile, considerable effort was devoted to theoretical analysis of the performance of the 802.11 EDCA [2-5]. However, it cannot guarantee strict QoS required by real-time services such as voice and video without proper network rate control mechanisms. It has been proven that the QoS requirements of the real-time traffic can be satisfied if the input traffic is properly regulated[6]. Meanwhile, it is found that in unsaturated case the 802.11e EDCA achieves the maximum throughput and small delay because of the low collision probability[7,8]. To keep the network operating in unsaturated case, it is crucial to regulate total input traffic. In [6], Chen integrated two admission control schemes and a rate control scheme relying on the average delay estimate and the channel busyness ratio. Lee proposed a bandwidth control scheme by combing the IEEE 802.11e EDCA protocol to overcome the guaranteed bandwidth issue in multi-rate environments [9]. Antoniou proposed a Lotka-Volterra-based congestion control (LVCC) scheme to regulate the input flows without considering the QoS differentiation [10]. Yaghmaee [11] and Chen [12] proposed a priority-based rate control algorithm for service differentiation.

The transmission rate of the traffic can be controlled based on two criteria. First, the injected traffic should not break off the original transmitting traffic, and all the traffic would be co-existing and served. Second, the regulated traffic should be able to promptly access the whole bandwidth in order to utilize the channel efficiently. One may argue that this can be easily achieved if the channel access parameters such as AIFS and CW are set much larger than those for the real-time traffic. However, this approach is problematic in that it will unnecessarily impede the best effort traffic from accessing the channel even when there is no heavy real-time traffic in the network, leading to channel under-utilization and unreasonably large delay for the best effort traffic.

In this paper, to guarantee the strict QoS differentiation and maximize the utility of limited network sources, a bio-inspired rate control scheme is proposed to optimize the transmission rate of each data flow. The stability of the proposed control scheme is analyzed under different network conditions.

TABLE I
RECOMMENDED IEEE 802.11E EDCA PARAMETER SETTING

Prio_	AC	Designation	AIFS	CWmin	CWmax	TXOP
3	AC(3)	Voice	2	7	15	0.003
2	AC(2)	Video	2	15	31	0.006
1	AC(1)	Best effort	3	31	1023	0
0	AC(0)	Background	7	31	1023	0

The remainder of this paper is organized as follows: Section 2 introduces the protocol of IEEE 802.11e EDCA. The extended Lotka-Volterra model is introduced in Section 3. In Section 4, we introduce the bio-inspired rate control scheme. Section 5 presents the performance of bio-inspired rate control scheme. The paper is concluded in Section 6.

II. IEEE 802.11E EDCA PROTOCOL

Since the demands of multimedia applications over WLANs increase tremendously in recent years, which requires the wireless network paradigm to be rethought in the view of need for mechanisms to deliver multimedia content with a certain level of quality of service (QoS). The IEEE 802.11 Task Group E has developed a new standard known as the IEEE 802.11e to provide the QoS support.

According to the IEEE 802.11e standard, the EDCA mechanism extends the DCF mechanism of traditional IEEE 802.11 protocol to enhance the QoS support in the MAC-layer by introducing four access categories $AC[n]$ ($n = 0, 1, 2, 3$) to serve different types of traffic, which includes AC_VO (for voice traffic), AC_VI (for video traffic), AC_BE (for best effort traffic) and AC_BK (for background traffic). To simplify the notations, we rename four ACs as $AC[3]$, $AC[2]$, $AC[1]$ and $AC[0]$ from the highest priority to the lowest priority in the rest of this paper. Each queue $AC[n]$ transmits packets with an independent channel access parameters including: Minimal Contention Window Size ($CW_{\min}[n]$), Maximal Contention Window Size ($CW_{\max}[n]$), Arbitration Inter-Frame Space Number ($AIFS[n]$), and the limit of consecutive Transmission Opportunity ($TXOP[n]$). The recommended value of each parameter is shown in Table I.

To achieve service differentiation among four ACs, instead of using fixed DCF Interframe Space (DIFS) as in IEEE 802.11 DCF mechanism, EDCA assigns $CW_{\min}$, $CW_{\max}$, $AIFS$ and $TXOP$ with different values to manipulate the successful transmission probability of different types of frames. If one AC has a smaller value of $AIFS$ or $CW_{\min}$ or $CW_{\max}$, then this AC has more chances to access the wireless medium and transmit the waiting or arriving frames. For $AC[i]$ and $AC[j]$ ($0 \leq i < j \leq 3$), then $CW_{min}[i] \geq CW_{min}[j]$, $CW_{max}[i] \geq CW_{max}[j]$, and $AIFS_i \geq AIFS_j$. Note that in the above inequalities, at least one must be strictly "not equal to" as shown in Table I. Each queue within a station is treated as an individual virtual station, and the backoff procedure of each AC is the same as that of DCF. When a collision occurs among different ACs within the same station, the AC with a higher priority is granted the opportunity to transmit, while the AC with a lower priority is kept waiting, i.e., suffers from a virtual collision.

III. EXTENDED LOTKA-VOLTERRA MODEL

In order to achieve the better performance and QoS differentiation for IEEE 802.11e EDCA WLANs. We use the bio-inspired model to regulate the input data flows. The nature of the world shows that the dynamics of many biological systems and laws governing them are based on a surprisingly small number of simple generic rules which yield collaborative and effective patterns for resource management, task allocation and social differentiation without the need of any externally controlling entity[13]. For example, population dynamics has traditionally been the dominant branch of mathematical biology which studies how populations of species change in time and space as well as the process that cause these changes.

Population dynamics can be modeled with a simple balance equation that describes how the overall population size of species changes over time as a result of species interaction with each other as well as with non-living parts of their surroundings (i.e. resources). Proposed by Lotka and Volterra, the well-known Lotka-Volterra models concerning ecological population modeling have been extensively investigated in the literature[10,14]. When two or more species live in proximity and share the same basic requirements, they usually compete for resources, food, habit, or territory. A deterministic, competitive Lotka-Volterra system with n species is given by [10,14]

$$\frac{dx_i}{dt} = x_i \left[r_i - \sum_{j=1}^{n} a_{ij} x_j \right], \quad i = 1, 2, ..., n \tag{1}$$

where x_i represents the population size of species i at time t, the constant r_i is the growth rate of species i, n is the number of species in an ecosystem, and a_{ij} represents the effect of inter-specific (if $i \neq j$) or intra-specific (if $i = j$) competition. The quotient r_i/a_{ii} is the carrying capacity of the ith species in absence of other species. In a vector form, we can rewrite (1) as

$$dx/dt = diag\,(x_1, x_2, ..., x_n)\,[B - Ax)]$$

where $x = (x_1, x_2, ..., x_n)^{\mathrm{T}}$ is an n-dimensional species state vector, $B = (r_1, r_2, ..., r_n)^{\mathrm{T}}$ is the set of growth rate of each species, $A = (a_{ij})_{n \times n}$ is an $n \times n$ matrix, known as the community matrix, and superscript $^{\mathrm{T}}$ denotes the transpose operation.

In this paper, we borrow the idea of population dynamics to analyze the optimal sending rate of each traffic flow under changing network conditions. A WLANs can be considered as analogous to an ecosystem. An ecosystem comprises of multiple species that live together and interact with resources and competitors to meet their needs for survival and coexist. Similarly, a WLANs involves a number of wireless stations. Each station has a limited buffer size to store packets and is able to initiate a traffic flow. Traffic flows can be seen as species that compete with each other for available network resources while traversing the access point to the user. The number of bytes per traffic flow corresponds to the population size of each species. Moreover, the species of an ecosystem have different positions in its biological chain, i.e. some species are much stronger and powerful than others, they will consume more resources from the surrounding environment. This phenomenon can also been seen in WLANs, that the traffic flows with a higher priority are much more important than those with a lower priority, and bandwidth of the network will be priorly allocated to the traffic flows with the highest priority, which means that the packets of the flow with the highest priority have more opportunities to be transmitted. In analogy with ecosystems, the goal of the WLANs is expected to be the coexistence of all traffic flows and achieve QoS differentiation.

IV. PROPOSED BIO-INSPIRED RATE CONTROL SCHEME

According to the above extended Lotka-Volterra competitive model, there are five correspondences between a WLANs and an ecosystem, i.e. 1) the traffic flows n initiated by each node play the role of competing species; 2) the number of bytes x_i sent by a traffic flow within a given period refers to the population size of a species; 3) the transmission rate of each traffic flow is affected by inter-actions among competing flows as well as the available bandwidth, named inter-specific or intra-specific coefficient a_{ij}; 4) the growth rate r_i of each flow refers to the growth rate of each species; 5) the limited bandwidth N of a WLANs can be seen as the resource in the ecosystem.

A. Considering the QoS Differentiation

The transmission rate evolution of each flow will be driven by variations in available bandwidth of source/relay nodes and by the injection of unpredictable traffic load along the network path towards the user. Each station is expected to initiate a traffic flow when triggered by a specific event or a periodic sensing task. In order to analyze the difference of competition from inter-specific or intra-specific data flows, we redefine the inter-specific competition coefficient of different flows as a_{ij} and the intra-specific competition coefficient of the same type flows as β_i. To support the service differentiation between the above four ACs in the IEEE 802.11e EDCA as described in Section II, we give two assumptions as follows:

1. The effect of inter-specific competition coming from flow j to flow i can be neglected if the priority of $AC[j]$ is lower than that of $AC[i]$, i.e. The higher priority $AC[i]$ will be granted to transmit frames when colliding with $AC[j]$. However, according to the access procedure of IEEE 802.11e EDCA protocol as shown in Fig.1, (where Short Interframe Space (SIFS) is the small time interval between the data frame and its acknowledgement; PCF Interframe Space (PIFS) is one of the interframe space used in IEEE 802.11 based WLANs.) the $AIFS$ values of $AC[2]$ and $AC[3]$ are identical as listed in Table I, so in this paper, we consider the competition from $AC[2]$ to $AC[3]$. Then the inter-specific competition

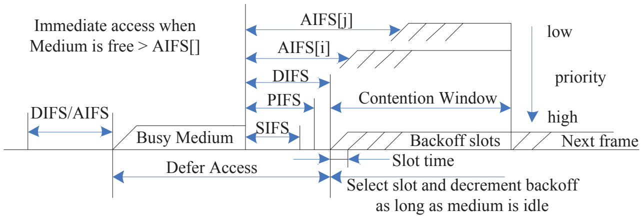


Fig. 1. IEEE 802.11e EDCA access procedure

coefficients are

$$\begin{cases} a_{ij} > 0, & 0 \le i < j \le 3 \\ a_{32} > 0, & i = 3, j = 2 \\ a_{ij} = 0, & otherwise \end{cases}$$

2. The effect of intra-specific competition of any traffic flow i with its number increasing or decreasing is a constant, i.e. the coefficient $a_{ii} = a_{jj} = \beta$.

Then the proposed bio-inspired rate control scheme based on the extended Lotka-Volterra model for WLANs with considering the QoS differentiation can be written as:

$$\begin{cases} \dot{x}_3\left(t\right) = r_3 x_3 \left[\left(1 - \frac{\beta x_3}{N_3}\right) - a_{32}\frac{x_2}{N_2}\right] \\ \dot{x}_2\left(t\right) = r_2 x_2 \left[\left(1 - \frac{\beta x_2}{N_2}\right) - a_{23}\frac{x_3}{N_3}\right] \\ \dot{x}_1\left(t\right) = r_1 x_1 \left[\left(1 - \frac{\beta x_1}{N_1}\right) - a_{13}\frac{x_3}{N_3} - a_{12}\frac{x_2}{N_2}\right] \\ \dot{x}_0\left(t\right) = r_0 x_0 \left[\left(1 - \frac{\beta x_0}{N_0}\right) - a_{03}\frac{x_3}{N_3} - a_{02}\frac{x_2}{N_2} - a_{01}\frac{x_1}{N_1}\right] \end{cases} \tag{2}$$

where x_3, x_2, x_1 and x_0 means the transmission rate of priority queue $AC[3]$, $AC[2]$, $AC[1]$ and $AC[0]$, respectively.

B. Stability Analysis

The proposed Bio-inspired competitive rate control scheme is adaptive to bursty traffic flows. For example, the transmission rate will reach to the optimal maximal value when other data flows are removed; However, while some higher priority flows are injected into the network unpredictably, the transmission rates of the former flows are reduced smoothly according to the competitions and available bandwidth. So the real-time transmission rate is very important to show the validation of the proposed control scheme and its performance. Based on the nonlinear ordinary differential Equation (2), the real-time transmission rate can be derived:

$$x_3(t) = \frac{N_3 w_3 x_3(0)}{\beta N_2 x_3(0) + \left[N_3 w_3 - \beta N_2 x_3(0)\right] e^{-\frac{w_3 r_3}{N_2} t}}$$

$$x_2(t) = \frac{N_2 w_2 x_2(0)}{\beta N_3 x_2(0) + \left[N_2 w_2 - \beta N_3 x_2(0)\right] e^{-\frac{w_2 r_2}{N_3} t}}$$

$$x_1(t) = \frac{N_1\left(N_2 N_3 - w_1\right) x_1(0)}{N_2 N_3 \beta x_1(0) + \varphi_1 e^{-\frac{N_2 N_3 - w_1}{N_2 N_3} \cdot r_1 t}}$$

$$x_0(t) = \frac{N_0\left(N_1 N_2 N_3 - w_0\right) \cdot x_0(0)}{\beta N_1 N_2 N_3 x_0(0) + \varphi_0 e^{-\frac{N_1 N_2 N_3 - w_0}{N_1 N_2 N_3} \cdot r_0 t}}$$

where $w_3 = N_2 - a_{32}x_2$, $w_2 = N_3 - a_{23}x_3$, $w_1 = N_2 a_{13} x_3 + N_3 a_{12} x_2$, $w_0 = N_1 N_2 a_{03} x_3 + N_1 N_3 a_{02} x_2 +$

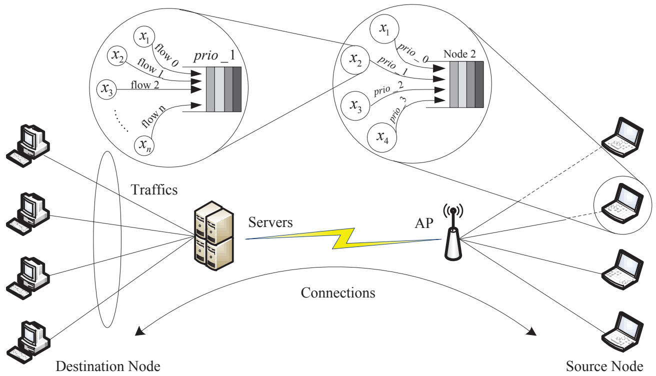


Fig. 2. Network topology

$N_2N_3a_{01}x_1$, $\varphi_1{=}N_1\left(N_2N_3-w_1\right)-\beta N_2N_3x_1\left(0\right)$, $\varphi_0 = N_0\left(N_1N_2N_3-w_0\right)-\beta N_1N_2N_3x_0\left(0\right)$.

In order to guarantee the stability of WLANs, the proposed rate control scheme should be sure that the real-time transmission rate can converge to a stable equilibrium point (EP) as soon as possible. There are sixteen stable EPs by solving the Equation (2), however, it is meaningless unless all the elements in the EP are positive, i.e. $x_0^* > 0$, $x_1^* > 0$, $x_2^* > 0$ and $x_3^* > 0$.

Then the stable equilibrium point x^*, i.e. the desirable transmission rate of each flow, can be calculated as:

$$\begin{cases} x_3^* = \frac{a_{32}-\beta}{a_{23}a_{32}-\beta^2}N_3 \\ x_2^* = \frac{a_{23}-\beta}{a_{23}a_{32}-\beta^2}N_2 \\ x_1^* = \frac{N_1}{\beta}\left[1-\frac{a_{12}(a_{23}-\beta)+a_{13}(a_{32}-\beta)}{a_{23}a_{32}-\beta^2}\right] \\ x_0^* = \frac{N_0}{\beta}\left\{1-\frac{a_{03}(a_{32}-\beta)+a_{02}(a_{23}-\beta)}{a_{23}a_{32}-\beta^2}\right. \\ \qquad \left. -\frac{a_{01}}{\beta}\left[1-\frac{a_{13}(a_{32}-\beta)+a_{12}(a_{23}-\beta)}{a_{23}a_{32}-\beta^2}\right]\right\} \end{cases} \tag{3}$$

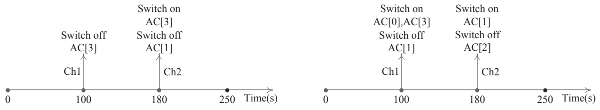
V. PERFORMANCE ASSESSMENT

A. Experiment environment and setting

In order to evaluate the performance of the proposed bio-inspired rate control scheme for IEEE 802.11e EDCA WLANs, simulation studies are used to evaluate the performance in terms of graceful performance degradation, self-adaptivity, scalability and service differentiation. In addition, evaluation studies investigate how parameters affect the performance of our approach in terms of stability, convergence and provide effective parameter setting rules. The simulation experiments are conducted in a WLANs, the data flows are transmitted by wireless medium through Access Point (AP) to the Destination Node (DN) as shown in Fig.2. The time interval between successive evaluations of the number of bytes sent by Source Node (SN) is set to 1 second. The parameters (Para) of the proposed rate control scheme shown in Equation (3) are set in Table II.

TABLE II
PARAMETER SETTING

Para	value	Para	value	Para	value	Para	value
a_{01}	1	a_{13}	1.3	r_1	1	N_1	1024
a_{02}	1.4	a_{23}	1.1	r_2	1	N_2	1024
a_{03}	1.5	a_{32}	1	r_3	1	N_3	1024
a_{12}	1.2	r_0	1	N_0	1024	β	4



(a) Test 1 (b) Test 2

Fig. 3. Removing and/or injecting traffic flow

B. Stability analysis under different traffic loads

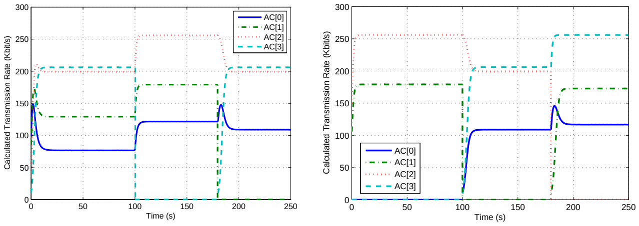
Two random network scenarios (i.e. Test1 and Test2) with two changes, such as removing or injecting traffic flows, are used to evaluate the performance of the proposed rate control scheme, such as the stability, scalability and adaptivity. Each scenario with random initial rate of traffic flows has two changing network states, change1 (Ch1) and change2 (Ch2)), as shown in Fig.3 and three global stable states (i.e. stable, stable1 and stable2) as shown in Table III. In Test1, we switch off the flow $AC[3]$ at $t = 100s$, and then switch $AC[3]$ on and $AC[1]$ off at $t = 180s$. While in Test2, we switch $AC[0]$, $AC[3]$ on and $AC[1]$ off at $t = 100s$, and then switch $AC[1]$ on again and $AC[2]$ off at $t = 180s$. Individual element in Table III is the transmission rate. Moreover, assuming that all traffic flows have the same characteristics of the growth rate r, the intra-specific competition coefficient β and the maximum capacity N of each data flow.

TABLE III
THE EP OF THE PROPOSED MECHANISM UNDER DIFFERENT NETWORK CONDITIONS

Test	Priority	Initial	Stable	Stable1	Stable2
		0s	100s	180s	250s
Test1	$AC[0]$	100.0	76.6	121.6	108.9
	$AC[1]$	80.0	129.2	179.2	0.0
	$AC[2]$	40.0	199.3	256.0	199.3
	$AC[3]$	10.0	206.1	0.0	206.1
Test2	$AC[0]$	0.0	0.0	108.9	116.8
	$AC[1]$	100.0	179.2	0.0	172.8
	$AC[2]$	150.0	256.0	199.3	0.0
	$AC[3]$	0.0	0.0	206.1	256.0

As observed in Table III, the experiments of Test1 and Test2 have the same values of stable EP, i.e. The point (76.6,129.2,199.3,206.1) is the global stable EP for all flows co-existing in the bandwidth-limited WLANs. When the flow $AC[3]$ becomes extinct at $t = 100s$ for some unknown reasons in Test1, the other priority flows will soon adaptively reach another new EP (121.6,179.2,256.0,0.0). After the instant $t = 180s$, the flow $AC[3]$ is injected into the network again, at the same time $AC[1]$ is switched off, then the system converges to a new EP. Similarly, Test2 also shows the excellent performance of the proposed mechanism in terms of adaptivity, scalability and stability. When $AC[1]$ is switched off and $AC[0]$, $AC[3]$ are switched on at $t = 100s$, the system reaches the stable EP (108.9,0.0,199.3,206.1), and then the WLANs will reach another new stable EP (116.8,172.8,0.0,256.0) after switching off $AC[2]$ and switching on $AC[1]$ at $t = 180s$ in Test2.

Fig. 4 takes a close look at the behavior of all traffic flows with differentiated priority under changing network load. We aim to reveal the process of the system keeping stable after changes in network state. As can be seen, when the data flow is changed for some reasons, the system can re-converge to a new stable EP quickly for its characteristic of self-adaptive. Moreover, the proposed mechanism provides smooth calculated transmission rates for all the traffic flows, which also assists in avoiding the probability of buffer overflow and network congestion. When some high priority emergency data streams are injected into the network, the proposed mechanism can also achieve graceful performance degradation.



(a) Test 1 (b) Test 2

Fig. 4. Calculated transmission rates

C. Parameter setting and analysis

According to the second assumption of Section IV.A, the effect of intra-specific competition of any traffic flow is a constant, the impact of coefficient β on a realistic network environment in investigated in this section. Each scenario, concerning different combinations of a_{ij}, β, r and N values, is executed 10 times and the average values of metrics over all scenarios are presented below.

When β increases from 1.5 to 5 as shown in Fig. 5, the difference in transmission rates of all data flows is reduced, the remaining difference in data flow rate is only caused by the different inter-specific competition coefficients. With the increasement of value β, i.e. the competitive effect of flow j on the sending rate of flow i is much less than that from the inside of flow i, the total sending rate of all data flow is decreased. Even though there is no upper bound for β value, it is worth pointing out that as β increases, the EP value decreases and the quality of the received data at the DN may be reduced.

The phase plane of the scenarios with different values of β as shown in Fig. 6 illustrates the stability, rapid convergence and differentiation of the transmission rate of the four different priority flows. As observed in Fig. 6(c) when $\beta = 4$, the transmission rate of each flow can converge to the global stable point without any fluctuations. Moreover, with the increment of intra-specific competition coefficient β, the phase plane inclines to a small region (the EP), which means that there is less difference among four species. However, when the value of intra-specific competition coefficient is equal to 1.5(i.e. the inequality $a_{ij} < \beta$ is not satisfied, for $a_{12} = 1.5$), the network system is not very stable as shown in Fig.6(a), which is identical to the analysis of Section IV.A and can be effectively avoided from proper parameter settings.

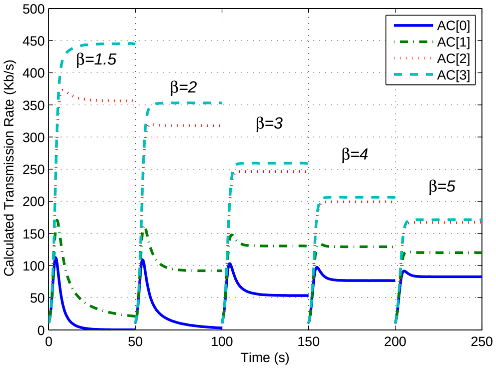
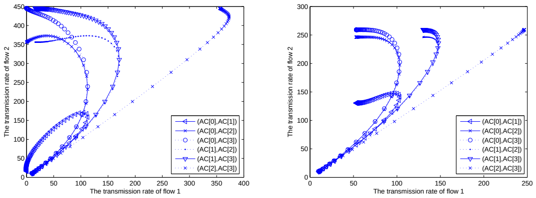
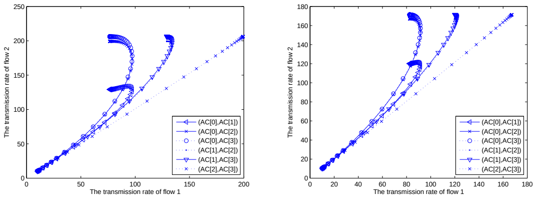


Fig. 5. The equilibrium point with different β values



(a) β=1.5 (b) β=3



(c) β=4 (d) β=5

Fig. 6. Phase plane of two species

Fig.7 shows the throughput of different priority flows with β varies from 1.5 to 5. The throughput of higher priority AC is much bigger than that of lower priority AC. And according to the curved surface, the value of intra-specific β can be set for special purpose.

VI. CONCLUSION

In this paper, we proposed a novel bio-inspired rate control scheme to meet the differentiated QoS requirements for various applications in IEEE 802.11e EDCA WLANs. Based on the extended competitive Lotka-Volterra model, the proposed rate control scheme considers traffic flows with differentiated QoS requirements. And the effect of injected bursty traffic

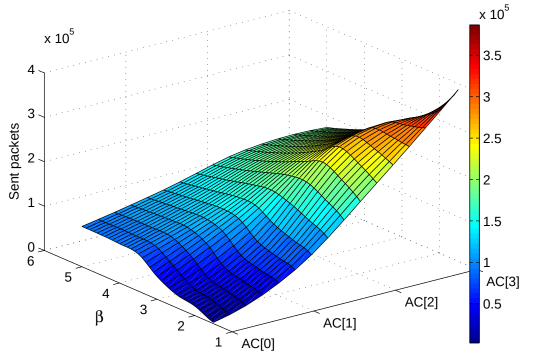


Fig. 7. The throughput of each priority flow with different β values

flows on the system stability was also taken into consideration based on the limited network resources and competitions from other traffic flows. It was proven that the scheme has a global stable EP and can fast re-converge to a new EP under changing network conditions, while keeping all traffic flows co-existing and serviced with differentiated QoS. The source traffic rates could be adjusted optimally according to the value of EP. From the analysis of simulation results, we illustrated how the variations of the scheme's parameters influence stability, scalability and distinction of traffic flows. Performance evaluations suggested certain values for parameters a_{ij}, β_i and r_i that are able to avoid the network congestion and guarantee bandwidth for high priority real time traffic.

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REFERENCES

[1] C.H. Foh, Y. Zhang, Z.F. Ni, J.F. Cai. Scalable Video Transmission over the IEEE 802.11e Networks Using Cross-Layer Rate Control. In Proc. ICC Communications 2007, Glasgow, Scotland, June 2007.
[2] J. Hui, M. Devetsikiotis. A unified model for the performance analysis of IEEE 802.11e EDCA. IEEE Transactions on Communications, 2005, 53(9): 1498-1510.
[3] X.W. Yao, W.L. Wang, S.H. Yang. Video streaming transmission: performance modelling over wireless local area networks under saturation condition. IET Communications, 2012,6(1):13-21.
[4] J.Y. Lee, H.S. Lee. A performance analysis model for IEEE 802.11e EDCA under saturation condition. IEEE Transactions on Communications, 2009, 57(1): 56-63.
[5] P. Serrano, A. Banchs, P. Patras, A. Azcorra. Optimal Configuration of 802.11e EDCA for Real-Time and Data Traffic. IEEE Transactions on Vehicular Technology, 2010, 59(5): 2511-2528.
[6] X. Chen, H.Q. Zhang, X.J. Tian, Y.G. Fang. Supporting QoS in IEEE 802.11e wireless LANs. IEEE Transactions on Wireless Communications, 2006, 5(8): 2217-2227.
[7] J. Hu, G. Min, M.E. Woodward, W. Jia. A Comprehensive Analytical Model for IEEE 802.11e QoS Differentiation Schemes under Unsaturated Traffic Loads. In Pro. ICC Communications, 2008 :241-245.
[8] S.H. Nguyen, H.L. Vu, L.L.H. Andrew. Performance Analysis of IEEE 802.11 WLANs with Saturated and Unsaturated Sources. IEEE Transactions on Vehicular Technology, 2012, 61(1):333-345.
[9] Y. Xiao, Y. Zhang, M. Nolen, J.H. Deng, J. Zhang. A Cross-Layer Approach for Prioritized Frame Transmissions of MPEG-4 Over the IEEE 802.11 and IEEE 802.11e Wireless Local Area Networks. IEEE Systems Journal, 2011, 5(4):474-485.
[10] P. Antoniou, A. Pitsillides. A bio-inspired approach for streaming applications in wireless sensor networks based on the Lotka-Volterra competition model. Computer Communications, 2010, 33(17): 2039-2047.
[11] Yaghmaee M.H., Adjeroh D.A. Priority-based rate control for service differentiation and congestion control in wireless multimedia sensor networks. Computer Networks. 2009,53(11):p. 1798-1811.
[12] Chen Y.L., Lai H.P. Priority-based transmission rate control with a fuzzy logical controller in wireless multimedia sensor networks. Computers and Mathematics with Applications (2011). Doi:10.1016/j.camwa.2011.09.034.
[13] Dressler F., Akan O.B. A survey on bio-inspired networking. Computer Networks, 2010,54(6): 881-900.
[14] Zhu, C. and G. Yin, On competitive Lotka-Volterra model in random environments. Journal of Mathematical Analysis and Applications, 2009,357(1): p. 154-170.
[15] Antoniou, P., Pitsillides, A. Towards a scalable and self-adaptive congestion control approach for autonomous decentralized networks. Third European Symposium on Nature-inspired Smart Information Systems (NiSIS), 2007.