An Improved EDCAF for Multirate Cross-layer Design in Wireless Networks

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ABSTRACT

IEEE 802.11e provides the guaranteed quality of service (QoS) by providing different transmission priorities. IEEE 802.11e improves the media access control layer of IEEE 802.11 to satisfy the different QoS requirements by introducing two channel access functions: the enhanced distributed channel access (EDCA) and the HCF controlled channel access (HCCA). This paper proposes an improved EDCAF (IEDCAF) by combining the cross-layer concept and IEEE 802.11e EDCAF protocol; a multirate discrete Markov chain model is analyzed for the system with multiple transmission rates. According to the obtained results, IEDCAF improves performance especially in throughput and fairness. IEDCAF also makes the different QoS requirements be processed efficiently and flexibly.

Keywords: IEEE 802.11e, cross-layer, EDCA, HCF, quality of service (QoS)

1: INTRODUCTIONS

In recent years, wireless transmission technology is widely applied for the applications of data, voice, video and even multimedia. Quality of service (QoS) must be considered while priority issues are applied in different kinds of traffics. IEEE 802.11e standard is proposed to achieve the guaranteed QoS requirements [1]. IEEE 802.11e consists of two channel access schemes: the enhanced distributed channel access (EDCA) and the HCF controlled channel access (HCCA). For each access category (AC), an enhance variant of DCF, called the enhanced distributed channel access function (EDCAF). EDCAF provides the prioritized QoS to enhance the original IEEE 802.11 distributed coordination function (DCF). HCCA uses a hybrid coordinator (HC) to centrally manage the medium access and wireless resources, which enhances the IEEE 802.11 point coordination function (PCF) to provide the parameterized QoS, but these improvements are only used for MAC layer [2]-[6].

Different stations may obtain channels with the same probability in the EDCAF of IEEE 802.11e, if the stations have the same contention parameters regarding different physical rates, where the contention parameters include arbitration interframe space (AIFS), the size of contention window (CW) and persistence factor (PF). However, EDCAF ignores that the station with lower transmission rate occupies a channel longer than the others with higher transmission rates under multiple transmission rates. The waiting interval may seriously affect system performance and QoS guarantee in wireless networks [7].

This paper proposes an improved EDCAF (IEDCAF) by using cross-layer concept and considering the effect of multiple rates, which is a simple and efficient dynamic tuning scheme to select an appropriate set of contention parameters according to the transmission rate indicated by physical layer. IEDCAF can efficiently avoid the decrease of the bandwidth utilization induced by the multiple transmission rate and make access point (AP) provide the guaranteed QoS stably and efficiently. Some researches use discrete Markov chain model [8]-[13] or mean value analysis [14] to analyze the performance of IEEE 802.11 or IEEE 802.11e but only considering one physical rate. This paper proposes a multirate discrete Markov chain model to analyze the multirate applications in the real wireless infrastructure.

2: IEDCAF SYSTEN DESCRIPTION

According to the IEEE 802.11 specification [15], a packet may be sent by using two different rates. A basic transmission rate may be used by the physical layer convergence protocol (PLCP), while the payload of the medium access control (MAC) may dynamically be sent at highest transmission rate depending on signal-to-noise ratio (SNR). Receiver knows the transmission rate of the MAC payload by verifying the PLCP header; the frame format of the IEEE 802.11b physical layer is shown as Fig. 1. We assume that all frames have the same MAC payload size hence the higher transmission rate yields the shorter transmission time.

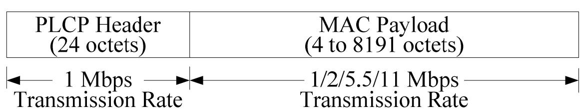

Fig. 1 IEEE 802.11b physical layer frame format

IEDCAF is based on the IEEE 802.11e infrastructure.

Fig. 2 shows how IEDCAF works in the cross-layer design, while Fig. 3 illustrates the IEDCAF process. AP periodically broadcasts beacon frames to all stations, where the beacon frame contains the priority matrix of IEDCAF and all communication information. The contention parameters of all traffics are decided by the priority matrix which is updated by AP according to the network conditions. In order to have a stable QoS guarantee, a station sends AP the minimum bandwidth requirement for each traffic before transmission.

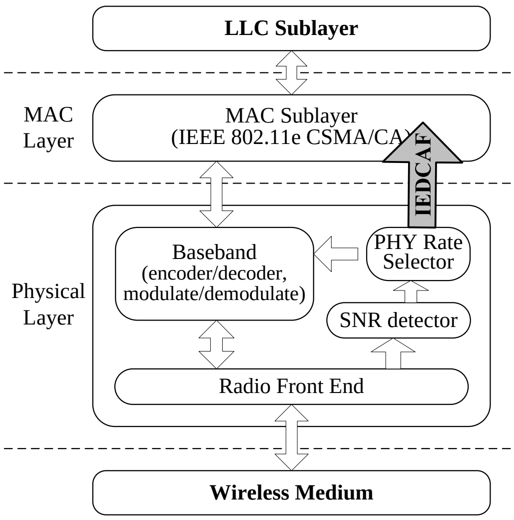

Fig. 2 The cross layer design for IEDCAF.

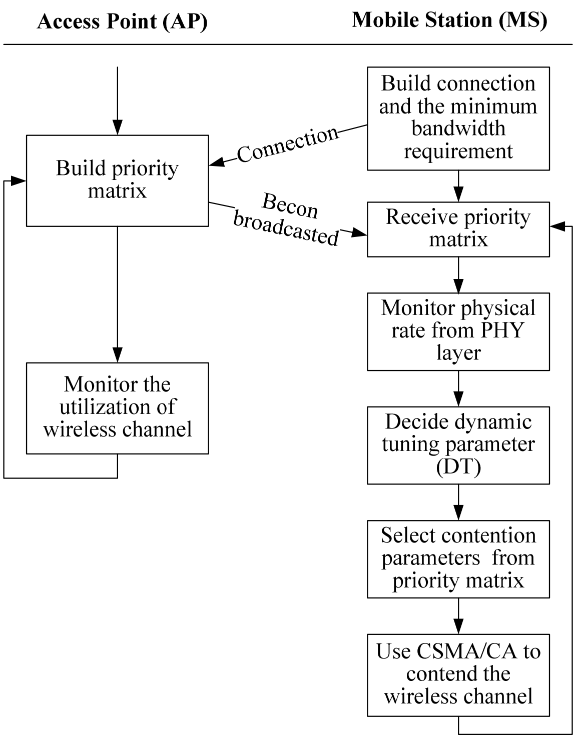

Fig. 3 The block diagram of the IEDCAF process

Priority matrix is an $N \times M$ matrix constructed by the bandwidth utilization ratio and the traffic access categories. *PM(r,i)* is the element of priority matrix, where r ($0 \le r \le N-1$) and i ($0 \le i \le M-1$) present the priority of bandwidth utilization and the access category, respectively, as shown in Fig. 4. That is, each station may have up to N priorities of bandwidth utilization and M access categories, e.g., there are five categories, AC(0)~AC(4), and five priorities for each category, r(0)~r(4), in the priority matrix.

The contention parameters include AIFS, CW and PF. Each packet contains a different AIFS number (AIFSN) corresponding to the different AIFS interval and distinguishing its priority shown as Eq. (1), where T_{Slot} and *SIFS* represent the slot time and the interval of short interframe space (SIFS). Generally the smaller AIFS and CW represent the shorter channel access delay and higher priority. In EDCAF, a backoff time, T_B, can be obtained by randomly selecting a number between 0 and CW, where a new CW is calculated depending upon the old CW and PF shown as Eq. (2).

$$AIFS[PM(r,i)] = AIFSN[PM(r,i)] \times T_{Slot} + SIFS \quad (1)$$

$$T_B = random[0, CW] \times T_{Slot} \quad (2)$$

where $CW_{min} \le CW \le CW_{max}$ and

$$CW_{new} = (CW_{old} + 1) \times PF - 1$$

	AC(0)	AC(1)	• • •	AC(M-1)
r(0)	PM(0,0)	PM(0,1)	• • •	PM(0,M-1)
r(1)	PM(1,0)	PM(1,1)	• • •	PM(1,M-1)
r(2)	PM(2,0)	PM(2,1)	• • •	PM(2,M-1)
⋮	⋮	⋮	⋮	⋮
r(N-1)	PM(N-1,0)	PM(N-1,1)	• • •	PM(N-1,M-1)

Fig. 4 The format of the priority matrix

According to the transmission rate decided by the physical layer, we define a parameter, called dynamic tuning (*DT*), to realize the bandwidth utilization in the wireless channel shown as Eq. (3), where R_{phy} and BW_{req} denote the transmission rate and the bandwidth requirement, respectively. The smaller *DT* value presents having enough bandwidth, the shorter channel occupied time and better QoS guarantee, e.g., $DT=1$ presents the transmission rate of a station just satisfies its bandwidth requirement; $DT>1$ presents the transmission rate cannot satisfy the bandwidth requirement and the QoS guarantee; $DT<1$ represents the transmission rate can satisfy the bandwidth requirement well.

$$DT = \frac{BW_{req}}{R_{phy}} \quad (3)$$

A multirate station uses a set of suitable categories with *PM(r,i)* parameters to contend the wireless channel based on the selected physical rate, where the contention parameters are dynamically tuned and broadcasted by AP. Fig. 5 shows an example of priority matrix, where AP classifies the *DT* parameters to 5 priorities and 4 access categories, e.g., r(0)~r(4) present $0<DT<0.5$, $0.5\leqq DT<1$, $DT=1$, $1<DT<2$, $2\leqq DT$, respectively, with the priorities of $r(0)> r(1)> r(2)> r(3)> r(4)$ for each category. For example, in the IEEE 802.11b environment, a station is to build up a new connection AC(0) with the bandwidth requirement 3Mbps. The station may select the contention parameters of *PM(0,0), PM(1,0), PM(3,0) or PM(4,0)* for *DT*=0.27 at *r(0)* with the rate 11Mbps, *DT*=0.54 at *r(1)* with the rate 5.5Mbps, *DT*=1.5 at *r(3)* with the rate 2Mbps or *DT*=3 at *r(4)* with the rate 1Mbps, respectively. Therefore, AP can dynamically tune the contention parameters to reduce the impact of throughput and QoS induced by the lower rate stations.

	AC(0)	**AC(1)**	**AC(2)**	**AC(3)**
r(0) : 0<DT<0.5	PM(0,0)	PM(0,1)	PM(0,2)	PM(0,3)
r(1) : 0.5≤DT<1	PM(1,0)	PM(1,1)	PM(1,2)	PM(1,3)
r(2) : DT=1	PM(2,0)	PM(2,1)	PM(2,2)	PM(2,3)
r(3) : 1<DT<2	PM(3,0)	PM(3,1)	PM(3,2)	PM(3,3)
r(4) : 2≤DT	PM(4,0)	PM(4,1)	PM(4,2)	PM(4,3)

Fig. 5 An example of priority matrix by the order of 5×4

3: IEDCAF SYSTEM MODEL

In this section, the analytical model for the multirate EDCAF is established and analyzed. The wireless channel is assumed to be ideal without considering the issues of path loss, propagation delay, bit error rate and hidden nodes; each traffic category transmits packets under saturation mode, i.e., the transmission queue for each category is always nonempty. The analytical model of IEDCAF is obtained by extending the original discrete Markov chain model of EDCAF [13], called the multirate discrete Markov chain model, whose state transition diagram is shown as Fig. 6.

In Fig. 6, each state represents a category with *PM(r,i)* in a slot time and a state transits at the end of a slot time. Each state contains six parameters (*L, i, r, j, k, d*), where *L, i, and r* indicate the location and physical rate of a station, the type of access category, and the *DT* value and priority of bandwidth utilization, respectively; *j* denotes the current backoff stage for the *j*th retry; *k* denotes the current value of backoff counter after taking the value from $[0, W_{L,i,r,j}-1]$; and *d* denotes the remaining frozen time (AIFSN slots) before the deferred access finished.

To validate the multirate Markov chain model, we compare the results obtained by simulation and numerical method to investigate how the performance is affected by the different physical rates and contention parameters. To simplify calculation, we assume that all stations operate in the basic access mode under the IEEE 802.11e protocol [1] and there are two types of stations: fixed and mobile. Each station has one active AC with the same packet size and operates at the saturation mode, i.e., the transmission queue is always nonempty and every station always has a packet available for transmission. The fixed station always connects to AP at the range of 11Mbps; and based on the IEEE 802.11b mode, the mobile station (MS) is far away from AP and selects a suitable rate (11/5.5/2/1 Mbps) according to the received signal strength. We evaluate throughputs for two cases depending on different assumptions that case 1 and case 2 consider the same and the different contention parameters under different physical rates, respectively, where the related parameters are listed in Table 1.

Table 1 parameters used in the analysis

Parameters	Case 1		Case 2	
	Fixed STA	MS	Fixed STA	MS
CW_{min}	3		3	
CW_{max}	15		15	15/31/63/127
AIFSN	2		2	2/2/3/3
PF	2		2	
Retry limit	3		3	
Packet size	8184 bits		8184 bits	
Physical rate	11 Mbps	11/5.5/2/1 Mbps	11 Mbps	11/5.5/2/1 Mbps

Figs. 7 and 8 compare the throughputs obtained by simulation and numerical under different physical rates in case 1 and case 2, respectively. It is obvious that these results obtained by simulation and numerical are very close under the acceptable errors. Table 2 shows the probabilities of transmission attempt to contend communication channel at the first backoff stage for fixed and mobile stations in case 2.

Table 2 The probabilities of transmission attempt at the first backoff stage in case 2

i = 0 & r = 0		Stationary prob. of the initial state (L,i,r,0,0,0)
L=0 (11 Mbps)	Fixed	0.0092675
	Mobile	0.0092675
L=1 (5.5 Mbps)	Fixed	0.0082179
	Mobile	0.0063485
L=2 (2 Mbps)	Fixed	0.0132376
	Mobile	0.0012145
L=3 (1 Mbps)	Fixed	0.0096685
	Mobile	0.0010629

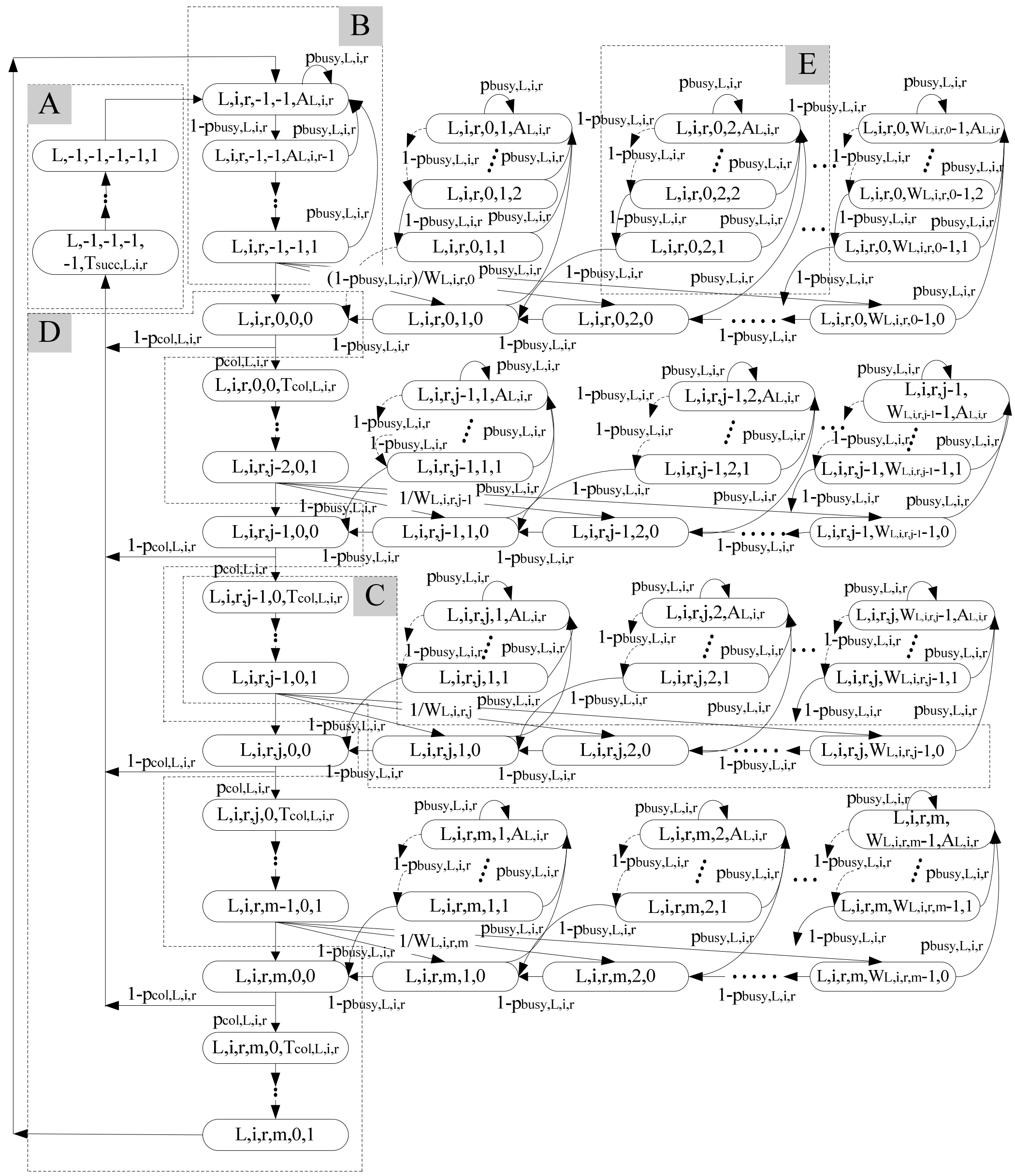

Fig. 6 The state transition diagram of multirate discrete Markov chain model

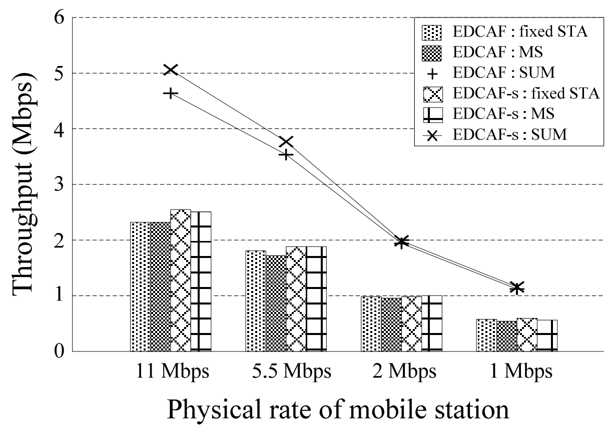

Fig. 7 The throughput comparison for case 1

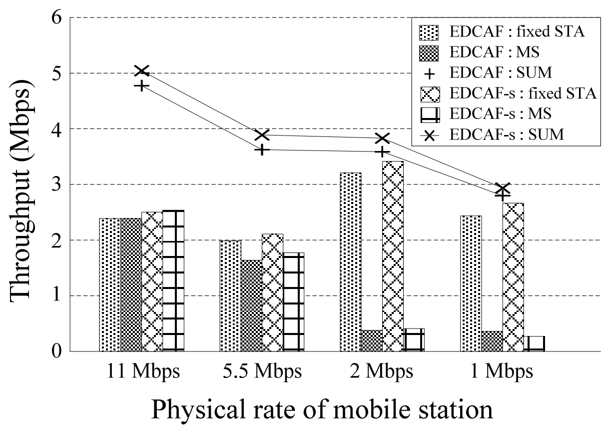

Fig. 8 The throughput comparison for case 2

According to the previous results, we simply made a summary as follows. In case 1 with the same contention parameters, a lower rate station needs a longer transmission time to transmit the same size packet, which increases the channel occupied probabilities of successful transmission and collision detection. In addition, it reduces the probability of transmission attempt and increases the probabilities of occupying channel and backoff stage in higher rate station. In case 2, the different values of AIFSN, CW_{min}, and CW_{max} will impact the frozen probability of AIFS, the idle probability of backoff stage, the transmission probability, the collision probability, and even the normalized throughput. Therefore the lower rate station will cause the unfairness of bandwidth usage and dominate the system throughput. In order to guarantee the QoS requirements, the multirate stations must be dynamically allocated different contention parameters and priorities.

4: SIMULATION EXPERIMENTS

The SNR of the receiving signal will be degraded with the increase of the distance, when a station moves away AP. In order to maintain the signal quality, the station has to use the lower transmission rate for the longer distance. We consider the situation of stations moving with different bandwidth requirements and physical rates for simulation in this section. Based on the IEEE 802.11b specification, a station selects a suitable transmission rate (11Mbps, 5.5Mbps, 2Mbps and 1Mbps) depending on the distance from AP shown as Fig. 9. Furthermore, we ignore the problems of path loss, propagation delay, BER and hidden nodes; we assume each station operates at the saturation mode as mentioned before.

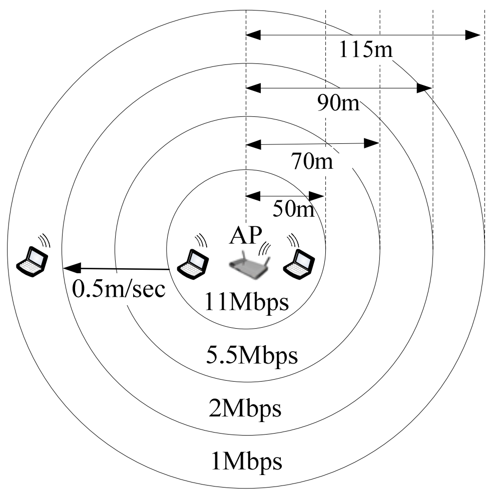

Fig. 9 A suitable transmission rate is selected depending on the distance from AP.

Table 3 The related parameters used in simulation

Category	AC0
Traffic	Stream 1
Bandwidth requirement	2.4 Mbps
Packet size	1024 bytes
Physical header (including preamble)	192 bits
MAC header (including CRC)	272 bits
Slot time	20 μs
SIFS	10 μs
DIFS	50 μs
Persistence factor	2
Retry limit	5
Physical layer rate	1/2/5.5/11 Mbps
STA moving speed	0.5 m/s

Table 4 The assumed priority matrix in the simulation

Parameters		AC (0)		
r(0)	0 < DT < 1	*PM(0,0)*	AIFSN	2
			CW_{min}	7
			CW_{max}	31
r(1)	DT = 1	*PM(1,0)*	AIFSN	2
			CW_{min}	15
			CW_{max}	63
r(2)	1 < DT	*PM(2,0)*	AIFSN	2
			CW_{min}	31
			CW_{max}	127

We consider there are two stations located in the region of the physical rate 11 Mbps. One station is fixed and always transmits at 11Mbps, while another station is mobile and moves away from the AP at the speed of 0.5 m/s when the simulation starts. The related parameters used in simulation are listed in Table 3. Both stations are assumed to have only one access category AC0 and one traffic type of stream 1, whose priority matrix is shown as Table 4. Fig. 10 shows the throughput for each station against different physical rates from the aspect of mobile station. The legacy 802.11e EDCAF can provide QoS if the physical rate satisfies the bandwidth requirement. However, EDCAF makes the throughputs of both fixed and mobile stations drop to 0.67 Mbps, when the physical rate (especially at 1Mbps) cannot provide the QoS requirements; even if the fixed station has the physical rate 11Mbps to provide its own QoS requirement; consequently the two stations cannot obtain the guaranteed QoS. For the lack of bandwidth, IEDCAF slightly reduces the throughput of mobile station to guarantee the QoS of the fixed station when mobile station cannot satisfy the bandwidth requirement. IEDCAF can still guarantee the bandwidth requirement of 2.4 Mbps to the fixed station whose physical rate meets the bandwidth requirement. It is clearly that a lower rate station results in a larger degradation of throughput under the same contention parameters. An appropriate tuning of contention parameter can improve the bandwidth utilization of WLAN.

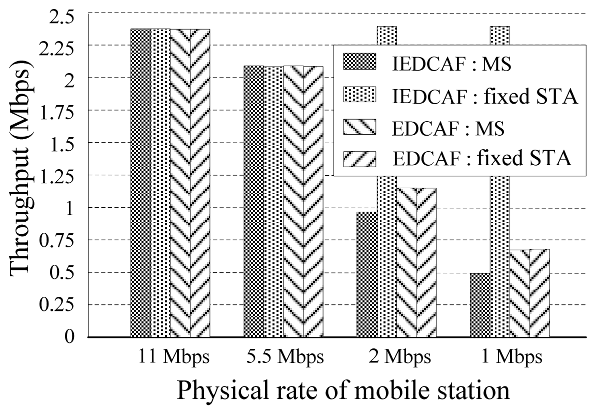

Fig. 10 Throughput of a station against different physical rates for mobile station.

According to the above shown results, IEDCAF considers the multirate effect and improves performance in the multirate wireless environment. IEDCAF keeps the simple architecture of the legacy EDCAF and maximizes the effective bandwidth utilization. IEDCAF dynamically adjusts the range of *DT* parameter in the priority matrix to control the priority of streams and benefit the bandwidth utilization in the multirate WLAN. In summary, IEDCAF can provide more stable and more efficient QoS guarantee than the legacy EDCAF.

5: CONCLUSION

Based on the cross-layer concept, the algorithm of MAC layer can be improved by the information of the transmission rate at physical layer. The stations can choose the appropriate contention parameters in priority matrix to contend the wireless channel according to the conditions of wireless network. IEEE 802.11e EDCAF configures the contention parameters to provide the different QoS requirements based on the assumption of the same physical rate, which will easily cause the channel unfair especially for communicating with lower rate station. IEDCAF uses the *DT* parameters to adjust its own contention parameters to decide its own priority and to maximize the bandwidth utilization and throughput. In the meanwhile, AP can be implemented to immediately adjust the priority matrix to get the maximum bandwidth utilization and the QoS guarantee according to the condition of wireless channel.

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