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Interframe-Space Control for Fair Throughput Guarantee in Wireless LANs with Hidden Stations

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Abstract—**This paper presents a study of ensuring throughput fairness in wireless local area networks (WLANs) with hidden stations (STAs). In the conventional enhanced distributed channel access (EDCA) mechanism, we found throughputs between stations became unfair due to the hidden-station problem even if the same quality-of-service (QoS) priority was given to the stations. In this paper, a dynamic control mechanism called one-step control is proposed to solve this problem, and it uses the interframe-space (IFS) parameter of EDCA and adaptively adjusts the IFS to an appropriate value to achieve throughput fairness according to common information on throughput in the network. The simulation results verified that the proposed mechanism could reduce the influences of hidden stations and ensure throughput fairness while total throughput could be adequately maintained.**

I. INTRODUCTION

In WLANs, stable bandwidth control becomes one of the major issues with higher requirements for quality of service (QoS). IEEE 802.11e introduced enhanced distributed channel access (EDCA), which is an extension of the distributed coordination function (DCF), to prioritize QoS for real-time flows in infrastructure WLANs [1]. EDCA supports the delivery of traffic with differentiated user priorities accomplished by an access category (AC) specific parameter set, which are defined by a contention window (CW), arbitration interframe space (AIFS), and transmission opportunity (TXOP) limits to supply medium-access-control (MAC) level QoS [2].

As the increasing demand for applications with bidirectional flows such as voice/video telephony and peer-to-peer content sharing via WLANs, the QoS of uplink flows has become vital importance. EDCA can adequately provide distributed channel access control. However, due to the uncertainty in distributions in WLANs, the existence of hidden-station problem can cause difficulties in QoS control for uplink flows, and it causes the throughputs of uplink flows to become unfair arised from the inequality of frame collisions even though the same QoS priority is given to them. In addition, the throughput of an STA in a hidden-station relationship with many other STAs can be greatly decreased because of the large collision rate. Though IEEE802.11 uses a request to send/clear to send (RTS/CTS) handshake, it cannot completely solve this problem; according to our analysis, the throughputs of STAs are still unfair even when RTS/CTS is used.

Many researches have been focused on improving the MAC of IEEE802.11 [3]-[9], and some of them has addressed improvements to throughput fairness [7]-[9]. Fang et al., [7], introduced a new backoff mechanism called Fair MAC (FMAC) where CWs were controlled based on successfully sent data frames during a time interval, which differs from the backoff mechanism for legacy DCF and EDCA. They also designed a new fair MAC from the game theoretical approach [8]. Although these mechanisms can certainly improve throughput fairness, they have introduced the need for large modifications to EDCA. Distributed deficit round-robin (DDRR), which was proposed by Atikom et al. [9], is also a MAC protocol provisioning throughput fairness. However, this method has many parameters to be adjusted and they do not mention how to determine the parameters according to the total number of hidden stations.

AIFS is the idle period before the backoff mechanism starts decreasing the backoff counter [1][2]. By using this, EDCA differentiates transmission opportunities between flows; a flow with a smaller AIFS can obtain a TXOP earlier and a larger number of TXOPs than flows with larger AIFSs. AIFS can be derived from:

$$\begin{aligned} &AIFS[AC] \\ &\quad = AIFSN[AC] \times aSlotTime + aSIFSTime \end{aligned} \qquad (1)$$

where $aSlotTime$ means the slot time and $aSIFSTime$ is the period of short IFS. The minimum AIFSN to provide the highest priority is 2, which makes AIFS equal to distributed IFS (DIFS) and is commonly used in non-QoS IEEE802.11 MAC as an IFS before decreasing the backoff counter.

This paper proposes a dynamic AIFS control mechanism to ensure throughput fairness between flows having the same QoS requirements in hidden-station topologies. In this mechanism, the access point (AP) broadcasts the average throughput in the network as a reference value for STAs via beacons, and STAs increase or decrease their AIFSs one by one based on their throughputs. We validated the proposed mechanism from a comparative evaluation with EDCA through computer simulations, in which we not only evaluated throughput fairness but also total throughput and the stability of the control mechanism. The details of one-step control are described in the next section.

II. PROPOSED ONE-STEP CONTROL MECHANISM

We first describe some basic parameters of our one-step control and then describe how it works. We have assumed that each STA only transfers one uplink flow and have not considered inactive (not sending/receiving any flow) STAs. The parameters are defined as follows.

- Small_AIFSN: The small AIFSN value used for assisting to induce more transmission opportunities.
- Large_AIFSN: The large AIFSN value used for assisting to induce fewer transmission opportunities.
- Sta_Throughput: The throughput of each STA.
- Sta_CollisionRate: The collision rate of each STA.
- Ave_Throughput: The average throughput value for all STAs.

The collision rate is defined as the ratio of the packet collision count to the successfully transmitted packet count, as given by:

$$Sta\_CollisionRate = \frac{PacketCollisionCount}{TransmittedPacketCount} \quad (2)$$

Assume there are N STAs and one AP in a WLAN. We obtain $Ave\_Throughput$ by:

$$Ave\_Throughput = \frac{\sum_{i=1}^{N} Sta\_Throughput(i)}{N} \quad (3)$$

where i indicates each station. We use throughput as reference value. The algorithm is described below:

1) At every beacon interval, AP broadcasts the value of $Ave\_Throughput$ calculated by $Sta\_Throughput$ for the period from the beginning of simulation till the latest beacon signal, which is included in the information field of the beacon.
2) Each STA compares its $Sta\_Throughput$ with $Ave\_Throughput$ upon receiving a new acknowledgement (ACK) from AP. Here $Sta\_Throughput$ belongs to the period from the beginning of simulation till the latest ACK is received. If the $Sta\_Throughput$ is larger than ($Ave\_Throughput$ $\times$ (1 + $\frac{1}{G}$)) and its AIFSN value is less than $Large\_AIFSN$, the AIFSN is increased by 1 to reduce its transmission opportunities. Otherwise, if the $Sta\_Throughput$ is less than ($Ave\_Throughput$ / (1 + $\frac{1}{G}$)) and its AIFSN value is larger than the $Small\_AIFSN$, the AIFSN value is decreased by 1 to increase its transmission opportunities.
3) When the new beacon arrives, $Ave\_Throughput$ will be updated.

We introduce a parameter called G, i.e., a control factor that can affect the precision of throughput fairness; a higher precision of throughput fairness may need a larger value. The flow chart for the algorithm is in Fig. 1.

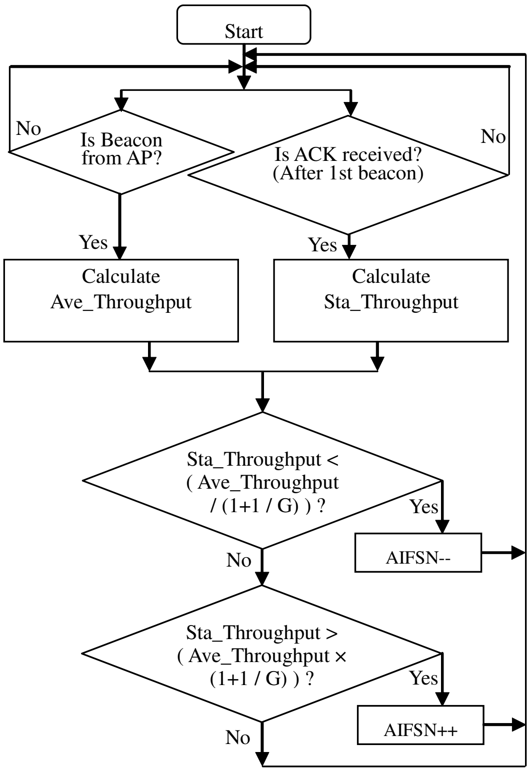

Fig. 1. Algorithm for proposed one-step control mechanism

However, we do not need to apply this algorithm to all STAs; STAs with the lowest throughput should use small AIFSNs to increase their transmission opportunities. Therefore, AP in our mechanism detects the lowest throughput and broadcasts this value during the first few beacon intervals, and AIFSNs of STAs which recognized in the state of the lowest throughputs are fixedly set to $Small\_AIFSN$. In this paper, $Small\_AIFSN$ is set to 2 and equal to the initial and minimum value of EDCA.

III. SIMULATION DESCRIPTION

We evaluate the performance of the proposed one-step control by means of QualNet network simulator with the simulation parameters in Table I. Figure 2 shows the simulation model called Topoplogy 6:3 , in which Clusters A and B are in the relation of hidden stations and cannot hear signals from each other. There are 6 STAs in Cluster A and 3 STAs in B. We assumed STAs 1 to 9 would continuously send the same constant bit rate (CBR) flows to an AP as uplink traffic, and an STA connected to the AP would receive the CBR from the AP as downlink traffic. All the STAs were initiated with the same level of QoS because we have addressed the issue of fairness in this paper. We limited the simulation time to 30 s because control should be stabilized within such short periods, especially in practical situations.

IV. SIMULATION RESULTS

A. Using Topology 6:3

1) Performance of EDCA: We have given the simulation results for conventional EDCA in Figs. 3 and 4. The uplink throughput and collision rate in the figures in this paper are given as:

$$Throughput = \frac{\sum_{i=1}^{M} Sta\_Throughput(i)}{M} \quad (4)$$

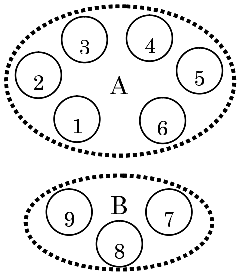

Fig. 2. Topology 6:3

TABLE I
SIMULATION PARAMETERS

aSlotTime	9 [μs]
SIFS	16 [μs]
DIFS	34 [μs]
Physical transmission rate	24 [Mbps]
CBR traffic packet size	1536 [Byte]
Parameters of EDCA	CWmin = 15, CWmax = 1023, AIFSN = 2, TXOPLimit = 0 ms
Uplink data rate	Nodes (1 - 9): 3.5 Mbps
BER	0
Simulation time	30 [s]

$$CollisionRate = \frac{\sum_{i=1}^{M} Sta\_CollisionRate(i)}{M} \quad (5)$$

M is the number of STAs in the same cluster, which is 6 for Cluster A and 3 for B with Topology 6:3. The horizontal axes of Figs. 3 and 4 indicate downlink throughput, while the vertical axes indicate the uplink throughput and collision rate, which we discuss here. The throughput in Fig. 3 becomes unfair because there are hidden stations, and the throughput for Cluster B is almost zero when the downlink traffic increases. Cluster B in Fig. 4 has a much higher collision rate than that of the A. From the Topology 6:3, we can see Cluster A has 3 hidden stations and Cluster B has 6. Therefore, Cluster B has more hidden stations than A and this induces higher collision rates and lower throughput.

2) Performance of proposed one-step control: We first used Topology 6:3 defined in Fig. 2. The AIFSN of Cluster B, which has the lowest throughput, is kept the same as the initial parameter of EDCA, and we only apply the mechanism to Cluster A. Here, we set $Large\_AIFSN$ and G to 12 and 16, but they were not limited to these; our one-step control mechanism was not sensitive to the parameters. The simulation results are shown from Figs. 5 to 8. By using the one-step control mechanism, the fairness of throughput has been greatly improved, and the total throughput is also adequately maintained. Fig. 8 plots the average AIFSN for Cluster A observed for the simulation time. The average AIFSN for the figures in this paper is defined as

$$Sta\_Ave\_AIFSN(k) = \frac{\sum_{i=Small\_AIFSN}^{Large\_AIFSN} i \times N(i)}{\sum_{i=Small\_AIFSN}^{Large\_AIFSN} N(i)} \quad (6)$$

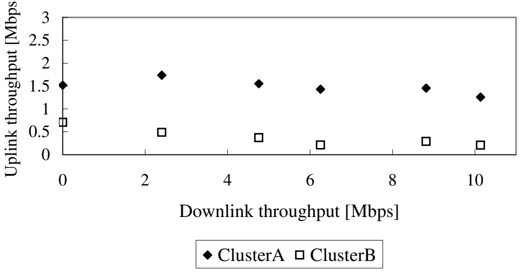

Fig. 3. Throughput of EDCA with topology 6:3

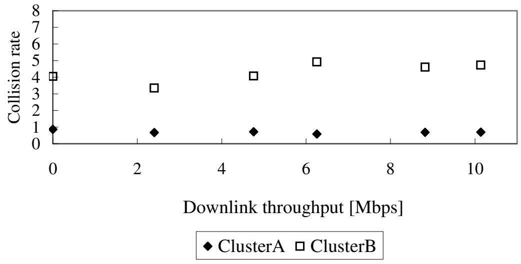

Fig. 4. Collision rate of EDCA with topology 6:3

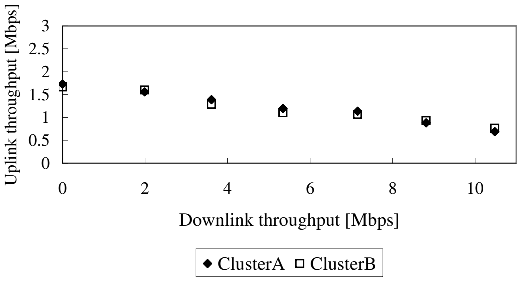

Fig. 5. Throughput of proposed one-step control with topology 6:3 (Small_AIFSN=2 Large_AIFSN=12)

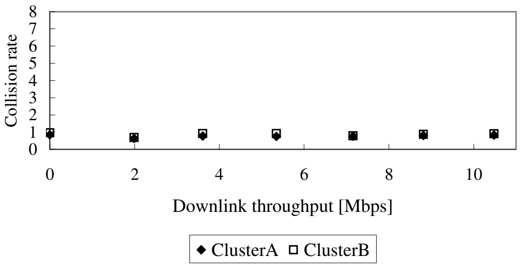

Fig. 6. Collision rate of proposed one-step control with topology 6:3 (Small_AIFSN=2 Large_AIFSN=12)

$$Average\_AIFSN = \frac{\sum_{k=1}^{M} Sta\_Ave\_AIFSN(k)}{M} \quad (7)$$

In Eq. (6), i indicates the AIFSN value used for the control mechanism, $N(i)$ is the total number of statistical times while AIFSN is set to i for an STA during the simulation time, and k means each station in the same cluster. $Sta\_Ave\_AIFSN(k)$

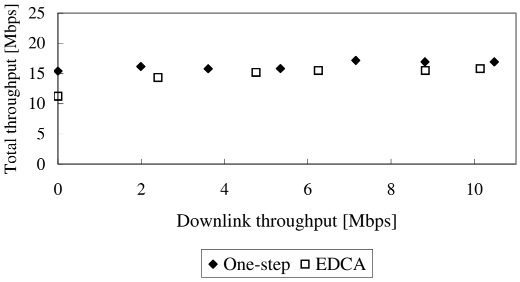

Fig. 7. Total throughputs of proposed one-step control (Small_AIFSN=2 Large_AIFSN=12) and EDCA with topology 6:3

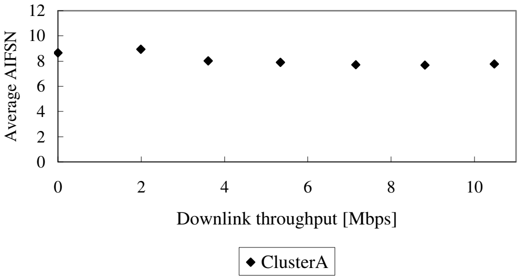

Fig. 8. Average AIFSN for ClusterA of proposed one-step control with topology 6:3 (Small_AIFSN=2 Large_AIFSN=12)

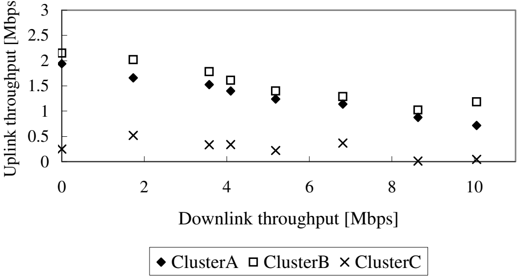

Fig. 10. Throughput of EDCA with topology 6:2:1

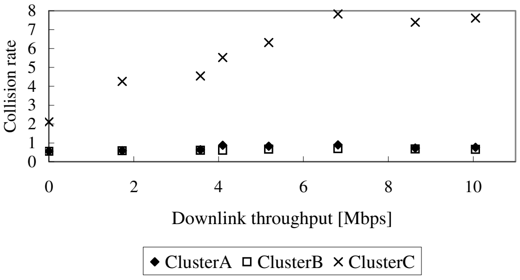

Fig. 11. Collision rate of EDCA with topology 6:2:1

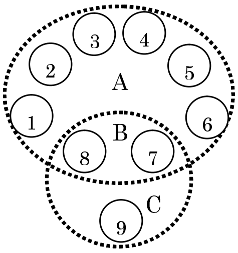

Fig. 9. Topology 6:2:1

is defined as the ratio of the total AIFSN value to the total times the AIFSN is used for an STA. According to Eq. (7), we can see the $Average\_AIFSN$ is the average AIFSN value for one cluster, as the k is the same as that in Eq. (6) and M indicates the total number of stations in one cluster. From Fig. 8, we can see the $Average\_AIFSN$ can be kept in a stable state despite the varying throughputs of downlink traffic.

B. Using Topology 6:2:1

To further test the one-step control mechanism, we designed a more complicated and practical topology called 6:2:1, given in Fig. 9. In Topology 6:2:1, STAs from 1 to 6 in Cluster A and STA 9 in Cluster C have the relation of hidden stations, while STAs 7 and 8 in Cluster B can sense signals from both Clusters A and C.

1) Performance of EDCA: The simulation results for EDCA using Topology 6:2:1 are shown in Figs. 10 and 11. We can see that throughput unfairness is associated with the number of hidden stations. Cluster B has the highest throughput and lowest collision rate since it has no hidden stations, while the performance of Cluster C has been adversely affected because it has the largest collision rate induced by the hidden-station relationship with Cluster A. Furthermore, comparing Fig. 11 with Fig. 4, we can see that the collision rates of STA 9 with Topology 6:2:1 and Topology 6:3 are all at high levels, meaning that the effect of the hidden-station relationship on an STA is determined by the number of STAs in the whole network and in the relation of hidden stations to it. In both the topologies we discuss in the paper, there was a maximum of six hidden stations for one STA, which is considered to be one of the worst cases because, in practical situations, all hidden stations are not always active.

2) Performance of proposed one-step control: We kept the AIFSN of Cluster C, which has the lowest throughput, the same as the initial parameter of EDCA, and applied the control mechanism to Clusters A and B. $Large\_AIFSN$ was set to 12 and G was set to 16, which are the same as with Topology 6:3.

The simulation results are presented in Figs. 12 to 15. We can see that throughput fairness can be adequately achieved, and the total throughput of the control mechanism is satisfactorily maintained at the same level as EDCA. The $Average\_AIFSN$ value is in a stable state according to the number of hidden stations in the topology. Cluster B has a larger $Average\_AIFSN$ value due to its optimal conditions (no hidden station) requiring a higher AIFSN value to reduce the transmission opportunities, while Cluster A has one hidden station and needs a smaller $Average\_AIFSN$ than that of

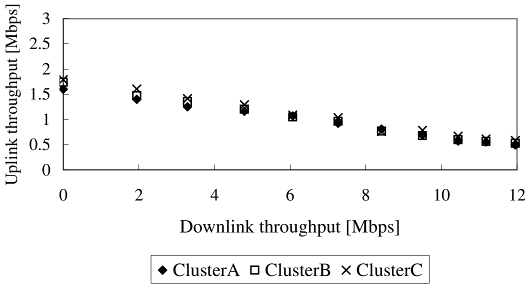

Fig. 12. Throughput of proposed one-step control with topology 6:2:1 (Small_AIFSN=2 Large_AIFSN=12)

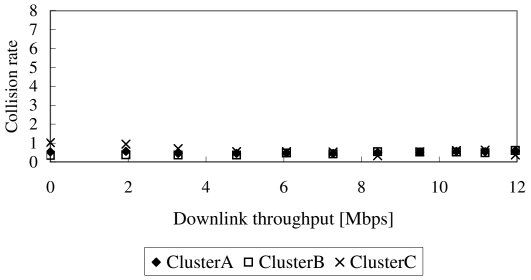

Fig. 13. Collision rate of proposed one-step control with topology 6:2:1 (Small_AIFSN=2 Large_AIFSN=12)

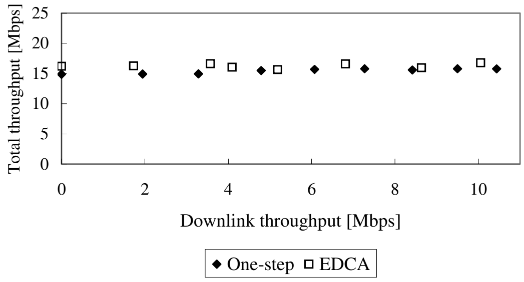

Fig. 14. Total throughputs of proposed one-step control (Small_AIFSN=2 Large_AIFSN=12) and EDCA with topology 6:2:1

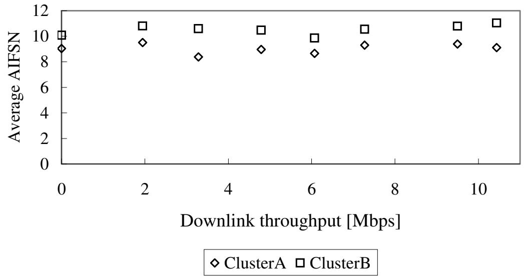

Fig. 15. Average AIFSN for Clusters A and B of proposed one-step control with topology 6:2:1 (Small_AIFSN=2 Large_AIFSN=12)

Cluster B to obtain fair throughput. For example, the average AIFSN for Clusters A and B are being kept at levels near 8 and 10 despite the variety of downlink traffic.

C. Discussion

Since the one-step control mechanism worked well with different topologies even by using the same AIFSN and G, we found that it was not sensitive to these parameters. To further demonstrate the sensitivity, we modified the $Large\_AIFSN$ to 20 instead of 12. We obtained good throughput fairness when the simulation time is increased to 90 s. The required time for reaching stable status is longer than that in the case of $Large\_AIFSN$ equaled to 12, by which the time for reaching stable status is shorter than 30 s. Increasing the value of $Large\_AIFSN$ could still yield good throughput fairness, but needed longer periods to obtain stability.

V. CONCLUSIONS

We studied what effect hidden stations had on throughput performance and found that throughput became unfair due to the hidden-station problem. We proposed the one-step control mechanism, which is an extension of the conventional EDCA, to improve the throughput fairness of networks with hidden stations. The simulation results confirmed that the proposed mechanism can reduce the impact of hidden stations and improve the fairness of throughput without decreasing the total throughput. The total collision rate can also be reduced to a great extent, which is effective in saving energy for the whole network. The proposed mechanism is also proved to be very stable under different conditions, and it can provide good flexibility and work well without being sensitive to the control parameters. In further research, we intend to extend our algorithm and focus on satisfying multiple QoS requirements within a network.

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