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Virtual Multi-AP Access for Transport-Level Quality Improvement in Wireless Local Area Networks with Hidden Stations

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SUMMARY The demand of using applications that assume bidirectional communication such as voice telephony and peer-to-peer using wireless stations has been increasing and especially, the rapid increase of uplink traffic from wireless terminals is expected. However, in uplink WLANs, the hidden-station problem remains to be solved. In this paper, we point out this hidden-station problem and clarify the following unfairness between UDP and TCP uplink flows: 1) the effect of collision caused by hidden-station relationship on throughput and 2) the instability of the throughput depending on the number of hidden stations. To solve these problems, we propose a virtual multi-AP access mechanism. Our mechanism first groups stations according to the hidden-station relationship and type of transport protocol they use then assigns a virtually isolated channel to each group, which enables STAs to communicate as if STAs in different groups are connected to different isolated APs (virtual APs: VAPs). It can mitigate the effect caused by collisions between hidden stations and eliminate the contention between UDP and TCP uplink flows. Its performance is shown through simulation.

key words: *wireless LAN, hidden-station problem, transport protocol, throughput*

1. Introduction

The recent enhancement of IEEE802.11 wireless local area networks (WLANs) has enabled us to obtain variable multimedia services. Voice telephony and video streaming services via Internet access using infrastructure WLANs are widely used. In addition to such real-time multimedia services, peer-to-peer (P2P) applications via WLANs, including information sharing and interactive games, have attracted considerable attention [1], [2]. Thus, the rapid increase in uplink traffic from stations (STAs) to an access point (AP) is expected, which means it has become more important to support the quality of service (QoS) in uplink WLANs. However, in uplink WLANs, the well-known hidden-station problem causes difficulties in QoS for uplink flows because of unfair collision probability [3], [4].

In this paper, we deal with QoS among wireless STAs in uplink WLANs that serve flows under a contention-based medium access control (MAC) protocol, that is, distributed coordination function (DCF). Using simulations, we observe uplink performances in mixed environments of user datagram protocol (UDP) and transmission control protocol (TCP) uplink flows where hidden stations exist, which has not been discussed by any prior work. The results show two differences between UDP and TCP in: 1) the effect of collision caused by hidden-station relationship on throughput and 2) the instability of the throughput depending on the number of hidden stations. Unfortunately, it is difficult to solve both of these problems using conventional ideas as explained in detail in Sect. 2.

Therefore, we propose a virtual multi-AP access mechanism for resolving these problems in infrastructure WLANs. Our mechanism groups STAs according to the hidden-station relationship and types of transport protocol then assigns a virtually isolated channel to each group, which enables STAs to communicate as if STAs in different groups are connected to different isolated APs (virtual APs: VAPs). It can mitigate the effect caused by collisions between hidden stations and eliminate the contention between UDP and TCP uplink flows. We have a couple of options to split a single physical channel to multiple virtual channels, i.e., time dimensional splitting or frequency dimensional splitting. In this paper, to minimize modification from the standard DCF, we propose a time-dimensional channel splitting mechanism, in which transmission permitted periods are assigned to each group as virtual channels. Since an AP can easily detect transport types of flows, the additional implementation complexity of our scheme is not significant. Moreover, to further improve performance, our mechanism can be combined with conventional schemes that are used where no hidden stations exist.

The rest of the paper is organized as follows. In Sect. 2, we summarize previous work related to the hidden-station problem and the unfairness of performance that the difference between UDP and TCP causes. In Sect. 3, we propose a virtual multi-AP access. The simulation parameters are described in Sects. 4, and Sect. 5 shows the performance of the proposed mechanism. Finally, Sect. 6 concludes this paper.

2. Related Work

In this section, we present several previous approaches on QoS in IEEE 802.11 WLANs. Here we highlight two categories: 1) a solution for the hidden-station problem and 2) an approach for improving the unfairness of performance between UDP and TCP.

Though IEEE802.11 defines a request-to-send/clear-to-

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send (RTS/CTS) handshake to overcome the hidden-station problem, it can not completely solve this problem. Many studies have focused on solving this problem. Although [5]–[7] can certainly improve throughput, these mechanisms do not mention the stability and fairness. The approach in [8] modified the fair medium access control (FMAC) proposed in [9], which assigns bandwidth based on the theoretical estimation where hidden stations exist. Several approaches such as [10] and [11] deal with the hidden-station problem by partitioning the STAs into groups. In [10], the probability of collisions between hidden stations can be reduced. However, hidden stations happen to belong to the same group, so this problem can not be solved. In [11], an algorithm for resolving this problem was proposed, which takes into account the fairness between hidden stations. However, [11] has not been validated by simulations. Moreover, all of these schemes do not take into account transport protocols of transfered flows. Some readers may point out that we would not have to solve the hidden-station problem if we adopted the point coordination function (PCF) standardized in IEEE 802.11 [12] instead of DCF. In reality, PCF does not work desirably in the recent densely-deployed wireless environment [13] because PCF has no mechanism that handles external interference.

In general, the throughput of TCP uplink flows severely degrades in the presence of heavily loaded UDP uplink flows. In WLANs, this can result in a bottleneck of the TCP ACKs from AP which has the same priority with STAs. IEEE802.11e supports service differentiation, which introduced enhanced distributed channel access (EDCA). However, if there is more traffic with QoS demanding the use of UDP, not TCP, EDCA has little effect on improving TCP performance. Many MAC protocols have been proposed to improve TCP performance [14]–[16]. The scheme in [17] can detect the degradation of TCP performance in the presence of UDP, which has been considered only in ad hoc networks. Several schemes in [18]–[20] improve the performance by giving more channel access to AP than STAs. The Assured Rate MAC Extention (ARME) proposed in [21] provides TCP with a fair treatment with respect to UDP. However, these schemes have not been validated in networks where hidden stations exist.

3. Virtual Channel Assignment

In this section, we propose a novel virtual channel assignment mechanism. It can mitigate the effect caused by collisions between hidden stations and eliminate the contention between UDP and TCP uplink flows. The following subsections describe the procedure of the mechanism in detail.

3.1 Grouping Algorithm

First, similar to the mechanisms described in [11], each STA needs to inform an AP of STAs list which it detected by the carrier sensing, before it sends a flow. AP detects the hidden-station relationship in the network from lists and transport protocols of the flows from the upper layer. After measuring, our proposed mechanism groups STAs connected to an AP according to the hidden-station relationship and type of transport protocol. This grouping algorithm is given as follows.

i) For every i=0,1,..., if STA_i uses two different transport protocols, it is virtually considered as two nodes, each of which uses a single transport protocol. Let n denote the total number of STAs including the virtual nodes.
ii) Initialize: add STA_0 to group G_0. i=1, j=0, m=0.
iii) Pick the group(s) in which no hidden station for STA_i exists and all the STAs are using the same transport protocol as STA_i from group G_j (j=0,1,...,m).
iv) Choose the group with the minimum number of STAs from the groups picked at the previous step. If no group was picked, m=m+1 and add STA_i to G_m.
v) i=i+1. If i=n, terminate algorithm. Otherwise, back to Step iii).

Our algorithm can be applied even to complicated topologies and STAs simultaneously using different transport protocols. For example, as shown in Fig. 1 (a), our grouping algorithm assigns STA C, which has no hidden stations, to the group where STA D belongs. This is because each group tries to have an equal number of STAs as possible according to step iv), which leads to a fair contention level for every group. On the other hand, when a STA sends two or more flows using the same transport protocol, we deal with it as one flow and assign it to a group. However, when a STA sends both UDP and TCP flows as in Fig. 1 (b), we consider it as two STAs sending TCP and UDP flows respectively to separate their transmissions, as mentioned above in step i). This is because even the STA sending both TCP and UDP flows suffers from the poor throughput of TCP flows by the coexistence with UDP flows.

3.2 Virtual Multi-AP Access Based on DCF

We here describe our virtual multi-AP access based on DCF. As shown in Fig. 2, our mechanism assigns a virtually isolated channel to each group formed in Sect. 3.1, which enables STAs to communicate as if STAs in different groups are connected to different VAPs. In this paper, adopting a

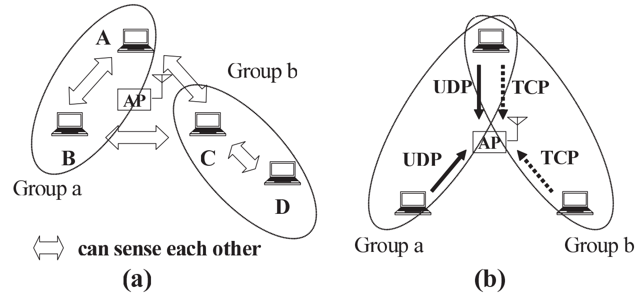

Fig. 1 Example of grouping.

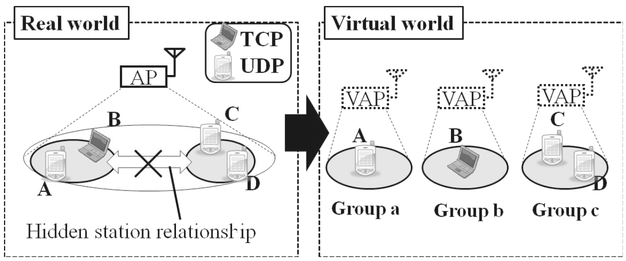

Fig. 2 Virtual AP.

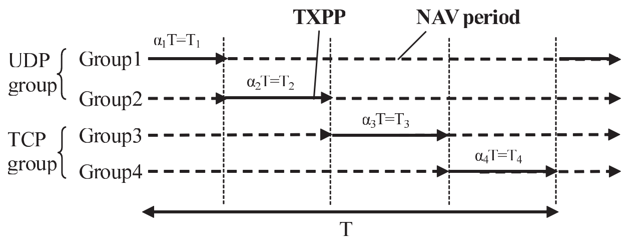

Fig. 3 Alternating between TXPP and NAV periods.

time slot as a virtually isolated channel, our mechanism assigns a transmission permitted period (TXPP), where DCF is applied, and network allocation vector (NAV) period to each group.

3.2.1 Calculation of TXPP

After several groups of STAs are derived with our proposed grouping algorithm, an AP calculates the duration of TXPP for each group then assigns TXPP and NAV period for each group. STAs within the same group contend for access to the wireless channel during the TXPP. While, the NAV period is defined as the period where STAs can not transmit any data frame. While a TXPP is allocated to a group, NAV periods are allocated to other groups. An example allocation of TXPP is shown in Fig. 3. T_i, which is the duration of the TXPP allocated to Group j (with $j = 1,2,\ldots,m$), is defined by the following equation:

$$T_j = \alpha_j T \qquad \left(\sum_j \alpha_j = 1\right), \tag{1}$$

where T represents the total TXPP, which is equal to the time duration of one TXPP assignment cycle, and α_j is the TXPP ratio of Group j. The proposed mechanism avoids collisions among different groups and enables us to flexibly handle QoS by adjusting α_j based on user requirements or the operator policy. Assuming that each STA sends only one uplink flow, we determine α_j in proportion to β_j defined as;

$$\beta_j = \sum_i D(R_{ij}), \tag{2}$$

where R_{ij} is the physical transmission rate of STA_i in Group j and $D(R)$ is the time duration needed for transmitting one data frame with physical transmission rate R [8]. Note that

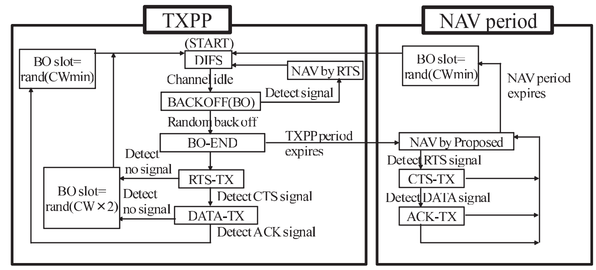

Fig. 4 Flow chart of STA.

α_j is proportional to the number of STAs belonging to group j when the physical transmission rate is uniform. This follows the principle of DCF, in which transmission opportunities are given uniformly to every STA.

We will mention the effect of α_j on throughput in Sect. 5.3. We have to mention, when STAs require a specific constant throughput for each, grouping may reduce the utilization efficiency by splitting shared resource into smaller pieces. However, as we will show in Sect. 5, it should be highly prioritized in QoS management to resolve collisions caused by hidden-stations. To optimize the utilization efficiency in our TXPP assignment, ultimately, we would need to determine TXPP according to required throughputs. Although we consider this optimization out of scope in this paper, at least, we will mention the effect of α_j in the above equation on throughput in Sect. 5.3.

3.2.2 Action of AP and STAs

The process for moving between TXPP and NAV periods is described below:

i) An AP broadcasts the grouping information including the TXPP duration, the total duration of TXPP T, and the start time of the first TXPP for each group via the first beacon signal.
ii) Each STA sets a NAV upon receiving the beacon signal and enters the TXPP at the start time of the first TXPP.
iii) Each STA in the TXPP shifts to the NAV period if the deadline of the TXPP comes before its backoff slot becomes zero.
iv) Each STA in the NAV period shifts to the TXPP after T from its previous TXPP, and repeats iii) to iv).

A flow chart of the above procedure is shown in Fig. 4. In step iii), collisions between hidden stations belonging to the neighboring groups could happen when the STA in the TXPP transmits RTS just before the TXPP expires. To avoid these collisions, we set the deadline of the TXPP to an earlier time than the start of the next TXPP. If the hidden-station relationship or the transport protocol information changes, shifted to step i), the AP broadcasts new grouping information using the beacon signal, and every STA updates its NAV and TXPP. Note that, even during the NAV period, STAs are allowed to receive data frames in the downlink and return CTS and MAC-ACK. Our virtual multi-AP access needs not to be used in the downlink because no hidden-station exists there.

3.3 Scalability

Though much research has been done to develop IEEE 802.11 WLANs, most of the methods do not work well in networks with hidden-station relationships. However, these methods can be incorporated into our mechanism, where STAs work based on the conventional DCF without hidden-station relationships. Moreover, in our mechanism, any STA contends only with other STAs using the same transport protocol, which enables us to individually innovate the appropriate scheme to each transport protocol. We show an example of this enhancement of our mechanism in Sect. 5.4. Thus, we can say that our proposed mechanism has a high scalability.

4. Simulation Description

To validate our mechanism, we implemented it into the QualNet 4.5 network simulator. All simulations were done with the simulation parameters listed in Table 1. We set the physical transmission rate uniform. Since RTS/CTS is used in our simulation, the difference of physical transmission rates between STAs is not technically important in our study. We designed the network topology in which ten stations upload simultaneously data to a corresponding node (CN) in Fig. 5. As shown in this figure, Clusters A and B are in the hidden-station relationship and can not detect signals from each other. The reason we used this topology is because the two-cluster case most obviously characterizes the fundamental effect of the hidden-station relationship, though our mechanism can be flexibly applied to more complicated topologies. We assumed that each STA sent one uplink flow which uses either UDP or TCP and that the required throughput of each UDP flow was uniform. We did not consider inactive (not sending/receiving any flow) STAs. We compared the proposed mechanism with other schemes, namely, the conventional DCF, the TCP-ACK prior scheme [18], and the hidden-grouping scheme [11]. In this paper, we assume that the hidden-grouping scheme acts exactly like our mechanism, except grouping algorithm in Sect. 3.1. For readability, the proposed mechanism, the conventional DCF, the TCP-ACK prior scheme, and the hidden-grouping scheme are respectively denoted as 'Proposed', 'DCF', 'TCP-ACK prior', and 'Hidden grouping' in the following figures.

Table 1 Simulation parameters.

Smulator	QualNet4.5 [22]
Wireless system	IEEE802.11a [23]
RTS/CTS	ON
Phy. trans. rate	24 [Mbps]
Data frame size (UDP)	1500 [bytes]
Maximum segment size (TCP)	1500 [bytes]
Beacon interval	200 [ms]
TCP	Reno+SACK
Receive buffer size	65000 [bytes]
UDP flow	CBR (Constant Bit Rate)
Required rate per UDP flow	4 [Mbps]
TCP flow	FTP (File Transfer Protocol)
Bit Error Rate	0
Simulation time	60 [s]

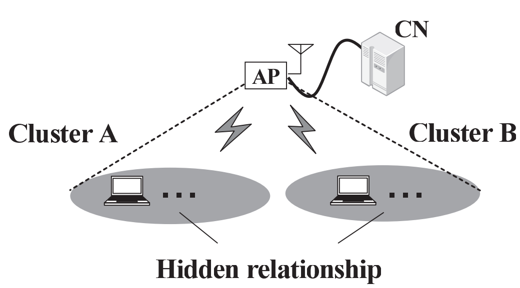

Fig. 5 Topology with hidden-station relationship.

5. Simulation Evaluation

5.1 Multiple UDP Uplink Flows

We consider a network scenario with only UDP uplink flows, which performs the conventional DCF and our mechanism. In this case, our algorithm classifies STAs of Clusters A and B into Groups a and b, respectively, because it makes groups only based on the hidden-station relationship when all STAs in the network is using the same transport protocol. Here, Our mechanism allocates the TXPP to each Group in proportion to the number of STAs belonging to each Group along Eqs. (1) and (2) with uniform physical transmission rate.

First, we evaluated the proposed mechanism by varying the number of hidden stations. Figures 6 and 7 show the average throughput and collision rate with varying the number of STAs in Cluster A while fixing the total number of STAs to ten. We define the collision rate as the ratio of the number of RTS collisions to the total number of transmitted RTSs. From Fig. 6, we can see that in the conventional DCF, the throughputs become unstable against the number of hidden stations. This instability makes it too difficult to control the communication quality. Moreover, the throughput of the conventional DCF becomes unfair between Clusters A and B. However, Fig. 7 shows that in the conventional DCF, Cluster A has a higher collision rate than that of B. This is because Cluster A has more hidden stations than B, which induces higher collision rates and lower throughput. However, Cluster A has higher throughput than B despite a higher collision rate only when there is one STA in Cluster A because the STA does not detect any signal from other STAs, which allows it more transmission opportunities than those in Cluster B. In contrast to DCF, the proposed mechanism maintains its stability and improves the throughput fairness between Clusters A and B with increasing the total throughput. Moreover, the collision rate has significantly decreased, which can be of great benefit in saving energy in real uses of WLANs.

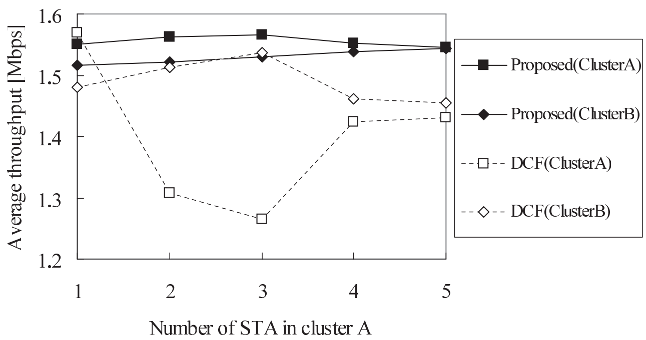

Fig. 6 Throughput according to variation of topology with only UDP flows.

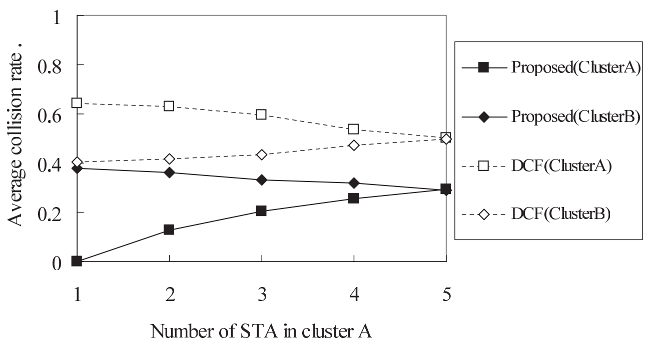

Fig. 7 Collision rate according to variation of topology with only UDP flows.

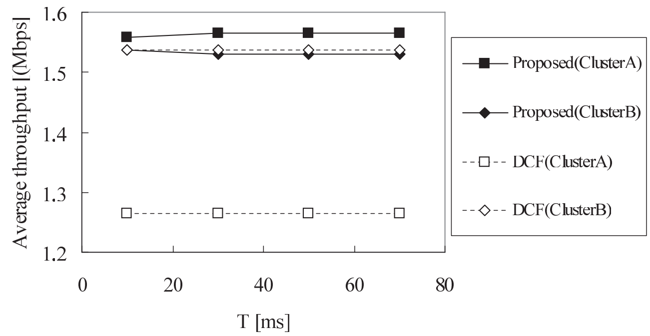

Fig. 8 Throughput according to variation of T in model 1.

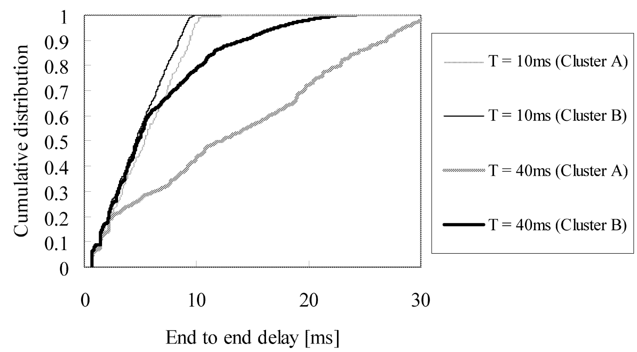

Fig. 9 End to end delay with only UDP flows.

Table 2 Traffic models.

	ClusterA	ClusterB
Model 1	3 (UDP)	7 (UDP)
Model 2	3 (TCP)	7 (TCP)
Model 3	4 (UDP)+1 (TCP)	1 (UDP)+4 (TCP)

In Fig. 6, the throughput of cluster A in DCF became the worst when the number of STAs in cluster A is three. First, as the number of STAs in the same cluster increases, each STA suppresses its transmission based on CSMA/CA. On the other hand, as the number of STAs in the other cluster increases, collisions happen more frequently because of the hidden-station problem. Therefore, we consider that the combined effect of these two factors minimized the throughput in cluster A when the number of STAs was three.

Next, we evaluated the proposed mechanism by varying the total TXPP, T. We use model 1 in Table 2 as the traffic model. Figure 8 shows the effect of T on the average throughput. The results plotted in this figure indicate that a single flow can get the same throughput, independently of their T. This is due to the fact the overhead induced by the transition between TXPP and NAV periods is almost independent of T. In Fig. 9, the cumulative distribution of the end-to-end delay time from STAs to CN is shown. We can see that the delay tends to increase in the proposed mechanism as T increases. This is because the increase in T increases NAV duration. However, the delay time is acceptable as long as we set T to less than 40.

5.2 Multiple TCP Uplink Flows

We consider a network scenario with only TCP uplink flows with the conventional DCF, the TCP-ACK prior scheme, and our mechanism. In the TCP-ACK prior scheme, an AP uses PIFS access, which leads to no collisions between the AP and STAs. Though some researches have shown the effect of the scheme prioritizing TCP-ACK, no one has verified it in a topology where hidden stations exist. As in the previous section, our algorithm classifies STAs of Clusters A and B into Groups a and b respectively, and allocates a TXPP to each Group in proportion to the number of STAs.

As in Sect. 5.1, we first evaluated the proposed mechanism by varying the number of hidden stations. In Figs. 10 and 11, we show that the average throughput and collision rate with a varying number of STAs in Cluster A while fixing the total number of STAs to ten. From Fig. 10, we can see that in the conventional DCF, the throughputs become unstable against the number of hidden stations and become unfair between Clusters A and B. If we compare the unfairness of throughput in the conventional DCF between Figs. 6 and 10, we can see that the unfairness in Fig. 10 is much more serious than that in Fig. 6, and we should mention the throughput of Cluster A in Fig. 10 becomes almost zero when there is one STA in Cluster A. This is because the TCP congestion control adjusts the sending rate of a TCP flow according to the network condition, which means the collision rate has a much greater effect on the TCP throughput than that of

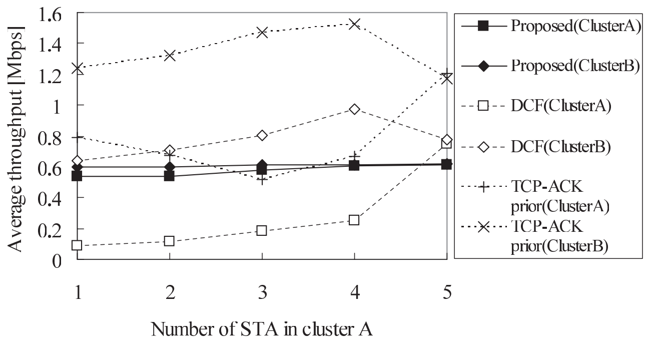

Fig. 10 Throughput according to variation of topology with only TCP flows.

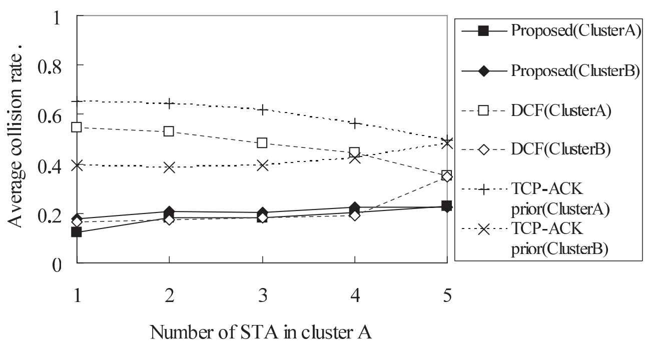

Fig. 11 Collision rate according to variation of topology with only TCP flows.

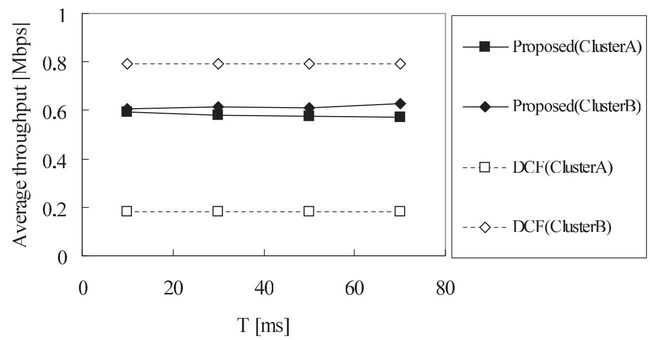

Fig. 12 Throughput according to variation of T in model 2.

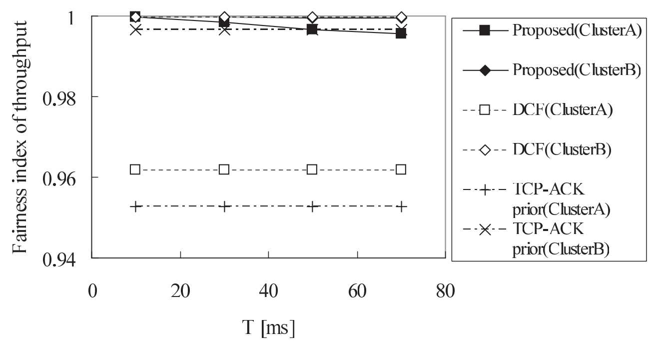

Fig. 13 Fairness index according to variation of T in model 2.

UDP. This is evident from Fig. 11, which shows that Cluster A has a much higher collision rate than B. In Fig. 10, we can see that in the TCP-ACK prior, the throughput is the largest of all schemes because STAs transmit frames close to the maximum segment by equally obtaining transmission opportunities and high collisions, as shown in Fig. 11, though it remains unstable. This instability could be worse in a more complicated topology, which would be a serious problem for QoS. However, using the proposed mechanism, the stability and fairness of throughput have been greatly improved, and the collision rate has been reduced. Moreover, as mentioned in Sect. 3.3, our proposed mechanism can easily introduce conventional schemes including the TCP-ACK prior. If the TCP-ACK prior scheme is incorporated to our mechanism, STAs in both Clusters A and B could obtain a throughput of around 1.2 Mbps.

Next, we evaluated the proposed mechanism by varying the total TXPP, T. Here, we use model 2 in Table 2. Figure 12 shows the average throughput with varying T. It can be seen that the throughput is independent of T, that is, under Model 2 the proposed mechanism performs almost as well as Model 1. Figure 13 shows the effect of T on fairness of throughput. Here, we evaluated the fairness index [24] as the degree of fairness. When the average throughput per flow is O, and X_i, and n show the throughput for STA i and the number of STAs, fairness index f is given as:

$$x_i = X_i/O \tag{3}$$

$$f = \left(\sum x_i\right)^2 \Big/ \left(n \sum (x_i)^2\right), \tag{4}$$

A score of 1.0 means that all TCP flows have equal throughput. We can see in Fig. 13 that the fairness indexes of cluster A is smaller than those of B in DCF and TCP-ACK prior, whereas the fairness index of the proposed mechanism is almost 1 despite cluster. This superiority of the proposed mechanism results from no collisions caused by the hidden-station relationship.

5.3 Mixed UDP and TCP Uplink Flows

To illustrate a more realistic network, we consider a network scenario with mixed UDP and TCP uplink flows, and simulated model 3 in Table 2. The performance of our proposed mechanism is compared with that of the conventional DCF, the TCP-ACK prior scheme and the hidden-grouping scheme. We set the total TXPP, T to 40 ms.

The average throughputs of conventional schemes and our proposed mechanism are shown in Table 3. First, to show the effect caused by hidden station collisions on the throughput, we observed the performance of the conventional schemes. From Table 3, we can see that the throughput unfairness occurs by hidden station collisions in DCF and TCP-ACK prior, while no collisions between hidden stations leads to fairness between Clusters A and B in Hidden grouping. However, the poor throughputs of TCP flows caused by the coexistence with UDP flows remain unsolved in all schemes. This unfairness could be worse in a more complicated topology, which would lead to the instability.

Table 3 Throughput [Mbps] comparison for DCF, TCP-ACK prior, Hidden grouping, and proposed.

	Cluster		Transport		All
	CL.A	CL.B	UDP	TCP	
DCF	2.4	0.4	2.5	0.34	1.4
TCP-ACK prior	1.6	1.0	1.6	1.1	1.3
Hidden-grouping	1.3	1.2	1.7	0.79	1.3
Proposed	1.3	1.4	1.3	1.3	1.3

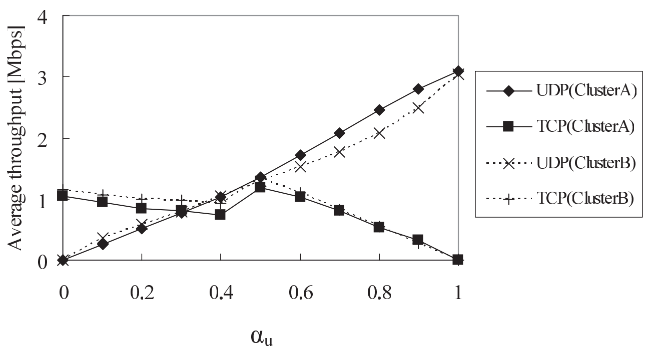

Fig. 14 Throughput of proposed mechanism according to variation of α_u in model 3.

Next, we observed the performance of the proposed mechanism. Our algorithm classifies STAs serving UDP and TCP flows in Clusters A and B into Groups a, b, c, and d, respectively because it makes groups based on both hidden-station relationship and transport protocol. Here, according to Eqs. (1) and (2), when phsycal transmission rate is uniform, our mechanism allocates the TXPP to each Group in proportion to the number of STAs belonging to each Group, that is, $\alpha_a = 0.4, \alpha_b = 0.1, \alpha_c = 0.1, \alpha_d = 0.4$. From Table 3, we can see that our proposed mechanism achieves the fair throughput independently of the hidden-station relationship and type of transport protocol. Moreover, our proposed mechanism maintains the total throughput at the same level as conventional schemes.

Moreover, our mechanism can flexibly control the performance of UDP and TCP flows by handling the total ratio α_u of UDP Groups (that is, $\sum_{j}^{UDP} \alpha_j$). Figure 14 shows the average throughputs of the proposed mechanism by varying α_u from 0 to 1. As α_u increases, the throughputs of UDP flows increase while maintaining fairness between Clusters A and B. TCP flows also denote the same tendency of UDP flows, while the throughputs of TCP flows when the α_u is 0.5 become larger than those when the α_u is 0.4. This is because the segment size at 0.5 tends to be larger than at 0.4. While STAs at 0.4 transmit data frames before the amount of data becomes a maximum segment size in TCP level, those at 0.5 accumulate data during the longer NAV period. From Fig. 14, we can conclude that the proposed mechanism improves the throughput fairness between Clusters A and B, and enables us to flexibly allocate bandwidth between UDP and TCP.

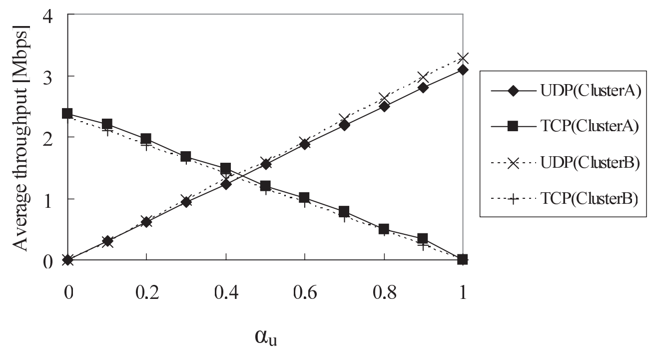

Fig. 15 Throughput of proposed mechanism with conventional schemes according to variation of α_u in model 3.

5.4 Evaluation of Scalability

We show an example of the scalability of the proposed mechanism mentioned in Sect. 3.3. Here, we incorporate the optimal minimum contention window for UDP and TCP proposed in [25] and [26], which efficiently utilizes channel by adjusting contention window according to the number of contending STAs, in our virtual UDP and TCP groups, respectively. Figure 15 shows the average throughputs of the proposed mechanism with these schemes versus the value of α_u. From this figure, compared with Fig. 14, we can see that the average throughputs of both UDP and TCP increase. When α_u is from 0 to 0.5, that of TCP flows is greatly improved. This is because STAs sending TCP flows transmit the data frame close to the maximum segment size due to the effect of prioritizing TCP-ACK [26]. Furthermore, the fairness of throughput between Clusters A and B is also improved. Thus, we can easily obtain further improvement by combining the proposed mechanism with conventional schemes that were designed for non hidden-station networks.

5.5 Evaluation in More Complicated Topology

The contribution of this paper is to show the basic mechanism and the basic performance of our virtual multi-AP access. However, readers may be interested in how our mechanism would work if the topology was more complicated and the number of groups was limited due to an implementation constraint. As mentioned in Sect. 3.1, our algorithm is obviously applicable to any complicated topologies. However, since it forms more groups as the number of hidden-station relationships increases, the algorithm is infeasible if the number of groups is limited to a certain number. In that case, instead of the algorithm, we could use the optimization algorithms as below. The optimal grouping $S*$ is obtained from

$$S* = \underset{S}{\mathrm{argmin}}(\text{avg no. of hidden stations});$$
$$\text{subject to } m = M :$$

where S is a possible grouping pattern and M is the total

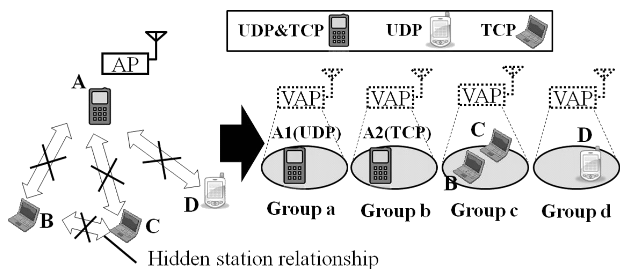

Fig. 16 Complicated topology (Transport info.: "UDP flow: A, D", "TCP flow: A, B, C", Hidden info.: "A has B, C, D", "B has A, C", "C has A, B", "D has A").

Table 4 Throughput [Mbps] and collision rate in complicated topology.

		A1	A2	B	C	D	All
DCF	Throughput	2.7	0.75	2.0	2.2	6.1	2.8
	Coll. rate	0.35	0.39	0.29	0.29	0.22	0.29
Proposed	Throughput	3.1	2.5	2.2	2.4	2.9	2.6
	Coll. rate	0.018	0.12	0.16	0.15	0.052	0.098

number of groups. This algorithm allows us to expect the increase of the total throughput. On the other hand, when we want to improve the lower-bound throughput, the algorithm can be

$$S* = \underset{S}{\text{argmin}}(\text{max no. of hidden stations for a STA});$$
$$\text{subject to } m = M :$$

The performance of these algorithms with $M = 4$ in a complicated topology in Fig. 16 is shown in Table 4. Note that the above two algorithms bring us the same solution for this example. From Table 4, compared with DCF, the fairness between STAs is greatly improved by our mechanism while maintaining the total throughput. It should be out of scope in this paper how to selectively use the above algorithms and the detail analysis to limit our discussion in this paper to the basic mechanism and the basic performance of our virtual multi-AP access.

6. Conclusion

In this paper, we pointed out hidden-station problems and showed the following unfairness between UDP and TCP uplink flows: 1) the effect of the collision caused by the hidden-station relationship on the throughput and 2) the instability of the throughput depending on the number of hidden stations, which had not been clarified previously. In order to resolve these problems, we propose a virtual multi-AP access mechanism in infrastructure WLANs. Our mechanism groups STAs according to the hidden-station relationship and types of transport protocol then assigns a virtually isolated channel to each group, which enables STAs to communicate as if STAs in different groups are connected to different VAPs. It can mitigate the effect caused by collisions between hidden stations and eliminate the contention between UDP and TCP uplink flows. The results from the simulation showed that our mechanism achieved stable and fair throughput and a smaller collision rate independently of the number of hidden stations. Moreover, our mechanism provides a fair bandwidth allocation to UDP and TCP by controlling TXPP. Finally, we showed possible further improvement of the proposed mechanism by introducing the conventional schemes for use where no hidden stations exist and the effectiveness of the proposed mechanism in a more complicated topology.

Our future research will include the proposal of frequency dimentional splitting mechanism and simulations under different network configurations.

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