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An Intelligent Mechanism for Increasing the Bandwidth Utilization of Qos Applications in Ad Hoc Wireless Networks

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Abstract: - The increasing use of ad hoc networks for transferring multimedia applications such as voice, video, and data, leads to the need to provide QoS support. The provision of QoS relies on resource reservation. Precise estimation of remaining bandwidth is an essential part of resource reservation. However, it is difficult even if the ad hoc networks are static. This is because that the remaining bandwidth of each node is relative to the scheduling policy of the adopted MAC layer protocol and may be a probability distribution. In this paper, we first propose an estimation method of remaining bandwidth when the adopted MAC layer protocol is carrier sense multiple access with collision avoidance (CSMA/CA). Since CSMA/CA is a contention-based MAC protocol, arbitrary transmission sequence (schedule) of flows is possible and the bandwidth utilization is inefficient. We propose an intelligent mechanism, called *priority number*, to avoid some inefficient schedules of CSMA/CA. By the aid of priority number, the remaining bandwidth of each node may be increasing and the bandwidth utilization can be improved.

Key-Words: - Ad hoc; Bandwidth; MAC; QoS; Schedule

1 Introduction

An ad hoc network consists of a collection of wireless nodes in which each node communicates with one another without the aid of wired based stations. Since each node has a limited effective range, distant nodes communicate through multihop paths with other nodes in the middle as routers. In order to provide quality delivery to delay sensitive applications such as voice and video in the next generation wireless networks, it is required and conceivable to support quality of service (QoS) in a routing protocol [1].

QoS guarantees can be attained with appropriate resource reservation techniques. Precise estimation of remaining bandwidth is necessary to perform bandwidth reservation. It is a trivial task in wired networks since the underlying medium is a dedicated point-to-point link with fixed capability. However, it is difficult even if the ad hoc networks are static. This is because that the radio channel of each node is shared with all its neighbors in wireless networks. It causes that the remaining bandwidth of each node is relative to the scheduling policy of the adopted MAC layer protocol and may be a probability distribution.

Many QoS routing protocols in ad hoc networks are resource reservation-based protocols and have been proposed in recent literature [2]-[6]. In [2]-[4], the estimation methods of bandwidth for the underlying MAC protocol are not specified. In [5], a simple estimation method of bandwidth has been proposed for carrier sense multiple access with collision avoidance (CSMA/CA). In this method, the remaining bandwidth of a node is equal to the raw data rate minus the amount of bandwidth required for existing flows that are in the radio coverage of the node. However, the estimation does not consider the *hidden route problem* that has been addressed in [6].

Hidden route problem indicates that the available bandwidth of a node is overestimated in [5]. In [5], a new flow only considered its available bandwidth and did not consider that the available bandwidth of its neighbor flows. It causes that admitting a new flow may violate the bandwidth requirements of some existing flows. The hidden route problem has been considered in the estimation method of bandwidth proposed in [6]. However, QoS violation still occurs in some situations.

In this paper, we first propose a correct estimation method of remaining bandwidth when the adopted MAC layer protocol is CSMA/CA. Since CSMA/CA is a contention-based MAC protocol, arbitrary transmission sequence (schedule) of flows is possible and the bandwidth utilization is inefficient. We propose an intelligent mechanism, called *priority number*, to avoid some inefficient schedules of CSMA/CA. By the aid of priority number, the remaining bandwidth of each node may be increasing and the bandwidth utilization can be improved.

The rest of the paper is organized as follows. Section 2 briefly discusses related work for bandwidth reservation in CSMA-based ad-hoc networks. Section 3 proposes a correct estimation method of remaining bandwidth when the adopted

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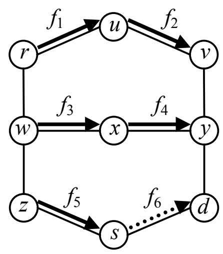

Fig. 1. An example to show the estimation methods proposed in [5] and [6].

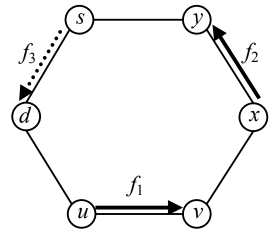

Fig. 2. Another example to show the QoS violation occurred in the estimation method proposed in [6].

MAC layer protocol is CSMA/CA. In Section 4, the operation of CSMA/CA with priority number will be described in detail and the corresponding estimation method of bandwidth will be proposed. The bandwidth utilization of CSMA/CA with priority number will be studied in Section 5. Section 6 concludes this paper.

2 Related Work

In [5], the available bandwidth of a node is equal to the raw data rate minus the amount of bandwidth required for existing flows that are in the radio coverage of the node. For example, refer to Fig. 1. The raw data rate is 11 Mbps. The flows from f_1 to f_5 are existing flows with bandwidth requirements from b_1 to b_5 respectively, where b_1=3 Mbps, b_2=4 Mbps, b_3=2 Mbps, b_4=3 Mbps and b_5=3 Mbps. The flow, f_6, is a new flow from node s to node d. According to the estimation method proposed in [5], the available bandwidth of s is 8 Mbps (i.e., $11-b_5=8$). The available bandwidth of d is 5 Mbps (i.e., $11-b_4-b_5=5$). So the available bandwidth of f_6 is 5 Mbps. However, the estimation method does not consider the *hidden route problem* addressed in [6].

Hidden route problem indicates that the available bandwidth of a node is overestimated in [5]. In [5], a new flow only considered its available bandwidth and did not consider the available bandwidth of its neighboring flows. Admitting a new flow may violate the bandwidth requirements of some existing flows. In the above example, if the bandwidth requirement of f_6, b_6, is 5 Mbps, admitting f_6 increases the bandwidth consumption in the radio coverage of node y to $b_2+b_3+b_4+b_6$=14 Mbps, which violates the raw data rate (11 Mbps). Since CSMA/CA is a contention-based MAC protocol, the bandwidth requirements of some flow that passes through node y (i.e., f_4) may be violated. The hidden route problem was considered in the estimation method proposed in [6]. We use the same example in Fig. 1 to explain the estimation method. To estimate the available bandwidth of s, one not only needs to consider s, but also needs to consider all its neighbors. So the available bandwidth of s is 5 Mbps (i.e., $\min\{11-b_5, 11-b_3-b_5, 11-b_4-b_5\}$). Similarly, the available bandwidth of d is 2 Mbps (i.e., $\min\{11-b_4-b_5, 11-b_5, 11-b_2-b_3-b_4\}$). The available bandwidth of f_6 is 2 Mbps.

Although the hidden route problem was considered in [6], QoS violation still occurs in some situations. For example, refer to Fig. 2. The raw data rate is 2 Mbps. The flows, f_1 and f_2, are existing flows and both bandwidth requirements are all 1 Mbps. The flow, f_3, is a new flow from node s to node d. According to the estimation method in [6], the available bandwidth of s is 1 Mbps (i.e., $\min\{2-b_2, 2-b_2, 2-b_1\}$) and the available bandwidth of d is 1 Mbps (i.e., $\min\{2-b_2, 2-b_1, 2-b_1\}$). So the available bandwidth of f_3 is 1 Mbps. If the bandwidth requirement of f_3 is 1 Mbps, f_3 can be admitted to transmit. However, no matter how an ideal schedule of transmission is adopted, the bandwidth requirements of f_1, f_2 and f_3 cannot be satisfied in the real conditions.

3 Bandwidth Estimation in CSMA-Based Ad-Hoc Networks

Precise estimation of remaining bandwidth is necessary to perform bandwidth reservation. Since available bandwidth is not only related to the constraints for the conflict-free transmissions, but also the scheduling policy of the underlying MAC protocol. So we must discuss them first.

3.1 Conflict-Free Transmission

Assume that the effective transmission distance of every node is equal. The cases that the neighboring flows can transmit simultaneously without interference are discussed as follows. Considering three cases in Fig. 3, f_1 and f_2 are neighboring flows of each other. If the underlying MAC protocol can solve the hidden terminal problem [7] (case (c)) without

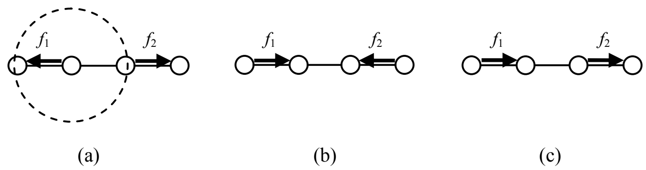

Fig. 3. Three cases of neighboring flows: case (a), case (b) and case (c).

carrier sense and RTS/CTS handshake, f_1 and f_2 can transmit simultaneously without interference in case (a) and case (b). Unfortunately, all CSMA-based protocols relied on these two mechanisms to solve the hidden terminal problem.

If the carrier sense mechanism is adopted, the exposed terminal problem [8] (case (a)) arises. If the RTS/CTS handshake is adopted, f_1 and f_2 cannot transmit simultaneously in case (b) due to Network Allocation Vector (NAV) [9]. Concluded with previous discussion, if the underlying MAC protocol is a CSMA-based protocol, a flow can transmit only when all neighboring nodes of the sender and the receiver of the flow do not transmit and receive packets at the same time (i.e., neighboring flows cannot transmit simultaneously in all cases of Fig. 3).

3.2 Scheduling Policy

Considering the following scenario, the topology of the ad-hoc network is the same as the example in Fig. 1. The raw data rate is 3 Mbps. f_1 to f_5 are existing flows with bandwidth requirements 1 Mbps. f_6 is a new flow from node s to node d. Since CSMA/CA is a contention-based MAC protocol, arbitrary transmission sequence of flows is possible. In order to simplify the representation of a schedule, we assume that the transmission unit is 1 Mb and consider the following two schedules. Schedule A: f_1, f_4 and f_5 transmit at first (according to the discussion of previous subsection, f_1, f_4 and f_5 can transmit simultaneously without interference). Then f_2 and f_3 transmit continuously after the transmission of f_1, f_4 and f_5 finished. Schedule B: f_2 and f_5 transmit first. Then f_1 and f_4 transmit second. f_3 transmits finally. In this scenario, we can observe that the available bandwidth of f_6 is relative to the schedule of flows. Since f_6 cannot transmit at the time when f_4 or f_5 transmits, the available bandwidth of f_6 is 2 Mbps in schedule A and 1 Mbps in schedule B. Since arbitrary schedule of flows is possible, the available bandwidth of f_6 is a probability distribution.

3.3 Calculation of Available Bandwidth

In the previous discussion, we can know that determining the probability distribution for a new flow f_k in any arbitrary scenario is difficult. Besides, in order to perform the QoS guarantees, a stringent admission control (or a conservative bandwidth reservation) is necessary. Therefore, we resort to determine the maximum bandwidth, denoted by B_k, so that i) the probability of satisfying the requirement of f_k is equal to one hundred percent when the bandwidth requirement of f_k is B_k, and ii) the bandwidth requirements of existing flows should not be violated after admitting f_k.

We first present some notations and assumptions used to model the ad-hoc network. An ad-hoc network can be conveniently represented by an undirected graph G=(V, E), where each vertex in V uniquely corresponds to a node and each edge (u, v) in E denotes that u and v can communicate with each other. There are some existing flows[1] in the ad-hoc network and each one is associated with a required bandwidth. Denote by F the set of existing flows, and a bandwidth of b_i Mbps is required for each flow $f_i \in F$. Each node has the same transmission range, raw data rate of B Mbps and a MAC layer FIFO transmission queue. Assume that t_i is the time when the flow f_i is admitted and data packets of b_i Mb will arrive in the transmission queue of the sender of f_i at t_i, t_i+1, t_i+2, … and so on.

For ease of discussion, we ignore the overhead caused by collision and backoff algorithm in our calculation of B_k. Bianchi [10] has approximately derived an "*effective capacity*" for single-hop transmissions by considering both the collision and backoff behavior. The capacity estimation is beyond the scope of this paper. Suppose that T_i is the time requirement for f_i so that f_i can complete the transmission of b_i Mb data packets before t_i+T_i, t_i+1+T_i, t_i+2+T_i, … and so on. Assume that T_F is the maximum one of T_i, for all flow $f_i \in F$. If T_F exceeds a second, then the bandwidth requirement of some flow is violated. Calculating B_k can be accomplished by the aid of $T_{F\cup\{f_k\}}$. In order to determine T_F, an *interference flow graph*, G_F =(V_F, E_F), can be constructed as follows.

- V_F : there is a vertex $i \in V_F$ if and only if there is a flow $f_i \in F$.

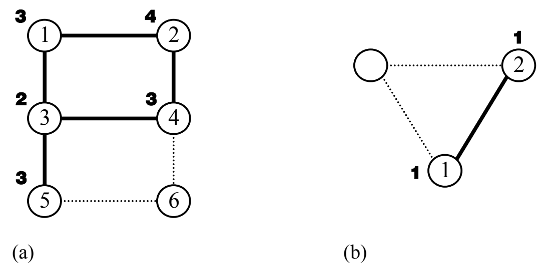

Figure 4. Two examples of interference flow graph G_F (or $G_{F\cup\{f_k\}}$).
(a) The example in Figure 1. (b) The example in Figure 2.

- E_F : there is a edge $(i, j) \in E_F$ if and only if f_i and f_j cannot transmit simultaneously without interference.

Let $N_F(i)$ denote the set of neighbor vertices of i in G_F. Then we have the following theorem.

Theorem 1. T_F is bounded above by $\max\{\sum_{j\in N_F(i)\cup\{i\}} b_j : \forall i \in V_F\}/B$ when the underlying MAC protocol is a CSMA-based protocol.

Proof. Suppose conversely that

$$T_F > \max\{\sum_{j\in N_F(i)\cup\{i\}} b_j : \forall i \in V_F\}/B \cdot$$

So there is a flow f_a, whose

$$T_a > \max\{\sum_{j\in N_F(i)\cup\{i\}} b_j : \forall i \in V_F\}/B \cdot$$

T_a is composed of the transmitting time and the waiting time. Since f_a needs b_a/B seconds to transmit b_a Mb data packets, the waiting time of f_a is lager than

$$(\max\{\sum_{j\in N_F(i)\cup\{i\}} b_j : \forall i \in V_F\} - b_a)/B \cdot$$

f_a can not seize the channel if and only if a neighbor flow of f_a is transmitting. However, the amount of time when a neighbor flow of f_a is transmitting is equal or less than

$$(\sum_{j\in N_F(a)\cup\{a\}} b_j - b_a)/B \cdot$$

Since the amount of time when a neighbor flow of f_a is transmitting is less than the waiting time of f_a, there are some time periods such that f_a is waiting and all neighbor flows of f_a do not transmit at these time periods. It is a contradiction.

Q.E.D.

According to the definition of B_k, for a new flow f_k, $T_{F\cup\{f_k\}} \le 1$ if $T_F \le 1$ and the bandwidth requirement of f_k, denoted by b_k, is not more than B_k. According to it and Theorem 1, the B_k of a new flow f_k satisfies the following condition.

- When $b_k = B_k$,

$$\max\{\sum_{j\in N_{F\cup\{f_k\}}(i)\cup\{i\}} b_j : \forall i \in V_{F\cup\{f_k\}}\}/B = 1 \cdot$$

By observation of G_F and $G_{F\cup\{f_k\}}$, the above equation can be simplified as follows.

- When $b_k = B_k$,

$$\max\{\sum_{j\in N_{F\cup\{f_k\}}(i)\cup\{i\}} b_j : \forall i \in \{k\} \cup N_{F\cup\{f_k\}}(k)\}/B = 1 \cdot \quad (1)$$

Then B_k can be determined by (1). Each item in the “max” function, called *neighborhood traffic*, represents the amount of bandwidth required for flows that are in the neighborhood of some flow. In (1), to calculate B_k of a new flow f_k, the neighborhood traffic of f_k and the neighborhood traffic of all neighbor flows of f_k are considered in the “max” function. We use two examples to explain the calculation of B_k. The one is the same as the example in Fig. 1. Fig. 4(a) illustrates the G_F (or $G_{F\cup\{f_k\}}$) of the example. The B_6 of f_6 can be determined as follows.

- Since $\max\{(b_4+b_5+B_6), (b_2+b_3+b_4+B_6), (b_3+b_5+B_6)\}=11$, B_6 is 2 Mbps.

Another one is the same as the example in Fig. 2. Fig. 4(b) illustrates the G_F (or $G_{F\cup\{f_k\}}$) of the example. The B_3 of f_3 can be determined as follows.

- Since $\max\{(b_1+b_2+B_3), (b_1+b_2+B_3), (b_1+b_2+B_3)\}=2$, B_3 is 0 Mbps.

B_k is the available bandwidth of f_k when the schedule of transmissions is the worst one for f_k. So an exact bandwidth reservation can be performed according to B_k to guarantee the bandwidth requirements.

4 An Intelligent Mechanism to Increase the Bandwidth Utilization

The bandwidth utilization of CSMA/CA is inefficient because CSMA/CA is an unscheduled MAC protocol. Some inefficient schedules will reduce B_k of a new flow f_k (e.g. in the scenario of Section 3.2, B_6 is not

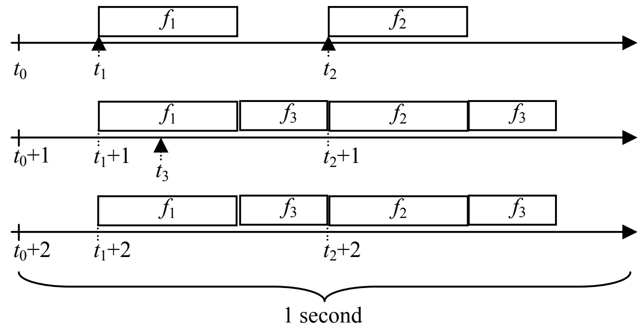

Figure 5. The operation of priority number.

more than 1Mbps due to the Schedule B). In this section, an intelligent mechanism, called priority number, is proposed to avoid some inefficient schedules of CSMA/CA.

4.1 Priority Number

Priority number is a distributed mechanism to schedule the transmission sequence of flows. Assume that $F=\{f_1, f_2, \ldots, f_{k-1}\}$ and all flows are admitted sequentially according to their index, i.e., t_i is earlier than t_j if and only if $i<j$. When a new flow f_k is admitted, the priority number of f_k, denoted by $PN(f_k)$, is assigned for f_k and $PN(f_k)=\max\{PN(f_i)$: for all $i \in N_{F\cup\{f_k\}}(i)$ $\}+1$. $N_{F\cup\{f_k\}}(i)$ is the set of neighboring vertices of i in the corresponding interference flow graph of $F \cup \{f_k\}$.

We use the example in Fig. 1 to explain the assignment of priority number. Assume that the flows from f_1 to f_6 are admitted sequentially according to their index. At first, f_1 is admitted and $PN(f_1)$ is 1 because the corresponding vertex of f_1 in the interference flow graph has no neighboring vertex. When f_2 is admitted, $PN(f_2)$ is 2 because the corresponding vertex of f_1 in the interference flow graph is the neighboring vertex of the corresponding vertex of f_2. Similarly, when f_3 is admitted, $PN(f_3)$ is 2. When f_4 is admitted, $PN(f_4)$ is 3 because the corresponding vertices of f_2 and f_3 in the interference flow graph are the neighboring vertices of the corresponding vertex of f_4, and $\max\{PN(f_2), PN(f_3)\}$ is 2. When f_5 and f_6 are admitted sequentially, $PN(f_5)$ is 3 and $PN(f_6)$ is 4 respectively.

The scheduling policy of CSMA/CA with priority number is that the priority of f_i seizing the channel is higher than the priority of f_j if $PN(f_i)<PN(f_j)$. Fig. 5 illustrates the operation of CSMA/CA with priority number. Assume that f_1, f_2 and f_3 are neighboring flows of each other. When f_3 is admitted and wants to seize the channel at t_3, f_1 also wants to seize the channel. Since $PN(f_1)<PN(f_3)$, the transmission of f_3 is deferred by f_1. When f_3 transmits until t_2+1, f_2 also wants to seize the channel. Since $PN(f_2)<PN(f_3)$, the transmission of f_3 is deferred again by f_2.

Priority number can be implemented by adjusting the inter-frame space and the contention window. On the other hand, in order to avoid the priority number increased unrestrainedly, when the transmission of a flow has accomplished, the priority number of it will be released and the priority numbers of other flows will be dynamically shifted by periodical beacons. The detailed protocol design has been omitted because the space is limited. In this paper, we focus our effort on studying the bandwidth utilization of CSMA/CA with priority number.

4.2 B_k for CSMA/CA with Priority Number

When the underlying MAC protocol is a contention-based protocol, B_k of a new flow f_k depends on not only the neighborhood traffic of f_k, but also the neighborhood traffic of all neighbor flows of f_k (according to (1)). In this subsection, we prove that B_k of a new flow f_k is only dependent on the neighborhood traffic of f_k, when the underlying MAC protocol is CSMA/CA with priority number. Assume that $F=\{f_1, f_2, \ldots, f_{k-1}\}$ and all flows are admitted sequentially according to their index. Let $F_i=\{f_1, \ldots, f_i\}$. Then we have the following theorem.

Theorem 2. T_F is bounded above by $\max\{\sum_{j\in N_{F_i}(i)\cup\{i\}} b_j : \forall i \in V_F\}/B$ when the underlying MAC protocol is CSMA/CA with priority number.

Proof. Suppose conversely that

$$T_F > \max\{\sum_{j\in N_{F_i}(i)\cup\{i\}} b_j : \forall i \in V_F\}/B \cdot$$

So there is a flow f_a, whose

$$T_a > \max\{\sum_{j\in N_{F_i}(i)\cup\{i\}} b_j : \forall i \in V_F\}/B \cdot$$

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T_a is composed of the transmitting time and the waiting time. Since f_a needs b_a/B seconds to transmit b_a Mb data packets, the waiting time of f_a is lager than

$$(\max\{\sum_{j\in N_{F_i}(i)\cup\{i\}} b_j : \forall i \in V_F\} - b_a)/B \cdot$$

In CSMA/CA with priority number, f_a can not seize the channel if and only if a flow f_i which is a neighboring flow of f_a is transmitting, and $PN(f_i)<PN(f_a)$. We call such flow the *prior flow* of f_a. Since f_j is a prior flow of f_a, for all $j \in N_{F_a}(a)$, the amount of time when a prior flow of f_a is transmitting is equal or less than

$$(\sum_{j\in N_{F_a}(a)\cup\{a\}} b_j - b_a)/B \cdot$$

Since the amount of time when a prior flow of f_a is transmitting is less than the waiting time of f_a, there are some time periods such that f_a is waiting and all prior flows of f_a do not transmit at these time periods. It is a contradiction.

Q.E.D.

Recall that for a new flow f_k, $T_{F\cup\{f_k\}} \leq 1$ if $T_F \leq 1$ and $b_k \leq B_k$. According to it and Theorem 2, the B_k of a new flow f_k under CSMA/CA with priority number satisfies the following condition.

- When $b_k=B_k$, $\max\{\sum_{j\in N_{F_i}(i)\cup\{i\}} b_j : \forall i \in V_{F\cup\{f_k\}}\}/B = 1 \cdot$

Since $T_F \leq 1$ and $T_{F\cup\{f_k\}} = 1$,

$$\max\{\sum_{j\in N_{F_i}(i)\cup\{i\}} b_j : \forall i \in V_{F\cup\{f_k\}}\}/B = \sum_{j\in N_{F\cup\{f_k\}}(k)\cup\{k\}} b_j \; /B \cdot$$

So the condition can be simplified as follows.

- When $b_k=B_k$, $\sum_{j\in N_{F\cup\{f_k\}}(k)\cup\{k\}} b_j \; /B = 1 \cdot$ (2)

Then B_k can be determined by (2). The value of the summation function, called *prior neighborhood traffic*, represents the amount of bandwidth that is required for the prior flows of f_k. In (2), to calculate B_k of a new flow f_k, the prior neighborhood traffic of f_k is only considered. Therefore, B_6 is 5 Mbps in Fig. 1 (i.e., $b_4+b_5+B_6=11$) and 0 Mbps in Fig. 2 (i.e., $b_1+b_2+B_3=2$) when the underlying MAC protocol is CSMA/CA with priority number.

5 Performance Evaluation

Simulation was made to evaluate the bandwidth utilization of CSMA/CA with priority number and pure CSMA/CA. Simulation modules were developed by C++ to simulate the behaviors of these two MAC protocols. A static ad-hoc network of 200 nodes which were randomly spread in a 600m×600m area was simulated. The radio transmission range of each sending node was assumed 70 meters. The raw data rate was 11 Mbps and the transmission unit (the size of data packets) was 1 Kb.

The overhead caused by collision and backoff algorithm had not been considered in our simulation. In other words, the contention phase and all control frames handshaking had not been implemented in our simulation. It is because the overheads in CSMA/CA with priority number and pure CSMA/CA were similar and not the dominated factor of bandwidth utilization. The medium access control was simulated by a centralized control instead of the contention phase and all control frames handshaking. So the time axis was simply divided into continuous time slots and 1 second was divided into 11000 slots.

300 connections (flows) had been generated continually through the simulation. The bandwidth requirement of each flow was randomly assigned from 1 to 5 Mbps. The admission control used in CSMA/CA with priority number was according to (2). The admission control used in pure CSMA/CA was according to (1). Two performance criteria were used to evaluate the performance of CSMA/CA and CSMA/CA with priority number: throughput and admitted ratio. The criteria were defined as follows.

- throughput = the number of received packets per second × packet size.
- $\text{admitted ratio} = \dfrac{\text{the number of admitted flows}}{\text{the number of generated flows}}$.

Fig. 6 and Fig. 7 compared the throughput and the admitted ratio, respectively, with respect to CSMA/CA with priority number and pure CSMA/CA when the number of generated flows varied. CSMA/CA with priority number was superior to the pure CSMA/CA in both metrics because the pure CSMA/CA is an unscheduled MAC protocol. According to (1) and (2), it is not difficult to see that the available bandwidth on a link under pure CSMA/CA is always less than the available bandwidth on the link under CSMA/CA with priority number.

6 Discussion and Conclusion

The increasing use of ad hoc networks for transferring multimedia applications such as voice, video, and data, leads to the need to provide QoS support. QoS guarantees of many QoS sensitive applications can be attained with appropriate resource reservation techniques. Precise estimation of remaining bandwidth is necessary to perform bandwidth reservation. Although many QoS routing protocols is resource reservation-based protocols and have been proposed in CSMA-based ad hoc networks,

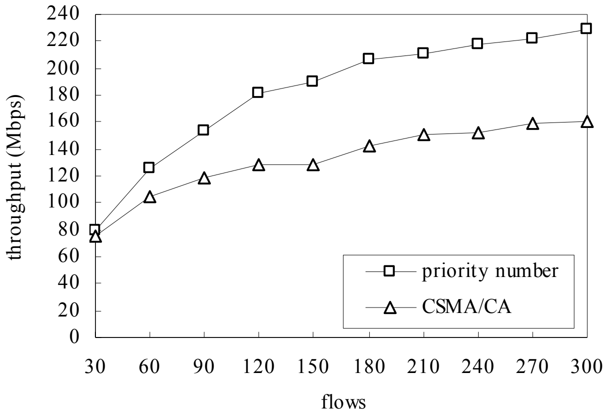

Fig. 6. The throughputs of CSMA/CA and CSMA/CA with priority number when the number of generated flows varied.

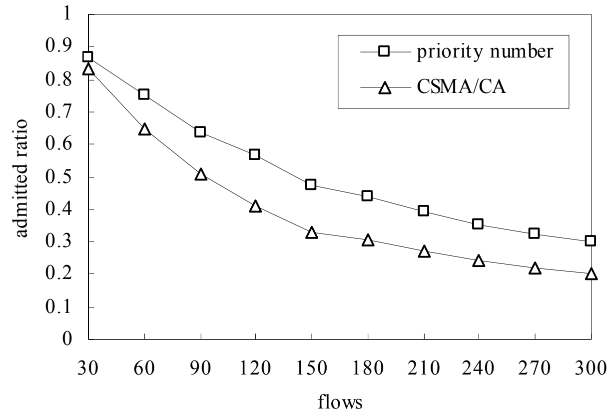

Fig. 7. The admitted ratios of CSMA/CA and CSMA/CA with priority number when the number of generated flows varied.

all of them do not provide an exact bandwidth reservation to avoid QoS violation.

In this paper, we first propose a correct estimation method of remaining bandwidth when the adopted MAC layer protocol is CSMA/CA. However, the bandwidth utilization of CSMA/CA is inefficient because CSMA/CA is an unscheduled MAC protocol. So an intelligent mechanism, called *priority number*, has been proposed to avoid some inefficient schedules of CSMA/CA. By the aid of priority number, the remaining bandwidth of each node may be increasing and the bandwidth utilization can be improved.

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