Routing and Admission Control in IEEE 802.16 Distributed Mesh Networks

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***Abstract*—QoS provisioning in wireless mesh networks has been known to be a challenging issue. In this paper, we propose a new routing method (using SWEB as metrics) that is well-suited in IEEE 802.16 distributed, coordinated mesh mode. Also, an admission control algorithm (TAC) which utilizes the token bucket mechanism is proposed. The token bucket is used for controlling the traffic patterns for easy estimating the bandwidth required by a connection. In the TAC algorithm, we apply the bandwidth estimation by taking into account the hop count and delay requirements of real-time traffics. TAC is designed to guarantee the delay requirements of real-time traffics, and avoid the starvations of low priority traffics. With the proposed routing metrics, the admission control algorithm and the inherent QoS support for the IEEE 802.16 mesh mode, a QoS-enabled environment can be established. Finally, extensive simulations are carried out to validate our algorithms, and show good performance results.**

***Index Terms*—IEEE 802.16, wireless mesh networks, WiMAX**

I. Introduction

As wireless technology evolves, IEEE 802.16[1], or WiMAX (Worldwide Interoperability for Microwave Access), appears to be a great competitor to IEEE 802.11 or 3G networks for its wide coverage and high data rate. In the IEEE 802.16 standards, meshing functionality is included as an optional mode. We propose a simple routing method using Shortest Widest Effective Bandwidth (SWEB) as metrics and a Token bucket-based Admission Control (TAC) to achieve QoS for real time traffics in the IEEE 802.16 mesh networks.

IEEE 802.16 is a standard that aims at the use of wireless metropolitan area network (WMAN). Two modes are defined in the standard: PMP (Point to Multi-Point) and mesh modes. In the PMP mode, the network architecture is similar to the cellular networks. That is, one base station (BS) is responsible for all its subscriber stations (SS). The communication can occur only between BS and SS. In the mesh mode, the networks architecture is similar to ad-hoc networks. In other words, each SS can be a source node and a router at the same time. The communication can occur between any two stations in the network.

IEEE 802.16 mesh network is time-slotted. Connections must reserve timeslots in advance for the actual transmissions. As IEEE 802.16 is mostly used as the network backhaul, the network traffic connections mostly occur between the BS and SS. Therefore, with an appropriate routing algorithm, the topology can be reduced into a routing tree. QoS of a connection along the path from the source station to the base station can be provided.

The remaining parts of this paper are organized as follows: Section II gives the background knowledge of token bucket mechanism and details of IEEE 802.16 mesh mode. Section III summaries the related works. In section IV and V, the SWEB and TAC are proposed. Simulation results are given in section VI. Finally, we conclude this paper in section VII.

II. Background

A. Token Bucket mechanism

Token bucket is a mechanism that controls the network

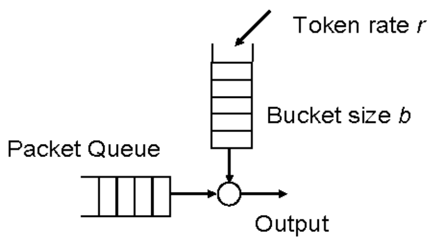

Fig. 1. Token bucket mechanism.

traffic rate injecting into networks. It works well for smoothing "bursty" traffics. This mechanism needs two parameters: token rate r and bucket size b. As in Figure 1 shows, each packet represents a unit of bytes or a packet data unit. Token is generated at the fixed token rate, and is stored in the bucket until it is full. A packet is not allowed to enter the network until it possesses a token. Therefore, in the time duration t, the maximum data volume to be transmitted will be

$$r \cdot t + b$$

The token bucket mechanism will be adopted to estimate the bandwidth required for each connection in IEEE 802.16 mesh networks which will be explained later.

B. IEEE 802.16 mesh mode

IEEE 802.16 mesh network is time-slotted. That is, the time

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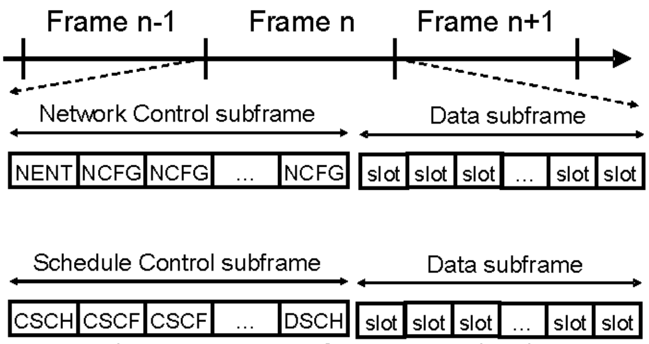

Fig. 2. Frame structures of IEEE 802.16 mesh mode.

is divided into equal-length time frames. Each time frame is composed of one Control subframe and one Data subframe. The control subframe carries control messages for scheduling, entries of new stations, and exchanging of basic network parameters, etc. The data subframe is composed by the time-slots for the actual data transmissions. The frame structure is given in figure 2.

There are two kinds of control subframes: Network Control and Schedule Control subframes. In Network Control subframes, MSH-NENT (Mesh-Network Entry) messages are used to provide the entries of new-coming stations. MSH-NCFG (Mesh-Network Configure) messages are sent by each station periodically to exchange the basic parameters of networks, such as: the identifier of the BS, hops to the BS, and neighbor number of the reporting stations, etc.

Two scheduling modes are defined in IEEE 802.16 mesh mode: centralized and distributed modes. In the centralized scheduling mode, the BS is in charge of all the transmissions happening in the mesh network. The resources are allocated by the BS with the MSH-CSCH (Mesh-Centralized Scheduling) and MSH-CSCF (Mesh-Centralize Scheduling and Configure) messages. In the distributed mesh mode, the scheduling information is carried by MSH-DSCH (Mesh-Distributed Scheduling) messages, whose transmission time is determined by the mesh election algorithm given in the standard. MSH-DSCH has four information elements (IEs): scheduling IE, request IE, availability IE, and grant IE. The Scheduling IE carries the information of next-transmission time used in the mesh election algorithm. The other three IEs are employed in the three-way handshake as described below:

1. The MSH-DSCH:request is made along with MSH-DSCH:availability, which is used to indicates the potential timeslots of the source station.

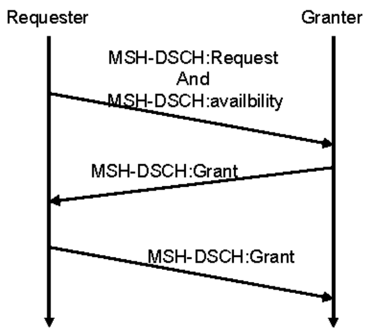

Fig. 3. Three-way handshake.

2. MSH-DSCH:grant is sent in response indicating a subset of the suggested availabilities that fit, if possible, the request.
3. MSH-DSCH:grant is sent by the original requester containing a copy of the grant from the requester, to confirm the schedule.

After the three-way handshake indicated in figure 3, the reservation of timeslots in the data subframe is completed.

In both centralized and distributed mesh modes, the QoS can be supported by the fields of the CID (Connection Identifiers) that is associated with each connection. There are three fields that explicitly define the service parameters:

1. Priority: This field simply defines the service class of the connection
2. Reliability: To re-transmit or not.
3. Drop Precedence: The likelihood of dropping the packets when congestion occurs.

III. Related Work

H. Shetiya and V. Sharma [2] proposed the algorithms of routing and scheduling under IEEE 802.16 centralized mesh networks. The routing metric is based on the evaluation of queue length on each station. It is fixed routing, which reduces the topology into a tree. The scheduling algorithm is based on a mathematical model to allocate enough timeslots among the traffic flows. Our previous work [3] that focused on the call admission control and packet scheduling in the IEEE 802.16 PMP mode. Also in this paper, a mathematical model is proposed to characterize the packets of different traffic flows.

Some other researches also focus on the IEEE 802.16 mesh mode: F. Liu et al. [4] proposed a slot allocation algorithm based on priority to achieve QoS. Z. J. Haas et al. [5] proposed an approach to increase the utilization of IEEE 802.16 mesh mode which adopted a cross-layer design. M. Cao et al. [6] proposed a mathematical model of IEEE 802.16 mesh distributed scheduler, mostly on the mesh election algorithm.

Douglas, S, J. De Couto et al. [7] proposed a new routing metrics called "ETX"("Expect Transmission Count"). ETX is suitable for wireless networks and is able to fit in any routing algorithms like DSR, DSDV.

IV. Our Routing Metrics: SWEB

A new routing method using SWEB (Shortest-Widest Efficient Bandwidth) metrics is proposed, which considers three parameters: packet error rate, $P_{i,j}$, capacity $C_{i,j}$ over the link (i,j) and the hop count, h, from the source to the destination. The packet error rate can be retrieved by the exchanging of MSH-DSCH messages, which is associated with a unique sequence number. The lost or error MSH-DSCH messages can be detected. The link capacity can be also known by the burst profile indicated in the MSH-NCFG messages. In MSH-NCFG messages, the hop count for a station to base station is also given. Therefore, our metrics in SWEB are easy to retrieve and suitable for IEEE 802.16 mesh networks.

The efficient bandwidth of a link (i,j) can be calculated as:

$$C_{i,j}(1 - p_{i,j}) \tag{1}$$

However, since the flow that comes in and leaves a node shares the bandwidth. Equation (1) should be divided by two to represent the available pass-through bandwidth. Therefore, the end-to-end (h hops) available bandwidth from node 1 to node $h+1$ is:

$$\frac{\min(C_{1,2}\cdot(1-p_{1,2}),C_{2,3}\cdot(1-p_{2,3}),\ldots,C_{i,i+1}\cdot(1-p_{i,i+1}),\ldots,C_{h,h+1}(1-p_{h,h+1}))}{2} \tag{2}$$

By additionally taking into account the hop count, h, we define our SWEB metrics for a potential path as:

$$SWEB = \frac{\min(C_{1,2}\cdot(1-p_{1,2}),C_{2,3}\cdot(1-p_{2,3}),\ldots,C_{i,i+1}\cdot(1-p_{i,i+1}),\ldots,C_{h,h+1}(1-p_{h,h+1}))}{2}\cdot\frac{1}{h} \tag{3}$$

The path with the largest path SWEB will be chosen.

V. Admission Control Algorithm: TAC

Our Token bucket-based Admission Control (TAC) has two essential parts. First, the bandwidth used by a connection must be estimated well. Second, the bandwidth estimation is used for implementing the admission control algorithm.

A. Bandwidth Estimation

If all the connections are under the control of token bucket mechanism, the bandwidth required at most within a time frame can be estimated as:

$$\frac{r_i \cdot f + b_i}{f}, \tag{4}$$

where r_i and b_i are the token rate and bucket size that associated with a connection i, respectively, and f is the frame length. However, the bandwidth required in equation (4) is over-estimated since the transmission burst does not happen in every time frame. To better estimate the bandwidth, consider the scenario in figure 4.

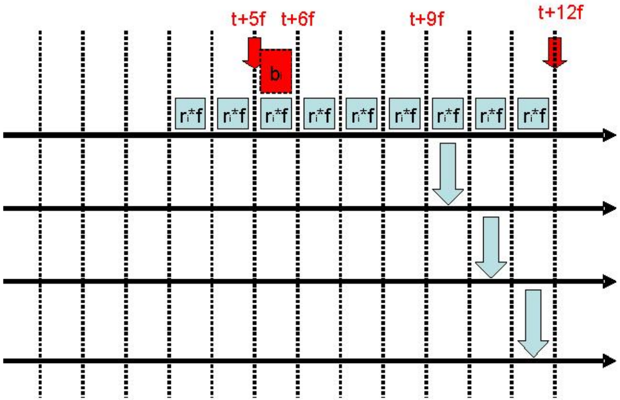

Fig. 4. Transmission Deadline of b_i Bits of Data.

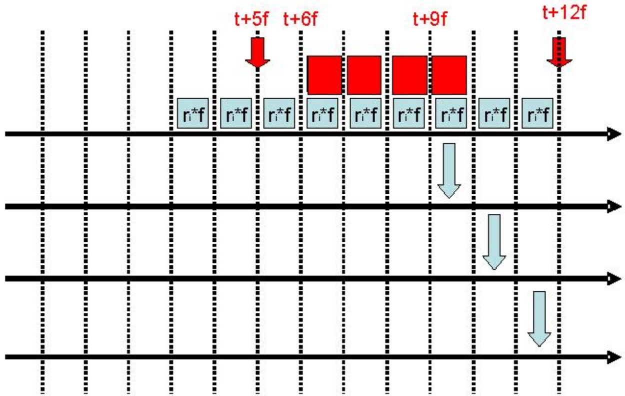

Fig. 5. Sharing b_i Bits of Data.

Let the hop count and transmission deadline of the flow in Fig. 6 is 3 and $7f$, respectively. Assume that the transmission burst occurs in time interval [$t+5f$, $t+6f$] and tokens stored in the bucket are completely consumed. In order to satisfy the delay requirement, these b_i bits of data must be sent by [$t+9f$, $t+10f$]. However, the frames from $t+6f$ to $t+10f$ can be used for sharing the b_i bits, as in figure 5. Therefore, the required bandwidth can be less.

Generally speaking, in order to meet the delay requirement, d_i frames, for real-time traffics. The packets generated at time t have to be sent by m_i frames after t, where

$$m_i = \left\lfloor \frac{d_i}{f} \right\rfloor - h \tag{4}$$

These m_i frames can be used to share the b_i bits of the burst data. Thus, in order to guarantee delay deadline, the maximum volume of data that should be sent in any given frame is:

$$r_i \cdot f + \frac{b_i}{m_i} \tag{5}$$

We use (5) as bandwidth estimation of a flow.

B. Admission Control

The above bandwidth estimation is used to implement the TAC algorithm. In TAC algorithm, we also define the minimum usage of timeslots by each connection to prevent starvation for lower-priority traffics. They are: *CBR_min*, *VBR_min* and *BE_min*. When a station receives a MSH_DSCH:Request, it examines whether the current usage

TABLE I
QoS Mappings

	Priority (3 bits)	Reliability (1 bit)	Drop Precedence (2 bits)
CBR	7	0	0
CBR_DG	4	0	1
VBR	6	0	0
VBR_DG	3	0	2
BE	5	1	0
BE_DG	2	1	3

of each class exceeds their minimum usage or not. If it is, the new-coming flow will be marked as downgraded flows. If a MSH-DSCH:Request comes in, the downgraded flows have larger possibilities to be preempted. On the other hand, if the current usage does not exceed its minimum usage, the flow will not be downgrade and have bigger change to preempt other downgraded flows.

Since the service levels in IEEE 802.16 mesh mode are identified in the fields of CID (Connection Identifiers), we have the QoS mapping in Table I. With the mappings, the down-graded flows can be marked. And by this information, our TAC algorithm is described as follows:

1.) A new flow with its *BW_req* (Bandwidth request) in the unit of data timeslots occurs. This source node computes its *BW_avail* (available bandwidth) as the total empty slot number.
2.) The station along the path that handles the request checks if the *BW_req*<*BW_avail* or not. If yes, go to step 3. Or else, go to step 4.
3.) The station determines to downgrade the flow or not, by comparing the current usage and the minimum usage of the traffic class. In either case, it grants the timeslots.
4.) The station checks if the current usage exceeds the minimum usage of the traffic class. If yes, the flow shall be rejected. Or else, go to step 5.
5.) Check the timeslots used by downgraded flows in the order of *BE_DG*, *VBR_DG*, and *CBR_DG*. If there are no such timeslots, the request is rejected. Or else, set these timeslots empty, which means to preempt these timeslots. It then grants the timeslots and updates the value of *BW_avail*.

TABLE II
THE PARAMETERS OF QPSK

QPSK coding rate	3/4
OFDM symbols in a frame	676
OFDM symbols in a control subframe	16
OFDM symbols in a data subframe	660
OFDM symbols in a timeslot	4
Number of data timeslots	165
Capacity of a timeslot	144 bytes

VI. SIMULATION RESULTS

The simulations are conducted in a 16-node topology, and the simulation area is a 4 km * 4 km square. The radio range is set as 1.5 km in radius. The frame length is chosen to be 8 ms. In the simulations, QPSK modulation is chosen. The details of QPSK are given in table II.

The data rate of the CBR traffic is 64 kbps, with 960-bit packet size, and the packet interval of 15 ms. The VBR traffic is at the average speed of 400 kbps. The mean packet size is 16000 bits sending at the interval of 40 ms. The packet size of BE traffics is 8000 bits and is sent every frame (8 ms).

A. Routing

The performance of the proposed SWEB for VBR traffics is compared with the ETX [7] and the shortest path routing algorithms.

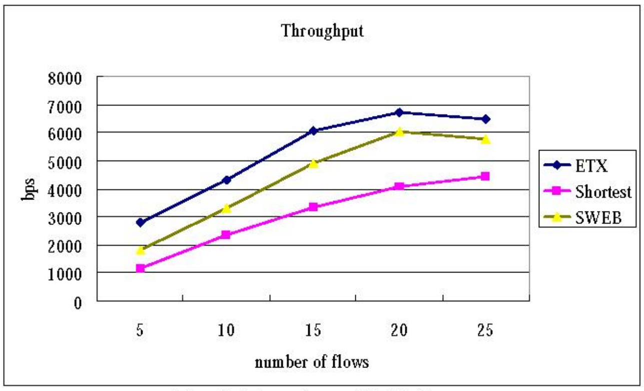

Fig. 6. Throughput of VBR flows.

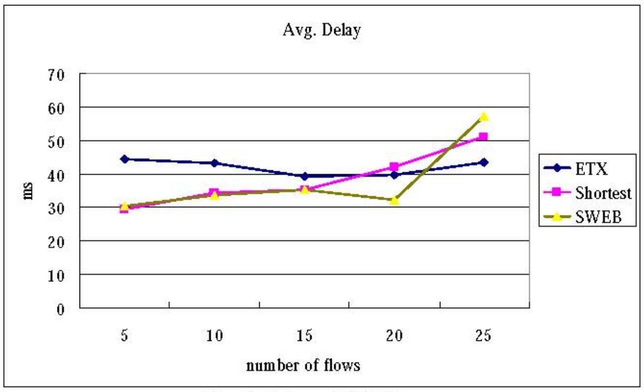

Fig. 7. Delay of VBR flows.

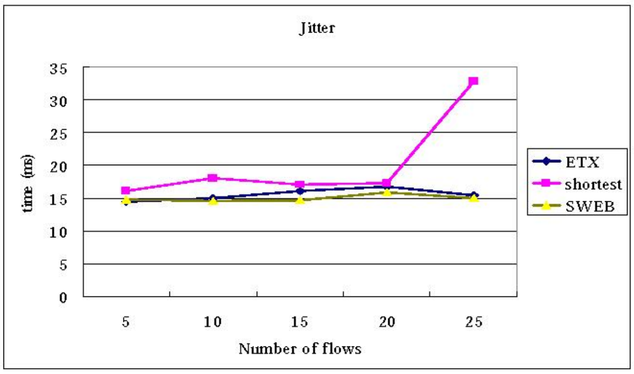

Fig. 8. Jitter of VBR flows.

TABLE III
TOKEN BUCKET MECHANISM PARAMETERS

	Token rate (bytes / frame)	Bucket size (bytes)	Delay requirements
CBR	120	8	40 ms
VBR	1500	500	80 ms
BE	7500	250	--

As shown in the figure 6 and 7, when number of flows is reaching 25, some VBR flows are preempted by CBR flows. Since ETX selects the route with the lowest packet error rate, the throughput is the highest. However, ETX causes the higher delay because it does not take the hop count into account. Similarly, the shortest path has the smallest delay, but the least

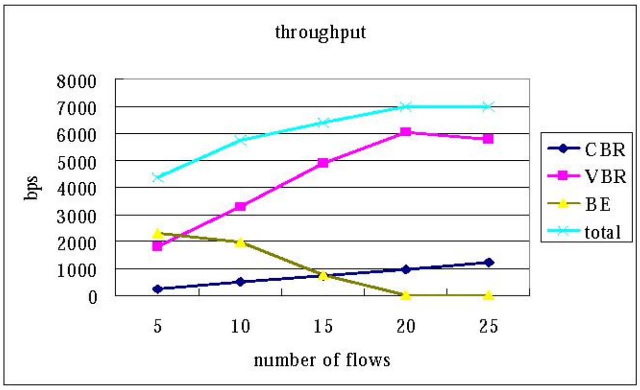

Fig. 9. Throughput for the original IEEE 802.16 mesh mode.

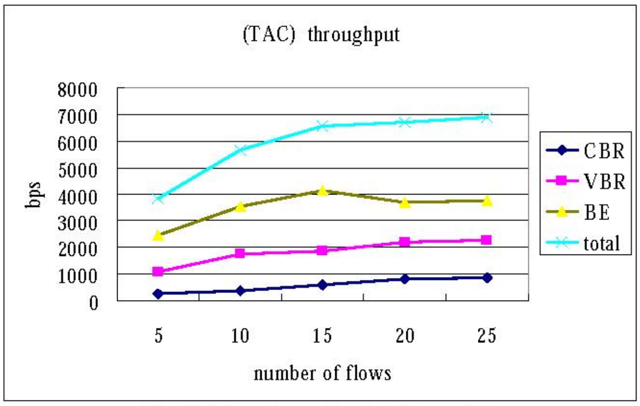

Fig. 10. Throughput when TAC is applied.

throughput. In Fig. 8, we can find that SWEB has the best performance in jitter which is important for real-time traffics. By these results, our SWEB routing metrics provide good delay, throughput and jitter in the overall.

B. Admission Control

In TAC algorithm, the minimum usage of each traffic class must be set. In the simulations, the *CBR_min*, *VBR_min* and *BE_min* are set as 10, 40 and 75 timeslots, respectively. Also, the parameters of token bucket are shown in table III.

We compare the throughput in figure 9 and 10. In figure 9, BE traffics suffer from preemption from higher priority traffic class, and therefore receive low throughput when network is heavily-loaded. By applying the TAC algorithm in figure 10, the BE flows has the guaranteed throughput by the minimum usage. The preemption occurs only in down-graded flows.

As in figure 11, around 12% of VBR-packets exceed the delay requirements when the number of flow is 25. However, in figure 12, it is reduced to around 7% for only VBR-downgraded flows when TAC is applied. It can be expected that for all VBR flows (VBR and VBR-downgraded), the ratio would be lower than 7%.

VII. CONCLUSIONS

In this paper, we proposed a new routing method using SWEB as metrics, and an admission control algorithm, TAC for IEEE 802.16 mesh networks. SWEB is applied in static routing environment and yields good throughput, delay and jitter. The TAC algorithm prevents the starvation of low-priority traffic flows and guarantees the delay requirements of the real-time flows. By SWEB and TAC, a QoS-enabled network environment can be realized with IEEE 802.16 mesh mode.

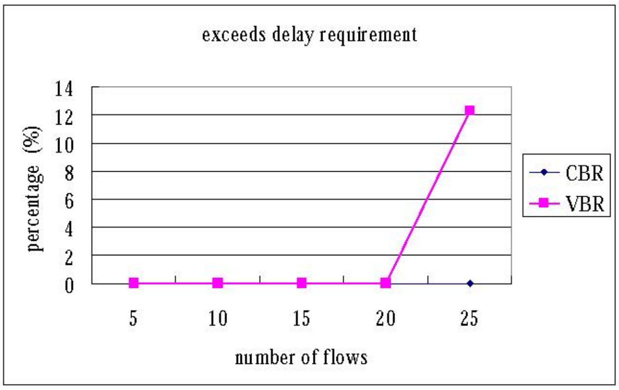

Fig. 11. The ratio of the realtime packets that exceeds the delay requirements for the original IEEE 802.16 mesh mode.

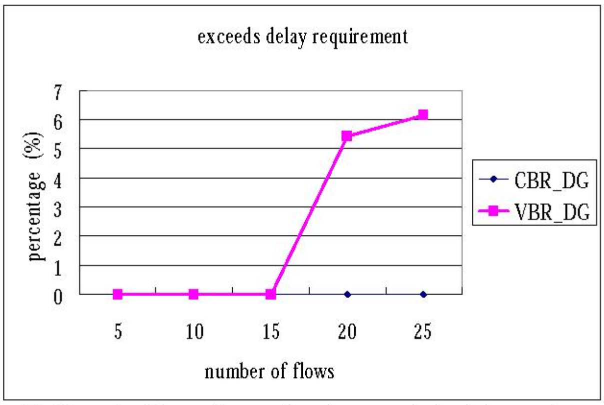

Fig. 12. The ratio of the realtime packets that exceeds the delay requirements when TAC is applied.

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