CHAPTER 3

Related Work

There are several researches on the mesh networks and IEEE 802.16 mesh mode. We shall briefly describe these researches in this chapter.

In [4], which is our former work, we focused on the admission control and packet scheduling in IEEE 802.16 PMP mode. In this paper, a mathematical model in characterizing traffic flows is also proposed. In Figure 3.1, the operation process is depicted, and the cubes with dotted-lines are not defined in the IEEE 802.16 standards.

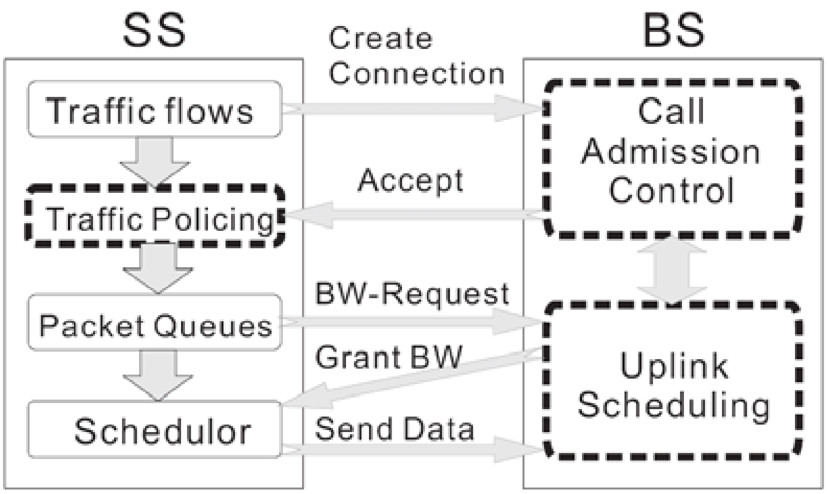

Figure 3.1: IEEE 802.16 PMP operation process.

In this paper, the bandwidth is estimated by the token bucket mechanism, and the Call admission control is implemented using these estimated bandwidth information. The principle of the CAC algorithm is: First, the system calculates the current available bandwidth. Second, for the new incoming flows, the system estimates the bandwidth it will take and the system will decide to grant this new flow or not. The CAC algorithm is as follows:

Step 1.

The system calculates the remaining uplink bandwidth B_{remain}:

$$B_{remain}=B_{uplink}-B_{UGS}-B_{rtPS}-B_{nrtPS}-B_{BE} .$$

Step 2.

Compare B_{remain} to the bandwidth requirement of the new connection.

- If there is enough capacity, the system accepts the incoming flow.
- If not, go to Step 3.

Step 3.

Check if the lower-class flows has taken more bandwidth than its threshold (T_{rtPS}, T_{nrtPS} ,or T_{BE}).

- If not, go to Step 4.
- If there is, the system will allocate the less time slots for these lower-class flows, then go to step 2.

Step 4.

Check if higher-class flows have taken more bandwidth than its threshold (T_{rtPS}, T_{nrtPS} ,or T_{BE}).

- If not, go to Step 5.
- If there is, the system will choose some higher-class flows to degrade their r_i. That is, “stealing” bandwidth from the upper-class flows.

Step 5. The system denies the incoming flow.

The traffic arrival is assumed to be Poisson arrivals, and the Markov chain model is used to analyze the scenarios of infinite queue and finite queue. In the infinite queue scenario, the average queuing delay is

$$d_{avg}=\frac{2r_i-\lambda_i}{2r_i(r_i-\lambda_i)}(1-\sum_{k=0}^{b-1}\pi(k))$$

, where r_i and b_i are the token rate and token bucket size in the token bucket mechanism, and λ_i is the mean arrival rate.

In the finite queue scenario, the queuing delay can be calculated as:

$$d_{avg} = \frac{\sum_{k=0}^{b_i+q-1}\left(\pi(k)\left(\sum_{j=Max(b_i-k+1,0)}^{\infty} P(j)\cdot Min(j+k-b_i,q)-N\right)\right)}{r_i}$$

And the average loss rate is:

$$l_{avg} = \frac{\sum_{k=0}^{b_i+q-1}\left(\pi(k)\left(\sum_{j=b_i+q-k+1}^{\infty} P(j)\cdot (j+k-b_i-q)\right)\right)}{\lambda_i / r_i}$$

In [5], Harish Shetiya and Vinod Sharma proposed the algorithms of routing and scheduling under IEEE 802.16 centralized mesh networks. In their works, the routing is static, and the routing metrics is developed by the queue length of each node. Therefore, the routing is simply applied by a shortest path algorithm like Dijkstra's or Bellman-Ford by assigning cost $\frac{1}{E(r(p_{i,j}))}$ to link (i, j), where $r(p_{i,j})$ is the transmission rate over the path (i, j).

In the admission control, the authors calculate the number of timeslots that is enough for CBR, VBR and TCP-controlled traffics. The real-time traffic is argued to have a lowest dropping rate. If the sufficient timeslots given to the flow, the dropping rate requirements will be met. Due to the network environment is centralized mesh mode, the MBS can do the calculations and assign these timeslots over the links. And then, the TCP and UDP traffics are handled jointly to provide QoS for the individual flows. However, the delay requirement of real-time flows is not considered. And the routing metrics based on the queue length should be fit in dynamic routing naturally.

In [6], Fuqiang Liu et al. proposed a simple slot allocation algorithm based on priority to achieve QoS on MAC layer. The algorithm is as follows:

Step 1

Compute the number of minislots (R) requested for transmitting within a frame, according to its Demand Level and Demand Persistence;

Step 2

Get the next MSH-DSCH transmission time (T) from the neighbor table which is stored locally;

Step 3

Look up R continuous available minislots at the same position of the continuous frames (the number is Demand Persistence) starting from time T.

Step 4

If step 3 is successful, return Grant to the requester.

Step 5

If step 3 fails, return failure information.

However, in their work, only MAC-layer QoS is met. In a mesh network environment, the QoS provisioning across the MAC and network layer is necessary.

In [7], Hung-Yu Wei and Zygmunt J. Hass proposed an efficient approach for increasing the utilization of WiMax mesh networks through appropriate design of mutli-hop routing and scheduling. As multiple-access interference is a major limiting factor for wireless communication systems, an interference-aware cross-layer design is adopted to increase the throughput. Both routing and scheduling algorithm is constructed, and the routing is as follows:

```
S ← {0}    //node 0 is the root node; Initialize the set of selected nodes
N_S ← {1,2,...,n}   //Initialize the set of unselected nodes
p(i) ← ∅ ,  i ∈ {1,2,...,n}   //Initialize parent node for node 1,2,…,n
Do if N_S ≠ ∅
        η ← argmax_{i∈N_S∩Neighbor(S)} σ(i)   //Node η with high σ(η) value joins first
        C(η) ← Neighbor(η)   //All nodes within transmission distance of η
        W(η) ← C(η)∩S   //Candidate parent nodes of node η
        p(η) ← argmin_{i∈W(η)} B(i)   //Select the node with minimum blocking
        Add η to S
        Remove η from N_S
END
```

And the scheduling algorithm is as follows:

```
t ← 1
While exist any Y(j)>0 for any link j
        k ← arg max_{∀j} Y(j)      //select link k
        B ← ∅     // set of blocked links in this iteration
        A ← ∅     // set of selected active links in this iteration
        While k ≠ ∅
                Add k to A
                Add Blocked_Neighbor(k) to B
                k ← argmax_{j∉A∪B:Y(j)>0} Y(j)
        End while
        ActiveLinks(t) ← A
        t ← (t+1)
        Y(j) ← Y(j)-1   ∀j∈ A
End while
```

In [8], Min Cao et al. proposed a mathematical model and an analysis of IEEE 802.16 mesh distributed scheduler, mostly on the mesh election algorithm. The authors discuss the scenarios when the Holdoff exponents are identical and no-identical. The experiments are conducted in a collocated and a general topology. And the three-way handshaking time can be estimated using their math model. However, when the Holdoff exponents are non-identical, the stations may collide when accessing the medium. Therefore, the medium accessing mechanism needs a careful design.

Ian F. et al. [9] had a detail survey on wireless mesh networks across the protocols, and all 5 layers in TCP/IP 5-layer model. Also, the possible challenges of wireless mesh networks are listed in the paper. In layer 2, the IEEE 802.16 protocol is introduced along with other possible solutions of mesh MAC layers. The architecture and the characteristics of wireless mesh networks are explained, and the application scenarios are described. In the paper, the standard that is going to or already has the support of meshing functionalities is being introduced. After the long discussions and protocol investigations, the paper concludes that any protocol improvement relying on one single layer can not entirely soble all the existing problems. All protocols ranging from physical to application layers needs to be improved, and the cross-layered design among these protocols is needed to reach a better performance. This survey paper provides the basic, essential knowledge of wireless mesh networks, and serves as the first step to the research of IEEE 802.16 mesh networks.

Douglas s. j. De Couto et al. [10] proposed a new routing metric called “ETX”, short for “expected transmission count”. The ETX is designed with two essential parameters: d_f *and* d_r, whose value is calculated by sending probe packets. d_f is the forward delivery ratio, which is used to measure the probability of successful data transmissions, while d_r is the reverse delivery ratio, which is used to measure the probability of successful ACK transmissions. With these two parameters, the ETX can be calculated as follows:

$$ETX = \frac{1}{d_f * d_r}$$

The design of ETX is suitable for wireless environments and is able to fit in the routing algorithms like DSDV, DSR … etc.

In [11], R. Draves et al. proposed a new routing metrics, which is modified from ETX. And, a routing algorithm is also proposed. In this paper, the proposed routing metrics is called ETT (Expected Transmission Time), and WCETT (Weighted Cumulative ETT). ETT is calculated as follows:

$$ETT = ETX * \frac{S}{B}$$

, S is packet size, and B is the physical bandwidth. WCETT is designed especially for multi-channel mesh network environments and is calculated as follows:

$$WCETT = (1-\beta) \cdot \sum_{i=1}^{n} ETT_i + \beta \cdot \max_{1<j<k} X_j$$

, X_j is the sum of the transmission time of hops on channel j. The largest X_j means the bottleneck of the route. After ETT and WCETT, the routing algorithm MR-LQSR is proposed.

In addition to the above-mentioned research papers, the details of IEEE 802.16 mesh network is introduced in [10]. All the issues including centralized, distributed scheduling, modulations, and security are briefly discussed in the documents. It helped to construct the overall procedures and concepts on IEEE 802.16 mesh mode. The details of frame format and the functionalities of each messages and fields in them, are found in the standard [2].