# CHAPTER 3

# Analyze IEEE 802.16 Distributed Scheduling Algorithm

Before we model the distributed scheduler in IEEE 802.16 Mesh Mode, we have to know its behavior. The main difference between the PMP and Mesh modes is that in the PMP mode, traffic only occurs between BS and SSs, while in the Mesh mode traffic can be routed through other SSs and can occur directly between SSs. Centralized scheduling and Distributed scheduling are the two scheduling types defined in the IEEE 802.16 standard. Depending on the transmission protocol algorithm used, the traffic scenario can be done on the basis of using distributed scheduling, or on the basis of centralized scheduling, or on a combination of both. In this thesis, we focus on the distributed scheduling in the mesh mode.

## 3.1. Global Scenario

As we mentioned in the previous introduction, the IEEE 802.16 mesh mode is more complex because, without any central control, every station competes for the channel in a distributed manner. There are no clearly separate downlink and uplink subframes in the mesh mode. The mesh mode frames are divided into two subframes, one is control subframe, and the other is data subframe. IEEE 802.16 mesh mode uses the control subframe to exchange the schedule information, which is saved in the MSH-DSCH will be introduced at next section. Each node computes its schedule information based on parameters from itself and its neighbors to decide the node's next transmission time. If a collision occurs with a node's neighbors after computing its next transmission time, the node has to run the competing algorithm, named MeshElection, to select which node wins. The winner occupies this time as its next transmission time; the loser has to back off.

## 3.2. MSH-DSCH in MAC Frame Structure

The IEEE 802.16 defined the mesh frame structure as a convenience to organize the mesh network. The frame is divided into two subframes. One is the data subframe, the other is control subframe. Every control subframe consists of sixteen transmission opportunities, which may be imaged as a "time slot", and every transmission opportunity equals seven OFDM symbols time. (Figure 3.1)

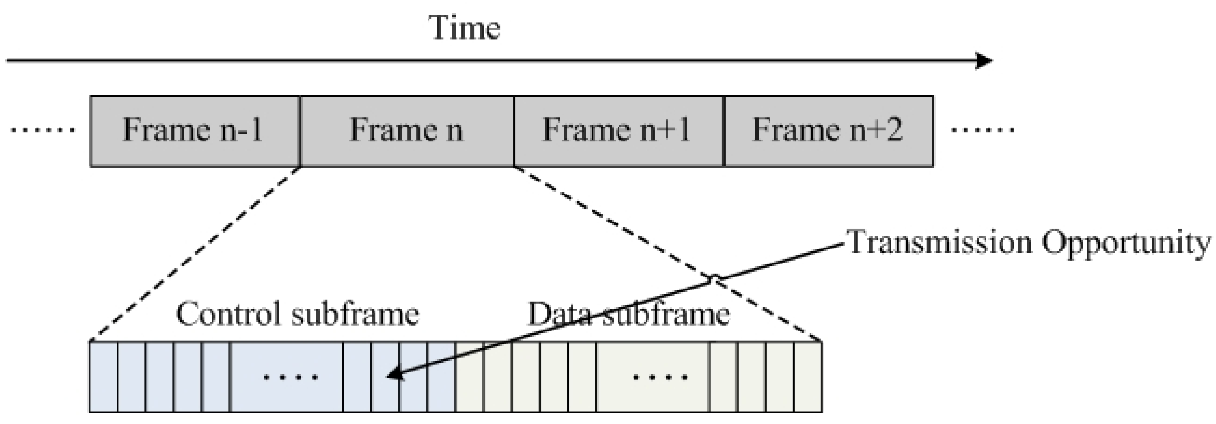


Figure 3.1 Data Subframe and Control Subframe

There are two control subframe types in a control subframe. One is network control that creates and maintains the cohesion between different systems. It also provides a new node to gain synchronization and initial network entry into a mesh network. The other is to coordinate scheduling of data transfers in system, namely, schedule control. The scheduling information is encapsulated here. Frames with the network control subframe occur periodically and all the other frames contain schedule control subframes tag along the network control subframe.

Two messages “MSH-NENT” and “MSH-NCFG” are used in the network control subframe. MSH-NENT means a mesh network entry, which is a message for a new node to gain synchronization and initial network entry into a mesh network; furthermore, MSH-NCFG means a mesh network configuration, provides a basic level of communication between nodes in different nearby networks. On the side, in the schedule control subframe, “MSH-CSCH” and “MSH-DSCH” means the mesh network centralized scheduling and the mesh network distributed scheduling, separately. MSH-DSCH is the key point that this thesis concentrates on.

As mentioned in this section’s first paragraph, we have introduced that every control subframe consists of sixteen transmission opportunities. Nevertheless, they are just the opportunities to own these time slots, but the really time slot occupied is indicated by “MSH-CTRL-LEN”. MSH-CTRL-LEN is a field saved in the MSH-NCFG message to express the control subframe length. MSH-DSCH-NUM is also saved in the MSH-NCFG message to express the number of MSH-DSCH opportunities in the schedule control subframe. Of course, what's left after MSH-DSCH-NUM is subtracted from MSH-CTRL-LEN becomes the number of MSH-CSCH opportunities. All of the parameters we introduced thus far are depicted in Figure 3.2.

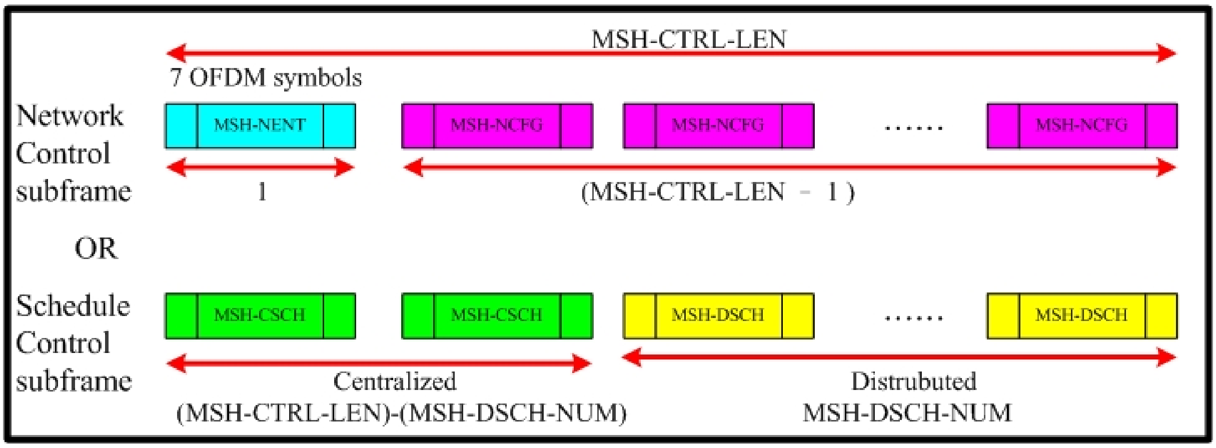


Figure 3.2: Network Control subframe and Schedule Control subframe

There is a parameter "Scheduling Frames" in the MSH-NCFG which specifies how many frames have a schedule control subframe between two frames with network control subframes in multiples of four frames. For example, there are 4 schedule control subframes, if Scheduling Frames equals 1; there are 8 schedule control subframes, if Scheduling Frames equals 2, …etc. (Figure 3.3)

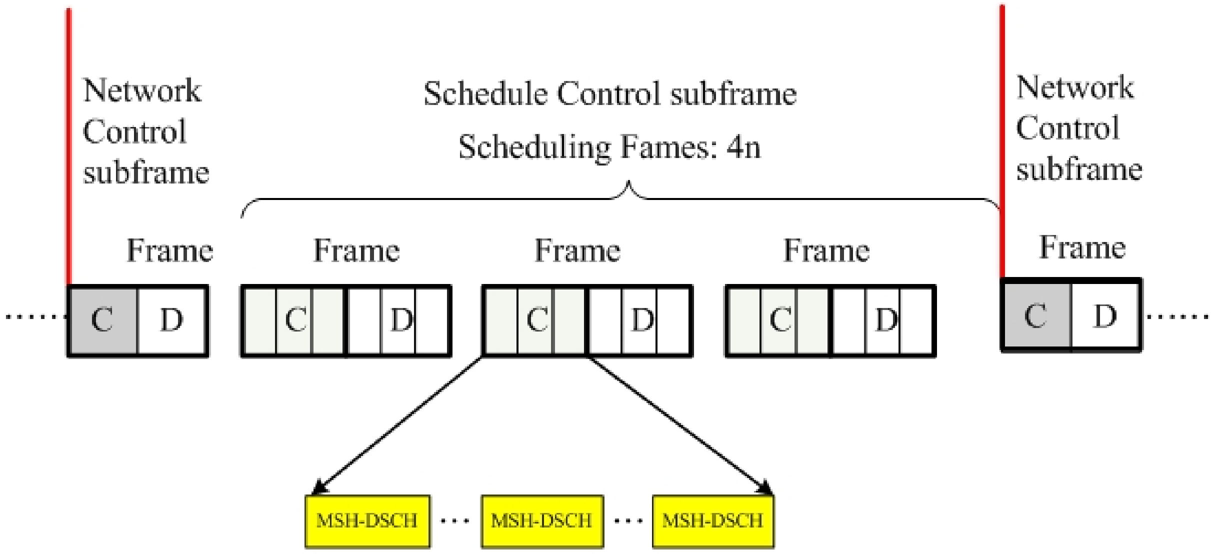


Figure 3.3: MSH-DSCH in the Schedule control subframe

## 3.3. Next Transmission Time and Transmission Holdoff Time

In this section, we will introduce parts of the terminologies and abbreviations in the IEEE 802.16 specification.

The schedule information for each node is described by two parameters **Next Xmt Time** and **Xmt holdoff Time**. In the IEEE 802.16 specification, **Next Xmt Time** is not employed directly. It uses **Next Xmt Mx** to calculate the **Next Xmt Time**. It doesn't use **Xmt holdoff Time**, neither. It uses **Xmt holdoff exponent** to calculate the **Xmt holdoff Time**. As the Figure 3.4 shows, **Next Xmt Mx** and **Xmt holdoff exponent** are two parameters in the MSH-DSCH message to perform the schedule information. So that whenever a node transmits MSH-DSCH message, every node has the schedule information of its neighbors.

| Syntax | Size | Notes |
|---|---|---|
| MSH-DSCH_Scheduling_IE() { | | |
| **Next Xmt Mx** | 5 bits | |
| **Xmt holdoff exponent** | 3 bits | |
| **No. SchedEntries** | 8 bits | |
| for (i=0; i< No_SchedEntries; ++i) { | | |
| **Neighbor Node ID** | 16 bits | |
| **Neighbor Next Xmt Mx** | 5 bits | |
| **Neighbor Xmt holdoff exponent** | 3 bits | |
| } | | |
| } | | |

Figure 3.4: Next Xmt Mx and Xmt holdoff exponent in the MSH-DSCH

(source: IEEE 802.16-2004)

### 3.3.1. Next Xmt Time

A node has to decide the next transmission time to know when to transmit the next MSH-DSCH message. There is a special terminology employed in the IEEE 802.16 specification to describe this transmission duration named "**Eligible Interval**". This next transmission time is denoted as **Next Xmt Time** and calculated from **Next Xmt Mx**. Assume "*Next*" is denoted as **Next Xmt Time** of an observed node; "*Mx*" and "*x*" means its corresponding **Next Xmt Mx** and **Xmt holdoff exponent** separately. Duration of **Next Xmt Time** could be shown as the following formula (1)defined in the standard.

$$2^{x} \cdot Mx < Next \le 2^{x} \cdot (Mx + 1) \tag{1}$$

By the observation of this formula, we know $2^{x}$ is the length of "*Next*". "*x*" is clearly an exponential value to express the length of "*Next*".

### 3.3.2. Xmt Holdoff Time

**Xmt Holdoff Time** is also a special terminology applied in the IEEE 802.16 specification to indicate that this node is not eligible to transmit messages. Assume "*Holdoff*" is denoted as **Xmt Holdoff Time** of an observed node; "*x*" means its corresponding **Xmt holdoff exponent**. Then, **Xmt Holdoff Time** could be shown as the following formula (2) defined in the standard.

$$\text{Holdoff} = 2^{x+4} \tag{2}$$

As explained in the previous section, we know $2^x$ is the length of "Next". From this formula, we know the holdoff time is in multiples of sixteen "Next".

### 3.3.3. Next Xmt Time and Xmt Holdoff Time on time axis

The following figure shows these variations on time axis. (Figure 3.5) **Earliest Subsequent Xmt Time** is a terminology in the standard to denote the earliest possible transmission time, without been determined. The parameters defined in the standard and will be discussed in this thesis are shown as Table 3.1.

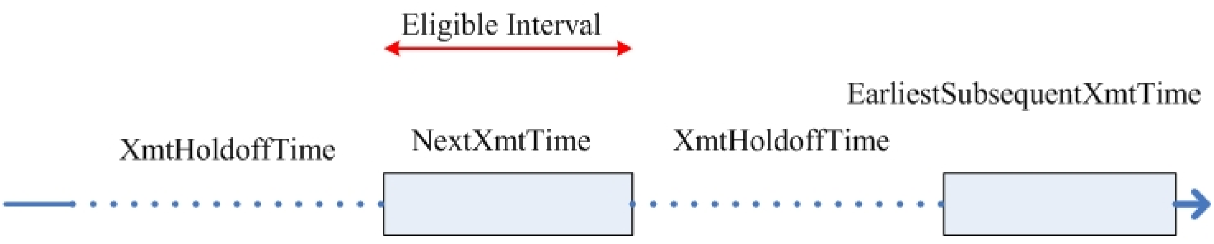


Figure 3.5: Next Xmt Time and Xmt Holdoff Time

Table 3.1: Abbreviation defined in the 802.16 Standard

| Abbreviation in the 802.16 Standard | Description |
|---|---|
| Xmt Time | Transmission time |
| Current Xmt Time | Current transmission time |
| Next Xmt Time | Next transmission time |
| Xmt Holdoff Time | Transmission holdoff time |
| Next Xmt Mx | Next transmission maximum, used for Next Xmt Time |
| Xmt Holdoff Exponent | Transmission hold off exponent, used for the Xmt Holdoff Time |
| Earliest Subsequent Xmt Time | Earliest subsequent transmission time |

## 3.4. Competing Behavior and Scheduling Algorithm

Distributed scheduling ensures that the transmissions are collision-free. There is an election algorithm named MeshElection defined in the IEEE 802.16 standard to achieve collision-free.

The competing behavior and scheduling algorithm occur in each of nodes which are activating all over the neighborhood in mesh network. For instance, we observe certain node's competing behavior and its scheduling algorithm. We assume this node as an observed node; its neighboring nodes are denoted as neighbors. In the period of the competing behavior happened on this observed node, the scheduling algorithm is been computed. First, observed node orders its neighbor table by the Next Xmt Time. Then for each entry of the neighbor table, adds the each neighbor's Next Xmt Time to its Xmt Holdoff Time to arrive at the neighbor's Earliest Subsequent Xmt Time, as in (3). Subsequently, sets Temp Xmt Time equal to this observed node's advertised Xmt Holdoff Time added to the current Xmt Time, as in (4). So far, the observed node understands its possible Next Xmt Time; even now it is just a Temp Xmt Time. The observed node also has its neighbors' information includes Next Xmt Time, Xmt Holdoff Time and Earliest Subsequent Xmt Time, simultaneously.

$$\text{Earliest Subsequent Xtm Time} = \text{Next Xmt Time} + \text{Xtm Holdoff Time} \tag{3}$$

$$\text{Temp Xtm Time} = \text{Current Xmt Time} + \text{Xtm Holdoff Time} \tag{4}$$

Depends on the information obtained previously, the observed node has the sufficient information to judge whether the possible collisions will occur or not. That is, there is a probability that this observed node's Next Xmt Time results in collision with neighbors' Next Xmt Time. The competing nodes are the subset of the neighbors with a Next Xmt Time eligibility interval that includes Temp Xmt Time or which an Earliest Subsequent Xmt Time equal to or smaller than Temp Xmt Time. These collision situations are depicted as Figure 3.6 to express the collisions will be occurred between an observed node's Next Xmt Time and its neighbors'. The neighbor i is save. The neighbor j has its Next Xmt Time at the same time with the observed node. Neighbor k owns its Next Xmt Time early but its Earliest Subsequent Xmt Time overlaps the observed node's Next Xmt Time. In brief, observed node has two collisions with neighbor j and neighbor k.

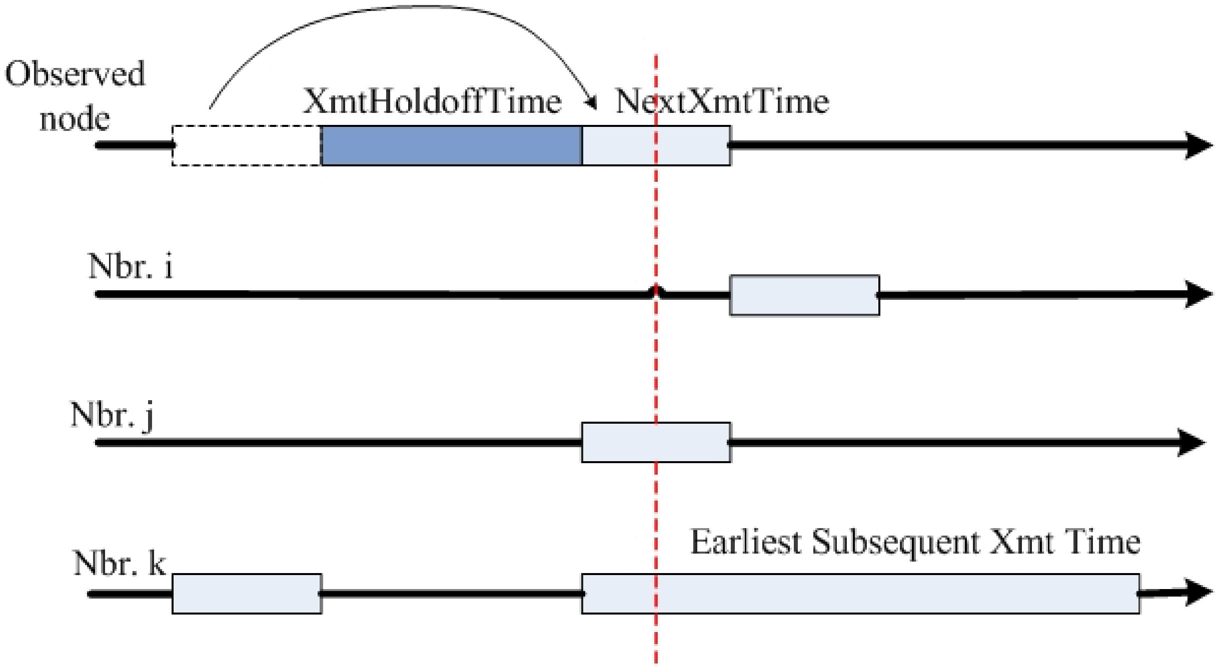


Figure 3.6: One node results in collision with neighbors

If the collision will happen on observed node's Next Xmt Time as mentioned previously, the algorithm MeshElection will be executed during this computing period of distributed schedule. MeshElection is a C code function implemented in the standard. The Boolean value will be come out after MeshElection. "TRUE" means that this observed node wins the competing; on the contrary, "FALSE" means not. Corresponding procedures of them are:

- TRUE: Set Temp Xmt Time to Next Xmt Time, and ends off this algorithm.

- FALSE: Temp Xmt Time need to back.

The Figure 3.7 and Figure 3.8 show the flowchart we introduced. In order to have the better presentation in the flowchart, abbreviations are used and described as Table 3.2.

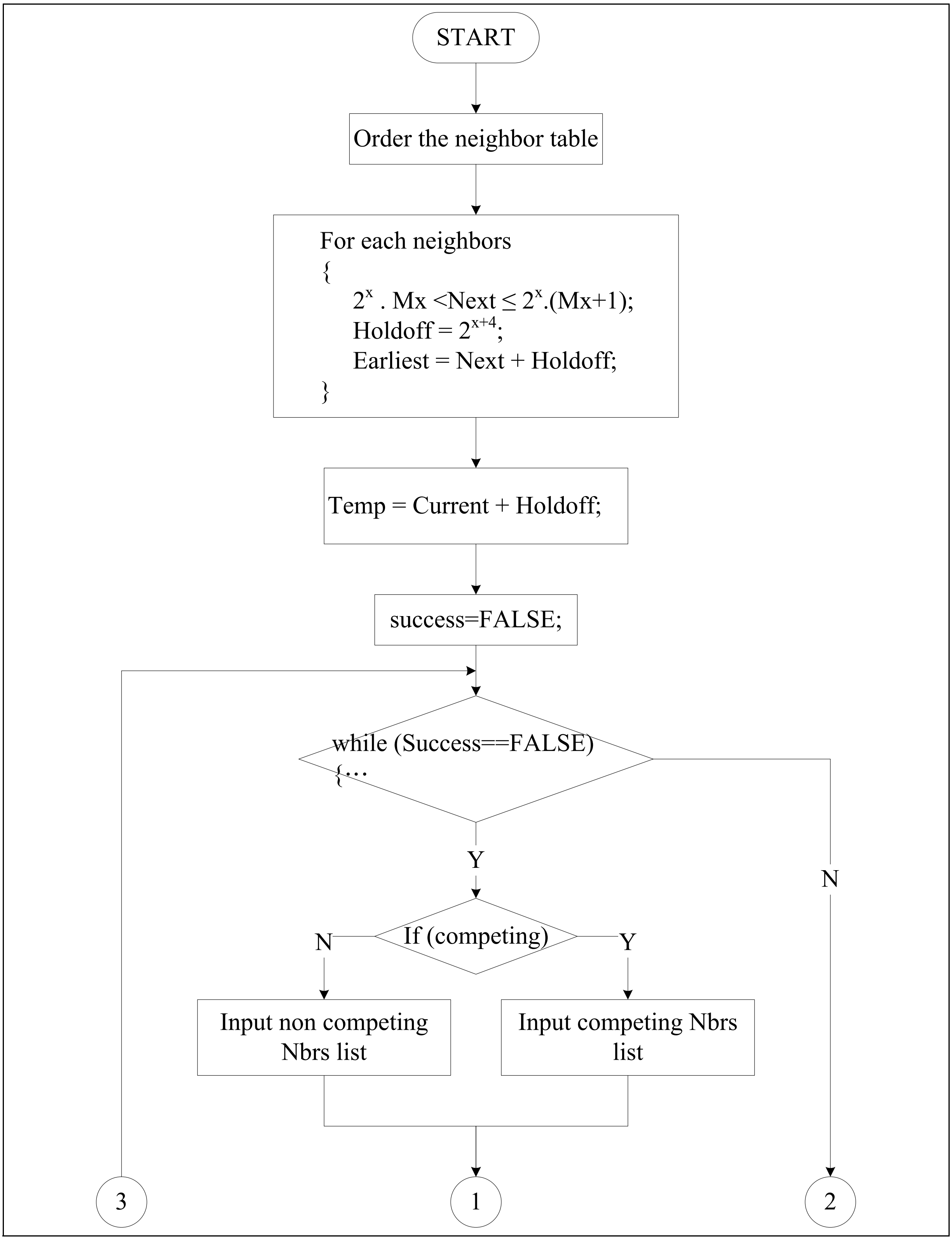


Figure 3.7: The flowchart of competing algorithm-1

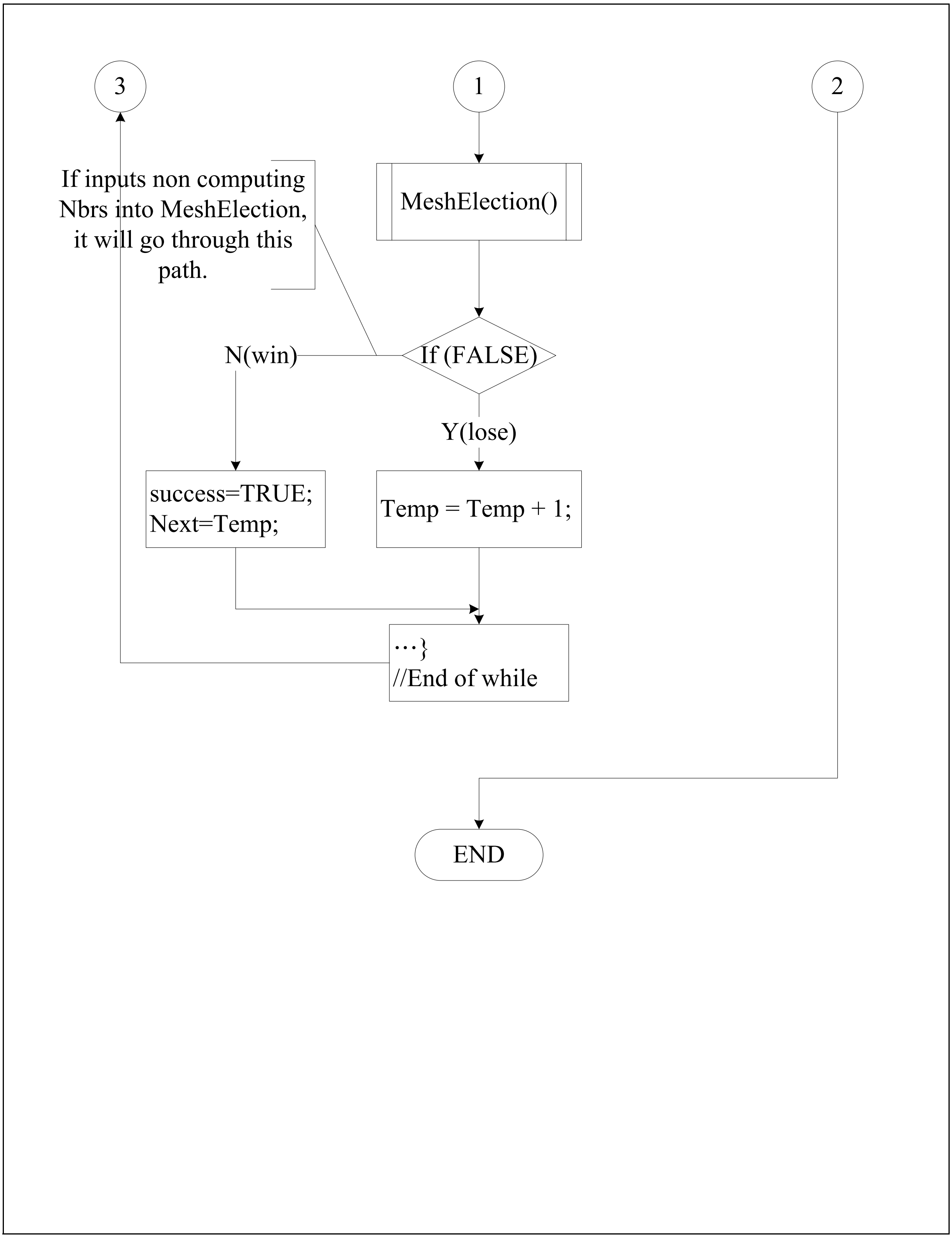


Figure 3.8 :The flowchart of competing algorithm-2

Table 3.2: The abbreviations in the flowchart

| Abbreviations in the Figure 3.7 and Figure 3.8 | Descriptions |
|---|---|
| Mx | Next Xmt Mx |
| Next | Next Xmt Time |
| Holdoff | Xmt Holdoff Time |
| Earliest | Earliest Subsequent Xmt Time |
| Temp | Temp Xmt Time |
| Current | Current Xmt Time |

## 3.5. Three-Way Handshaking

So far, the competing behaviors of control subframe in the distributed scheduling of IEEE 802.16 mesh mode are introduced. Thansmiting the MSH-DSCH message to the neighbors shall stable then subsequent data transmission may work better. Before data transmission, both of the coordinated and uncoordinated scheduling employs a three-way handshake to setup the connections with neighbors. This mechanism is used to convey the channel resources for the preparation of consequent data transmission. As follows, the three-way handshaking IEs (information elements) "**Request IE**", "**Availability IE**" and "**Grants IE**" are encapsulated in the MSH-DSCH, too. Hence it implies that the performance of MSH-DSCH packet traffic influences the three-way handshaking. This is why we concentrate upon the MSH-DSCH performance evaluation in this thesis.

- ”**Request-IE**” shall convey resource requests on per link basis. There is a Demand Persistence field in the request IE to submit the number of frames wherein the demand exists. (Figure 3.9)

- “**Availability-IE**” shall be used to indicated free minislot ranges that neighbors could issue Grants in.

- “**Grants-IE**” shall convey information about a granted minislot range selected from the range reported as available. Grants shall be used both to grant and confirm a grant, like the “acknowledge” in general communication protocol.

| Syntax | Size | Notes |
|---|---|---|
| MSH-DSCH_Request_IE() { | | |
| **Link ID** | 8 bits | |
| **Demand Level** | 8 bits | |
| **Demand Persistence** | 3 bits | |
| *reserved* | 1 bit | Shall be set to zero. |
| } | | |

Demand Persistence:

0 = cancel reservation
1 = single frame
2 = 2 frames
3 = 4 frames
4 = 8 frames
5 = 32 frames
6 = 128 frames
7 = Good until cancelled or reduced

Figure 3.9: Request IE Message

(source: IEEE 802.16-2004)

Followings are what the procedures of three-way handshaking are defined in the IEEE 802.16 standard.

- "MSH-DSCH-request" is made along with "MSH-DSCH-availabilities", which indicate potential slots for replies and actual schedule.

- "MSH-DSCH-grant" is sent in response indicating a subset of the suggested availabilities that fits, if possible, the request. The neighbors of this node not involved in this schedule shall assume the transmission takes place as granted.

- "MSH-DSCH-grant" is sent by the original requester containing a copy of the grant from the other party, to confirm the schedule to the other party. The neighbor of this node not involved in this schedule shall assume the transmission takes place as granted.

By the way, the handshaking is depicted to be clearer in the Figure 3.10

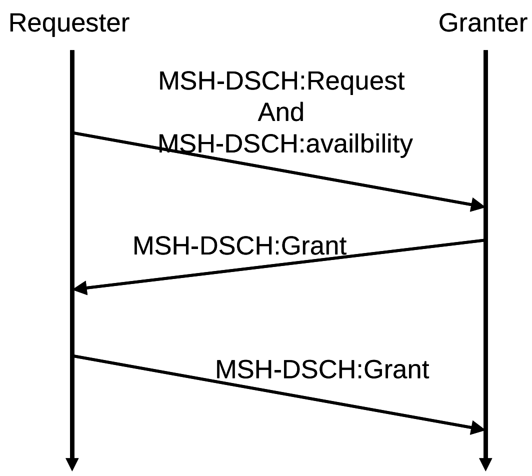


Figure 3.10: Three-way handshaking