Performance Optimization of the Initialization Process of IEEE 802.16 Mesh Networks

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Abstract

The IEEE 802.16-2004 standard defines a media access control (MAC) layer for a mesh network topology. In these networks, wide scale power outages can cause serious disruptions to digital services when the centralized scheduling mode is used. This result in very long service recovery times for all mesh nodes, since the Network Entry (NENT) region of the IEEE 802.16 mesh frame is too short to support such situation. In this paper we study the performance of the initialization process, due to service disruption, of IEEE 802.16-2004 mesh networks. We propose a new scheme to reduce considerably the recovery time of such networks. For the performance analysis we implemented a simulation model using the OPNET simulation package v14. Simulation results shows that the recovery time obtained with our proposed scheme can be reduced by 50\% compared with the default scheme defined in the standard.

1. Introduction

Broadband Wireless Access (BWA) Networks, which are based on the standard IEEE 802.16, have gained an increased interest during the last few years. This standard has become the best way to fulfill residential, small business and underserved rural areas demand for high speed Internet access, multimedia and voice services. The IEEE 802.16 standard is considered one of the most promising wireless access technologies due to its advantage of cost-effective and fast deployment.

The first version of the IEEE 802.16 protocol was completed in October 2001. This version was called IEEE 802.16-2001 [1] and it defines the air interface and MAC protocol for a wireless metropolitan area network (WMAN). It was intended for high-bandwidth wireless voice and data for residential and enterprise use. At the beginning of its development, this protocol was oriented to fixed wireless users with line of sight (LOS) in the 11-66 GHz spectrum range. In 2004 the aim of the 802.16 protocol was changed to support residential access and non line of sight (NLOS). The second version is called the IEEE 802.16-2004 standard [2] and it supports two operating modes of the MAC layer: 1) point to multipoint (PMP), where traffic occurs only between the Base Station (BS) and Subscriber Stations (SSs), and 2) mesh topology, where traffic can be routed through other SSs and can occur directly between SSs. The mesh mode is the extension to the PMP mode, with the advantage of less coverage path loss, coverage and robustness improved as subscribers are added. In the mesh mode, system throughput can be increased by using multiple-hop paths [3] and [4]. Thus, Wireless Mesh Networks (WMNs) can be used to extend cell ranges, cover shadowed areas and enhance system throughput.

The IEEE 802.16 mesh protocol has defined two scheduling mechanisms: distributed and centralized scheduling. In the former, a Mesh SS (MSS), termed also as node, competes for channel access using a pseudo-random election algorithm based on the scheduling information of the two-hop neighbors, and bandwidth reservation for data transmission in performed using a request-grant-confirm three-way handshaking procedure. In the latter, the Mesh Base Station (MBS) works like a headend and receives all bandwidth requests from all MSSs within a certain hop range and determines the among of granted resources for each node. Because all the control and data messages need to pass through the MBS, the scheduling procedure is simple, however the connection setup delay is long [5]. In operational mesh
networks, using centralized scheduling, service disruption events such as large scale power outages can seriously affect the system’s performance. Upon such events, all link connections between the MBS and the nodes are terminated. In this paper, we study the performance of the initialization process after service disruption. In order to study the performance of the MAC protocol of such mesh networks, we have developed a discrete event simulation model based on the OPNET simulation package v14.

Recent studies found in the literature focus on centralized and distributed schedulers. In [5] the authors identified two problems that occur during initialization of mesh network, the first case in which the NENT process fails and the other case when the process fails during LinkEst process. In [6], the authors realized a behavior comparison between different proposals to implement schedulers dividing in centralized coordinated, distributed coordinated, and the other the not-coordinated distributed ones, mentioned the problems and benefits obtains in different schemes, for example: the time effect in the broadcast delay (Holdoff), QoS, scalability and data scheduler. In [7], the authors discussed when new node allocating in overlapping area two WiMAX networks, network entry is considered from the load-aware point of view. While [8] describes the election based transmission timing mechanism, [9] evaluated the performance analyzing the effects and the two-hop neighborhood size on the distributed election, and in [10] the authors analyzed the problem with collision during transmission data with distributed scheduler.

In [11] previous work, we described the MAC layer mechanics for IEEE 802.16 mesh networks. In this paper, we studied the initialization considered the parameters for optimization transmission time, and we proposed an enhanced mechanism for Network Entry configuration messages.

The paper is structured as follows. Section 2 presents an overview of the relevant parts of the IEEE 802.16 mesh protocol. Section 3 derives the theoretical model for the performance of the uplink channel of the protocol. In Section 4, we present the performance analysis of the IEEE 802.16 protocol comparing analytical and simulation results. We conclude the paper in Section 5.

2. IEEE 802.16 Mesh Topology

Both scheduling modes use a generalized entry process that is described in the following section. For a detailed description of the scheduling process, in [1] we presented a comparative analysis of wireless broadband mesh and multi-hop networks based on the IEEE 802.16 protocol.

2.1 Mesh network synchronization

Network configuration (MSH-NCFG) and network entry (MSH-NENT) packets provide a basic level of communication between nodes in different nearby networks, whether from the same or different equipment vendors or wireless operators. These packets are used to synchronize both centralized and distributed control mesh networks.

This communication is used to support basic configuration activities such as: synchronization between nearby networks used (i.e., for multiple, co-located MBSs to synchronize their uplink and downlink transmission periods), communication and coordination of channel usage by nearby networks, and discovery and basic network entry of new nodes.

MSH-NCFG, MSH-NENT, and MSH-DSCH (distributed scheduling packets) can assist a node in synchronizing frame transmission. For these messages, the first control subframe, as described in Frame 1 of Fig.1, is divided into several transmission opportunities (TxOps), depending on the MSH_CTRL_LEN parameter. The first TxOp in a network control subframe contains a MSH-NENT message, while the remainder MSH-CTRL-LEN-1 TxOps contain MSH-NCFG messages. In scheduling control subframes, the MSH-DSCH-NUM TxOps assigned for MSH-DSCH messages come last in the control subframe. The MSH-NCFG messages also contain the number of their TxOps, which allows nodes to easily calculate the frame start time.

2.2 Initialization Process

For the centralized scheduling mechanism of the IEEE 802.16-2004 mesh protocol, after service disruption a node must performs the initialization process described as follows.

Node initialization and network entry procedures in mesh mode are in some aspects different from those in
PMP mode. A new node entering the network and carries on the following steps:

1) Scan for active network and establish network synchronization.
2) Obtain network parameters (from MSH-NCFG messages).
3) Open a Sponsor Channel.
4) Receive node authorization.
5) Perform node registration.
6) Establish IP connectivity.
7) Establish time of day.
8) Transfer operational parameters.

On initialization or after signal loss, a node search for MSH-NCFG messages to acquire synchronization with the mesh network. Upon receiving a MSH-NCFG message, the individual node acquire the network time from the message Timestamp field. A node may have nonvolatile storage in which the most recent operational parameters are stored and first try to re-acquire coarse synchronization with the network. If this fails, nodes begin to continuously scan the possible frequency band channels until a valid network is found. Once, the PHY has actually achieved synchronization, the MAC attempts to acquire network parameters while, at the same time, each node build its physical neighbor list.

A node remains in synchronization as long as it receives MSH-NCFG messages. A node accumulates MSH-NCFG messages at least until it receives a MSH-NCFG message from the same node twice and until it has received a MSH-NCFG: Network Descriptor with an operator ID matching (one of) its own if it has any. In parallel, the new node builds a physical neighbor list from the acquired information.

From the established physical neighbor list, the new node selects a potential sponsoring node out of all nodes having the Logical Network ID of the node for which it found a suitable Operator ID (Figure 2). The new node then synchronizes its time to the potential sponsor assuming 0 propagation delay after which it sends a MSH-NENT: NetEntryRequest including the Node ID of the potential sponsor.

Once the candidate node has selected one of its neighbors as the candidate sponsoring node it becomes a candidate node. To get further in the initialization procedure, the candidate node request the candidate sponsoring node to establish a temporary schedule that could be used for further message delivery during the candidate node initialization. The temporary schedule requested is termed sponsor channel.

The process is initiated by the candidate node, which transmit a MSH-NENT: NetEntryRequest message (a MSH-NENT message with type set to 0x2) to the sponsoring node. Upon reception of the MSH-NENT: NetEntryRequest message with the sponsor node ID equal to node ID of its own. The candidate sponsoring node assess the request and either opens the sponsor channel or reject the request.

The response is given in a MSH-NCFG message with an embedded data. If the candidate sponsoring node does not advertise the candidate node’s MAC address in the sponsor’s next MSH-NCFG transmission, then the procedure is repeated MSH_SPONSOR_ATTEMPTS times using a random backoff between attempts. If these attempts all fail, then a different candidate sponsoring node is selected and the procedure repeated (including re-initialization coarse network synchronization). If the selected candidate sponsoring node does advertise the candidate node’s MAC address, it continues to advertise this MAC address in all its MSH-NCFG messages until the sponsorship its termed.

Once the candidate node has received a positive response (a NetEntryOpen message) from the candidate sponsoring node in the MSH-NCFG message, it shall acknowledge the response by transmitting a MSH-NENT: NetEntryAck message (a MSH-NENT message with type set to 0x1) to the sponsoring node at the first following network entry TxOp. Before that the candidate node performs fine time synchronization. It makes a correction to its transmission timing by the estimating propagation delay indicated in the embedded MSH-NCFG: NetEntryOpen message.

If the sponsoring node accepts the request and opens a sponsor channel, the channel is ready for use immediately after the transmission of the acknowledgement message. At the same time, the candidate sponsoring node becomes the sponsoring node.

If the candidate sponsoring node embeds a MSH-NCFG: NetEntryReject, the new node performs the following action based on the rejection code.

0x0: Operator authentication value invalid
    The candidate node selects a new candidate sponsoring node with different operator ID.
0x1: Excess propagation delay
    The candidate node shall repeats its MSH-NENT:NetEntryRequest in the following network entry transmission opportunity to the same candidate sponsoring node.
0x2: Select new sponsor
    The candidate node shall select a new candidate sponsoring node.
If the candidate sponsoring node embedded neither MSH-NCFG: NetEntryOpen nor MSH-NCFG: NetEntryReject, the candidate node waits (with timeout time T23), for the next MSH-NCFG with NetEntryOpen from the candidate sponsoring node and resend the MSH-NENT:NetEntryRequest on timeout.

The candidate node and the sponsoring node use the schedule indicated in the NetEntryOpen message to perform message exchanges. After this is completed, the candidate node terminates the entry process by sending a MSH-NENT:NetEntryClose message to the sponsoring node in the network entry transmission immediately following a MSH-NCFG transmission from the sponsoring node, which Ack termination with MSH-NCFG:NetEntryAck.

In Fig. 2 we show the complete exchange messages of a remote node “Y” that carries on the network entry process throughout the sponsor node “X”, which in turn forwards the control messages to the MBS. The figure also includes the transmission time reported by our simulation model, using the parameters defined in Table 1.

![Figure 2. Exchange messages.](image)

### Table 1. Simulation Parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame Duration T&lt;sub&gt;F&lt;/sub&gt;</td>
<td>10 ms</td>
</tr>
<tr>
<td>OFDM symbol / frame</td>
<td>1024</td>
</tr>
<tr>
<td>OFDM symbol / slot</td>
<td>4</td>
</tr>
<tr>
<td>Opportunity transmission time / slot</td>
<td>68,359 μs</td>
</tr>
<tr>
<td>Bytes / OFDM symbol</td>
<td>8/64</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>25 MHz</td>
</tr>
<tr>
<td>Power Tx</td>
<td>0.3 W</td>
</tr>
<tr>
<td>Data rate</td>
<td>59 Mbps</td>
</tr>
<tr>
<td>Distance of SS to the BS</td>
<td>0.1 - 5 km</td>
</tr>
</tbody>
</table>

**3. Proposed Scheduling Control Process**

In the event of power outage, a candidate node needs first to synchronize with the mesh network as described in the previous section. Then, whenever the candidate node receives a MSH-NCFG with sponsored MAC address = 0x000000000000, the candidate node should transmit its first message (MSH-NENT: NetEntryRequest) to the sponsoring node or the MBS using contention-based access, in the following MSH-NENT TxOp. The other messages (MSH-NENT: NetEntryAck, and MSH-NENT:NetEntryClose) should be transmitted immediately using the following MSH-NENT TxOp, after the candidate node receives its associated MSH-NCFG messages, as described above. Therefore, the real problem is that in a power outage, tens of nodes would contend for those MSH-NENT TxOps, resulting in a low initialization system performance, due to a large number of collisions. The initialization performance is even worse if the configurations parameters (as described in Table 2) are not optimized for the transmission of MSH-NENT messages.

### Table 2. Scheduling Control Parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame Duration (F&lt;sub&gt;0&lt;/sub&gt;)</td>
<td>Defines the duration of a frame that contains control and data subframes, as shown in Figure.1[2-20ms]</td>
</tr>
<tr>
<td>XmtHoldoffExponent (XHE)</td>
<td>This a configuration parameter used to compute XmtHoldoffTime. [0-7]</td>
</tr>
<tr>
<td>XmtHoldoffTime (XHT)</td>
<td>Indicates the number of MSH-NCFG TxOps that a node needs to backoff after the NextXmtTime.</td>
</tr>
<tr>
<td>NextXmtMx (NXM)</td>
<td>This is a configuration parameter used to compute NextXmtTime-Interval. [0-31]</td>
</tr>
<tr>
<td>NextXmtTimeInterval (NXTI)</td>
<td>Indicates the next interval in which nodes are considered eligible for the transmission of its next MSH-NCFG message.</td>
</tr>
<tr>
<td>NextXmtTime (NXT)</td>
<td>Indicates the next MSH-NCFG TxOp.</td>
</tr>
<tr>
<td>EarliestSubsequent-XmTime (ESXT)</td>
<td>Defines the earliest TxOp that a node is eligible to transmit a MSH-NCFG message after NextXmtTime</td>
</tr>
<tr>
<td>Scheduling Frames (S&lt;sub&gt;v&lt;/sub&gt;)</td>
<td>Indicates how many frames have a schedule control frame between two frames including a network control subframe. [0,4,8,12,...,128]</td>
</tr>
<tr>
<td>MSH-CTRL-LEN (L&lt;sub&gt;v&lt;/sub&gt;)</td>
<td>Indicates the number of TxOp per network control subframe.</td>
</tr>
</tbody>
</table>
Since the standard [1] defines only one MSH-NENT TxOp of 7 OFDM symbols every $S_f$ frames, as illustrated in Figure 3a, we propose the following frame structure to optimize this region.

In our framing scheme, after power outage, we propose to use short preambles for the transmission of MSH_NENT messages. This can be possible by simply setting the Short Preamble Flag to 1 of the $Nbr$ Logical IE Information structure included in the MSH-NCFG message (with sponsored MAC address = 0x000000000000), as indicated in [1], section 8.3.3.6.

We also propose to use one Guard Symbol. This is also possible because the standard defines that the transition gap for all WirelessMAN-OFDM systems profiles should be $\leq 100 \mu$s (section 12.3, [1]). In Table 3, for all channel Bandwidths (BW) supported in the Mesh mode, the OFDM symbol duration ($T_s$) is $< 100\mu$s. In addition, all the other frames in the Mesh mode (such as Centralized Configuration, Centralized Scheduling and Distributed Scheduling) use one Guard Symbol. Therefore using one symbol for this transition gap is between the operational values.

By using short preambles and considering one Guard Symbol, we can in fact transmit two MSH-NENT messages in one TxOP as illustrated in figure 3b. In the first 4 OFDM symbols we can transmit one MSH-NENT message with Type = 0x02: NetEntryRequest. However, in the last 3 OFDM symbols we can only transmit either a MSH-NENT message with Type = 0x01: NetEntryAck or a MSH-NENT message with Type = 0x03: NetEntryClose. Thus, we just need to verify that the MAC PDU w/NENT fits in two OFDM symbols for the NetEntryRequest option and one symbol for the NetEntryAck/NetEntryClose options.

In Table 4 we show the channel coding per modulation supported in the Mesh mode. However, the transmission of control subframes (such as MSH-NENT and MSH-NCFG) must be sent using the mandatory coding scheme (QPSK with $\frac{1}{2}$ overall coding rate). The uncoded frame size in bytes that can be transmitted in one OFDM symbol is given by $N_{\text{uncod}} \times m \times CR/8$, where $N_{\text{uncod}}$ is the number of data subcarriers. Then, the MAC PDU w/MSH NENT:NetEntryReq (Figure 4.b) requires 35 bytes which can be transmitted using two OFDM symbols with the mandatory modulation scheme. The frame structure of the MAC PDU w/MSH NENT:NetEntryAck/NetEntryClose is the same as the MAC PDU w/MSH NENT:NetEntryRequest without the Request IE () field. This results in a frame of 13 bytes which can be transmitted using one OFDM symbol with the mandatory modulation scheme.

![Figure 3. Network entry frame structures.](image)

<table>
<thead>
<tr>
<th>BW (MHz)</th>
<th>$T_s$ (µs)</th>
<th>$S_f$</th>
<th>No. OFDM Symbols/frame</th>
<th>(\gamma) [%]</th>
<th>(\gamma) [%]</th>
<th>(\gamma) [%]</th>
<th>(\gamma) [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>93</td>
<td>119</td>
<td>0.1</td>
<td>0.2</td>
<td>0.3</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td>3.5</td>
<td>80</td>
<td>138</td>
<td>0.1</td>
<td>0.1</td>
<td>0.3</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td>5.5</td>
<td>51</td>
<td>219</td>
<td>0.0</td>
<td>0.1</td>
<td>0.2</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>7</td>
<td>40</td>
<td>277</td>
<td>0.0</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>10</td>
<td>28</td>
<td>400</td>
<td>0.0</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Table 3. NENT Channel Utilization.

<table>
<thead>
<tr>
<th>Modulation</th>
<th>Bits per symbol (m)</th>
<th>Uncoded block size [bytes]</th>
<th>Coded block size [bytes]</th>
<th>Overall coding rate (CR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QPSK</td>
<td>2</td>
<td>24</td>
<td>48</td>
<td>1/2</td>
</tr>
<tr>
<td>QPSK</td>
<td>2</td>
<td>36</td>
<td>48</td>
<td>3/4</td>
</tr>
<tr>
<td>16-QAM</td>
<td>4</td>
<td>48</td>
<td>96</td>
<td>1/2</td>
</tr>
<tr>
<td>16-QAM</td>
<td>4</td>
<td>72</td>
<td>96</td>
<td>3/4</td>
</tr>
<tr>
<td>64-QAM</td>
<td>6</td>
<td>96</td>
<td>144</td>
<td>2/3</td>
</tr>
<tr>
<td>64-QAM</td>
<td>6</td>
<td>108</td>
<td>144</td>
<td>3/4</td>
</tr>
</tbody>
</table>

Table 4. Channel coding per modulation.
In addition, we further enhance our proposed framing scheme by using 3 bits of the reserved filed in the MSH-NENT message format. With these 3 bits we propose to add the following parameters:

  0: Indicates normal operation, 1: indicates the nodes to entry the network after a power outage.
- NetEntry Transmission Opportunities, “NENT” (2 bits):
  0: 1 TxOp is required when NetPwrOut = 0.
  1: 2 TxOp are required when NetPwrOut = 1.
  2: 3 TxOp are required when NetPwrOut = 1.
  3: 4 TxOp are required when NetPwrOut = 1.

When the NetPwrOut flag is set to 1, it also indicates that our proposed framing structure, as described in Figure 4.b, should be employed for the network initialization process after power outage.

By using the proposed framing structure and the new parameters, the system performance, during the initialization process, is considerably improved, as we will demonstrate in the following sections. We just need to explain how the scheduling of the control messages is carried out.

In order to transmit the NCFG messages, the standard [1] defines that after the transmission of a NCFG message at the NXT TxOp, as shown in Figure 5, a node “X” must defer its transmission by a period of ESXT = 2^{XHE+4} TxOps, before contending again. Once the ESXT period of a node X has elapsed, such node should content in every TxOp during the interval 2^{XHE} XNM < NXTI ≤ 2^{XHE} (NXM+1), using an election procedure.

In order to carry on the initialization process, as described in Section B, each node should transmits their control messages according to the following two parameters time for mesh mode, these parameters are:

1. XmtHoldoffExponent (XHE)
2. NextXmtTime (NXT)

These variables calculate the time in that one node can begin to competing for the transmission opportunity. XmtHoldoffTime (XHT)

\[ XHT = 2^{XHE+4} \]  

NextXmtMx (NXM) value represent the interval in that node is able for competing and depends the XmtHoldoffExponent parameter. Fig 3 shows the distribution when the XHE = 7, then the range is calculated Pas

\[ 2^{XHE} XNM \leq NXT \leq 2^{XHE+1} XNM + 1 \]  

EarliestSubsequentXmtTime (ESXT) represent the time that one node could transmit the next time, that is the node is able competing TO, and is calculated as

\[ ESXT = 2^{XHE} XNM + 1 \]  

II. OPTIMIZATION NETWORK ENTRY SLOTS

We studied and developed a model with 1, 3 and 7 opportunity transmission for control message MSH-NENT and produced different behavior, in the standard is proposed that only one transmission opportunity (TO) assigned for MSH-NENT and seven TO, in the Fig 5 shown a multiframe with minislots allocation we propose. Table 1 shows the parameter simulation used, these parameters was chosen for realized more effective the communication, and we used path loss Erceg’s model with terrain A (Hilly/Moderate to Heavy Tree Density), considering rural community for coverage expanding. The number shown in the Fig. 5 the TOs NENT is sense when the data rate is greater than 59Mbps, because the NENT message contents 42KB

\[ DR = \frac{\text{Symbols} \times \text{NoBytes} \times 8}{\text{durationFrame} \times \text{slots}} \]  

III. SIMULATION MODEL

We implemented a detailed simulation model of the IEEE 802.16 MAC protocol network entry using the OPNET Package v. 14.5, as described in [4]. A hierarchical design was used and it is shown in Fig. 7. At the top level of the BWA network topology, the network components, for example the BS and SS, along with their connectivity are shown in Fig 7a. This image shown the tree generated after the simulation. The next level, Fig. 7b, defines the functionality of a SS in terms of components such as traffic sources, MAC interfaces, etc. The operation of each component is defined by a state machine (an example of which is shown in Fig. 7c). The actions of a component at a particular state are defined in Proto-C code such as that in Fig. 7d. This approach allows modifications to be applied to the operation of the IEEE 802.16 protocol and different optimizations and enhancements to be tested. The result the execution for our model is generated tree shown in Fig. 5a, it is observed that order in join into network is random depends the coverage and the time in that node result winner.
IV. PERFORMANCE EVALUATION

In order to validate the results we estimate the maximum throughput system. In Fig.7a shown the comparison between the simulation with and without collision, the graph without collision indicate the time that 100 nodes in join to network, near to 200 seconds obtained for program simulation Selection Time Algorithm, otherwise the graph with collision was obtained to simulation in OPNET model, the join time was approximant 600 seconds and we observed that the distance between both graphs grown together the number the nodes, in where there are a lot collisions.

The Fig 7b shown the principal claim this paper, the behavior with 1,3 and 7 NENT transmission opportunity, we could proof that with 7 NENT TO the performance grown significant, in time and number nodes. In Fig 7c, we proof use the XmtTimeMx parameter fluctuates between 1 and 7 and we verified that how it works correctly. Finally, in Fig 7d we decided that XmtHoldoffExponent affect direct the time in that a node late in next transmission.

V. CONCLUSIONS

In this paper a performance evaluation of several …

![Network model](image)

![Node model](image)

![Finite State Machine diagram](image)

![Proto-C](image)

Figure 7. Simulation model.

![Proto-C diagram](image)

![EarlySubsequentXmtTime](image)

Figure 6. EarliestSubsequentXmtTime

ACKNOWLEDGEMENT

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REFERENCES


