ELECTRONICS AND ELECTRICAL ENGINEERING
ISSN 1392 – 1215 2012. No. 1(117)
ELEKTRONIKA IR ELEKTROTECHNIKA

T 120 SYSTEM ENGINEERING, COMPUTER TECHNOLOGY
SISTEMŲ INŽINERIJA, KOMPIUTERINĖS TECHNOLOGIJOS

Enhanced Network Control for the Entry Process of IEEE 802.16 Mesh Networks

Y. Macedo, V. Rangel, J. Gomez
School of Engineering, National Autonomous University of Mexico,
Ed. Valdés Vallejo 3er piso, CP. 04510, México City, Mexico, phone: +52 55 56223142, e-mails: macedo@fi-b.unam.mx, victor@fi-b.unam.mx, javierg@fi-b.unam.mx

M. Lopez-Guerrero
Department of Electrical Engineering, Metropolitan Autonomous University,
Iztapalapa, 09340 - Mexico City, Mexico, phone: +52 55 5804-4633, e-mail: milo@xanum.uam.mx

R. Aquino
School of Telematics, University of Colima,
Av. Universidad # 333, C.P 28400, Colima, Col., México, phone: +52 312 3161165, e-mail: aquinor@ucol.mx

crossref http://dx.doi.org/10.5755/j01.eee.117.1.1051

Introduction

The IEEE 802.16-2004 standard [1] supports the following two operating modes of the Medium Access Control (MAC) sublayer: a) point to multipoint (PMP) mode, where traffic occurs only between the Base Station (BS) and Subscriber Stations (SSs), and b) mesh mode, where traffic can be routed through other SSs and can occur directly between SSs. In mesh mode, system throughput can be increased by using multiple-hop paths [2, 3]. 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 kinds of scheduling mechanisms: distributed and centralized. In the former, a mesh SS (MSS), also termed a node, competes for channel access using a pseudo-random election algorithm. This algorithm is based on scheduling information about its two-hop neighbors, and bandwidth reservation for data transmission is performed using a request-grant-confirm three-way handshaking procedure. In the latter, the mesh Base Station (MBS) works like a head end and receives all bandwidth requests from all MSSs within a certain hop range and grants resources for each node. Because all control and data messages need to pass through the MBS, the scheduling scheme is simple. However, the connection setup delay can be long [4, 5]. It is worth pointing out that in centralized scheduling, service-disruption events, such as large-scale power outages, can seriously affect system´s performance. This is due to the fact that upon such events, all link connections between the MBS and the nodes are terminated.

Most studies found in the literature focus on routing, performance analysis and optimization issues of centralized and distributed schedulers. However, only a few works discuss the network initialization process of IEEE 802.16 mesh networks.

As an overview of related work it can be mentioned that in [6], the authors presented a load-aware network entry mechanism that allows new nodes entering the network to sense the load and choose the lowest loaded MBS. In [7], the authors presented a performance optimization of the network entry and link establishment processes. They found that about 70% of the network configuration messages (MSH-NCFG) exchanged during the initialization process is successful, but this percentage can be increased up to 93% by minimizing the effects of hidden terminals.

Our work, however, is rather different from the previous ones. In this paper, we study the performance of the initialization process after a service disruption in IEEE 802.16 mesh networks, where the success rate of both MSH-NCFG and network entry messages (MSH-NENT) is much lower than the 70% reported in [7]. In such case, it is evident that new allocation schemes for these messages are needed in order to reduce recovery time. In this paper we propose a new scheme for schedule control that reduces recovery time as much as 98% when compared with the default scheme defined in the standard. Initial results of our proposed scheme were reported in [8], in the present paper we extend these results and, furthermore, we propose a simple theoretical model to estimate the maximum utilization consumed by network control messages.

IEEE 802.16 mesh topology

The centralized and distributed scheduling modes use an entry process that is described in the following section. For a more detailed description of the scheduling process the reader is referred to [9] where we also included a comparative analysis of wireless broadband mesh and multi-hop networks based on the IEEE 802.16 protocol.

Network configuration (MSH-NCFG) and network entry (MSH-NENT) messages provide the basic level of communication between nodes across different nearby networks, regardless of equipment vendors or wireless operators. These messages are used for synchronization in both centralized and distributed control of mesh networks. This communication is used to support basic configuration activities such as: synchronization between nearby networks (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 network entry of new nodes.

MSH-NCFG, MSH-NENT, and MSH-DSCH (distributed scheduling) messages can assist a node to synchronize the frame transmissions. As illustrated with frame 1 in Fig. 1, the first control subframe is divided in as many transmission opportunities (TxOps) as defined by the MSH_CTRL_LEN parameter.

The first TxOp in a network control subframe contains an MSH-NENT message, while the other MSH_CTRL_LEN - 1 TxOps include MSH-NCFG messages. The MSH-NCFG messages also contain the number of their TxOps, which allow nodes to easily calculate the frame start time. In schedule-control subframes (from frame 2 to frame 'n' in Fig. 1), the MSH_DSCH_NUM TxOps assigned for MSH-DSCH messages come last in the control subframe.

For the centralized scheduling mechanism of the mesh protocol [1], upon service disruption, a node must perform the initialization process described as follows.

Node initialization and network entry procedures in mesh mode are, in some aspects, different from those in point-to-multipoint (PMP) mode. A new node entering the mesh network carries out the following steps: 1) Scans for network activity and establishes network synchronization. 2) Obtains network parameters (from MSH-NCFG messages). 3) Opens a Sponsor Channel. 4) Receives node authorization. 5) Performs node registration. 6) Establishes IP connectivity. 7) Establishes the time of day. 8) Transfers operational parameters.

On initialization or after signal loss, a node searches for broadcast MSH-NCFG messages to acquire synchronization with the mesh network. Upon receiving an MSH-NCFG message, a node acquires the network time from the time-stamp field of the message. A node having non-volatile storage may retain the most recent operational parameters and may first try to re-acquire synchronization with the network using them. If this fails, nodes begin to continuously scan possible channels until a valid network is found.

A node completes the synchronization after it receives MSH-NCFG messages from the same node twice, and until it has received an MSH-NCFG message with Network Descriptor information containing an operator ID that matches its own, if it has any. In parallel, the new node builds a physical neighbor list from the recently acquired information.

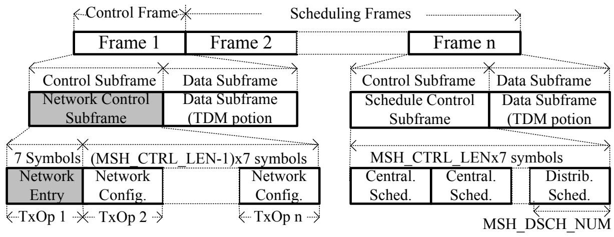

Fig. 1. Frame structure

The initialization process is started by a candidate node, which transmits an MSH-NENT: NetEntryRequest message to a potential sponsoring node, which can be the MBS or an intermediate node. Upon reception of the MSH-NENT: NetEntryRequest message with the sponsor node ID equal to the node ID of its own, the sponsoring node assesses the request and either opens the sponsor channel or rejects the request.

The response is given in an MSH-NCFG message with embedded data. If the 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 interval between successive attempts. If these attempts fail, then a different sponsoring node is selected and the procedure is repeated. If the selected sponsoring node advertises the MAC address of the candidate node, it continues to advertise this MAC address in all its MSH-NCFG messages until the sponsorship is ended.

Once the candidate node has received a positive response (a NetEntryOpen message) from the sponsoring. node in the MSH-NCFG message, it shall acknowledge the response by transmitting an MSH-NENT: NetEntryAck message to the sponsoring node at the following network entry TxOp.

Then, the candidate node and the sponsoring node use the schedule indicated in the NetEntryOpen message to perform message exchanges. This temporal schedule is called a sponsor channel, where all messages related to node configuration parameters are transmitted (i.e., Node Authorization, Node Registration, Establish IP connectivity, Establish the time of the day, and Transfer Operational Parameters).

After the configuration is completed, the candidate node ends the entry process by sending an MSH-NENT:NetEntryClose message to the sponsoring node in the network entry transmission immediately following an MSH-NCFG transmission from the sponsoring node. Upon receiving this message, the sponsoring node sends an Ack to confirm the end of the initialization process by sending an MSH-NCFG:NetEntryAck message to the candidate node.

In Fig. 2 we show the complete message exchange for the centralized and distributed scheduling methods. In the centralized scheme, node X and the MBS act as the candidate node and the sponsor node, respectively. Once node X is configured, it becomes a forwarding node so that other nodes, such as node Y, can be configured using the previously described initialization process. In this particular case, the MBS still remains as the sponsor node and node Y becomes the new candidate node.

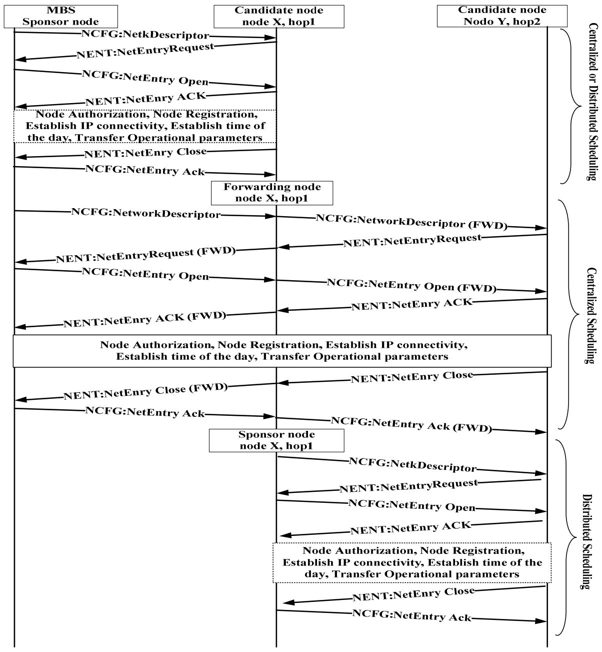

Fig. 2. Message exchange of the initialization process

In the distributed scheme, node X and the MBS node act as the candidate node and the sponsor node, respectively. However in the distributed scheme, when node X is configured, it becomes a sponsor node, which can directly configure other nodes, such as node Y. In the following sections we focus on the performance of the initialization process for the centralized scheme.

Proposed scheduling control process

In the event of a power outage, a candidate node first needs to synchronize itself with the mesh network as described in the previous section. Then, when the candidate node receives an MSH-NCFG with sponsored MAC address = 0x000000000000), the candidate node must transmit its first message (MSH-NENT: NetEntryRequest) to the sponsoring node or to the MBS using contention-based access in the following MSH-NENT TxOp. The other messages (MSH-NENT: NetEntryAck, and MSH-NENT: NetEntryClose) must be transmitted immediately using the following MSH-NENT TxOp, after the candidate node receives its associated MSH-NCFG messages as described above. Therefore, an arising problem is that after a power outage, tens of nodes will contend for these MSH-NENT TxOps, resulting in a poor performance of the system initialization due to a large number of collisions.

The initialization performance is even worse if the configuration parameters (described in Table 1) are not optimized for the transmission of MSH- NENT messages.

Since the standard [1] defines only one MSH-NENT TxOp of 7 OFDM symbols every S_f frames, as illustrated in Fig. 3a, we propose the following frame structure to optimize this region. In our framing scheme, after a power outage, we propose to use short preambles for the transmission of MSH_NENT messages. This can be done 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 possible because the standard defines that the transition gap for all WirelessMAN-OFDM system profiles should be less than 100 µs (Section 12.3, [1]). In Table 2 it can be seen that, for all channel bandwidths supported in the mesh mode, the OFDM symbol duration (T_s) is less than 100µs as computed by the following equations:

$$T_s = \left(\frac{1}{\Delta f}\right)(1+G) = \left(\frac{N_{FFT}}{nBW}\right)(1+G), \tag{1}$$

$$\Delta f = \left(\frac{f_s}{N_{FFT}}\right), \tag{2}$$

$$f_s = nBW, \tag{3}$$

where Δf is the frequency bandwidth of the orthogonal subcarrier, G is a factor that compensates for the cyclic prefix (G=1/8), f_s is the sampling frequency, N_{FFT} is the total number of subcarriers (i.e. N_{FFT}=256), and n is the sampling factor which depends on the channel bandwidth (BW) given in [1] (Section 8.3.2.4, p. 429).

Table 1. Parameters for scheduling control

Parameter	Description
Frame Duration (F_D)	Defines the duration of a frame that contains control and data subframes, as shown in Fig. 1 [2-20ms]
XmtHoldoffExponent (XHE)	This is a configuration parameter used to compute XmtHoldoffTime [0-7]
XmtHoldoffTime (XHT)	Indicates the number of MSH-NCFG TxOps that a node needs to backoff after the NextXmtTime
NextXmtMx (NXM)	This is a configuration parameter used to compute NextXmtTime-Interval [0-31]
NextXmt-TimeInterval (NXTI)	Indicates the next interval in which nodes are considered eligible for the transmission of its next MSH-NCFG
NextXmtTime (NXT)	Indicates the next MSH-NCFG TxOp
EarliestSubsequent-XmTime (ESXT)	Defines the earliest TxOp that a node is eligible to transmit a MSH-NCFG message after NextXmtTime
TempXmtTime (TXT)	Defines the next TxOp interval that a node uses to compete with other competing neighbors based on the Mesh Election procedure
Scheduling Frames (S_F)	Indicates how many frames have a schedule control frame between two frames including a network control
MSH-CTRL-LEN (L)	Indicates the number of TxOp per network control subframe

With the parameters mentioned above the maximum utilization consumed by network entry messages is below 2.5% of the channel capacity for most practical cases. In these cases, the channel bandwidths are between 7 and 25.6 MHz, as shown in Table 2.

The channel utilization is denoted by γ for different channel BW configurations, NENT TxOps and scheduling frames (S_F). This parameter is computed by

$$\gamma[\%] = 100 \times \frac{(NENT\ TxOps)\times 7}{\left(\frac{F_D}{T_S}\right)S_F}, \quad (4)$$

where F_D is the Frame Duration set to 10ms. The number 7 in (4) represents the number of OFDM symbols that require each TxOp. Only for special cases, when the channel bandwidth is 3.5MHz or lower, the maximum channel utilization may be up to 5.9% of the channel capacity. All other frames in the mesh mode (i.e. Centralized Configuration, Centralized Scheduling and Distributed Scheduling) use one Guard Symbol. Therefore, using one symbol for this transition gap is within operational values.

Table 2. NENT channel utilization

		NENT TxOps	1	2	4	1	2	4	1	2	4
BW	T_s	S_f	10	10	10	8	8	8	4	4	4
[MHz]	[µs]	No.OFDM symbol/frame]	γ [%]	γ [%]	γ [%]	γ [%]	γ [%]	γ [%]	γ [%]	γ [%]	γ [%]
3	84	119	0.6	1.2	2.4	0.7	1.5	2.9	1.5	2.9	5.9
3.5	72	138	0.5	1.0	2.0	0.6	1.3	2.5	1.3	2.5	5.1
5.5	46	219	0.3	0.6	1.3	0.4	0.8	1.6	0.8	1.6	3.2
7	36	277	0.3	0.5	1.0	0.3	0.6	1.3	0.6	1.3	2.5
10	25	400	0.2	0.4	0.7	0.2	0.4	0.9	0.4	0.9	1.8
25.6	10	1024	0.1	0.1	0.3	0.1	0.2	0.3	0.2	0.3	0.7

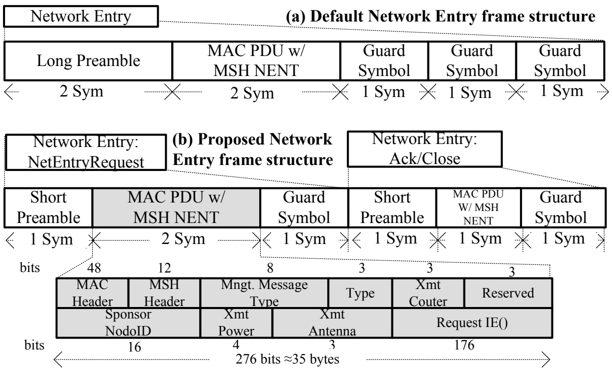

Fig. 3. Network entry frame structures

By using short preambles and considering one Guard Symbol we can, in fact, transmit two MSH-NENT messages in one TxOp as illustrated in Fig. 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 an MSH-NENT message with Type = 0x01: NetEntryAck or an MSH-NENT message with Type = 0x03: NetEntryClose. Thus, we just need to verify that the MAC PDU w/NENT fits into two OFDM symbols for the NetEntryRequest option and one symbol for the NetEntryAck or NetEntryClose options. In Table 3 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 overall coding rate CR=½, and m=2 bits per symbol. The uncoded frame size in bytes that can be transmitted in one OFDM symbol is given by

$$\beta = N_{used}\, m\, CR/8, \quad (5)$$

where N_{used} is the number of data subcarriers. Then, the MAC PDU with/MSH NENT:NetEntry Request (Fig. 3b) 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.

Table 3. Channel coding per modulation

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

In addition, we further enhance our proposed framing scheme by using 3 bits of the reserved field in the MSH-NCFG message format. With these 3 bits we propose to add the following parameters:

– ***NetEntry Power Outage Flag, “NetPwrOut”,*** (1 bit). 0: normal operation, 1: join the network in 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 Fig. 3b, should be employed in the 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 Fig. 4), node X must defer its transmission by a period of ESXT = 2^{XHE+4} TxOps, before contending again. Once the EXST period of a node X has elapsed, such node should contend in every TxOp during the interval defined by $2^{XHE}NXM < NXTI \leq 2^{XHE}(NXM+1)$, using an election procedure.

Performance evaluation

We implemented a detailed simulation model of the IEEE 802.16 MAC protocol network entry using the OPNET Package v. 14.5. The simulation model carries out the initialization process of candidate nodes (as shown in Fig. 2), using contention access for NENT messages, and using the election algorithm (as defined in [1], p. 345) for NCFG messages. In addition, we employed the transmission timing of control messages as suggested in [3]. To validate the results we also implemented a C++ program where both the NENT and NCFG messages are sent using the election algorithm defined in IEEE 802.16-2004.

For the performance analysis we employed a mesh network with 100 nodes, where 10 of these nodes (node1 to node10) are 1-hop away from the MBS, 30 nodes (node11 to node 40) are 2-hop away from the MBS and 60 nodes (node 41 to node 100) are 3-hop away from the MBS. The parameters used in the C++ program and in the simulation model are indicated in Table 4.

In Fig. 5a, we present the maximum delay that the mesh network takes to recover after a power outage, using our framing structure with 4 NENT TxOps per Network Control Subframe (*NetPwrOut=1, NENT =0x3).* Both models (simulation model and C++ program) leaded to nearly the same recovery delays for nodes that are up to 2-hop away from the MBS (node 1 to node 40). This behavior is to be expected since the number of collisions generated with the use of the simulation model is marginal and it does not affect the recovery delay. However, nodes that are 3–hop away from the MBS trigger a higher number of collisions since every message sent from nodes 41 to 100 should be forwarded twice to reach the MBS, provoking an increased number of collisions in the NENT region. This was the behavior observed in the experiments with the simulation model. Compared with the C++ program, the recovery delay given by the simulation model could be reduced from 580 to 220 seconds when an election algorithm is also used for the transmission of NENT messages.

Table 4. Simulation Parameters

Parameter	Value
Frame Duration T_F /OFDM symbol / frame	10ms / 1024
OFDM symbol / slot	4
TxOp time / slot	68.359 µs
Bandwidth	25.6 MHz
Data rate	59 Mbps
Distance of SS to the BS	0.1 - 5 km

In Fig. 5b we present the recovery delay using only the simulation model. We compare this delay using the default mechanism defined in the standard with our proposed framing structure. The default mechanism presents a very large recovery delay, due to a large number of collisions involving NENT messages, since only one NENT TxOp is allocated every ($S_f \times T_D$ =) 100 ms. For instance, using a network size of 20 nodes, the recovery delay reported by the simulation model was 660s. By using our proposed framing structure, with 2 and 4 NENT TxOps per Network Control subframe, we can considerably decrease the network recovery time to 33 and 13 seconds, respectively. This results in a maximum recovery time reduction of up to 98% (≈[1-13/660]×100).

However, having more NENT TxOps in the Network Control subframe increases the signaling overhead. In Table 3 we showed this overhead for different channel bandwidths suggested by the standard for the mesh protocol [1]. For example, for a channel bandwidth of 25.6 MHz, as used in the simulation model, the NENT overhead results in approximately 0.3% (≈100*NENT TxOps*7/1024*S_f) of the channel utilization when NENT TxOps = 4.

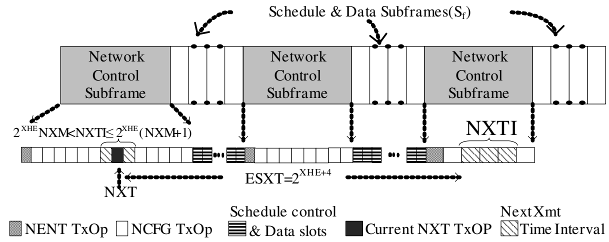

Fig. 4. Network control access

This overhead, in the worst case scenario, becomes 5.9% of the channel utilization when S_f= 4, BW = 3MHz and NENT TxOps =4 as shown in Table 2.

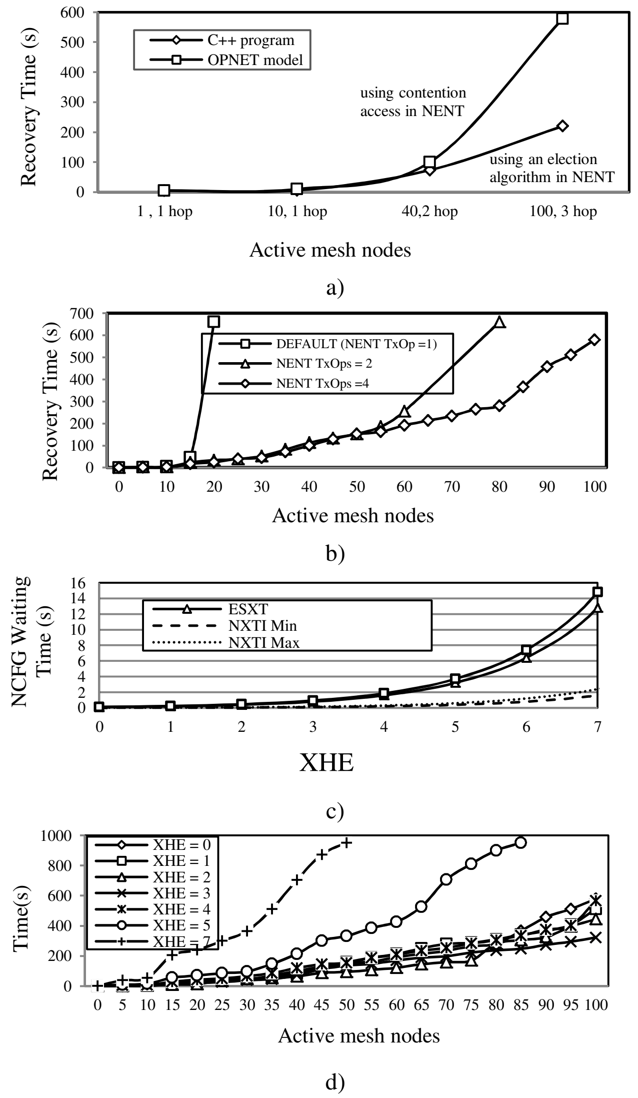

Fig. 5. Recover delay of the initialization process for different network configurations: a – recovery delay using the C++ Program and the simualtion model, NENT TxOps =4, XHE = 0; b – recovery delay using the simulation model, the default mechanism and the proposed framing structure, XHE = 0; c – Average waiting time between NCFG mesages, NENT TxOps = 4, L=10; d – recovery delay using the simulation model, and different XmtHoldoffExponent values, NENT TxOps = 4, L =1

In addition, in order to further reduce the recovery time, it is also necessary to optimize the election period for the transmission of NCFG messages, given by NXTI [2^{XHE}NXM+1, 2^{XHE}(NXM+1)]. From the two

$[2^{XHE}NXM+1, 2^{XHE}(NXM+1)]$. From the two configuration parameters: XHE and NXM, the former is the one that can modify the election period. For instance, having XHE = 2 results in an election window size of (2^{XHE} =) 4 NCFG TxOps, compared to 127 NCFG TxOps when XHE = 7. By increasing the election window, however, we also considerably increase the Earliest Subsequent Transmission Time (ESTX). Thus, the average waiting time for the transmission of every NCFG message is given by ESTX + $(NXTI_{Min}+NXTI_{Max})/2$, as shown in Fig. 5c. Hence, for XHE = 2 and 7, the average waiting times for NCFG messages were of 0.5 and 14.8 seconds, respectively, when NENT TxOps = 4 and L = 10.

Finally, in Fig. 5d we show how the recovery time is affected by XHE. We observe that for large networks, the minimum recovery delay is obtained with XHE = 3. The recovery delay is reduced from 580s, obtained with XHE = 0 (Fig. 5a and 5b), to 322s when XHE = 3 and there are 100 active nodes in the network. For medium size networks (between 20 and 75 nodes), however, the optimum performance was obtained with XHE = 2. This is to be expected, because the mean waiting time between NCFG messages is reduced by half. For example, with XHE = 2, the mean number of contending nodes per election window is between ($2^{XHE}*N/2^{(XHE+4)}$=)1.25 and 4.6. These users apply the same value for the election window which is equal to NCFG TxOps when the network size (*N*) ranges from 20 to 75 nodes. In contrast, when XHE = 3, the same number of contending users per election window (1.25-4.6) share 8 NCFG TxOps every 128 TxOps, compared to 64 TxOps when XHE = 2.

Conclusions

In order to validate our scheme, we compared our results with an OPNET simulation model with a C++ program. Both models presented nearly the same recovery delays for nodes that were 1 and 2 hop away from the MBS. Finally, by comparing the performance of our proposed scheme with the default mechanism we achieved a recovery time reduction of approximately 98%.

Acknowledgements

This work was supported by DGAPA, UNAM under Grant PAPIIT IN108910, IN106609, PAPIME PE 103807, CONACYT 105279, 105117. This work was also supported by the academic program PASPA from the School of Engineering and DGAPA, UNAM.

References

1. **IEEE 802.16–2004.** IEEE Standard for Local and Metropolitan Area Networks – Part 16: Air Interface for Fixed Broadband Wireless Access Systems // IEEE 802.16 Working Group, 2004.
2. **Bayer D.** Wireless Mesh Networks For Residential Broadband // Proceedings of the National Wireless Engineering Conference. – San Diego, USA, 2002.
3. **Bayer N., Sivchenko D., Xu B., Rakocevic V., J. Habermann.** Transmission timing of signaling messages in IEEE 802.16 based Mesh Networks // Proceedings of the European Wireless. – Greece, 2006.
4. **Cao M., Ma W., Zhang Q., Wang X.** Analysis of IEEE 802.16 Mesh Mode Scheduler Performance // IEEE Transactions on Wireless Communications, 2007. – Vol. 6. – No. 4. – P. 1455–1464.
5. **Cao M., Ma W., Zhang Q., Wang X., Zhu W.** Modelling and performance analysis of the distributed scheduler in IEEE 802.16 mesh mode // Proceedings of the ACM International Symposium on Mobile ad hoc Networking and Computing. – ACM, 2005. – P. 78–89.
6. **Feng J., Xia R.** Load–Aware Network Entry in WiMAX Mesh Mode // Proceedings of the International Conference on Computer Science and Software Engineering, 2008. – P. 1118–1121.
7. **Wang S. Y., Lin C. C., Fang K. H., Hsu T. W.,** "Facilitating the Network Entry and Link Establishment Processes of IEEE 802.16 Mesh Networks // Proceedings of the IEEE Wireless Communications and Networking Conference, 2007. – P. 1842–1847.
8. **Rangel V., Macedo Y., Gomez J., Lopez–Guerrero M., Aquino R.** Performance optimization of the initialization process of IEEE 802.16 mesh networks // Proceedings of the IEEE Conference on Electrical and Computer Engineering. – Calgary, Canada, 2010.
9. **Flores E., Aquino R., Rangel V., Garcia–Ruiz M. A., Edwards A.** MAC Layer Mechanism for Wireless WiMAX Networks with Mesh Topology // Proceedings of Electronics, Robotics and Automotive Mechanics Conference, 2008. – P. 151–156. http://dx.doi.org/10.1109/CERMA.2008.22.

Received 2011 01 14
Accepted after revision 2011 05 31

Y. Macedo, V. Rangel, J. Gomez, M. Lopez-Guerrero, R. Aquino. Enhanced Network Control for the Entry Process of IEEE 802.16 Mesh Networks // Electronics and Electrical Engineering. – Kaunas: Technologija, 2012. – No. 1(117). – P. 43–48.

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 a centralized scheduling mode is used. This results in very long service recovery times for all mesh nodes. In this paper we study the performance of the initialization process due to service disruption of IEEE 802.16-2004 mesh networks. We implemented a simulation model of the scheme using the OPNET simulation package v14. Simulation results show that the recovery times obtained with the proposed scheme can be reduced by up to 98% compared with the default scheme defined in the standard. Ill. 5, bibl. 9, tabl. 4 (in English; abstracts in English and Lithuanian).

Y. Macedo, V. Rangel, J. Gomez, M. Lopez-Guerrero, R. Aquino. Išplėstinė IEEE 802.16 tinklų pradžios proceso kontrolė // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2012. – Nr. 1(117). – P. 43–48.

IEEE 802.16-2004 standartas nusako MAC sluoksnį tinklo topologijoje. Tokiuose tinkluose energijos nutrūkimai gali sukleti didelių skaitmeninių paslaugų sutrikimų, esant centralizuotam planavimo režimui. Dėl to labai pailgėja paslaugų atnaujinimo trukmės visuose tinklo mazguose. Analizuojamas inicializavimo proceso veikimas sutrikus paslaugai IEEE 802.16-2004 tinkluose. Įdiegtas schemos imitacinis modelis, pagrįstas OPNET programa. Imitacijos rezultatai rodo, kad atkūrimo trukmes, naudojant siūlomą schemą, galima sumažinti iki 98 %, palyginti su standartine schema. Il. 5, bibl. 9, lent. 4 (anglų kalba; santraukos anglų ir lietuvių k.).