

On The Quasi-Interference Modeling Issue for Coordinated Distributed Scheduling in IEEE 802.16 Mesh Mode

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On The Quasi-Interference Modeling Issue for Coordinated Distributed Scheduling in IEEE 802.16 Mesh Mode

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Abstract—In this paper, we investigate the performance of coordinated distributed scheduling in IEEE 802.16 Mesh Mode, under realistic non-quasi-interference model. 802.16 coordinated distributed scheduling claims “collision-free” transmissions of MSH-NCFG and MSH-DSCH, which are two types of control messages using such scheduling algorithm, in the extended neighborhood (2-hop or 3-hop). However, under a realistic non-quasi-interference model, which is elaborated more in Section 3, such claim may not hold. Extensive simulation study has been conducted to evaluate the performance of such scheduling algorithm in practical scenarios, in terms of reception collision ratio, etc. We observe that, in specific scenarios, the collision ratio can be over 20% for 2-hop extended neighborhood, and about 7% for 3-hop extended neighborhood, which is significant. We also provide key observations on how to select appropriate *XmtHoldoffExponent* in order to alleviate collisions due to accumulative interference while limiting the scheduling interval, which may yield better overall scheduling performance considering that unsuccessfully transmissions of control message cause additional latency.

Keywords—IEEE 802.16, WiMax, Mesh Network, Distributed Scheduling, Interference

1 INTRODUCTION

The advent of IEEE 802.16 [1][2] standard is emerging as a promising broadband wireless technology to finally resolve the “last mile” Internet access in conjunction with IEEE 802.11. IEEE 802.16 originally is to provide fixed broadband access of up to 75 Mbps and typical base station infrastructure coverage of 5 miles in PMP (Point-to-Multipoint) operation mode, which is much greater than the coverage of 802.11. 802.16e has also been approved as the official standard for Mobile WirelessMAN on Dec. 7th 2005.

IEEE 802.16-2004 supports four PHY specifications for metropolitan area networks in the licensed bands (MMDS and ETSI), which are WirelessMAN-SC (SingleCarrier), -SCa, OFDM, OFDMA, as well as their counter parts (-SCa, -OFDM, and -OFDMA) for the unlicensed bands – WirelessHUMAN (Wireless High-Speed Unlicensed Metropolitan Area Networks). Most PHYs are designed for NLOS operation in frequency bands below 11 GHz, except – SC, which is for operation in the 10-66GHz frequency band, and supports both TDD and FDD operations.

802.16 MAC supports two modes: the point-to-multipoint (PMP) mode and the mesh mode. The former organizes nodes into a cellular like structure consisting of a base station (BS) and subscriber stations (SS). The channels are divided into uplink (from SS to BS) and downlink (from BS to SS), both shared among the SS’s. PMP mode requires all SSs to be within the transmission range and clear line-of-sight of the BS.

On the other hand, in the mesh mode, an ad hoc network is formed with all nodes acted as relaying routers in addition to their sender and receiver roles, although there may still be nodes to serve as BSs and provide backhaul connectivity.

For OFDM-based system, a system profile consists of one of the two basic MAC profiles—PMP or Mesh—and one of the six PHY profiles listed in Table 1. Three bandwidth sizes 1.75, 3.5 and 7 MHz are primarily considered for 3.5GHz ETSI band, 3 and 5.5 MHz channelizations are considered for MMDS bands, while the 10 MHz channelization can be used for unlicensed bands (U-NII).

In general, 802.16 provides many important features across the protocol stack, such as support of ATM and IP packet services through connection-oriented MAC addressing with CID (connection identifier), hybrid-ARQ (H-ARQ) at PHY, and dynamic link adaptation on a burst-by-burst basis. In addition to aforementioned features, TDM slot scheduling is also one of the most important technical aspects of 802.16, given its TDMA-based access method. The performance of scheduling algorithms becomes even more crucial in 802.16 Mesh mode where throughput is more likely to become the performance bottleneck of the system [14]. In this paper, we will focus on the behaviors of the claimed “collision-free” coordinated distributed scheduling algorithm of 802.16 Mesh mode under realistic, “non-quasi-interference” environments.

The coordinated distributed scheduling algorithm only takes account of interference caused by transmissions within the 1-hop or 2-hop neighborhood of the receiver. All other RF signals beyond the neighborhood are cut off from the algorithm, which we term as quasi-interference modeling. However, RF environments in real world cannot be modeled exactly as a quasi-interference model. We observe that in a realistic non-quasi-interference environment, collision-free cannot be guaranteed for 802.16 coordinated distributed scheduling. And the appropriate configuration of *XmtHoldoffExponent*, a scheduling parameter, may alleviate collision ratio and hence potential improve the overall scheduling performance.

Table 1. WiMAX Basic Profiles for WirelessMAN-OFDM

Identifier	Description
ProfM3_PMP	WirelessMAN-OFDM Basic packet PMP MAC profile
ProfM3_Mesh	WirelessMAN-OFDM Basic packet Mesh MAC profile
ProfP3_1.75	WirelessMAN-OFDM 1.75MHz channel Basic PHY prof.
ProfP3_3.5	WirelessMAN-OFDM 3.5MHz channel Basic PHY profile
ProfP3_7	WirelessMAN-OFDM 7 MHz channel Basic PHY profile
ProfP3_3	WirelessMAN-OFDM 3 MHz channel Basic PHY profile
ProfP3_5.5	WirelessMAN-OFDM 5.5MHz channel Basic PHY profile
ProfP3_10	WirelessMAN-OFDM 10 MHz channel Basic PHY profile

The remainder of the paper is organized as follows. 802.16 Mesh mode and details of coordinated distributed scheduling algorithm are described in Section 2. In Section 3, we discuss the quasi-interference issue that may potentially undermine the “collision-free” performance of the scheduling algorithm. In Section 4, we conduct extensive simulation study on scheduling performance under the realistic “non-quasi-interference” scenarios and present key observations. After summarizing related works in Section 5, we conclude the paper in Section 6.

2 BACKGROUND OF IEEE 802.16 MESH MODE

2.1 General Description of IEEE 802.16 Mesh Mode

802.16 offers both PMP and Mesh modes. The main difference between PMP and Mesh modes is that in the PMP mode, traffic only occurs between the BS and SSs, while in the Mesh mode, traffic can be routed through other SSs, and can occur directly between SSs. It’s worth noting that a concept of relay stations (RSs) and mobile multi-hop relay (MMR) networking has also been introduced for PMP mode in 802.16e, which may expand the coverage area and enhance throughput through multi-hop paths [11][12]. On the other hand, the Mesh mode implies the requirement of supporting multi-hop ad hoc networking by SSs. In order to achieve efficient collision-free multi-hop data transmissions, the Mesh mode defines three scheduling schemes, i.e., centralized, coordinated distributed, uncoordinated distributed scheduling, to resolve wireless interference in the 2 or 3-hop neighborhood of a node. (3-hop neighborhood is used in environments which are close to free-space.)

Figure 1 shows the frame structure of the Mesh mode. Each frame is divided into a control sub-frame consisting of MSH_CTRL_LEN (0-15) transmission opportunities and a TDM data sub-frame consisting of up to 256 minislots. For high reliability, all the transmission opportunities are in fixed length of 7 OFDM symbols (T_S). The duration of a minislot can be derived given the frame duration (T_F), the number of control transmission opportunities and minislots. Table 2 shows the defined WirelessMAN-OFDM frame duration code. There are two types of control sub-frame, i.e., schedule control sub-frame and network control sub-frame. The latter is re-occurring once for every $Scheduling_Frames$. The network control sub-frame provides basic functionality of network entry and topology management, while the schedule control sub-frame is to resolve the transmission schedule of data sub-frame. A node will not transmit in any minislot that is not reserved for its use. While reserved, each data transmission (a PHY burst with one or more MAC PDUs) may take multiple minislots, which is shown in Figure 2.

Table 2. WirelessMAN-OFDM frame duration (T_F ms) codes

Code	Frame duration (ms)	Frame per second
0	2.5	400
1	4	250
2	5	200
3	8	125
4	10	100
5	12.5	80
6	20	50
7-255	reserved	reserved

The network control sub-frame serves primarily for new nodes that want to gain access to the network. In each network control sub-frame, the first transmission opportunity is dedicated to network entry message (MSH-NENT) in an unreliable contention-based access. A successful network entry relies on additional handshake messages between the new node and the sponsor node. The remaining ($MSH_CTRL_LEN - 1$) transmission opportunities are dedicated to network configuration messages (MSH-NCFG) in a coordinated distributed scheduling access manner. The schedule control sub-frame is used to schedule minislots for TDM transmissions in the data sub-frame. However, the access of transmission opportunities in the schedule control sub-frame itself requires certain rules, which could be centralized, or distributed, or a combination of both scheduling methods. If both scheduling method co-exist, the first ($MSH_CTRL_LEN - MSH_DSCH_NUM$) transmission opportunities within the control sub-frame are allocated for centralized scheduling messages (MSH-CSCH/MSH-CSCF), while the remaining ones are for distributed scheduling messages (MSH-DSCH). The structure of aforementioned Mesh control messages are shown in Figure 3.

2.2 Coordinated Distributed Scheduling

Let’s first give a general picture of all scheduling algorithms. The centralized scheduling relies on a centralized coordinator, i.e., Mesh BS (MBS), to schedule MSH-CSCH/MSH-CSCF packets in a collision-free manner, which is the best for links supporting persistent traffic streams. The distributed scheduling can be further divided into coordinated distributed scheduling and uncoordinated distributed scheduling. The former, which is used by MSH-NCFG and MSH-DSCH, accesses the control transmission opportunities in a “collision-free” manner. On the other hand, the latter, which can be used only by MSH-DSCH, adopts a simple contention approach where collisions may occur if multiple nodes are transmitting in the same control transmission opportunity. Uncoordinated distributed scheduling is only best for links with occasional or brief traffic needs. Coordinated distributed scheduling is designed for general Mesh operations with substantial peer-to-peer traffic needs, which is the main focus of this paper.

The general concept of coordinated distributed scheduling is to let nodes running the scheduling algorithm independently derive pseudo random but predictable behaviors by exchanging 2- or 3-hop (for free space environments) neighborhood schedule information with each other. Both the randomness and predictability are achieved by dynamically constructing random generator seeds for each node according to a common rule. The seed for a node is constructed based on its unique node ID and the index (or timestamp) of the candidate interested transmission opportunity. Given the neighborhood information, the random number generated locally will be the same as the corresponding one generated at the neighboring node. Therefore, predictability is achieved. In detail, by using previously scheduled transmission opportunities, nodes compute and exchange their next collision-free transmission opportunities, as well as available schedules of their 2- or 3-hop neighbors, which is in the format of the following scheduling related parameters

$$\begin{cases} \text{NextXmtXm} :: 5\text{bits} \\ \text{XmtHoldoffExponent} :: 3\text{bits} \end{cases}$$

Given these two parameters of a specific neighbor, a node can determine an interval for NextXmtTime as well as $\text{EarliestSubsequentXmtTime}$ of the neighbor as the following:

$$\text{NextXmtXm} \cdot 2^{\text{XmtHoldoffExponent}} < \text{NextXmtTime} \quad (1)$$

$$\leq (\text{NextXmtXm} + 1) \cdot 2^{\text{XmtHoldoffExponent}}$$

$$\text{EarliestSubsequentXmtTime} = \text{NextXmtTime} + 2^{\text{XmtHoldoffExponent}+4} \quad (2)$$

Since the exact transmission opportunity of the neighboring node is unknown, as an implementation issue, one may define NextXmtTime to be the last transmission opportunity within the interval when calculating $\text{EarliestSubsequentXmtTime}$.

As shown in Figure 4, at the previously scheduled transmission opportunity, a node (namely the local node) will run an election algorithm to find its next collision-free transmission opportunity. Based on the calculated NextXmtTime time interval and $\text{EarliestSubsequentXmtTime}$, a node can exclude some neighboring nodes (e.g., Nbr 16 and 25 in Figure 4) from the competing neighbors of a particular candidate transmission opportunity X , which reduces the number of unnecessary idleness in the schedule and improve the utilization. For a particular candidate transmission opportunity starting from the $\text{EarliestSubsequentXmtTime}$ of the local node, if the local node generates the maximum random number amongst all the eligible competing nodes, it wins this transmission opportunity. Otherwise, it will keep incrementing the candidate transmission opportunity and running the same election algorithm until it wins the election [3]. For more details on all mesh scheduling algorithms and message specifications, please refer to [1][3].

3 QUASI-INTERFERENCE RF MODELING

We note that the coordinated distributed scheduling algorithm is aiming to achieve “collision-free” scheduling in a fixed environment. However, this claim is based on a simplified RF model in that wireless interference is mainly (if not only) considered if amongst nodes that are able to communicate with each other. In other words, it appears that there is no residue energy beyond a node’s one hop neighborhood. This simplified RF model facilitates the construction of a wired-like link graph of wireless network. The scheduling algorithm deals with the broadcast nature of wireless communications in such a link graph that interference from direct neighbors of a receiver is considered, while accumulative interference from nodes beyond direct neighbors of the receiver are ignored. Therefore, we call this type of RF modeling the “quasi-interference” modeling, with respect to the realistic RF modeling where the energy of all propagated signals are counted regardless the upper layer network topology .

Strictly speaking, 802.16 is aware of the discrepancy between quasi-interference model and the real world. That is the reason why it provides a 3-hop ExtendedNeighborType option. Evidently the larger the extended neighborhood is, the less number of concurrent transmissions can be scheduled in the network with finite number of nodes, which leads to less spatial re-use. In addition, a larger the extended neighborhood

incurs more communication overhead in terms of neighbor information exchanges, though it may not matter in TDMA given the fixed slot duration as long as the packet size does not exceed the limit and energy efficient is not a concern. On the other hand, using a smaller extended neighborhood (minimum of 2 hops) will increase the chance of collisions at receivers in a “non-quasi interference” real world.

In the next section, we conduct a simulation study to investigate the actually outcome of the coordinated distributed scheduling in several “non-quasi interference” scenarios varied by the topology and propagation models. Observations and analysis are presented.

4 SIMULATION STUDY UNDER NON-QUASI-INTERFERENCE SCENARIOS

We implement the IEEE 802.16 Mesh Mode in QualNet [13]. An OFDM system profile of Mesh MAC (ProfM3_Mesh) and 7MHz channelization at ETSI bands (ProfP3_7) has been used. The detail RF and MAC frame configuration are listed in Table 3, which also includes some RF parameters out of the scope of the defined system profile, but closely relevant to the performance of the simulation.

Since we are mainly interested in evaluating the performance of “collision-free” scheduling, multi-hop scenarios are constructed with 49 nodes and various propagation models. Identical $\text{XmtHoldoffExponent}$ have been used for all scenarios presented in this paper. However, consistent results have been observed for non-identical $\text{XmtHoldoffExponent}$ cases. Since both MSH-NCFG and MSH-DSCH (coordinated) uses the same distributed election algorithm to schedule the transmission opportunities on different “designated slots”, the same simulation test and analysis can be applied to both.

Table 3. Simulation configuration

PHY Profile:	
ProfP3_7: WirelessMAN-OFDM PHY profile for 7 MHz channelization	
Carrier frequency	3.5GHz ETSI licensed band
Channel bandwidth	7 MHz
Modulation	64-QAM 3/4 (Assuming fixed rate)
E_b/N_0 (for BER<10 ⁻⁶)	19.0 dB
OFDM raw bitrates	21.60 Mb/s (for $T_g=T_b/4$)
Receiver SNR threshold	23.894 dB
Noise power	-97.073 dBm (2.8027e-17 mW/Hz)
Receiver power sensitivity threshold	-73.179 dBm (minimum performance requirement -70 dBm)
Transmission Power	34.77 dBm (3W)
Antenna height	1.5 m
Antenna gain plus all implementation losses	-5.0 dB
MAC Profile:	
ProfM3_Mesh: WirelessMAN-OFDM Basic Packet Mesh MAC profile	
Frame duration	code {0x01} $T_F = 4\text{ms}$
Symbol duration	$T_S = 3.7037 \mu\text{s}$
Minislot size	1PS = 4 symbols
Control opportunity size	7 symbols
Scheduling Frames	8
MSH_CTRL_LEN	8
MSH_DSCH_NUM	8 (all for coordinated distributed scheduling)
Number of minislots	256

Using the fixed PHY profile with 64-QAM 3/4 modulation and high data rate, the RF coverage is limited. The following combinations of propagation models and topologies have been

studied

- Free space model + 49 nodes in grid formation with a grid distance of 300 m (network diameter = 8 hops)
- Free space model + 49 nodes uniformly distributed in 2.5kmx2.5km (network diameter = 10 hops)
- Two ray model + 49 nodes uniformly distributed in 2.5kmx2.5km (network diameter > 10 hops, not fully connected)
- ITM model + 49 nodes uniformly distributed in 1.1kmx1.1km mountainous terrain with relative elevation range of approximately 200 m. (network diameter = 10 hops). ITM is a terrain based RF model based on Longley-Rice model.

According to the standard specification [1], the *ExtendedNeighborhoodType::lbit* in the MSH-NCFG.NetworkDescriptor specifies whether 2-hop or 3-hop distributed election is used. The latter is advised for free space environment. In order to provide more insight of the scheduling behaviors in terms of interference, we generalized the distributed election algorithm to an n -hop extended neighborhood, where we pick $n = 2, 3, 4,$ and 10-hop.

The following set of performance metrics is collected:

- Reception collision ratio (%): overall collision ratio seen at receivers (only collisions caused by interference from concurrent transmissions are counted)
- Scheduling interval (XmtOp): overall average number of corresponding transmission opportunities between two consecutive scheduled slots
- Number of extended neighbors: overall average number of neighbors in the n -hop extended neighborhood

Note that by carefully setting the receiver power sensitivity and SNR threshold based on bit-energy-to-noise-density ratio (E_b/N_0), we can identify error receptions caused by interference from concurrent transmissions (i.e., received $SINR < SNR$ threshold, but received $SNR \geq SNR$ threshold, and received power \geq receiver power sensitivity). Also note that we only collect statistics in stabilized condition, and therefore exclude collisions in transient condition.

Figure 5 shows the result for aforementioned scenarios with identical *XmtHoldoffExponent* = 0 for all nodes. In Figure 5(a), substantial amount of collisions (more than 10%) occur for 2-hop scheduling. Especially for ITM model scenario, collision ratio exceeds 20%. It's worth noting that, although each scheduled transmission is the only transmission within 2-hop extended neighborhood, interference accumulated from concurrent transmissions outside the extended neighborhood does disrupt the correct receptions at a substantial level. When 3-hop scheduling, the reception collision ratio decreases for all scenarios. For the special case of grid topology and free space RF model, collision ratio reaches zero. However, for more general cases of uniform node distribution, especially for the Two Ray model scenario, collision ratio remains non-zero even for 10-hop scheduling. Generally speaking, the more number of concurrent transmissions outside the extended neighborhood, the more likely collisions will occur due to accumulative interference. The larger the extended

neighborhood is, the weaker each individual interference signal is. Furthermore, given the limited number of nodes in the simulation, the larger the extended neighborhood is, the less concurrent transmission occurs. Figure 5(b) shows the average schedule interval in terms of transmission opportunities (XmtOps). Given the *XmtHoldoffExponent* = 0, the holdoff interval between *NextXmtTime* and *EarliestSubsequentXmtTime* is 16 XmtOps. Because of the statistical fairness of the random generator, the average schedule interval will be no less than the maximum between the holdoff interval and the number of extended neighbors. The average number of extended neighbors for each scenario is shown in Figure 5(c), which is only affected by the combination of topology and propagation model of each scenario.

Figure 6 shows corresponding results for *XmtHoldoffExponent* = 4. Given a much larger holdoff interval (256 XmtOps), which is larger than the total number of nodes (49) in the simulation, the probability of concurrent transmissions is further reduced. As a result, much lower (10 folds decrease) reception collision ratios are observed in Figure 6(a). In Figure 6(b), the average scheduling intervals are all no less than the holdoff interval, which is much larger than the number of extended neighbors, shown in Figure 6(c) in this case. This also offers a solution to alleviate the inevitable interference and collisions by increasing the holdoff interval such that it may spread nodes' transmissions. Of course, there is a tradeoff of sacrificing the scheduling back turn-around time and spatial re-use efficiency. However, if the collision ratio is substantially high, such sacrifice may indeed improve the scheduling performance.

Figure 7 shows that the reception collision ratio decreases when *XmtHoldoffExponent* increases from 0 to 4, for extend neighborhood type of 2 and 3, respectively. Note that when it decrease fast when *XmtHoldoffExponent* increase from 0 to 1 and from 1 to 2, and slowly for larger *XmtHoldoffExponent* (3 and 4). This is because for the latter, the holdoff interval (128 and 256, respectively) is substantially larger than the number of nodes in the affected interference neighborhood, even larger than the total number of nodes in the network. As a result, the probability of concurrent transmissions has already been significantly "diluted", and keeping increasing the holdoff interval does not benefit much more. This result is useful for selecting appropriate *XmtHoldoffExponent* to alleviate collisions and in the mean time still maintaining short schedule interval, which may result in optimal scheduling performance if latency due to unsuccessfully control message transmissions is considered.

Figure 8 shows the overall average schedule interval with respect to *XmtHoldoffExponent*, for extend neighborhood type of 2 and 3, respectively. Since for most cases in our simulation (except for *XmtHoldoffExponent* = 0 in 3hop extended neighborhood scenarios), the number of neighbors in the extended neighborhood, are equal or smaller than the holdoff interval, therefore, the resulted schedule interval is close to the lower bound specified by the holdoff interval (i.e., the dot lines in Figure 8(a) and (b)), which is equal to $2^{XmtHoldoffExponent}$.

As relatively new standard, IEEE 802.16 has been studied much less than access technologies such as IEEE 802.11. Eklund et. al. presented a system level overview of 802.16 standards family in [4]. Redana and Lott modeled and compared the control message overhead between centralized and distributed scheduling mechanisms in [7]. From a different angle, Cao et. al. proposed a theoretic model to compute the schedule interval of 802.16 coordinated distributed scheduling in [5]. With the algorithm to grant data requests left open in the standard, the schedule interval is an important common performance metric that reflects the scheduling latency of coordinated distributed scheduling. Both general formulation and practical computable approximation under the assumption of geometric distribution of scheduling attempts after *EarliestSubsequentXmtTime* are presented. The model is validated through NS-2 simulation, which matches well with our QualNet results. Other related topics include QoS support in Mesh mode [6], and cross-layer optimization of routing based on MAC layer scheduling behaviors [8][9][10]. It's worth noting that maximizing spatial re-use and concurrent transmissions is the major idea behind many of such optimization efforts. However, most of proposed optimization schemes are based on the simplified quasi-interference model, in which accumulative interference beyond one hop of the sender is simply ignored. One example is the metric used to select the "best" neighbor to maximize concurrent transmissions at net entry [10]. Under realistic non-quasi-interference environment, the actual performance of such schemes needs more careful evaluation.

6 CONCLUSIONS AND FUTURE WORK

In this paper, we studied the performance of IEEE 802.16 coordinated distributed scheduling under realistic non-quasi-interference model. We observed that substantial amount of collisions may exist even with scheduling in 3-hop extended neighborhood. We also suggested that, by keep a balance between the holdoff interval and the reception collision ratio, the optimal overall scheduling latency may be achieved.

To locate such optimality, one of our future tasks is to develop analytical model that is able to capture behaviors of reception collision ratio, network topology, RF propagation models, as well as scheduling parameters under the non-quasi-interference scenarios. Based on such model, we also plan to predict the overall scheduling latency with message handshake under such non-quasi-interference scenarios where collision-free cannot be guaranteed. Such result is critical for the implementation-dependent algorithms for requesting, allocating, and granting data minislots, because it will minimize scheduling failures (to schedule data transmissions earlier before the completion of required control message handshake) and delayed schedules (to schedule data transmissions too late after the completion of control message handshake).

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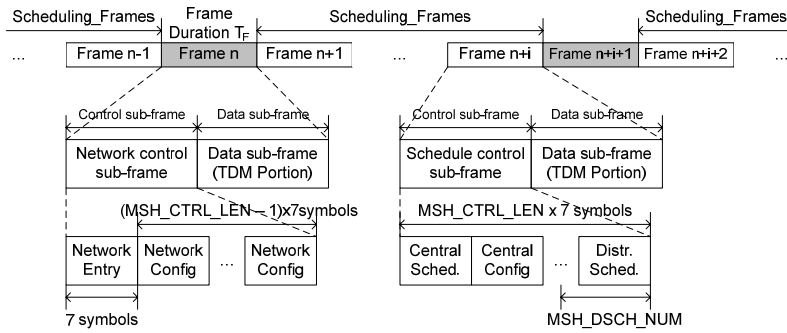


Figure 1. Mesh frame structure

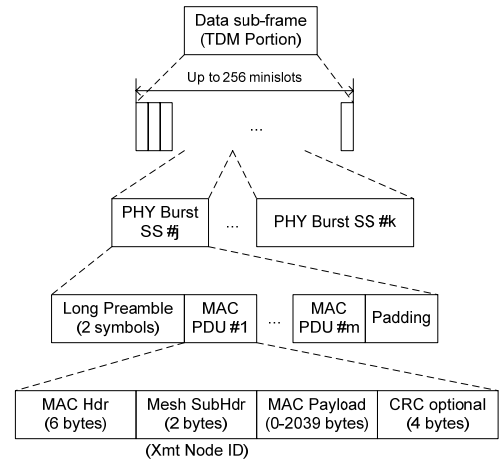


Figure 2. Data sub-frame structure

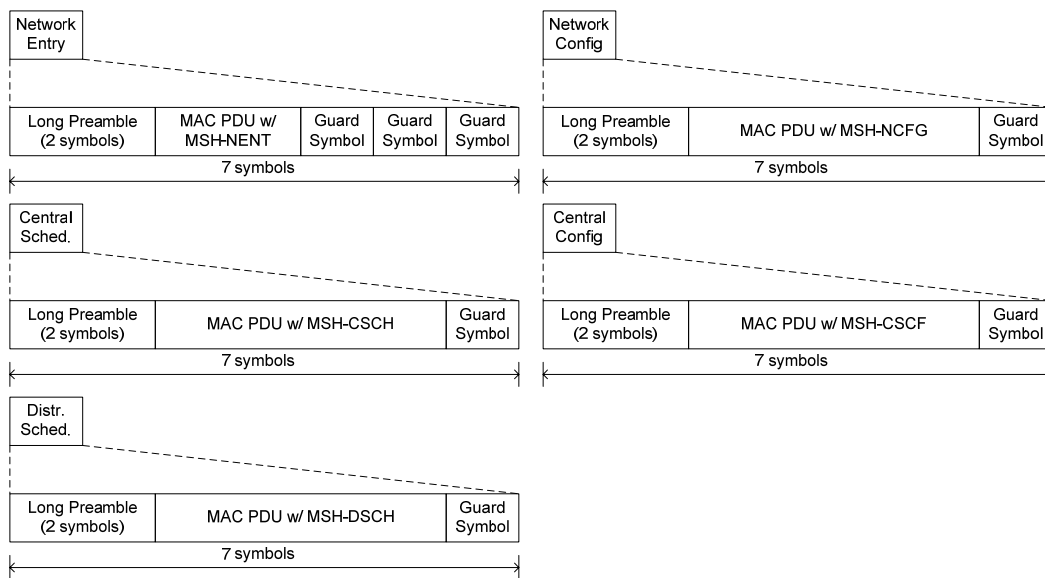


Figure 3. Mesh control message structure

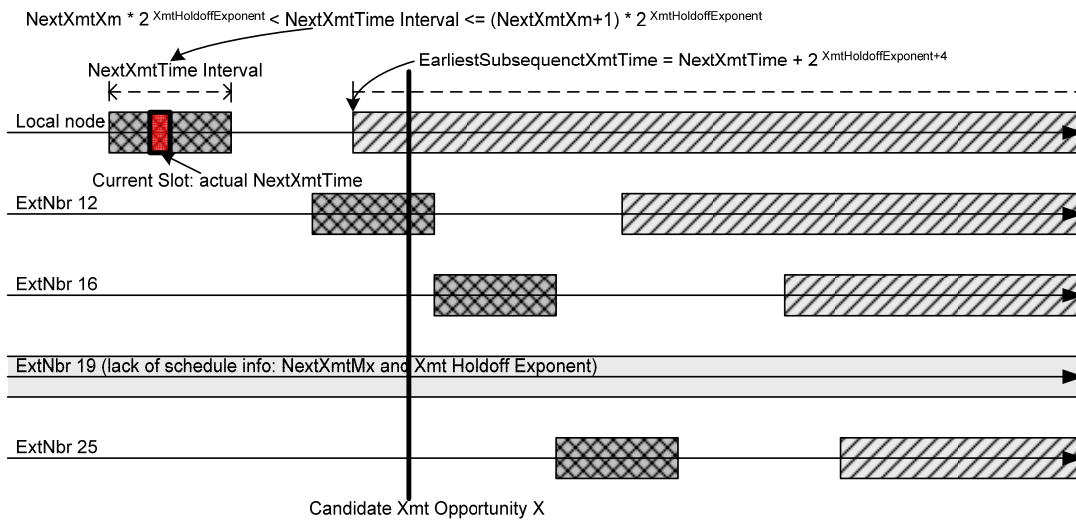


Figure 4. Coordinated distributed scheduling – Election-based approach

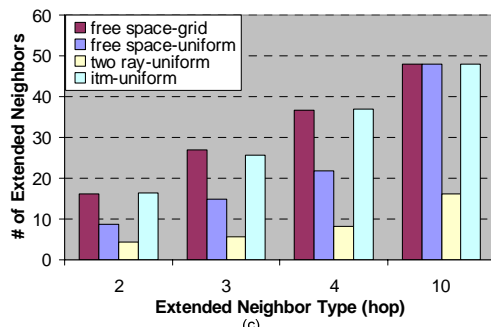
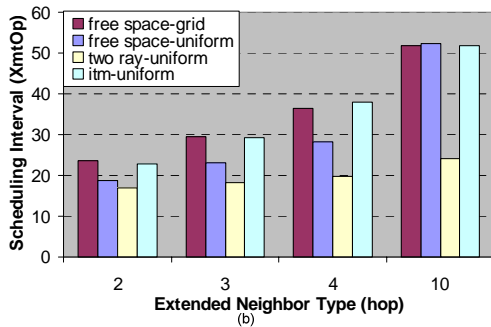
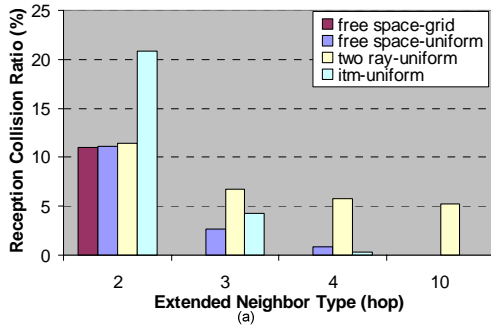


Figure 5. Collected performance metrics w. $XmtHoldoffExponent = 0$

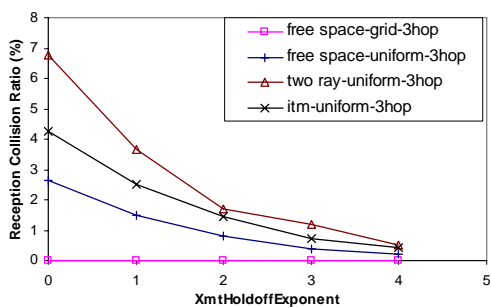
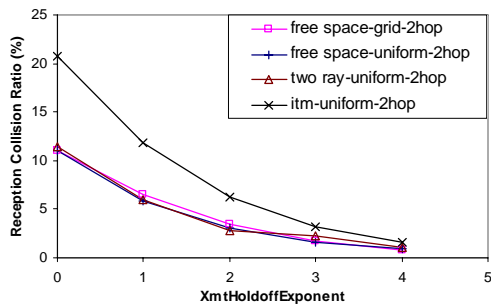


Figure 7. Reception collision ratio vs. $XmtHoldoffExponent$
(a) $ExtendedNeighborType = 2$ hop (b) 3 hop

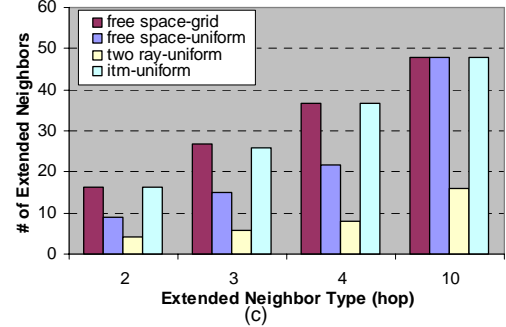
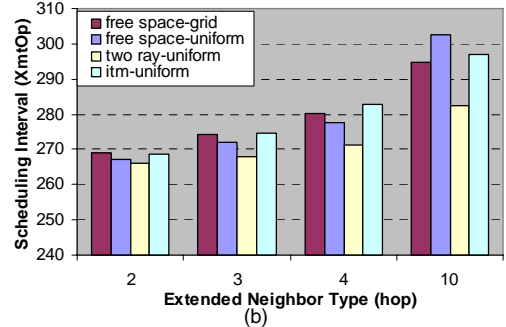
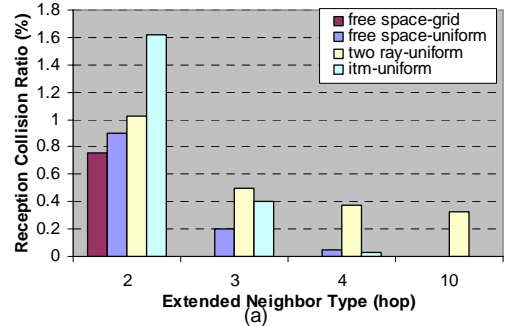


Figure 6. Collected performance metrics w. $XmtHoldoffExponent = 4$

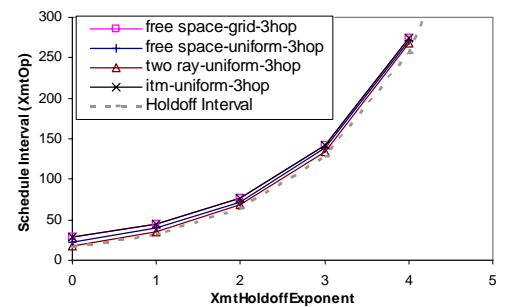
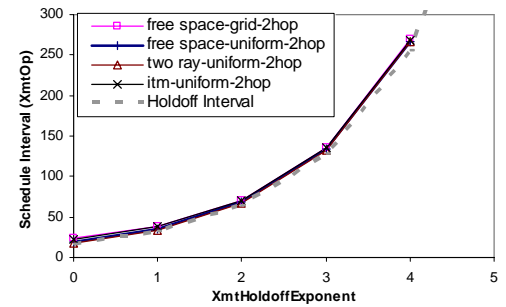


Figure 8. Schedule Interval vs. $XmtHoldoffExponent$
(a) $ExtendedNeighborType = 2$ hop (b) 3 hop