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Title	**Simulation of IEEE 802.16h and IEEE 802.11y Coexistence**
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Re:	Coexistence between IEEE 802.11y and 802.16h systems
Abstract	Simulation results on average throughput and packet delay of IEEE 802.11y and 802.16h systems under various coexistence mechanisms
Purpose	To help resolve the coexistence issues between IEEE 802.11y and 802.16h systems
Notice	
Release	
Patent Policy and Procedures	

Simulation of IEEE 802.16h and IEEE 802.11y Coexistence

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Introduction

The coexistence of IEEE 802.11y and IEEE 802.16h systems is of considerable interest to a number of organizations. There is a large likelihood for example, that such systems will have to work on a co-channel basis in the lightly licensed 3.650-3.700 GHz band in the US.

Objective

The purpose of this simulation is to examine possible coexistence approaches between co-channel and co-located generic IEEE 802.16h and 802.11y systems; the former system incorporates a TDD/TDMA multiple access control while the latter uses a CSMA/CA approach. The interference scenario will be simplified to lower the complexity of the simulations. We will consider a scenario in which the 802.16h base station and 802.11Y access point are in close proximity to each other and can thus interfere with each other. This includes these station's subscriber terminals.

In essence, if either the 802.16h Base Station and its associated subscriber stations and the 802.11y Access point and its associated subscriber stations transmit at the same time, interference is deemed to occur. All overlaps of simultaneous transmission times are construed as lost transmissions.

Coexistence is attempted only by modification of the 802.16h system and different scenarios are investigated, which are detailed in Annex B. The simulation will embody the following general attributes:

Both systems will be compared for the same amount of Total Offered Traffic. Uplink traffic will be a fraction (N) of the downlink (specified in Table 3 of Annex A), and this fraction will be fixed for any series of offered traffic. Total Offered Traffic will be the sum of the uplink and downlink offered traffic.

Offered traffic will have arrival statistics typical of IP.

Of interest to the simulation is the average throughput and delay exhibited by each system as a function of the offered traffic.

All systems will be assumed to operate at the same channel bandwidth and modulation as specified in Annex A.

IEEE 802.11y Model

The simulation will use a generic model of an IEEE 802.11 CSMA/CA (carrier sense multiple access with collision avoidance) basic access system, where an access point (AP) wishing to transmit data on an idle channel transmits a data burst and then waits for a positive acknowledgement (ACK) burst from the destination. Before an 802.11y station is to transmit it shall sense the medium to determine if another station is transmitting. The access point shall have a monitoring (clear channel assessment) period to determine channel occupancy. If the medium is determined to be idle, the transmission may proceed.

The CSMA/CA basic access scheme mandates that a gap of a minimum specified duration exist between contiguous burst sequences. At the end of a transmission the access point waits a fixed period of time called a Distributed Interframe Space (DIFS) and appends an additional backoff (BO) period. The 802.11y protocol adopts an exponential backoff scheme (called the Distributed Coordination Function-DCF). At the end of each burst transmission (and DIFS), and prior to the next, the backoff time is uniformly chosen in the range (0, cw-1). The value cw is called contention window, and depends on the number of transmissions failed for the burst. At the first transmission attempt, cw is set equal to a value Cwmin called the minimum contention window. After each unsuccessful transmission, cw is doubled, up to a maximum value CWmax. If a retransmission succeeds, cw is reset to CWmin .

All the relevant 802.11y parameters along with their default values used in the simulation may be found in Table 1 of Annex A.

IEEE 802.16h Model

IEEE 802.16h system employs OFDM PHY whose parameters are listed in Table 2 of Annex A. The initial simulation uses 5ms frames with a 3ms/2ms split for DL and UL sub-frames, respectively. To achieve coexistence between IEEE 802.16h and 802.11y operating in a co-channel manner, the 802.16h system may implement different coexistence mechanisms. These mechanisms are categorized into different coexistence scenarios as described in Annex B and will be compared through simulations.

Segregated 802.11y Model

This is a modified version of the IEEE 802.11 CSMA/CA protocol, where the DL and UL transmissions are periodically segregated in time through synchronization (similar to 802.16 DL and UL sub-frames). In the simulations, duration of the 802.11y DL and UL segregated time periods is set at 3ms and 2ms, respectively. The access to the segregated, synchronized spaces is based on the regular CSMA/CA and the MAC-level immediate acknowledgements are suppressed. Furthermore, on the DL direction, the 802.11y AP does not use a back-off mechanism as there are no other contending 802.11y users. All the other parameters are same as those given in Table 1 of Annex A.

Traffic Model

The two systems are assumed to have the same offered traffic statistics. Moreover, the uplink traffic will be simulated having the same statistics as the downlink traffic, except mean offered traffic on the uplink will be some fraction, N, of the downlink.

Packet sizes are assumed to be uniformly distributed in the range [0.1xMaxPacketSize, 0.9xMaxPacketSize] with MaxPacketSize defined in Table 3 of Annex A. The packet inter-arrival time follows exponential distribution with its mean determined by the mean packet size and the average bit-rate of the traffic source.

Simulation Setup

A packet-level simulation of different scenarios described in Annex B has been implemented. Average throughput and delay for each scenario are obtained through multiple independent iterations of the simulation under that particular scenario. Each iteration of the simulation runs for 100s with a 20s warm-up period to allow systems reach steady state (i.e. data collected during the first 20s is discarded).

For each scenario, the offered load is varied in 100kbps increments and each network's throughput and packet delay are recorded. Finally, these values are averaged over multiple independent iterations and the result is plotted versus the offered load.

Simulation Results

Part I: Coexistence of 802.16h with standard 802.11y

The first part of simulation results have been obtained with the standard IEEE 802.11y model described earlier. In Part II some results concerning the segregated 802.11y model will be presented. Detailed description of each coexistence scenario may be found in Annex B.

Scenario 1: Interference-Free Performance

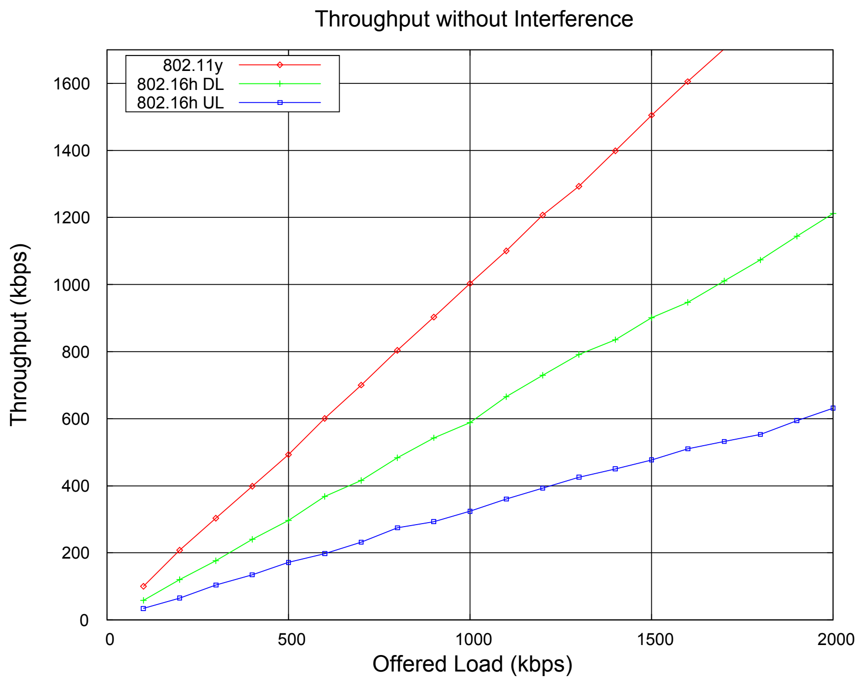

Figure 1. Throughput without interference vs. the offered load

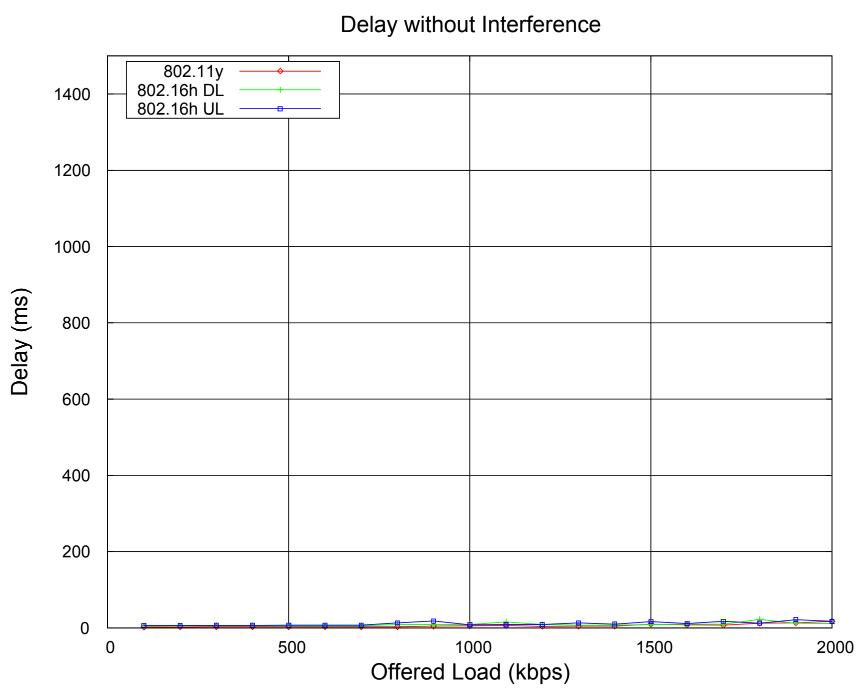

Figure 2. Delay without interference vs. the offered load

Scenario 2: Baseline

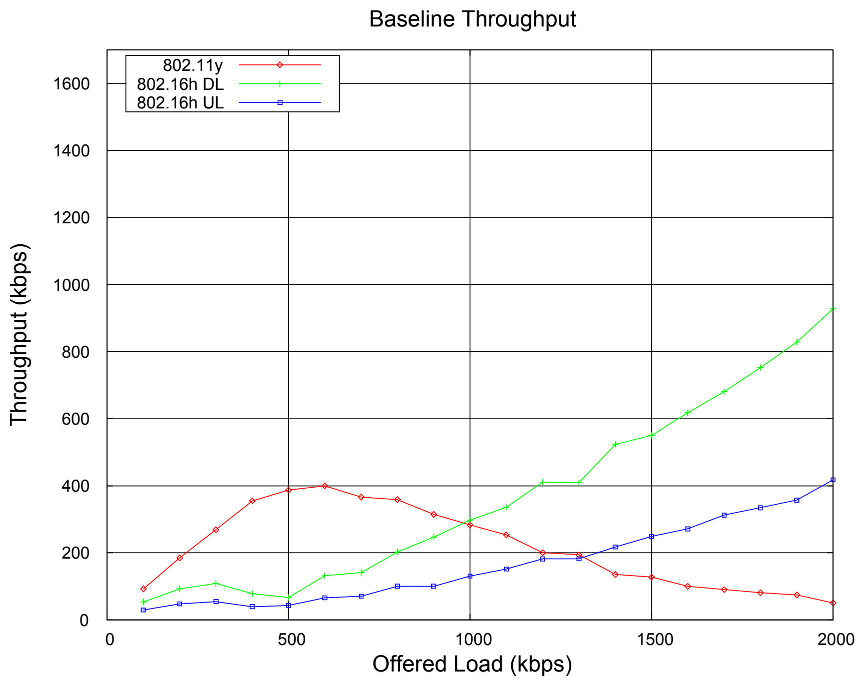

Figure 3. Baseline throughput vs. the offered load

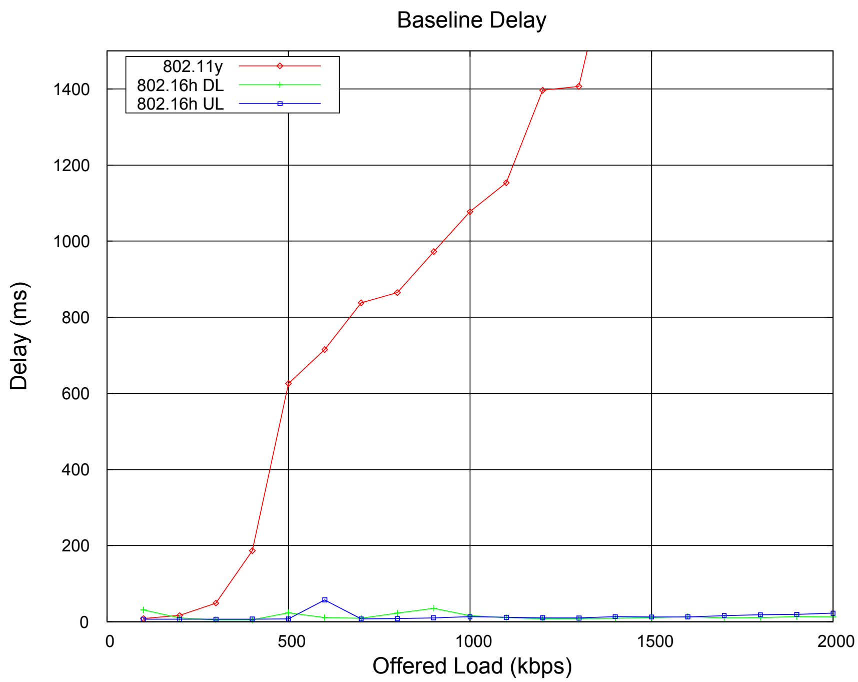

Figure 4. Baseline delay vs. the offered load

Scenario 3: LBT

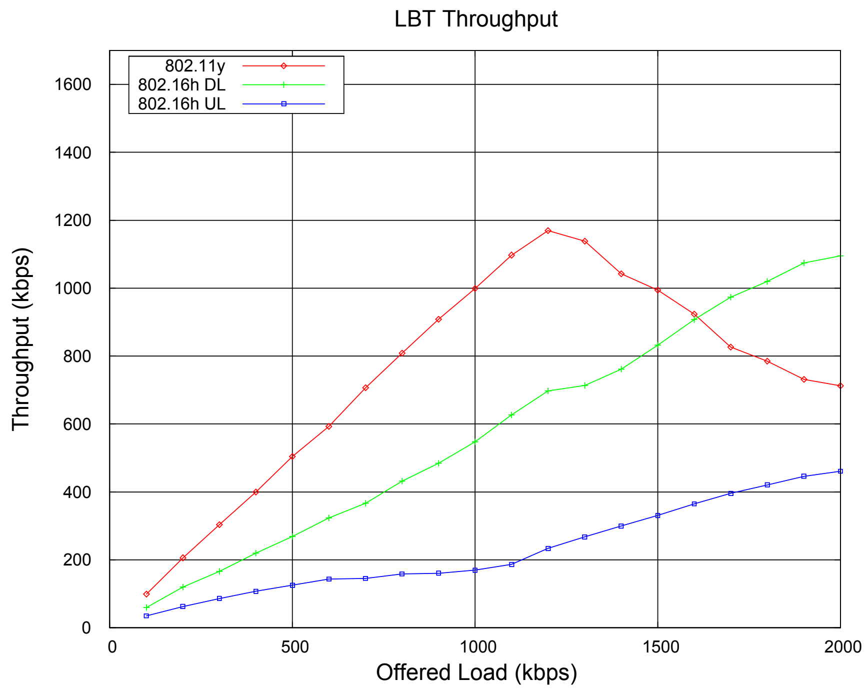

Figure 5. LBT throughput vs. the offered load

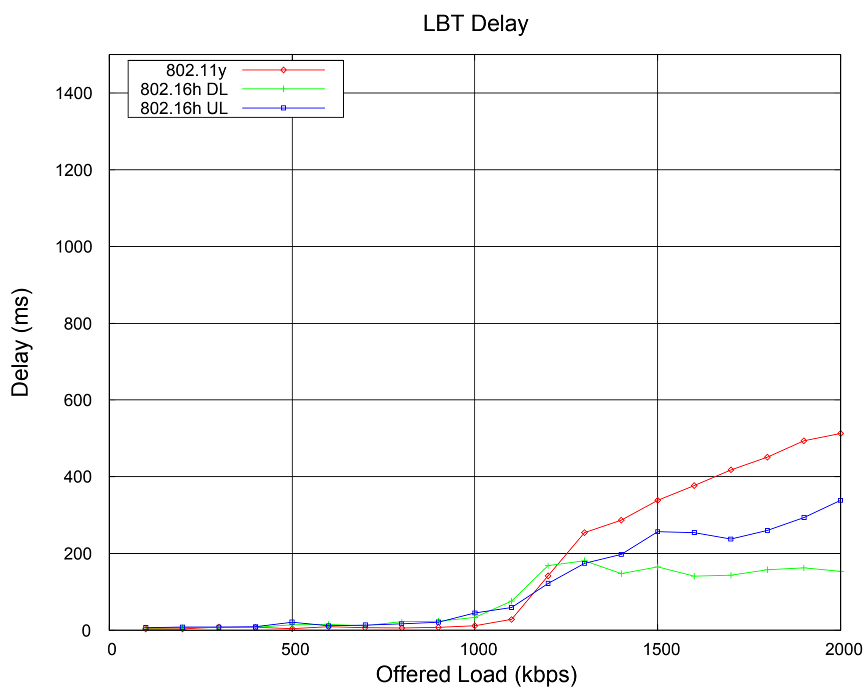

Figure 6. LBT delay vs. the offered load

Scenario 4: EQP

In order to study the performance of EQP mechanism, simulations were performed under different EQP periods (1/3/6/10/20 frames) while the EQP duration was fixed at 3 frames (15ms). Note that the EQP duration was chosen according to the minimum EQP duration requirement for a 5MHz channel as specified in Table h1 of [2].

Throughput analysis for different EQP periods:

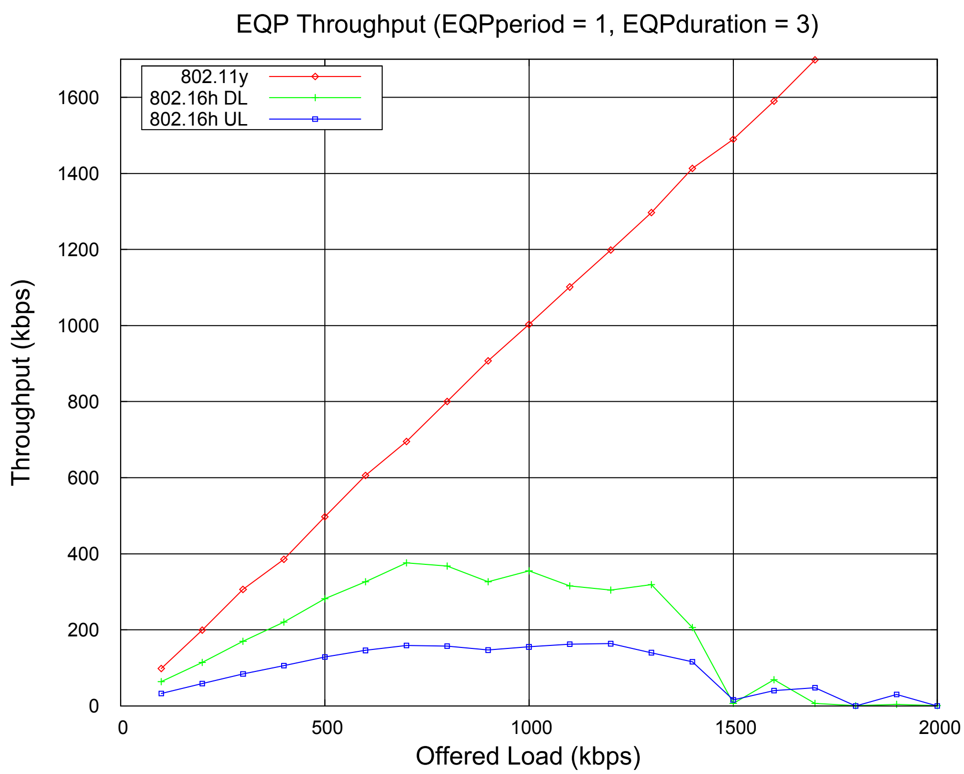

Figure 7. EQP throughput vs. the offered load (EQPperiod = 1, EQPduration = 3)

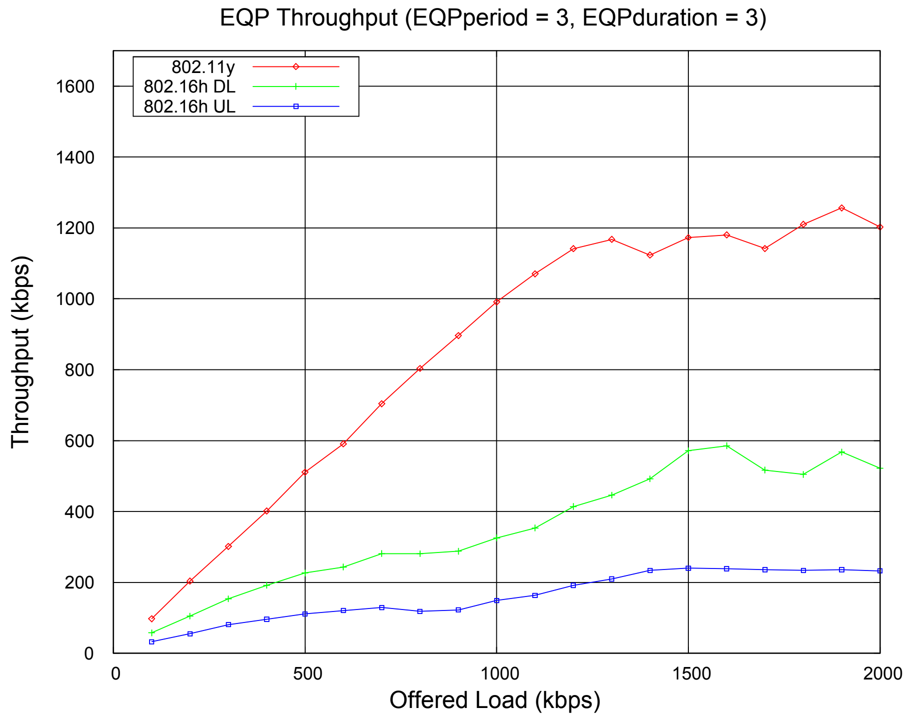

Figure 8. EQP throughput vs. the offered load (EQPperiod = 3, EQPduration = 3)

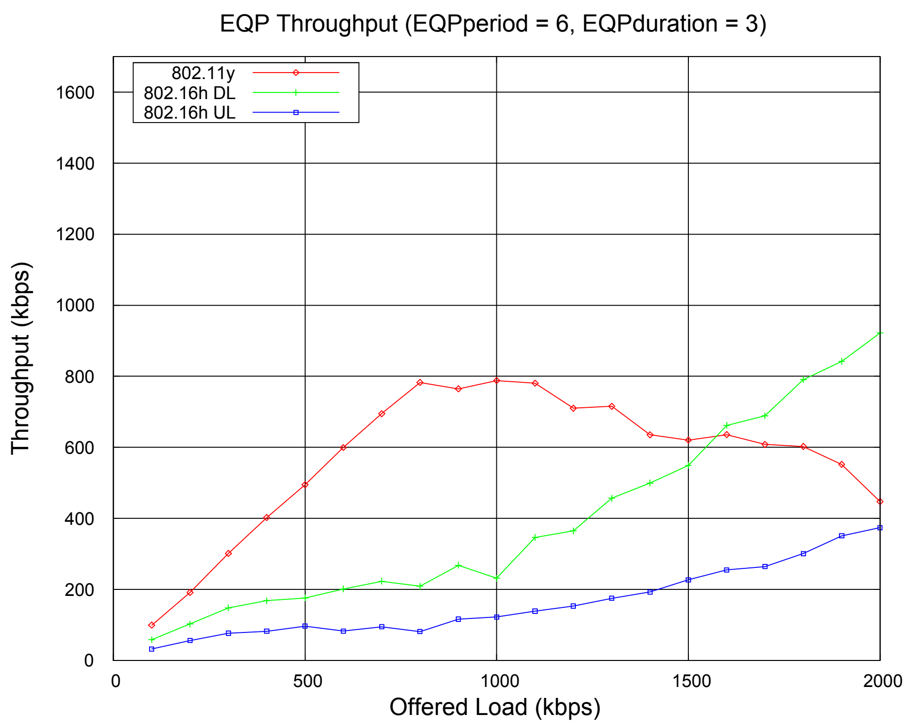

Figure 9. EQP throughput vs. the offered load (EQPperiod = 6, EQPduration = 3)

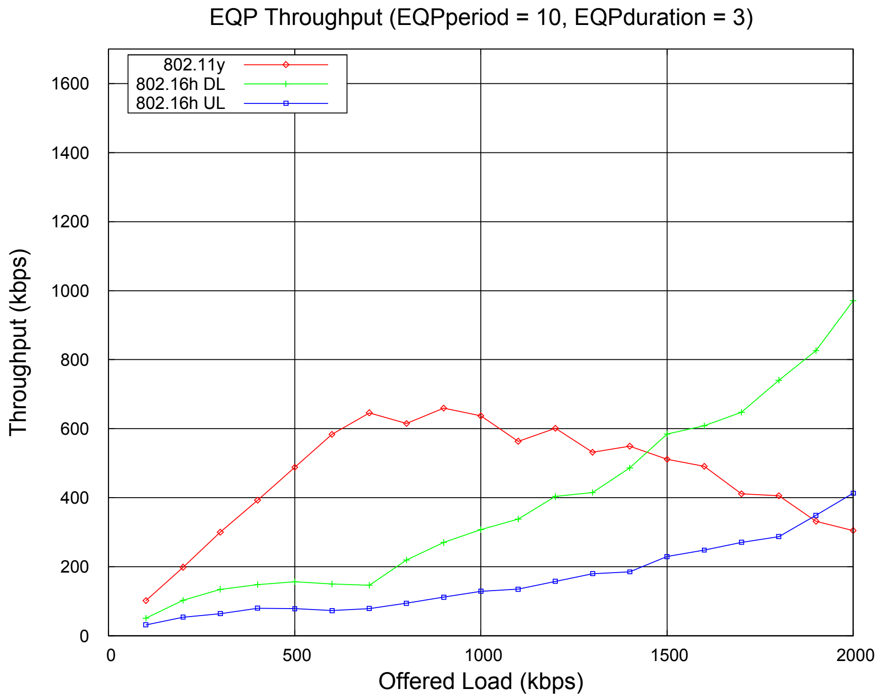

Figure 10. EQP throughput vs. the offered load (EQPperiod = 10, EQPduration = 3)

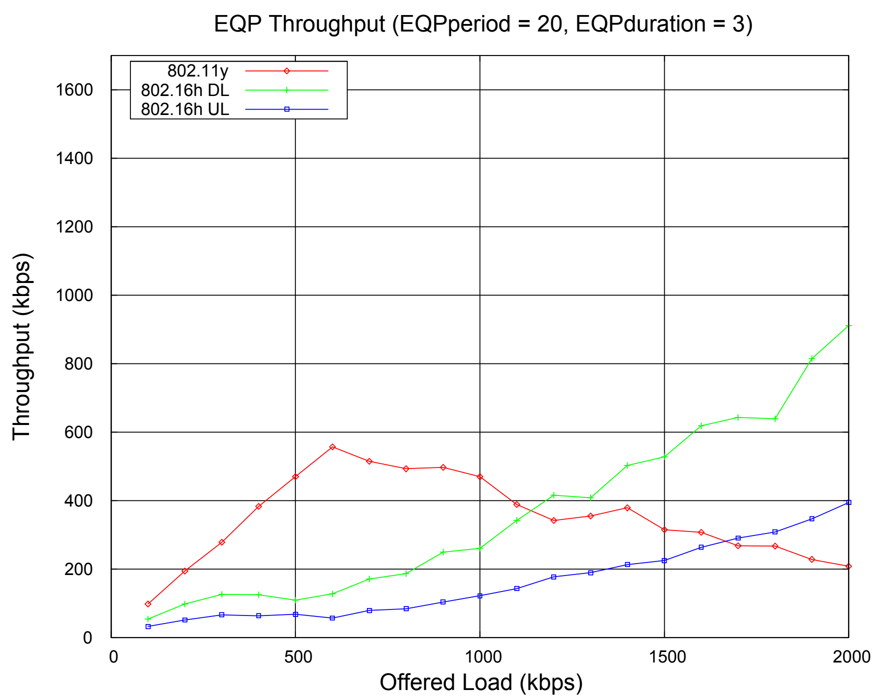

Figure 11. EQP throughput vs. the offered load (EQPperiod = 20, EQPduration = 3)

Delay analysis for different EQP periods:

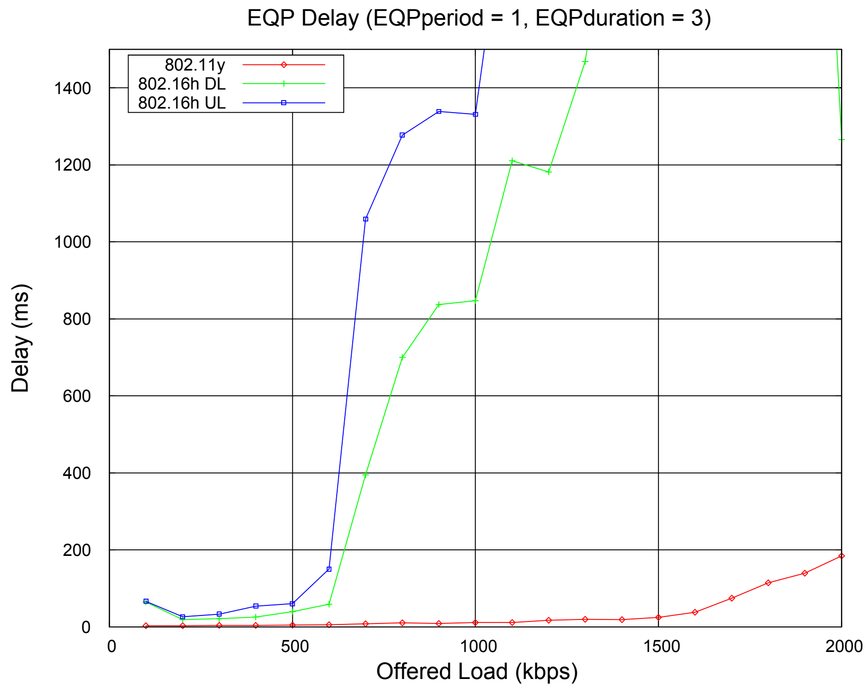

Figure 12. EQP delay vs. the offered load (EQPperiod = 1, EQPduration = 3)

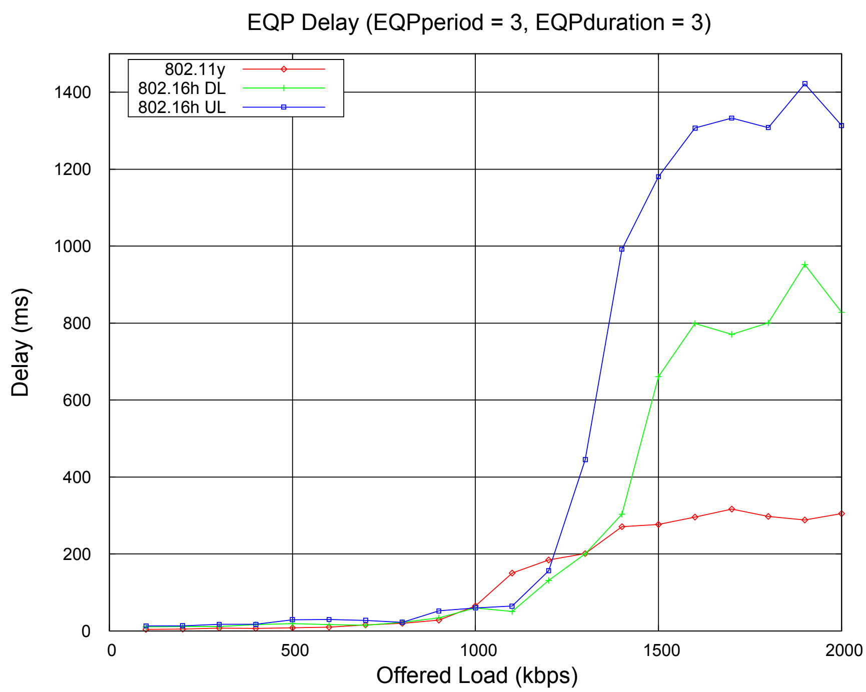

Figure 13. EQP delay vs. the offered load (EQPperiod = 3, EQPduration = 3)

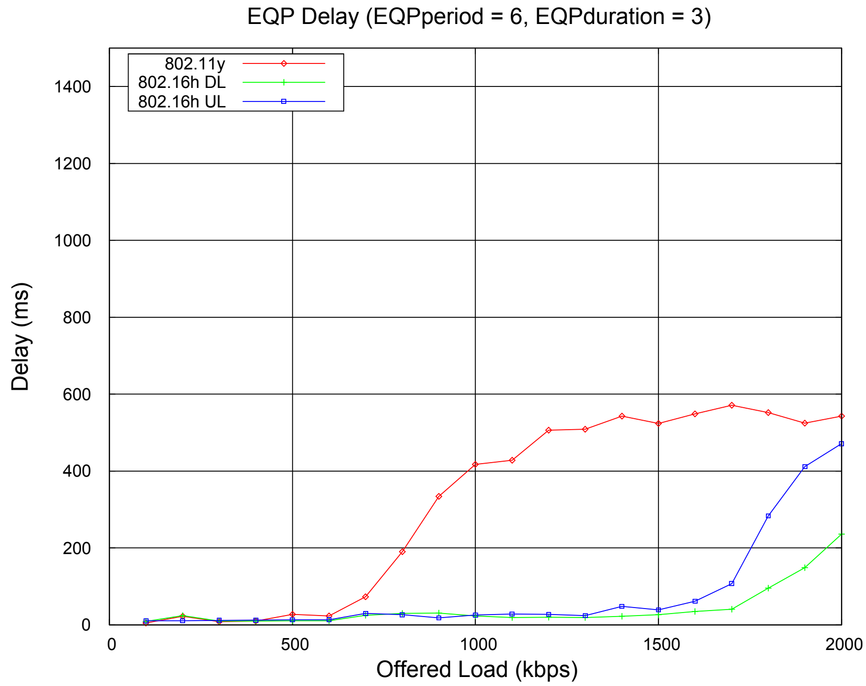

Figure 14. EQP delay vs. the offered load (EQPperiod = 6, EQPduration = 3)

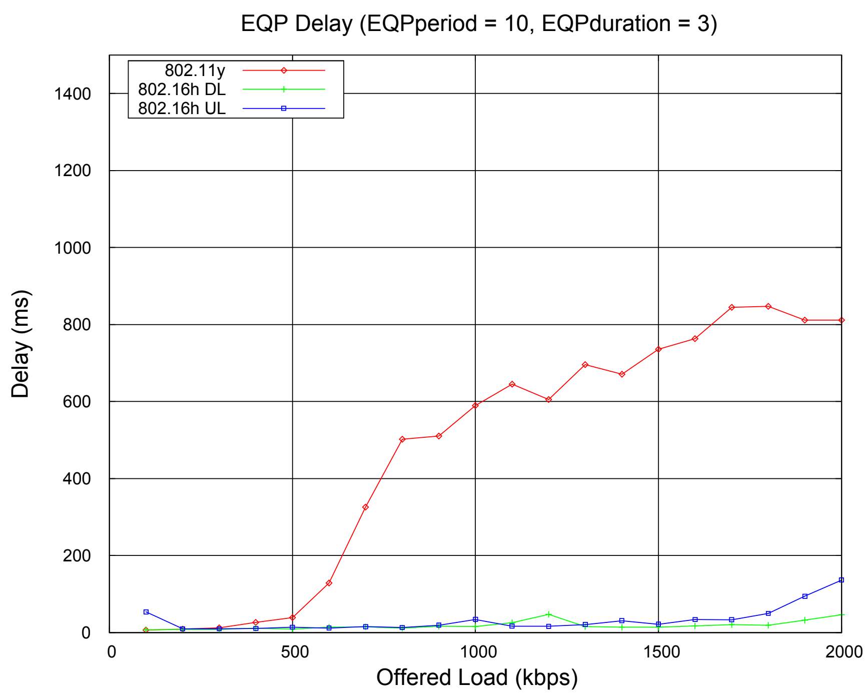

Figure 15. EQP delay vs. the offered load (EQPperiod = 10, EQPduration = 3)

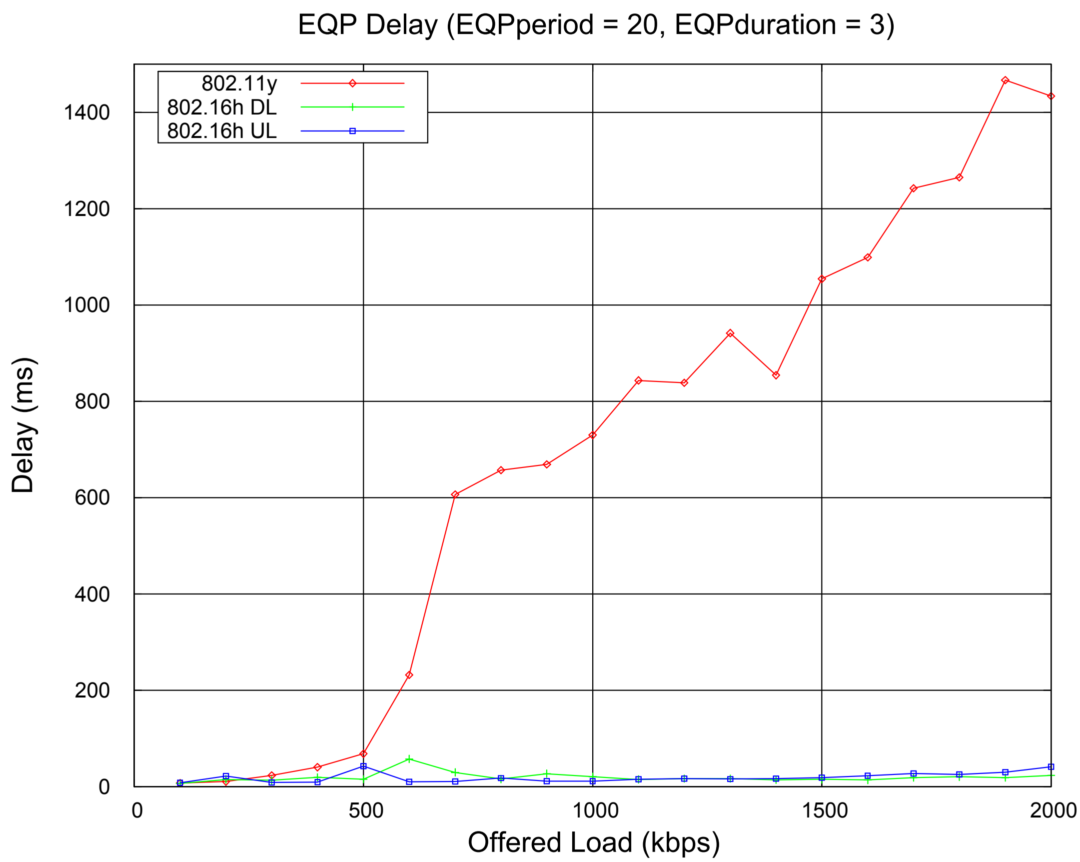

Figure 16. EQP delay vs. the offered load (EQPperiod = 20, EQPduration = 3)

Scenario 5: LBT + EQP

As in the case of EQP, simulations of this scenario were performed under different EQP periods (1/3/6/10/20 frames) while EQP duration was fixed at 3 frames (15ms).

Throughput analysis for different EQP periods:

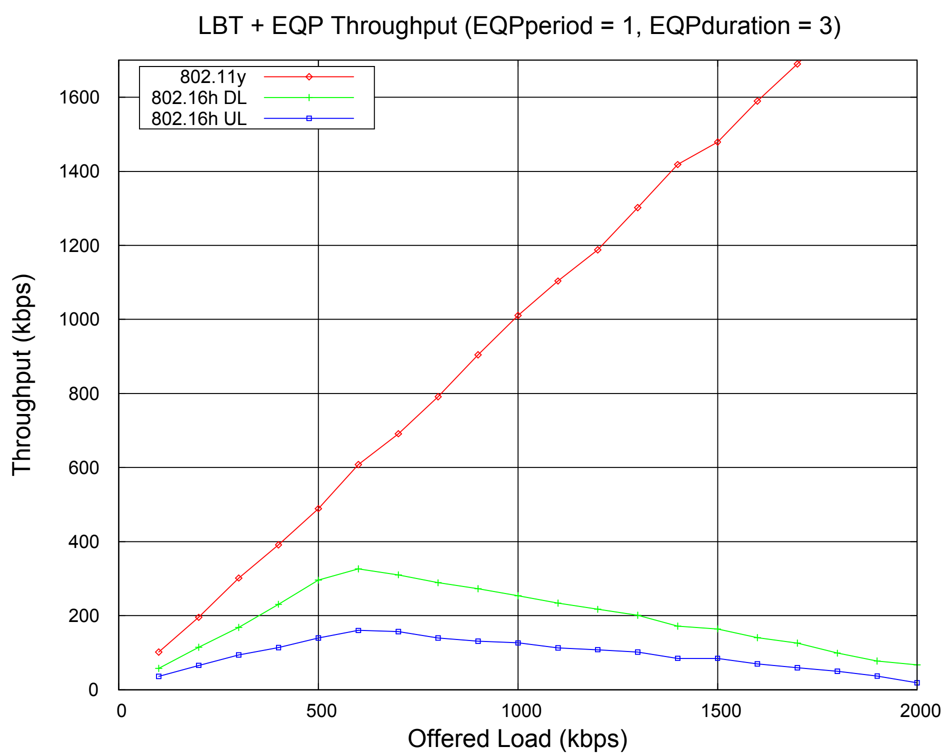

Figure 17. LBT + EQP throughput vs. the offered load (EQPperiod = 1, EQPduration = 3)

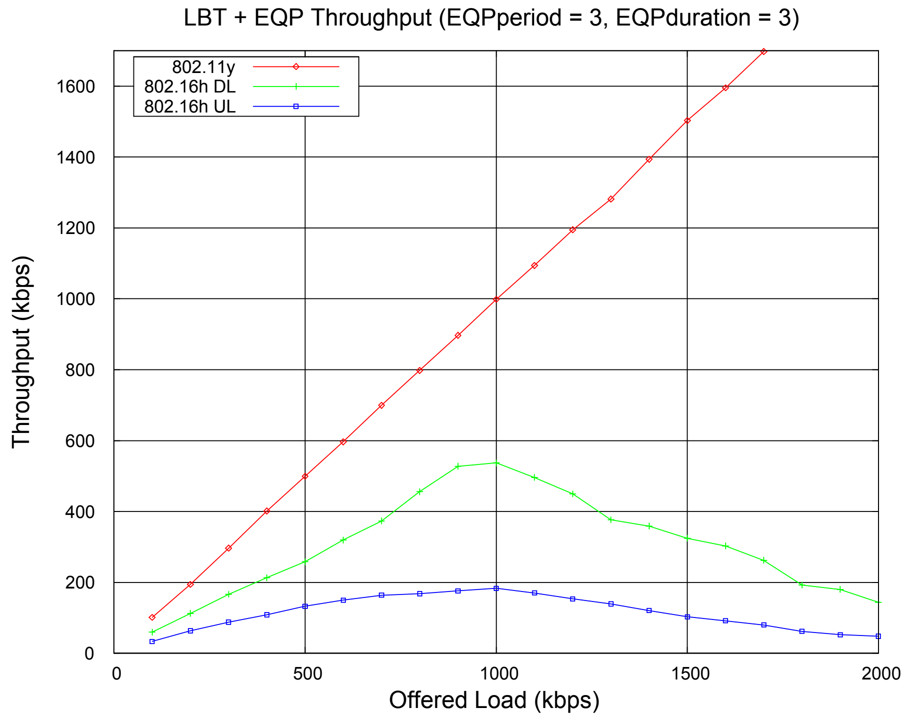

Figure 18. LBT + EQP throughput vs. the offered load (EQPperiod = 3, EQPduration = 3)

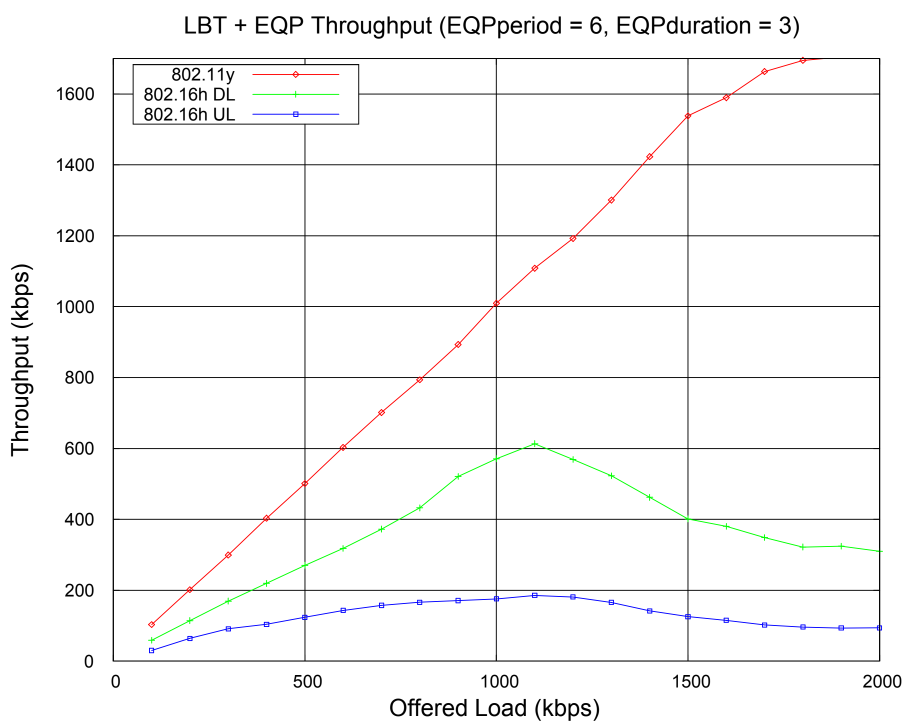

Figure 19. LBT + EQP throughput vs. the offered load (EQPperiod = 6, EQPduration = 3)

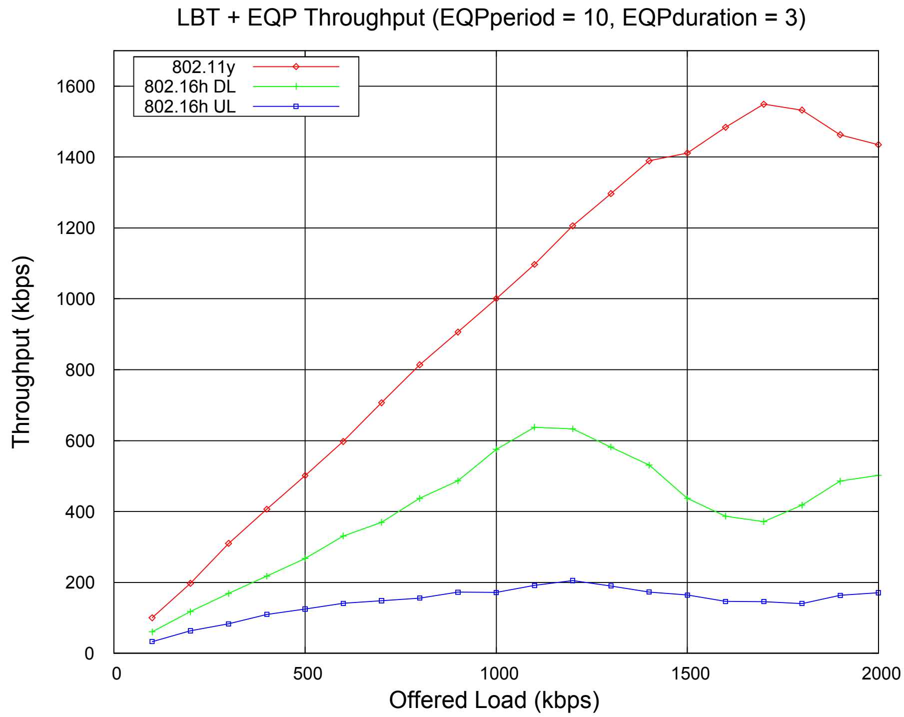

Figure 20. LBT + EQP throughput vs. the offered load (EQPperiod = 10, EQPduration = 3)

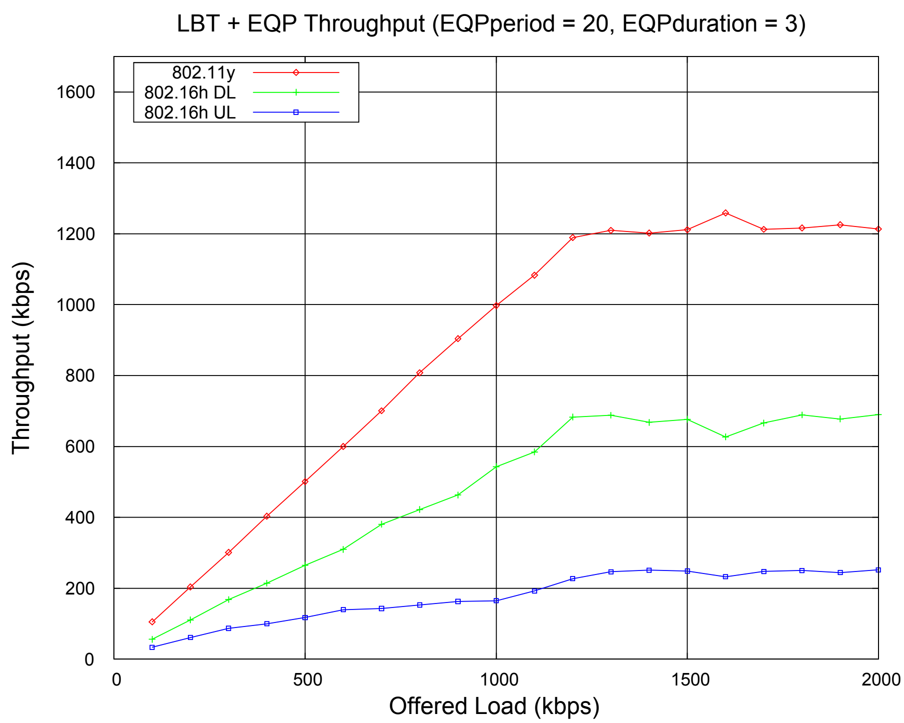

Figure 21. LBT + EQP throughput vs. the offered load (EQPperiod = 20, EQPduration = 3)

Delay analysis for different EQP periods:

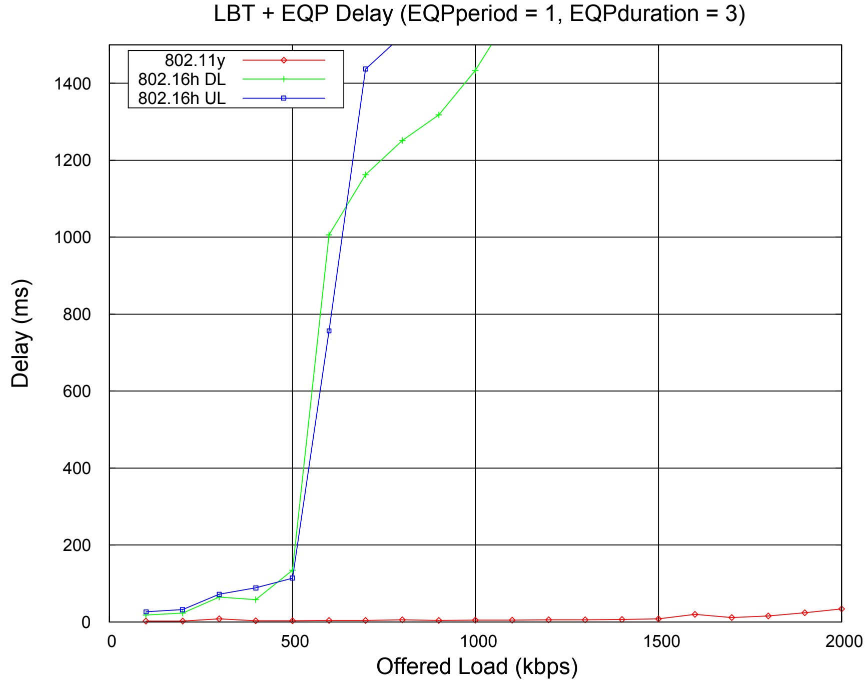

Figure 22. LBT + EQP delay vs. the offered load (EQPperiod = 1, EQPduration = 3)

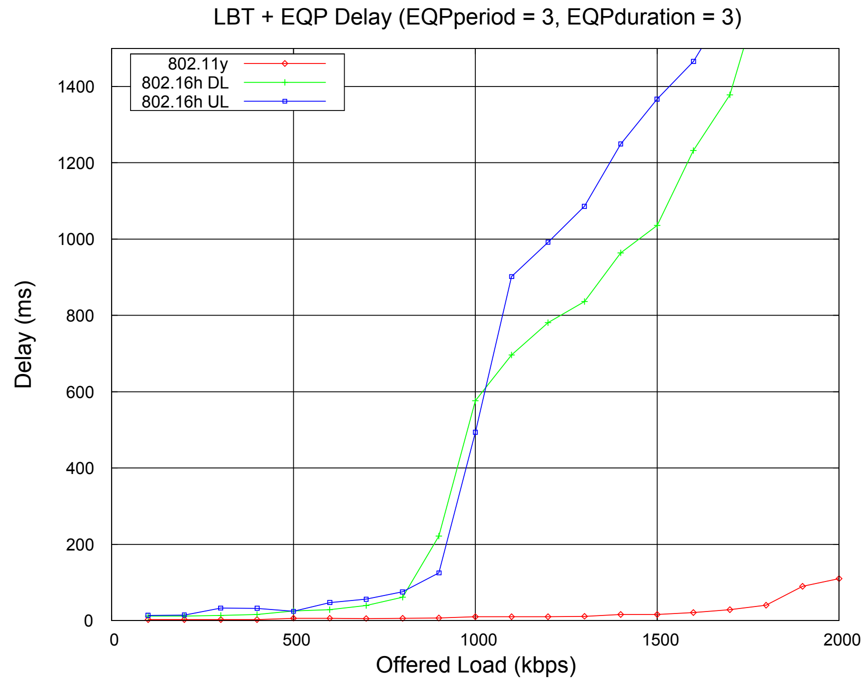

Figure 23. LBT + EQP delay vs. the offered load (EQPperiod = 3, EQPduration = 3)

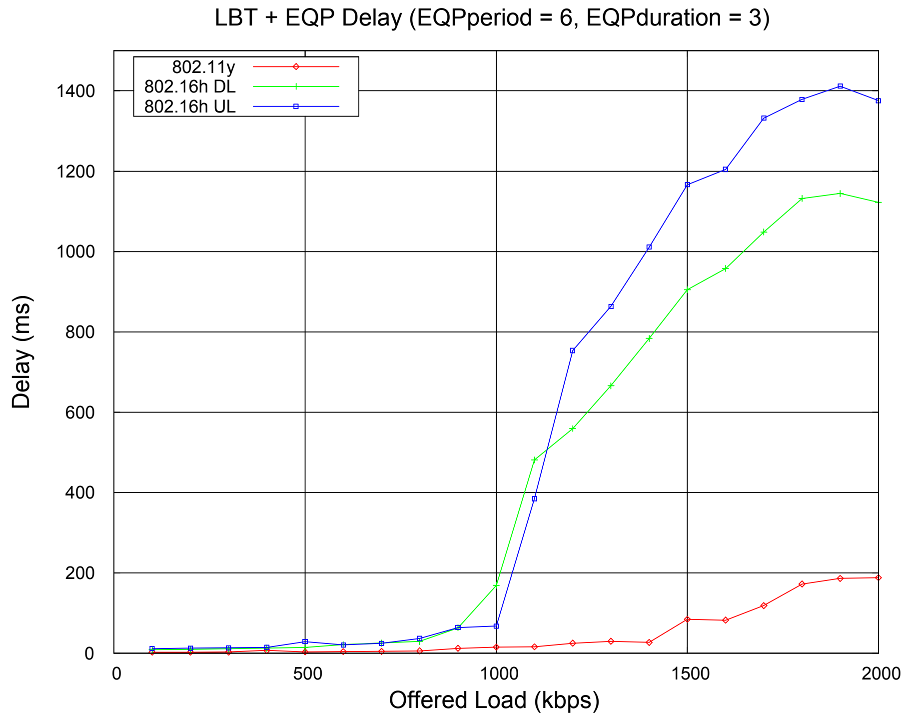

Figure 24. LBT + EQP delay vs. the offered load (EQPperiod = 6, EQPduration = 3)

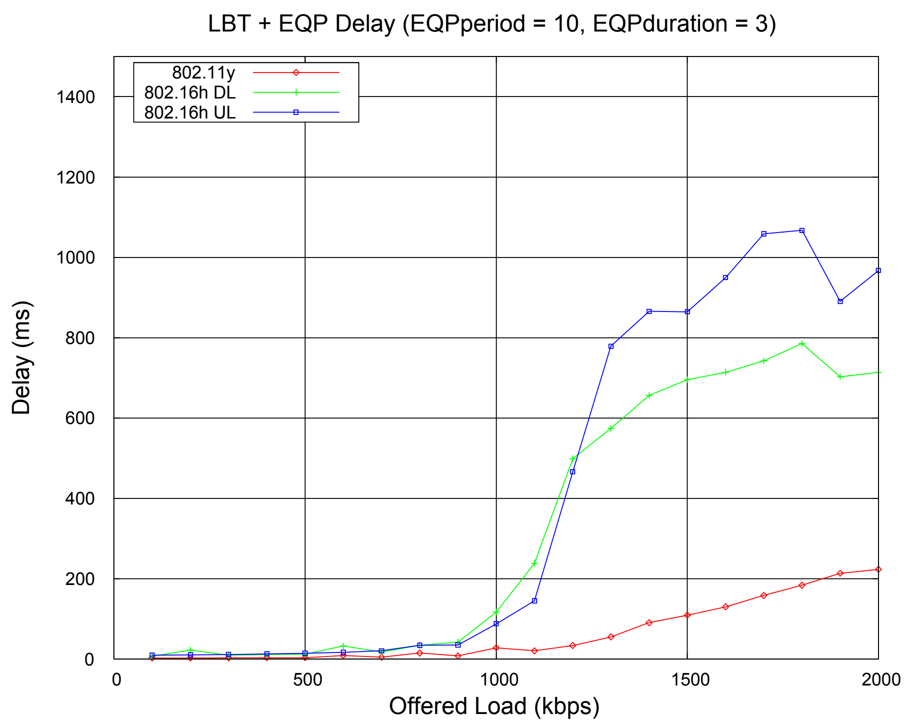

Figure 25. LBT + EQP delay vs. the offered load (EQPperiod = 10, EQPduration = 3)

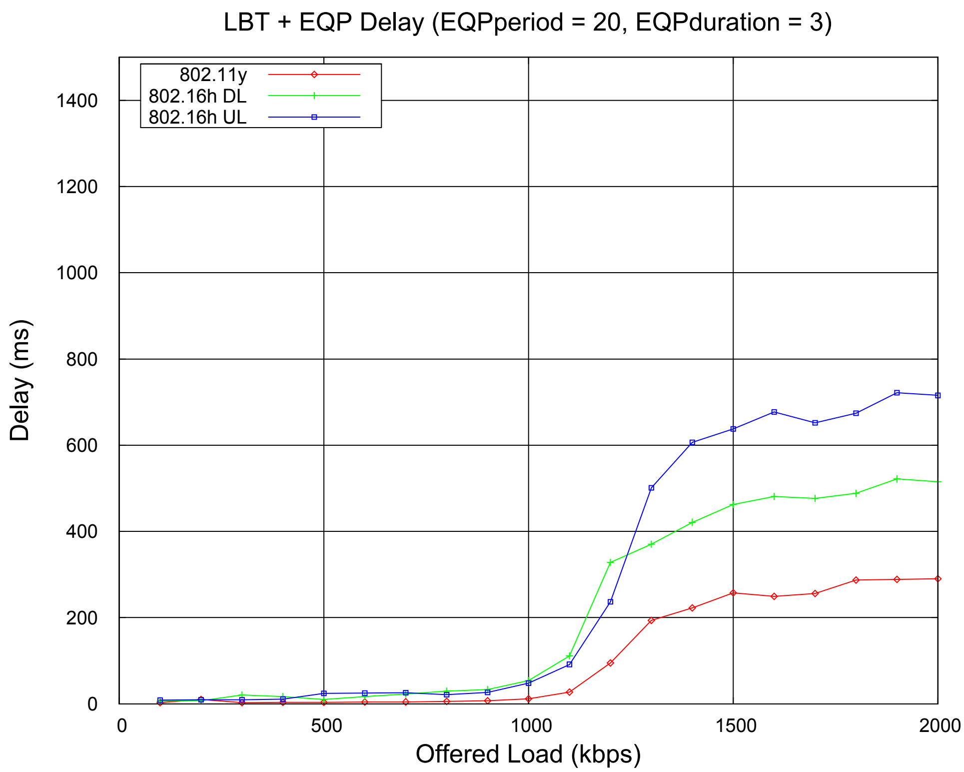

Figure 26. LBT + EQP delay vs. the offered load (EQPperiod = 20, EQPduration = 3)

Scenario 6: EQP + Padding

Simulation results under this scenario show that 802.16h load has no effect on the average throughput and delay of the 802.11y network as expected. This is due to the fact that 802.16h network occupies the medium for the same time period regardless of its traffic (i.e. using filling bytes).

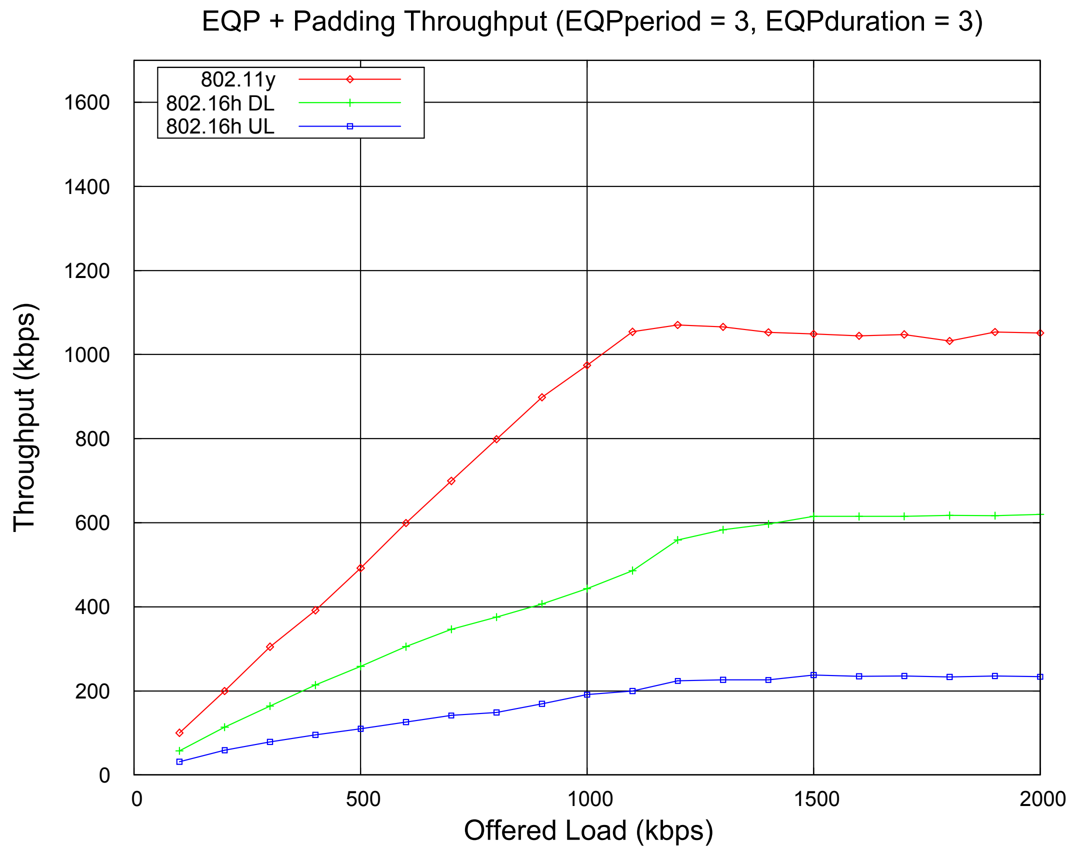

Figure 27. EQP + Padding throughput vs. the offered load (EQPperiod = 3, EQPduration = 3)

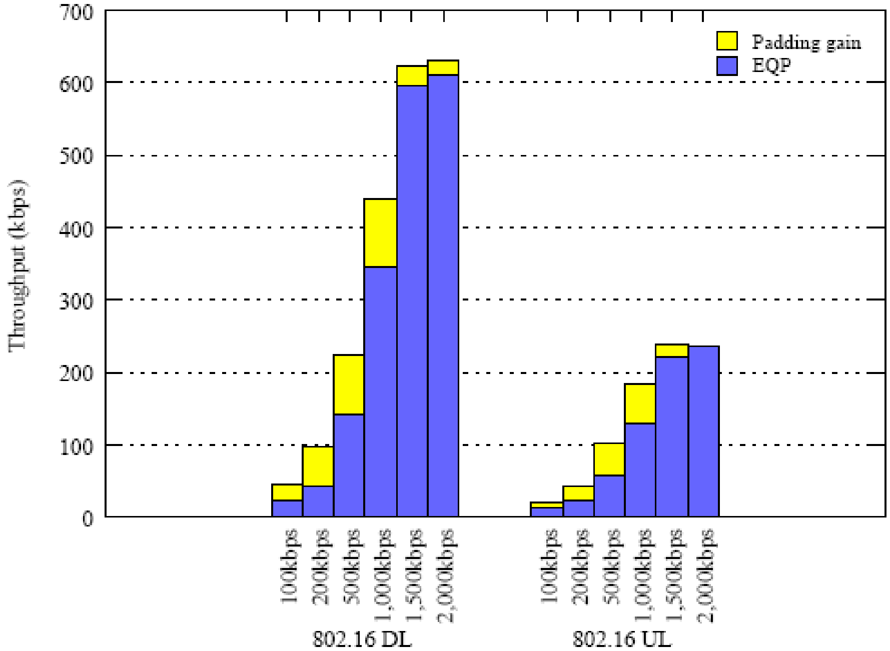

Figure 28. Relative throughput gain of padding (EQP + padding) over pure EQP at different offered load levels

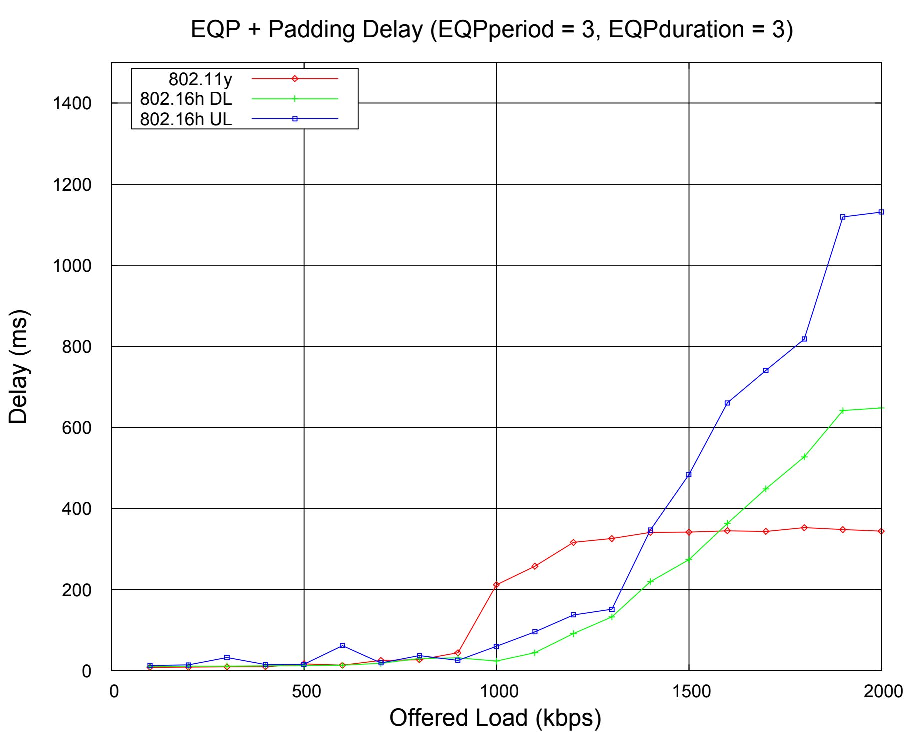

Figure 29. EQP + Padding delay vs. the offered load (EQPperiod = 3, EQPduration = 3)

Scenario 7: LBT + EQP + Padding

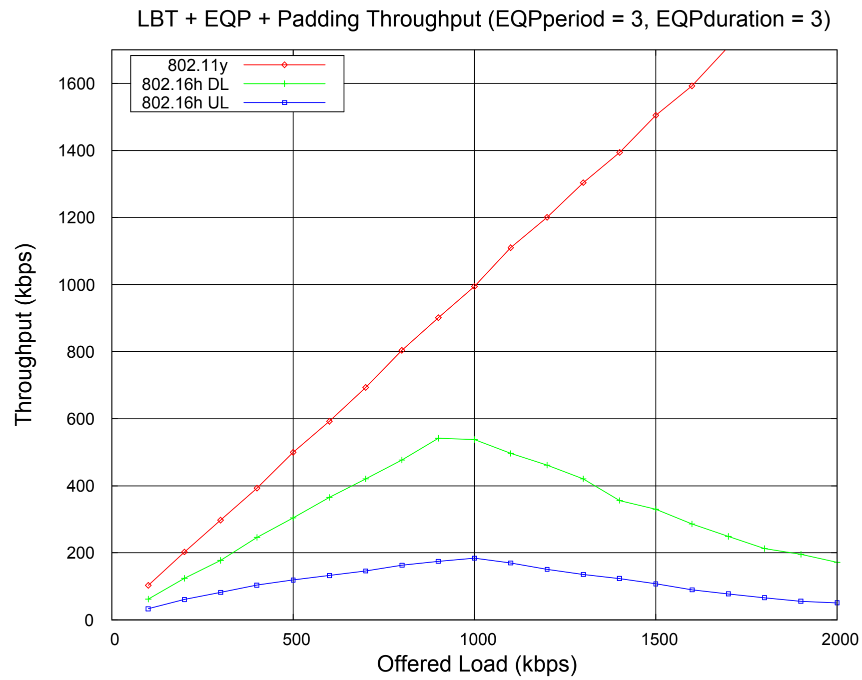

Figure 30. LBT + EQP + Padding throughput vs. the offered load (EQPperiod = 3, EQPduration = 3)

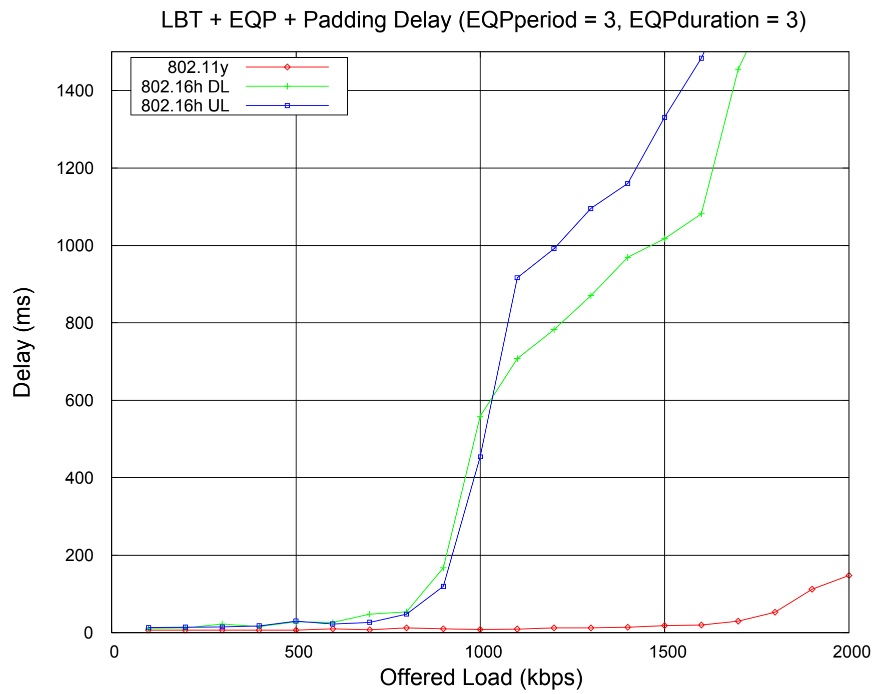

Figure 31. LBT + EQP + Padding delay vs. the offered load (EQPperiod = 3, EQPduration = 3)

Part II: Coexistence of 802.16h with segregated 802.11y

For simulations in Part II, the standard 802.11y model is replaced with the segregated 802.11y as described earlier. The segregated version aims to improve the performance by removing the contention between DL and UL transmissions of the 802.11y network (the UL transmissions however, would still contend with each other). As described earlier, in the segregated mode, the 802.11y AP and clients behave differently therefore, the throughput and delay of the 802.11y network in DL and UL directions will be shown separately.

In order to analyze the performance improvements, if any, the number of 802.11y clients is increased from 1 to 4 (i.e., 4 DL and 4 UL traffic flows). This in turn increases the contention level, thereby accentuating the impact of segregation. The total offered load to the 802.11y network will be divided evenly among the 4 users and the DL/UL traffic ratio is set as before (see Table 3 in Annex A). Finally, the duration of the segregated DL/UL periods is set 3ms and 2ms, respectively.

Scenario 1: Interference-Free Performance

It may be observed from the results that the standard 802.11y CSMA/CA protocol performs better for offer loads of up to about 2Mbps. However, with increasing load, the contention overhead becomes significant resulting in longer delays. In this case the segregated mode provides a better performance in terms of both throughput and delay on the DL.

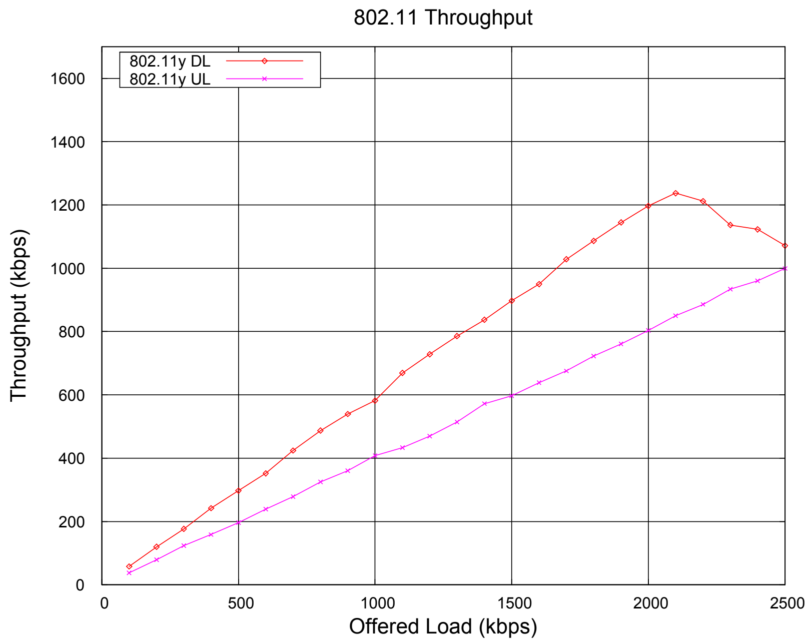

Figure 32. DL and UL throughput of the standard 802.11y without interference

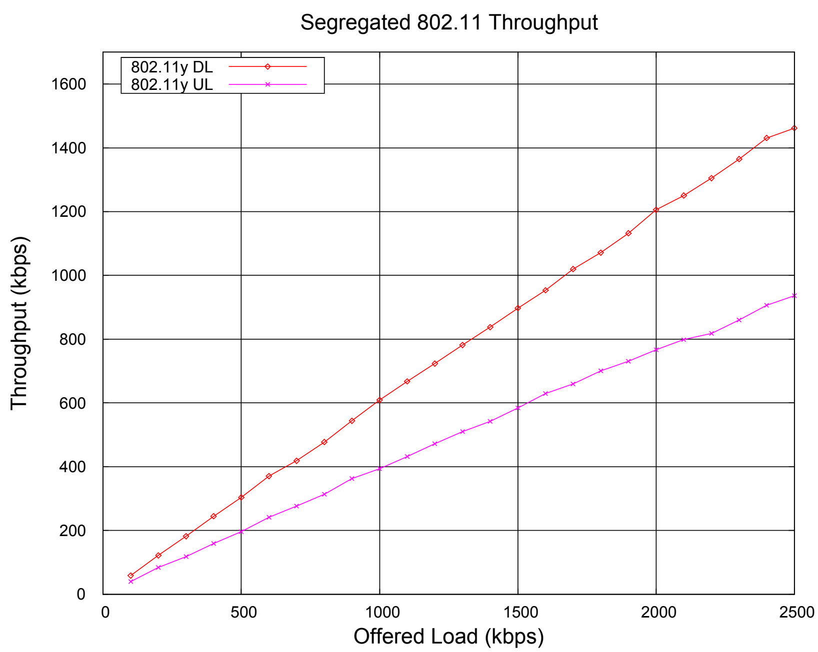

Figure 33. DL and UL throughput of the segregated 802.11y without interference

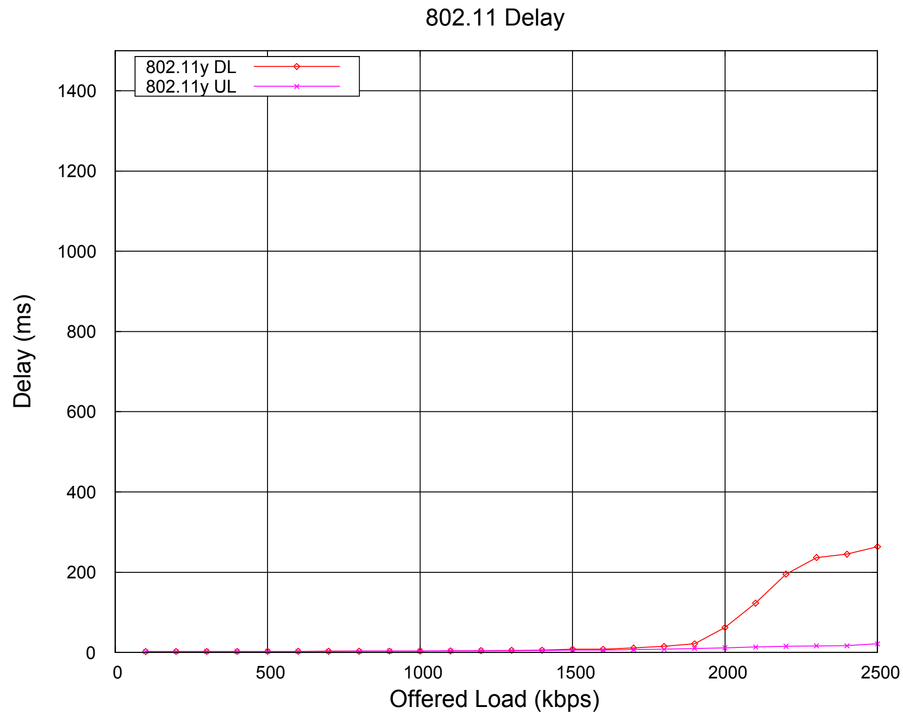

Figure 34. DL and UL delay of the standard 802.11y without interference

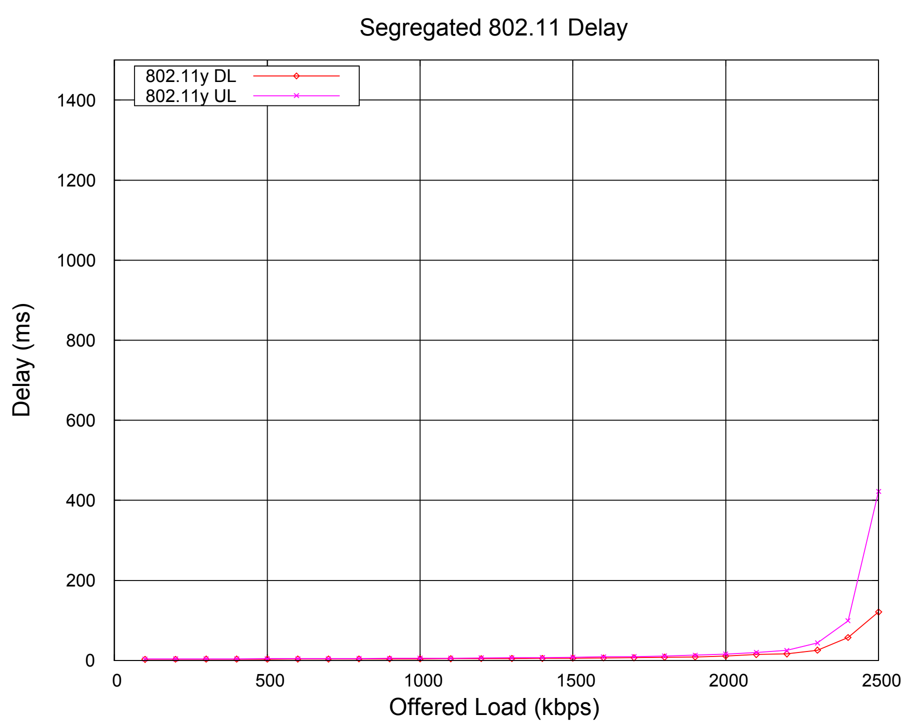

Figure 35. DL and UL delay of the segregated 802.11y without interference

Scenario 2: Baseline

As seen in the following results, the reduced contention level of the 802.11y network in the segregated mode is also beneficial to the 802.16h performance. For instance, at an offered load of 1Mbps, both DL and UL throughputs of the 802.16h network are almost doubled with the 802.11y network being in the segregated mode. Also note that 802.16h throughputs in Fig. 36 are lower compared to those seen in Fig. 3 since the number of contending 802.11y users has been increased from 1 to 4. This in turn results in a higher collision rate between the two networks, thereby degrading the 802.16h throughput.

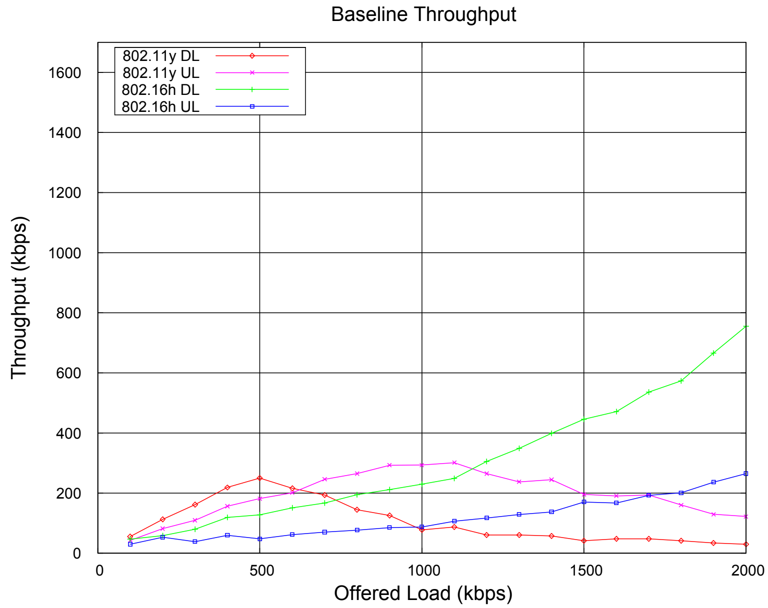

Figure 36. Baseline (with standard 802.11y) throughput vs. the offered load

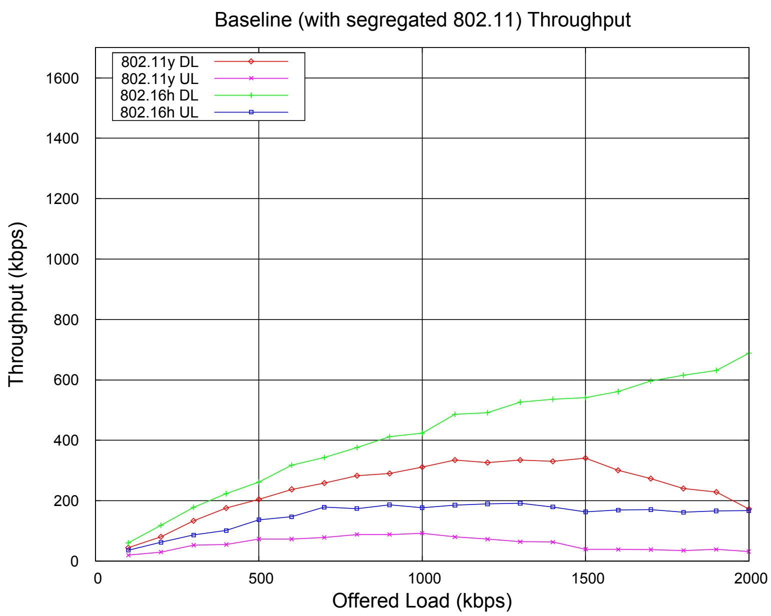

Figure 37. Baseline (with segregated 802.11y) throughput vs. the offered load

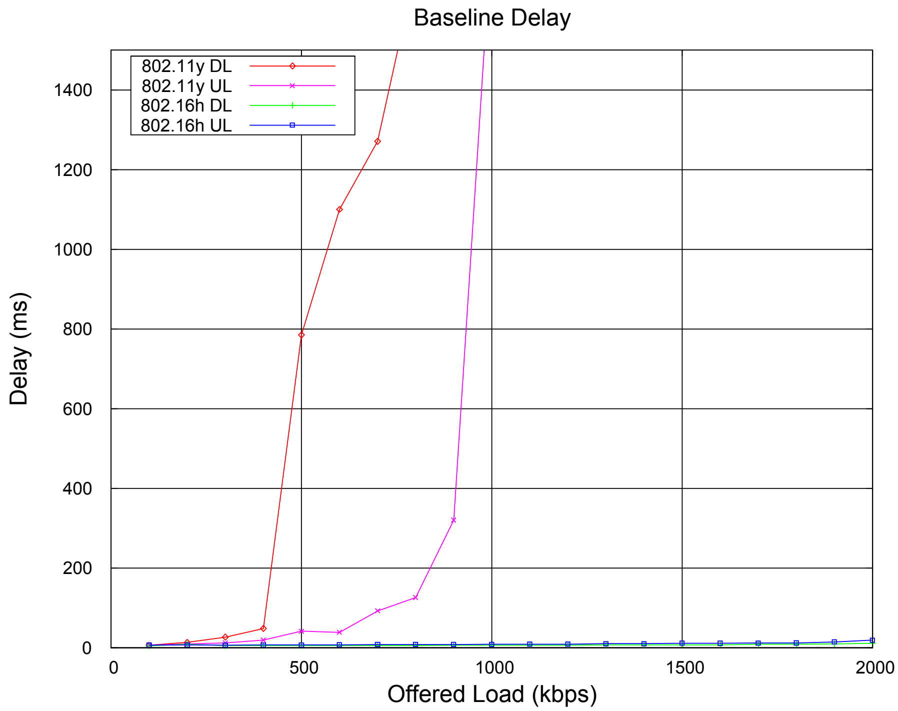

Figure 38. Baseline (with standard 802.11y) delay vs. the offered load

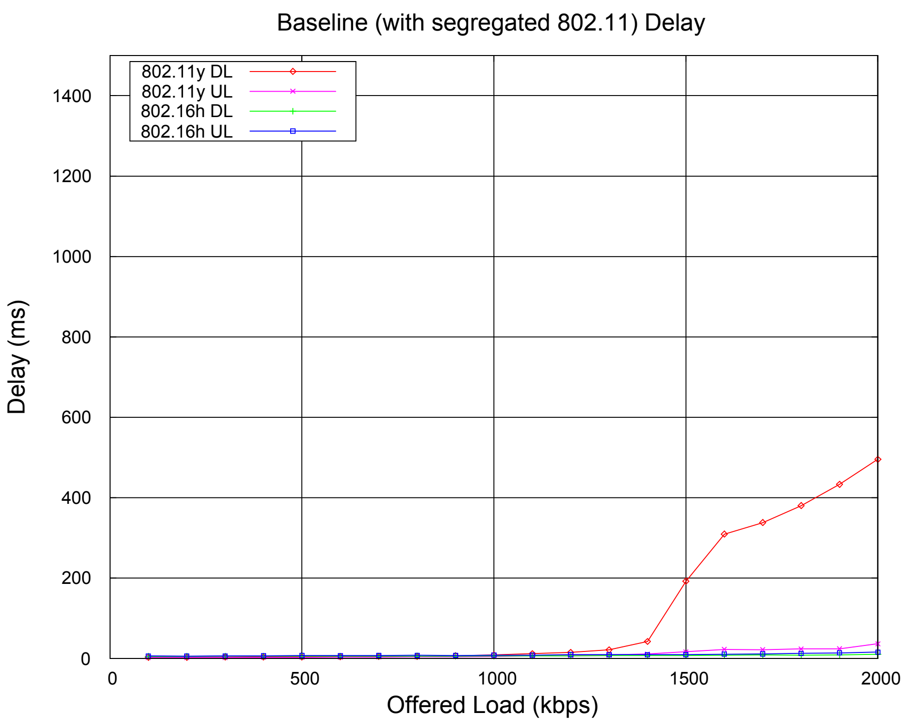

Figure 39. Baseline (with segregated 802.11y) delay vs. the offered load

Concluding Remarks

Following an analysis of the simulation results, several conclusions may be drawn.

- LBT mechanism has the best overall characteristics. For low to moderate (~1Mbps) offered loads both 802.11y and 802.16h systems coexist and minimally affect each other. Comparing Figures 1 and 5 against other results it may be observed that performance of LBT approaches that of the interference free scenario better than any of the other schemes.

- Comparing Figures 5 and 27, EQP with Padding is close to having the same performance as pure LBT.

- EQP alone is not beneficial to 802.16h especially at low to moderate offered loads.

Comparing Fig. 7 through 11, while increasing the EQP period is beneficial for 802.16h at higher loads, it is, somewhat counter intuitively, detrimental at low to moderate load. This is because of 802.11y being active during the EQP period (i.e. the active 802.16h frames). When the load on 802.16h is low, a longer EQP period will be more "sparse" compared to a shorter one thus giving 802.11y users more opportunities to take over the channel and degrade the 802.16h throughput. On the other hand with a high 802.16h load, the EQP period will be almost fully occupied (thus getting close to EQP + Padding) and 802.16 throughput will improve at the expense of the 802.11y's throughput.

- For low to moderate offered loads, LBT+EQP approaches pure LBT in performance for relatively higher EQP periods.

- The 802.11 seems to show the best overall resilience in face of competition for common bandwidth.

- Comparing Figures 36 and 37, synchronization and segregation of 802.11y seems to improve the performance in the baseline coexistence scenario however, the improvement is not as good as either of the LBT or LBT+EQP techniques.

Annex A: Simulation Parameters

The parameters used for configuration of the 802.11y and 802.16h systems have been summarized in Tables 1 and 2, respectively. 802.11y parameters are in line with those specified in [1] for a 5 MHz channel. 802.16h system employs OFDM PHY with 5ms frames (3ms DL, 2ms UL).

MAC Protocol	CSMA/CA
Channel Bandwidth	5 MHz
N_{FFT}	64
OFDM Sub-carriers	52
Data Sub-carriers	48
OFDM Symbol Duration	16 µs ($T_{FFT} + T_{GI}$)
Raw Bit-rate	3.0 Mbps (QPSK 1/2)
Basic Rate	1.5 Mbps (BPSK 1/2)
Slot Time	21 µs
SIFS	64 µs
Preamble Length	64 µs
CWmin	15
CWmax	1023
RTS/CTS	Disabled

Table 1. 802.11y parameters

MAC Protocol	TDMA TDD
Channel Bandwidth	5 MHz
n: Oversampling Factor	144/125
N_{FFT}	256
OFDM Sub-carriers	200
Data Sub-carriers	192
Cyclic Prefix	1/4
OFDM Symbol Duration	55.5 µs ($T_{FFT} + T_{CP}$)
Raw Bit-rate	3.3 Mbps (QPSK 1/2)
Frame Duration	5 ms
DL Sub-frame Duration	3 ms
UL Sub-frame Duration	2 ms
EQP Duration	3 frames (15 ms)
EQP Period	Varied from 1 to 20 frames
TTG	10 PS
RTG	10 PS

Table 2. 802.16h parameters

Transport Protocol	UDP
Offered Load	Varied from 100 kbps (lightly loaded) to 2.0 Mbps (overloaded)
DL/UL Load Ratio	60/40
Packet Inter-arrival Time	Exponentially distributed
MaxPacketSize	1500 Bytes
PktSizeLowerBound	0.1 * MaxPacketSize
PktSizeUpperBound	0.9 * MaxPacketSize
Packet Size	Uniformly distributed between PktSizeLowerBound and PktSizeUpperBound

Table 3. Traffic parameters

Annex B: Simulation scenarios for 802.16h and 802.11y coexistence

This is a summary of various scenarios implemented in the first round of simulations. In all simulations we assume that systems are collocated therefore, any interference results in collision. Each network's parameters, as well as the traffic model are as described in the Annex A.

Scenario 1: Interference-Free Performance

Under this scenario the two networks are assumed to be not interfering with each other (as if they are operating on non-overlapping channels). Therefore, the simulation results in each case will be determined solely by the performance of the corresponding standard. All the remaining scenarios assume collocated networks occupying the same channel.

Scenario 2: Baseline

This scenario assumes generic 802.11 and 802.16 systems without implementing any additional coexistence mechanisms and will serve as a benchmark against which other mechanisms will be evaluated.

Scenario 3: LBT

In this scenario, 802.16h system employs Listen-Before-Talk as detailed in Clause 6.4.3.5 of [2] by undertaking clear channel assessment before embarking on any transmission. Data that is deferred from transmission because of channel activity is buffered for the next transmission. Otherwise the system behaves in the same manner as normal 802.16h system. Note that LBT is applied independently to both DL and UL sub-frames as shown in the "revised" Figure h7 of [2]. The uplink monitoring period takes place in a regular manner at the Transmit/Receive gap of the 802.16h TTD cycle.

Scenario 4: EQP

This is the implementation of Extended-Quiet-Period concept for the 802.16h system, as described in Clause 6.4.3.3 of [2]. The EQPduration (integer number of quiet .16 frames) and the EQPperiod (integer number of active .16 frames before going into quiet period again) will be varied to quantify their effect on the average throughput and delay of each network.

Scenario 5: LBT + EQP

This is a combination of Scenarios 3 and 4 where EQP is performed periodically as in Scenario 4 with LBT being applied to the "active" (non-quiet) frames of 802.16h system.

Scenario 6: EQP + Padding

This is a variation on the EQP concept of Scenario 4 where the active (non-quiet) 802.16h frames are fully populated by padding bytes to prevent 802.11y's transmission. Note that padding is applied to both DL and UL sub-frames of the 802.16 network.

Scenario 7: LBT + EQP + Padding

This is similar to Scenarios 5 except that any active, but partially occupied, 802.16h DL or UL sub-frame will be fully populated by padding bytes.

References

[1] P802.11-REVma/D8.0, Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications, (Draft Revision of IEEE Std 802.11), Sept. 2006.

[2] P. Piggin, C802.16h-06/125r1, "Consolidation of UCP – Uncoordinated Coexistence Protocol".