Coexistence Guidelines for LTE in Unlicensed Spectrum Studies

Version 1.0

Document Revision History

Version	Date	Remarks
1.0	Approved: Oct. 19, 2015 Released: Nov. 4, 2015	Initial release

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1 Introduction

1.1 Scope

This document establishes the Wi-Fi - LTE Coexistence guidelines for simulation, device study and analysis.

The contents of the document are determined by the Coexistence Task Group.

This document is written for anyone who wishes to evaluate the impact of LTE on Wi-Fi. Wi-Fi Alliance welcomes non-member contributions to this document, provided that the contribution does not require the use of another's intellectual property.

This first version of this working document covers several simple scenarios as a starting point for study. Later document versions will add more complex topologies and traffic loading. This document will be revised to reflect real-world performance.

In this document, the term "LTE" will be used to represent any LTE technology that operates in the unlicensed spectrum, including but not limited to LTE-U and LAA.

Wi-Fi Alliance considers that a deployed system transmitting in an unlicensed channel is operating fairly to Wi-Fi if the impact of the system on Wi-Fi users in the channel is no worse than the impact that would result from an additional Wi-Fi network introduced into the channel supporting the same traffic load as the system. A technology capable of being used in unlicensed channels is fair to Wi-Fi if its deployed implementations will always operate fairly as described above.

1.2 Purpose

The advent of LTE being used in unlicensed spectrum has brought many questions as to how Wi-Fi and LTE technologies will share the same spectrum. The results of many studies have been published; however each study focuses on a particular narrow aspect of the coexistence interaction, often times in very different scenarios.

This document seeks to provide a common basis upon which future Wi-Fi / LTE coexistence studies may be conducted and provides a strong foundation upon which to build an unlicensed LTE test plan. There are three important aspects which should be the basis of coexistence studies.

1. Identify the appropriate key performance indicators (KPIs) that characterize the performance of different types of traffic and specify how the KPIs should be measured and presented.
2. Specify the topologies of the Wi-Fi/LTE networks to be studied which includes the number of devices, their geographic spacing, and other physical characteristics of the setup.
3. Define the type and mix of data traffic that loads the network under study.

The purpose of this coexistence analysis is to determine whether an LTE network impacts a Wi-Fi network any more than a Wi-Fi network impacts another Wi-Fi network. Given the basis mentioned above this analysis can be conducted either through simulations or by experimentation with physical devices.

1.3 Acronyms and Definitions

This section lists the acronyms and definitions presented throughout this document. Table 1 gives the acronyms while Table 2 gives the definitions.

Table 1. Acronyms

Acronym	Definition
Ack	Acknowledgment
A-MSDU	Aggregated-MSDU
AP	Access Point

Avg	Average
BCC	Binary Convolutional Code
CCA	Clear Channel Assessment
CCA-ED	Clear Channel Assessment, Energy Detection
CCA-SD	Clear Channel Assessment, Signal Detect
CDF	Cumulative Distribution Function
Ch	Channel
CRC	Cyclic Redundancy Check
CTS	Clear to Send
DL	Down Link
ED	Energy Detection
EDCA	Enhanced Distributed Channel Access
eNB	Evolved Node B
FTP	File Transfer Protocol
GHz	Giga Hertz
GI	Guard Interval
LDPC	Low Density Parity Check
LTE	Long Term Evolution
m	meters
MAC	Medium Access
MCS	Modulation
MPDU	MAC Protocol Data Unit
ms	millisecond
MSDU	MAC Service Data Unit
NLOS	Non Line of Sight
OFDM	Orthogonal Frequency Division Modulation
PER	Packet Error Rate
PL	Path Loss
PPDU	PLCP Protocol Data Unit
PS	Power Save
QAM	Quadrature Amplitude Modulation
RTS	Ready To Send
Rx	Receiver
SNIR	Signal to Noise and Interference Ratio

STA	Station
TBTT	Target Beacon Transmit Time
TR	Transmitter/receiver
Tx	Transmitter
UE	User Equipment
UL	Up Link
UPT	User Perceived Throughput
VoIP	Voice over Internet Protocol

Table 2. Definitions

Term	Definition
LAA	3GPP LTE Licensed Assisted Access
LTE-U	LTE Unlicensed as per the LTE-U Forum
Wi-Fi	A trademark of Wi-Fi Alliance, used to refer to technology based on the IEEE 802.11 standards or Wi-Fi Alliance specifications

1.4 References

Knowledge of the references in this section is required for the understanding and implementation of this report. If a listing includes a date or a version identifier, only that specific version of the document is required. If the listing includes neither a date nor a version identifier, the latest version of the document is required.

[1] 3GPP_36889-031_Study-on-LAA

[2] 11-14-0980-10-00ax-simulation-scenarios

[3] 11-14-0571-08-00ax-evaluation-methodology

[4] Proposed Wi-Fi Control Plane Metrics for LAA Coexistence Simulation V2

[5] WMM (including WMM-Power Save and Admission Control) Specification

[6] LTE-U Forum, LTE-U SDL Coexistence Specifications V1.2: http://www.lteuforum.org/uploads/3/5/6/8/3568127/lte-u_forum_lte-u_sdl_coexistence_specifications_v1.2.pdf

[7] IEEE 802.11 11-14/571

[8] Voice-Enterprise Test Plan

2 Methodology and Criteria

There are two categories of Wi-Fi Coexistence studies.

- Wi-Fi Baseline, where the performance of one or more W-Fi networks operating on the same channel is measured.
- Wi-Fi and LTE Coexistence, where one or more Wi-Fi APs is replaced by an LTE device so that the impact of LTE on Wi-Fi performance can be assessed.

2.1 Setup

2.1.1 Wi-Fi Baseline Study Setup

The Wi-Fi Baseline study measures the effect one Wi-Fi network has on another Wi-Fi network. For the purposes of establishing the effects of LTE signals on Wi-Fi communications these Wi-Fi Baseline studies serve as the control set.

As shown in Figure 1, one AP is placed at position 1 and the other AP is placed at position 2. Each AP is connected to its own pool of STAs, and the number of STAs is varied from 1 to N. The studies should be conducted with APs from different manufacturers.

Each set of Wi-Fi STAs were located opposite their target AP. Both APs were connected to a Data Traffic Generator via a Gigabit Ethernet switch using Gigabit Ethernet cables.

Figure 1 depicts the Wi-Fi Baseline study setup.

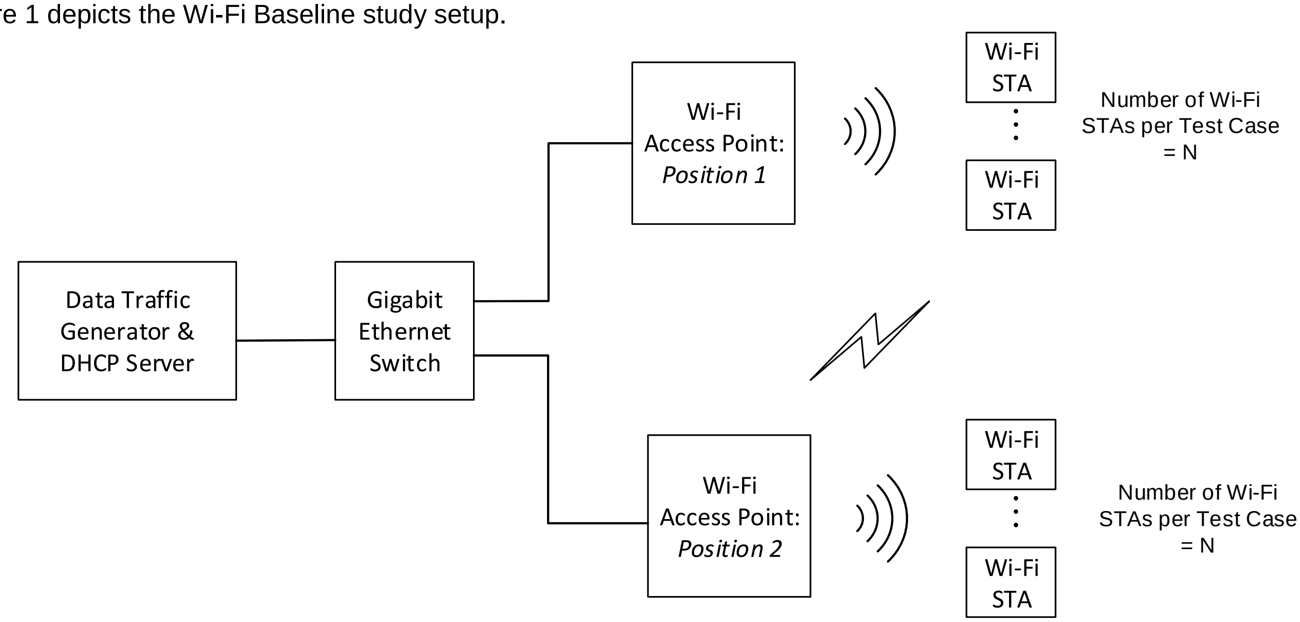

Figure 1. Wi-Fi Baseline Study Setup

2.1.2 Wi-Fi and LTE-DC Coexistence Study Setup

The Wi-Fi and LTE-DC Coexistence study setup is shown in Figure 2. This setup is similar to the Wi-Fi Baseline setup except that the AP and pool of STAs in position 2 is replaced with an LTE device and a pool of 1 to N LTE UEs.

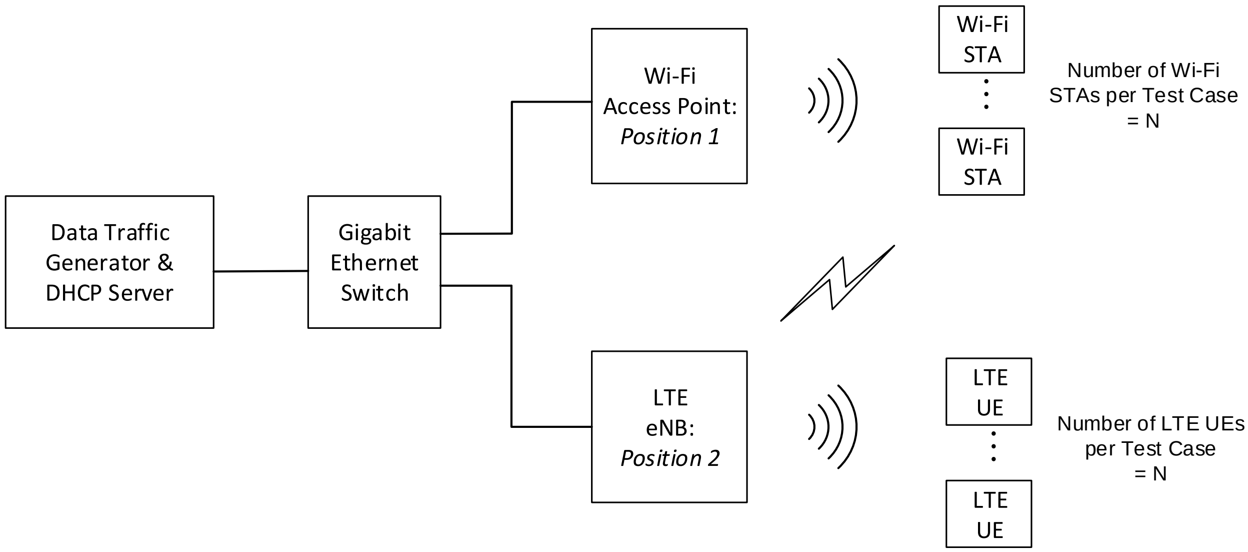

Figure 2. Wi-Fi and LTE Coexistence Study Setup

Because LTE test equipment was not available at the time of writing this document, the LTE transmissions shall be produced with a signal generator. If/when LTE equipment is available, the LTE studies shall be performed using actual equipment, noting the manufacturer, model and revision numbers. As implementations may vary considerably, studies must be repeated with each different equipment set available.

2.2 Study Criteria

2.2.1 Simulation and Device Study Goals

The simulations and device studies shall examine the results of wireless networks coexisting in the same physical space. These networks are referred to as the Wi-Fi network(s) and the LTE network(s) in this document.

Each simulation model and device study model will be executed first with both networks being Wi-Fi networks. Then the simulation will be repeated with a Wi-Fi network(s) and an LTE network(s). Therefore each model will describe the parameters for:

1. The Wi-Fi network(s)
2. The Wi-Fi network(s) and LTE network(s)

The results of each simulation and device study will be evaluated according to the criteria in section 0.

Simulations and device studies follow the same scenarios and traffic models outlined in this document but are pursued independently with standalone goals.

2.2.1.1 Simulation Goals

The simulation goals are:

1. To identify critical protocols and parameters that improve or deteriorate the Wi-Fi / LTE coexistence behavior.
2. To evaluate the impact on protocols and parameters in Wi-Fi and LTE on their coexistence behavior using the methodology to evaluate coexistence behavior as described in this section.

The simulation parameters for both Wi-Fi and LTE should be standards based. The Wi-Fi simulation parameters should be chosen based on the 802.11 standard and Wi-Fi Alliance certified behavior. The LTE simulation parameters should be based on 3GPP for LTE-LAA, and the parameters listed in Appendix A for LTE-U.

Examples of parameters to simulate are listed below.

Wi-Fi network parameters: CCA, EDCA parameters, TXOP limit, frame aggregation level, PHY parameters, etc.
LTE network parameters: LBT scheme, duty cycle parameters, PHY parameters, etc.

2.2.1.2 Device Study Goals

The device study goal is to characterize the impact of an LTE signal on a Wi-Fi network using certified devices in a controlled environment. The study results can then be compared to a baseline network consisting of only Wi-Fi devices.

2.2.2 Study Parameter Specifications

This section details the Wi-Fi study parameter specifications that shall be used for both simulations and device studies, unless explicitly described otherwise in the specific simulation/study scenario. Refer to Appendix A for the vendor specific LTE parameters.

2.2.2.1 Common Radio Parameters for all Simulation Scenarios

Each simulation scenario shall use the PHY, MAC and propagation parameters defined in this section unless separately specified in a particular scenario.

Table 3. PHY Parameters

Parameter	Description
Band	All BSSs at 5 GHz
BW	40 MHz BSS at 5 GHz, study both networks at position 2 on primary channel and on secondary channel. The network at position 2 may operate on primary 20 MHz channel, secondary 20 MHz channel or at the entire 40 MHz.
Data Preamble Type	11ac
STA TX Power	15 dBm per antenna (simulation, target for OTA study)
AP TX Power	20 dBm per antenna (simulation, target for OTA study)
AP Number of TX antennas	All APs with 2 antennas (simulation), 2 or 3 (OTA)
AP Number of RX antennas	All APs with 2 antennas (simulation), 2 or 3 (OTA)
STA Number of TX antennas	All STAs with 1 antennas
STA Number of RX antennas	All STAs with 1 antennas
AP antenna gain	+0 dBi
STA antenna gain	-2 dBi
Noise Figure, UE and Wi-Fi	7 dB
MCS	802.11ac MCS table with 256 QAM Phase 1: Single stream only Phase 3: Consider multi-streams
Rate adaptation	Simulation: Minstrel (https://www.nsnam.org/wiki/GSOC2009Minstrel) Calculate EWMA 10 times per second. Set ath_ewma_level to 25. OTA studies: use the client's native algorithms but gather histogram/CDF per section 3

Channel Coding	LDPC and BCC code For packet length PL, estimate the PERPL using PERPL = 1-(1-PERPL0)PL/PL0 In case of BCC, PL0 is 32 bytes for less than 400 bytes and 1458 bytes for other sizes In case of LDPC, PL0 is 1458 bytes for all packet sizes
CCA-SD	-82 dBm and preamble decoding
CCA-ED	-62 dBm
Detection	Energy detection and preamble detection. Refer to Appendix 4 of Evaluation Methodology [3] .
OFDM symbol length	4 µsec (long GI), 3.6 µsec (short GI)
Guard Interval	Short
Colliding packet reception	Strongest PPDU captured within capture window

Table 4. MAC Parameters

Parameter	Description
Access protocol parameters	EDCA with default parameters Per WMM Spec [5], Table 13 and Table 15.
Aggregation and TXOP Limit	Devices transmit AMPDUs containing 32 MPDUs each Use TXOP Limits per Access Category (per WMM Spec [5]), where given. Where TXOP Limit is “0”, use 5.632 ms limit. Recommendation is to perform at least one simulation study (Simple Model scenario) with 15 ms TXOP limit, and report the results for further analysis.
Max number of retries	For simulation: 10. For device studies, use the default setting for the device.
RTS/CTS Threshold	RTS/CTS used for all AMPDU transmissions

Table 5. Propagation Parameters

Parameter	Description
Distance-based Path Loss	Computed on the basis of 3-D distance, with a minimum 3-D distance of 1 meter. Formulas shall be evaluated with carrier frequency equal to 5 GHz for channels within the 5 GHz band.
Path Loss Model	PL(d) = 40.05 + 20*log10(fc/2.4) + 20*log10(min(d,dBP)) + (d>dBP) * 35*log10(d/10) + 7*W Where: d = max(3D-distance [m], 1) fc = frequency in GHz W = number of office walls traversed in x-direction plus number of office walls traversed in y-direction dBP = 5 m typical office, NLOS, up to 30 ms delay spread dBP = 10 m typical large open space, indoor outdoor, NLOS 50 ns delay spread dBP = 20 m large open space 100 ns delay spread dBP = 30 m large open space, 150 ns delay spread
Fading Model	TGac channel model D NLOS for all the links.
Shadowing	Log-normal with 5 dB standard deviation, iid across all links

2.2.3 Desired Criteria

The following criteria indicate the desired performance of coexisting systems for both simulations and device studies. The pass/fail test criteria in a coexistence test plan is for future study and is not captured in this release of the document.

In general, the desired criteria is that the introduction of a co-channel LTE network will not impact an existing Wi-Fi networks performance any more that introduction of a similar co-channel Wi-Fi network, as illustrated in Table 6.

Table 6. Desired Performance Criteria

Criteria	Wi-Fi Network Performance Compared to Wi-Fi / LTE Coexistence Performance
Data Traffic	
Throughput	Wi-Fi / Wi-Fi ≥ Wi-Fi / LTE
Packet Loss	Wi-Fi / Wi-Fi ≤ Wi-Fi / LTE
Frame Re-transmission Rate	Wi-Fi / Wi-Fi ≤ Wi-Fi / LTE
Beacons and Power Save Signaling Frames	
Packet Loss	Wi-Fi / Wi-Fi ≤ Wi-Fi / LTE
Jitter	Wi-Fi / Wi-Fi ≤ Wi-Fi / LTE
VoIP and Read-Time Video[1]	
Latency	Wi-Fi / Wi-Fi ≤ Wi-Fi / LTE
Jitter	Wi-Fi / Wi-Fi ≤ Wi-Fi / LTE
Packet Loss	Wi-Fi / Wi-Fi ≤ Wi-Fi / LTE
Frame Re-transmission Rate	Wi-Fi / Wi-Fi ≤ Wi-Fi / LTE
Notes: 1. While measuring the VoIP criteria, do not exceed the thresholds that would cause an outage as defined in section 3.4.	

2.3 Data Analysis

The simulation or device studies shall be repeated for X iterations. The CDF for each of the performance metric defined in section 3 shall be obtained for each STA and for all of the Wi-Fi STAs of the non-replaced Wi-Fi networks. For example, assuming the total number of STAs of the non-replaced Wi-Fi networks is m and with X iterations, the CDF of each performance metric shall be obtained using mX values for each metric.

When mixed traffic is considered, the CDF shall be obtained for each performance metric, separately for each traffic type. The average, the 5th percentile, median and 95th percentile values for each performance metric shall be calculated. For VoIP traffic, the 98th percentile of latency shall also be recorded.

The Wi-Fi networks shall then be replaced with LTE networks. The CDF and statistics of the performance metrics in Wi-Fi networks shall then be obtained using the same procedure as above.

Since the LTE-U network only consists of downlink (DL) traffic, the Wi-Fi network traffic shall also only consist of DL. The Wi-Fi network, however, may have both UL and DL traffic.

The data and results analysis shall be captured in separate document(s).

3 Traffic Models and their Performance Metrics

3.1 Full Buffer Model

3.1.1 Traffic Description

In the Full Buffer model, data is always available to send. The recommended MSDU size is 1500 bytes.

3.1.2 Throughput Metric

Throughput is measured as the total data bytes delivered during the interval divided by the interval period. The interval period is recommended to be at least 500ms, or at least as long as one LTE on/off cycle.

Throughput shall be measured at regular intervals for both uplink and downlink Wi-Fi traffic.

Calculate the CDF, average, and the fifth percentile for each device as well as the overall average for all devices.

3.1.3 Packet Loss Metric

A lost packet is defined as a packet that entered the source for transmission but was never received by the destination. Lost packets are those which exceeded the retry threshold (as specified in Table 3). The packet loss metric is calculated as a percentage of lost packets to the total packets attempted.

Packet loss shall be measured at the top of the MAC layer for simulations, and at the MAC layer or above for device studies.

3.1.4 Frame Re-transmission Rate Metric

The retransmission rate is the total number of times a frame is sent after the first transmission attempt. A frame could be resent due to failure to successfully receive the frame transmission, or failure to correctly receive the (layer 2) ACK of the transmission.

The retransmission rate is the percentage ratio of retransmissions to initial frame attempts. The retransmission rate may exceed 100%.

Retransmission rate shall be measured at the bottom of the MAC layer for simulations and measured using a sniffer trace for device studies. Note that measuring retransmission based on a sniffer trace represents a lower value than that can be measured using simulation due to packet losses in the sniffer. The measurement may be made more reliable by cabling up the sniffer.

3.2 File Transfer Model

3.2.1 Traffic Description

The traffic for the File Transfer model is specified in IEEE 802.11 11-14/571 [7] .

3.2.2 User Perceived Throughput (UPT) Metric

For the File Transfer model, the user perceived throughput is measured for each file transferred, as the total data bytes (size of the file) divided by the file transfer duration. The file transfer duration is the time from when the file arrives at the entry point (the transmitting STA or LTE device) until the end of the last successful transmission and delivery of the file contents at the receiver.

Throughput shall be measured for both uplink and downlink Wi-Fi traffic.

Calculate the CDF, average, and fifth percentile for each device as well as the overall average for all devices.

3.2.3 Packet Loss Metric

A lost packet is defined as a packet that entered the source for transmission but was never received by the destination. Lost packets are those which exceeded the retry threshold (as specified in Table 3). The packet loss metric is calculated as a percentage of lost packets to the total packets attempted.

Packet loss shall be measured at the top of the MAC layer for simulations, and at the MAC layer or above for device studies.

3.2.4 Frame Retransmission Rate Metric

The retransmission rate is the total number of times a frame is sent after the first transmission attempt. A frame is resent due to failure to successfully receive the frame transmission, or failure to correctly receive the (layer 2) ACK of the transmission. The retransmission rate is the percentage ratio of retransmissions to initial frame attempts. Note that the rate may exceed 100%.

Retransmission rate should be measured at the bottom of the MAC layer for simulations and measured using a sniffer trace for device studies.

3.3 Web Browsing Model

3.3.1 Traffic Description

The traffic for the Web Browsing model is specified in IEEE 802.11 11-14/571 [7] .

3.3.2 User Perceived Throughput (UPT) Metric

For the Web Browsing model, the user perceived throughput is measured for each file transferred, as the total data bytes (size of the file) divided by the file transfer duration. The file transfer duration is the time from when the file arrives at the entry point (the transmitting STA or LTE device) until the end of the last successful transmission and delivery of the file contents on the receiver.

Throughput shall be measured for both uplink and downlink Wi-Fi traffic.

Calculate the CDF, average, and fifth percentile for each device as well as the overall average for all devices.

3.3.3 Packet Loss Metric

A lost packet is defined as a packet that entered the source for transmission but was never received by the destination. Lost packets are those which exceeded the retry threshold (as specified in Table 3). The packet loss metric is calculated as a percentage of lost packets to the total packets attempted.

Packet loss shall be measured at the top of the MAC layer for simulations, and at the MAC layer or above for device studies.

3.3.4 Frame Retransmission Rate Metric

The retransmission rate is the total number of times a frame is sent after the first transmission attempt. A frame is resent due to failure to successfully receive the frame transmission, or failure to correctly receive the (layer 2) ACK of the transmission. The retransmission rate is the percentage ratio of retransmissions to initial frame attempts. Note that the rate may exceed 100%.

Retransmission rate should be measured at the bottom of the MAC layer for simulations and measured using a sniffer trace for device studies.

3.4 VoIP Model

3.4.1 Traffic Description

The VoIP traffic model is based on the G.729A standard with the following characteristics.

- Data rate =24 kbps
- Packet inter-arrival time = 20 ms
- Packet size = 60 bytes (payload plus IP header overhead)
- QoS uses AC_VO and AC_BE, as described in section 4.3.1
- Voice activity is assumed to be 100%
- Statistics are independently reported in each direction
- No associated control plane traffic is modelled

3.4.2 Latency Metric

Latency is defined as the time from when a packet arrives at the entry point on the source until it is successfully delivered at the exit point on the destination. Latency is measured at the top of the MAC for simulation, but can be measured higher in the network stack for device studies.

Latency shall be calculated using a per-device CDF for UL and DL traffic independently.

If the latency for either the UL or DL 98th percentile exceeds 50 ms, the device is considered in outage. The total number of VoIP devices considered to be in outage shall be reported.

Due to practical limitations, it may only be possible to measure packet-by-packet latency for a few seconds. In such cases, the latency metric shall be measured for the longest duration possible, at a time following the mid-point of the longer test run which gives the test environment time to settle. It is not acceptable to use a “smoothed” or averaged data set in place of packet-by-packet measurements.

3.4.3 Packet Loss Metric

A lost packet is defined as a packet that entered the source for transmission but was never received by the destination. Lost packets are those which exceeded the retry threshold (as specified in Table 3). The packet loss metric is calculated as a percentage of lost packets to the total packets attempted.

Packet loss shall be measured at the top of the MAC layer for simulations, and at the MAC layer or above for device studies.

A VoIP outage shall be reported if more than 3 consecutive lost packets or more than 1% lost packets is exceeded.

3.4.4 Jitter Metric

Jitter metrics shall be reported independently for UL and DL traffic. Refer to the Voice-Enterprise Test Plan [8] , Appendix E for the definition and suggested calculation of jitter.

Jitter shall be measured at the top of the MAC layer for simulations, and at the MAC layer or above for device studies.

Calculate two Jitter CDFs:

1. CDF for all of the STAs/UEs including those in outage
2. CDF for the clients that are not in outage

Due to practical limitations, it may only be possible to measure packet-by-packet jitter for a few seconds. In such cases, the jitter metric shall be measured for the longest duration possible, at a time following the mid-point of the longer test run which gives the test environment time to settle. It is not acceptable to use a "smoothed" or averaged data set in place of packet-by-packet measurements

3.5 Real-time Video Model

The details of the Real-Time Video model will be specified in Phase 3.

3.6 Beacon Loss, Jitter and Deferral Metrics

The beacon loss, beacon jitter, and deferral are defined in Proposed Wi-Fi Control Plane Metrics for LAA Coexistence Simulation V2 [4]. Table 7 summarizes the critical metrics and their preferred measurement methods.

Table 7. Beacon Metrics

Metric Description	Measurement Method – Deferral Rate	Measurement Method – Block Rate
Beacon Tx deferral or blocking at AP at TBTT due to ED exceeded	CDF of deferral periods for transmitted beacons	% of beacons that cannot be transmitted (dropped)
Beacon Rx blocking at STA due to SINR compression when both networks are transmitting at the same time (e.g. both below one another's ED threshold, or due to timing and starting a transmission without regard to ED)	N/A	% of beacons that cannot be received (CRC error)

3.7 Power Save Signaling Loss, Jitter and Deferral Metrics

The details of the Power Save Signaling model will be specified in Phase 3.

3.8 Rate Adaptation Metric

For practical reasons, device studies should use the device's native/built-in rate adaptation schemes. Rather than requiring any particular algorithm, a sniffer trace and analytics should be used to create a histogram and CDF of the actual MCS rate used over the study period.

4 Simulation and Study Scenarios

4.1 Introduction

The descriptions of the simulation and study scenarios in this section refer to the setup diagrams shown in Figure 1 and Figure 2.

In general the desired criteria is that the introduction of a co-channel LTE network will not impact an existing Wi-Fi networks performance any more that introduction of a similar co-channel Wi-Fi network.

For each scenario, the performance of the Wi-Fi network in position 1 is evaluated when operated in the presence of a co-channel Wi-Fi or LTE network in position 2 using the performance metrics specified in section 3. The LTE or Wi-Fi network in position 2 shall each have the same traffic characteristics, number of STAs/UEs and network topology as one-another.

Both full-buffer traffic and non-full-buffer traffic should be considered for all scenarios.

For each simulation scenario, simulate LTE transmissions as channel usage matching the range of timing parameters listed for each set of parameters in Appendix A. Each parameter set needs to be simulated independently.

For each scenario, simulate LTE transmissions with a signal generator matching the range of timing parameters listed for each vendor in Appendix A. The spectrum of the signal shall meet the signal bandwidth specified in section 2.2.2.1 and power level specified for each scenario. Each vendor shall be studied independently.

Each simulation/study scenario specifies the applicable traffic profiles.

4.2 Simple Model with Single STAs

4.2.1 Single STAs above the Energy Detection Clear Channel Assessment

This scenario consists of two networks, each with one STA/device, as shown in Figure 1. The environment must be configured to ensure that:

- All devices receive signals from each other above the CCA-ED
- The SNR is 25 dB or higher
- The SINR is effectively 0 dB or lower.

For device studies, ensure the APs, eNBs, STAs, and UEs are from different vendors/chipsets. Comparing results from different combinations of vendors for both the Wi-Fi and LTE networks shall provide enough variability in the results to gain confidence that the results are representative.

Scenarios:
1 STAs per AP/eNB

1. Full buffer traffic model run on both STAs to form the baseline
2. VoIP traffic model with AC_BE on both STAs
3. File Transfer traffic model on both STAs
4. Web Browsing traffic model on both STAs

Procedure:
The procedure below applies to all traffic model study cases unless a specific study model is noted.

1. For the full-buffer traffic model study, verify that no more than 50% duty cycle is obtained by the LTE aggressor in device studies, as per the LTE coexistence requirements.
2. Measure the impact of different LTE CSAT cycle times (i.e., sum of ON time and OFF time in a single cycle) on the Wi-Fi network using the performance metrics specified for each traffic model. Note that the CSAT cycle ON percentage may also vary.
3. Measure the impact of realistic rate adaptation (MCS selection) algorithms on the Wi-Fi network using the performance metrics specified for each traffic model.

Note that some rate adaptation algorithms may be sensitive to the last frame being lost during the LTE ON to LTE OFF transition.
4. For the VoIP traffic model, evaluate if the LTE coexistence (e.g., puncturing of LTE-U ON periods) is effective.
5. Evaluate if the LTE coexistence (e.g., puncturing of LTE ON periods) protects beacons by measuring their loss, delay and jitter.

4.2.2 Single STAs below the Energy Detection Clear Channel Assessment

This scenario shall be defined in Phase 3.

4.3 Simple Model with Multiple STAs

4.3.1 Multiple STAs above the Energy Detection Clear Channel Assessment

This scenario consists of two networks, each with multiple STAs/devices, as shown in Figure 1. The environment must be configured to ensure that:

- All devices receive signals from each other above the CCA-ED
- The SNR is 25 dB or higher
- The SINR is effectively 0 dB or lower.

For device studies, ensure the APs, eNBs, STAs, and UEs are from different vendors/chipsets. Comparing results from different combinations of vendors for both the Wi-Fi and LTE networks shall provide enough variability in the results to gain confidence that the results are representative.

Scenarios:
10 STAs per AP/eNB

1. Full buffer traffic model on all STAs used as the baseline
2. VoIP traffic model with 2 STAs using AC_VO, 2 STAs using AC_BE
3. File Transfer traffic model using 3 STAs
4. Web Browsing traffic model using 3 STAs

Procedure:
The procedure below applies to all traffic model study cases unless a specific study model is noted.

1. For the Full Buffer traffic model, verify that 50% duty cycle is obtained during device studies, or that 50% throughput is obtained in simulation with 50% duty cycle, as per the LTE coexistence requirements.
2. Measure the impact of different LTE CSAT cycle times (i.e., sum of ON time and OFF time in a single cycle) on the Wi-Fi network using the performance metrics specified for each traffic model. Note that the CSAT cycle ON percentage may also vary.
3. Measure the impact of realistic rate adaptation algorithms on the Wi-Fi network using the performance metrics specified for each traffic model. The recommended rate adaptation algorithms are MCS and Minstrel history-based. Note that some rate adaptation algorithms may be sensitive to the last frame being lost during the LTE ON to LTE OFF transition.
4. Measure the impact of different STA density cases for the performance metrics specified for each traffic model.
5. For the VoIP traffic model, evaluate if the LTE coexistence (e.g., puncturing of LTE-U ON periods) is effective.
6. Evaluate if the LTE coexistence (e.g., puncturing of LTE ON periods) protects beacons by measuring their loss, delay and jitter.
7. Vary the setup for the Wi-Fi network and then measure if the LTE parameters react fast enough to the changes in the Wi-Fi network. For example, one or more STAs could be added to the Wi-Fi network or the traffic load for the Wi-Fi network could be increased. (Applies to Phase 3 only)

4.3.2 Multiple STAs below the Energy Detection Clear Channel Assessment

This model shall be defined in Phase 3.

4.4 Dense Model

The Dense Model shall be defined in Phase 3.

4.5 Dense Model Enterprise Office

The Dense Model Enterprise Office shall be defined in Phase 3.

4.6 Multi-operator Model

The Multi-Operator Model shall be defined in Phase 3.

Appendix A LTE-U Timing Parameters

Table 8. Vendor A LTE-U Timing Parameters

Parameter	Values
Cycle time (Ton+Toff) Primary Channel	If co-located on a primary WLAN channel: 80ms
Cycle time (Ton+Toff) Secondary Channel	If co-located on a secondary WLAN channel: Above CCA_ED: 80ms Below CCA_ED: 160ms
Duty cycle (Ton / (Ton+Toff)) Primary Channel	Duty cycle used depends on the number of active Wi-Fi data transmitters (AP+STA). Exact CSAT duty cycle quantized to the highest duty cycle in the range: 1/16 * [1:8] x 100% lower than fair share (=1/N) where N is the number of Wi-Fi transmitters. Duty cycles <50% achieved through CSAT cycle skipping mechanism (see below): 1/16: {40 ON-600 OFF}, 640ms master cycle 2/16: {40 ON-40 OFF} x 1 times followed by {40 ON-520 OFF}, 640ms master cycle 3/16: {40 ON-40 OFF} x 2 times followed by {40 ON-440 OFF}, 640ms master cycle 4/16: {40 ON-40 OFF} x 4 times followed by {320 OFF}, 640ms master cycle 5/16: {40 ON-40 OFF} x 4 times followed by {40 ON-280 OFF}, 640ms master cycle 6/16: {40 ON-40 OFF} x 6 times followed by {160 OFF}, 640ms master cycle 7/16: {40 ON-40 OFF} x 6 times followed by {40 ON-120 OFF}, 640ms master cycle 8/16: {40 ON-40 OFF} x 8 times, 640ms master cycle CSAT duty-cycle is capped at 50% when operating on the primary channel.
Duty cycle (Ton / (Ton+Toff)) Secondary Channel	The minimum on-time is determined as per the procedure for the primary channel (above). The maximum on-time is capped at 87.5% and is a function of WLAN activity on the channel. Complete RF off during Toff.
Puncturing during Ton	2ms every 20ms, 1ms every 40ms – complete RF off (per “second version”) Both methods shall be studied.

Table 9 lists the maximum LTE-U timing parameters allowed, per the LTE-U Forum specifications v1.2 [6], clauses 5.1, 6.2.1, 6.2.2 and 6.2.3.

Table 9. Maximum LTE-U Timing Parameters Allowed

Parameter	**Values**
Cycle time (Ton+Toff)	LTE-U cycle time should be studied at two extremes (min and max): 80ms and 400ms.
Duty cycle (Ton / (Ton+Toff))	LTE on period duty cycle is 50% on, 50% off in the presence of 1 Wi-Fi coexisting system. Duty cycle is 33% on, 67% off in the presence of two Wi-Fi coexisting systems.
Puncturing during Ton	During LTE on portion of duty cycle, LTE is in full transmission for 50ms periods, followed by a 1 ms ABS period, and repeat. The waveform of the ABS signal is as follows: ABS subframe contains CRS signals. In time, CRS occupies OFDM symbols 0,4,7,11 out of the 14 OFDM symbols. In frequency, CRS can be considered wideband and occupying the entire 20 MHz for the OFDM symbol duration (~71.3µs)
LTE off period	During LTE off portion of duty cycle, LTE transmission is stopped, except for Rel-12 discovery signals, which continue. The waveform of such signals is as follows: For purposes of this evaluation, the duration of DRS can be considered to be 1ms in time and wideband in frequency (20 MHz). The periodicity of the DRS signal is not defined. As a typical example would be 1 ms signal every 40ms when the cell is OFF.