Texas Instruments
Technical Specification
for Soft Gemini 1.0
WLAN/Bluetooth Coexistence Enhancement

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1. Introduction

1.1 Technical Summary

1.1.1 Solution Overview

This enhancement is a software-only coexistence mechanism to keep the co-located WLAN and Bluetooth radios from interfering with each other, as both occupy the 2.4GHz band. TI has implemented this enhancement such that the algorithm resides completely in WLAN firmware running on the embedded CPU of the TNETW1100B MAC/BBP.

Using a simple 3-pin interface, as shown in **Figure 1**, the WLAN is able to control both it's own transmissions as well as the Bluetooth transmissions.

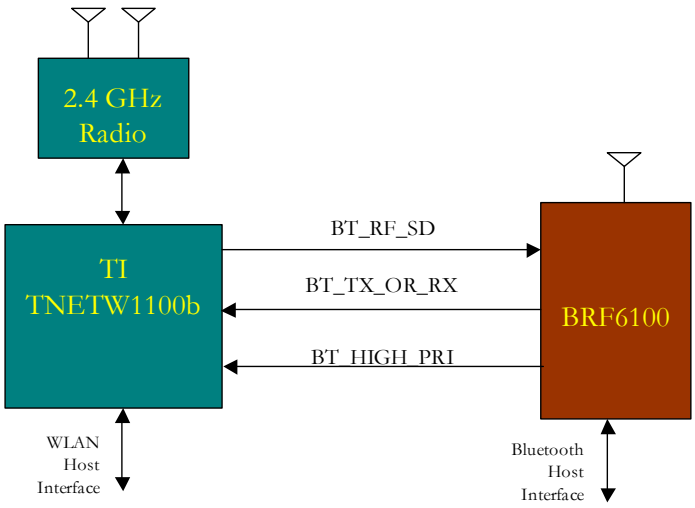

Figure 1: Soft Gemini Architecture

1.1.2 BT-Data / WLAN-Data Scenario

In Data-only mode (WLAN-Data and BT-Data), Soft Gemini employs a Time Division Multiplexing (TDM) algorithm on a even priority basis. This means that the throughput of both technologies will be effectively reduced, but the ability to communicate will be protected.

1.1.3 BT-Voice / WLAN-Data Scenario

In Bluetooth-Voice mode, this algorithm treats the Bluetooth voice signal as a no-compromise feature given the non-retransmitting, time-critical nature of HV3 packets. The algorithm attempts to insert WLAN packets in between the “gaps”, as shown in **Figure 2**, of the Bluetooth HV-3 packets to allow a limited, but maintained WLAN throughput.

Long TCP packets (in the order of 1500 bytes), can fit into these "gaps" between HV-3 packets only if a rate of 11Mbps (or higher) is used. This is why the STA uses a fixed rate of 11Mbps in coexistence mode. On the other hand, if an Access Point initiates rate fallback due to a non-response from the WLAN (which is self-blocked to protect the HV-3 signal) then the AP will often enforce a rate-fallback mechanism down to lower rate / greater range modes (1, 2, 5.5Mbps). The net effect of this is that the WLAN packet will now be too long to fit in the HV-3 “gaps”, and WLAN throughput will no longer be possible. It should be noted that even in the event of rate-fallback, testing has shown that the WLAN connection is maintained so the user will not need to re-authenticate to the network, though this ability could conceivably vary based on the Access Point itself.

Soft Gemini does not support HV2 or HV1 packets for Bluetooth-Voice, and enforces high-rate mode for WLAN upstream at all times for the maximum airtime efficiency, as shown in **Figure 2**.

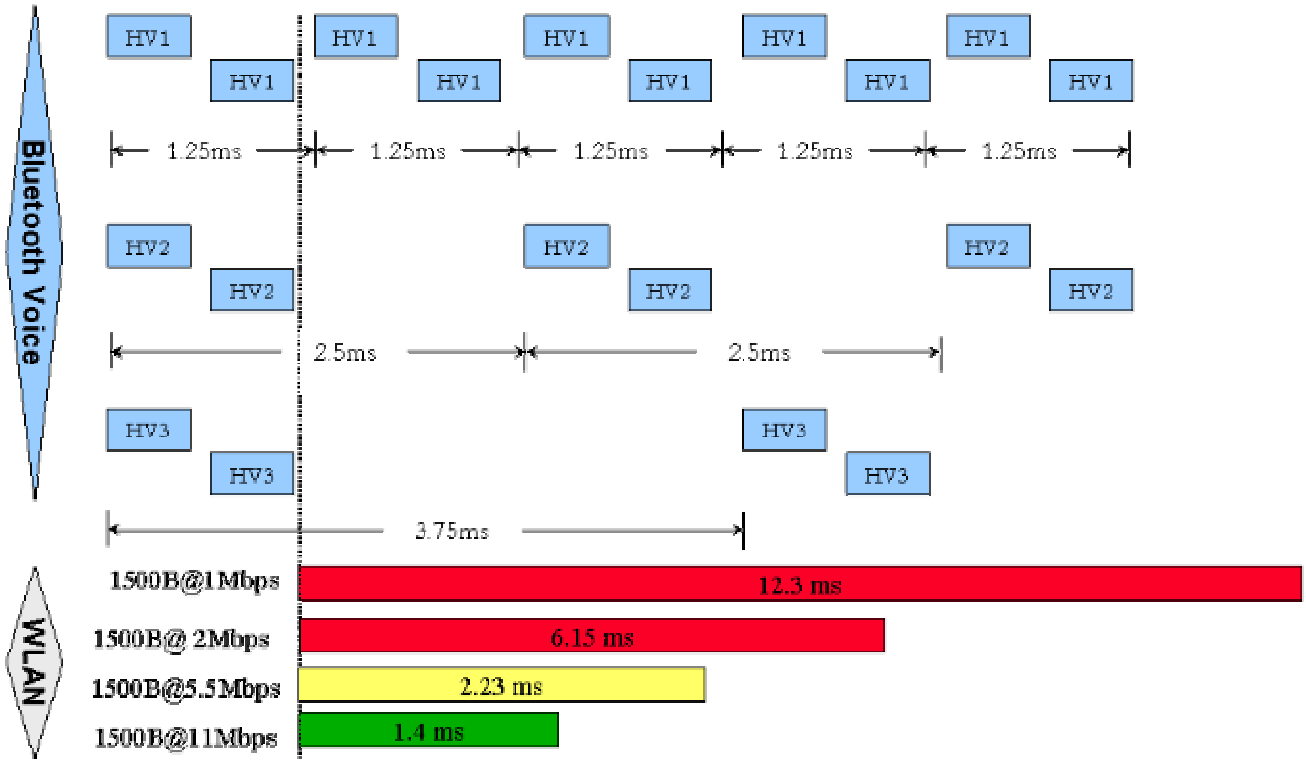

Figure 2: Bluetooth and WLAN packet length

1.2 Product Description

Soft Gemini enhancement resides completely in the WLAN firmware running on the embedded CPU of the TNETW1100B MAC/BBP. Partitioning of this solution is depicted in **Figure 3**.

In order to enable the driver to configure the Soft Gemini enhancement, dedicated API's are defined between the WLAN driver running on the host CPU, and the WLAN firmware running on the embedded CPU of the TNETW1100B MAC/BBP. These API's are static and shall be configured upon firmware initialization.

As stated above, Soft Gemini enhancement uses a simple 3-pin interface, as shown in **Figure 1**, between the WLAN and the BT modules. From a H/W design standpoint it is important to make sure that these 3 lines are pulled down with pull-down resistors. This provides definite zero logic states when one of the devices is turned off.

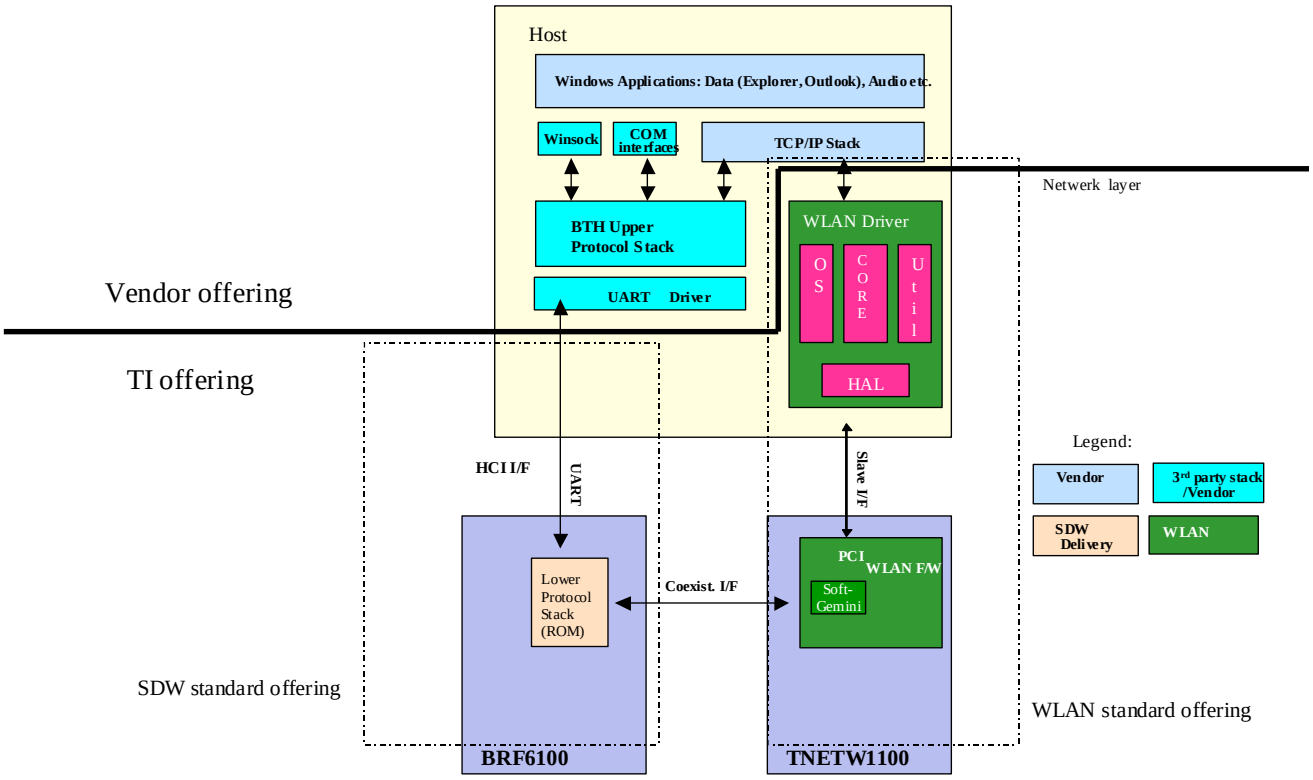

Figure 3: Solution Architecture

2. Product Description

2.1 Bluetooth Applications/Profiles Support

The following table gives the major BT applications and profiles that are supported by Soft Gemini1.0.

Application (Profile)	Supported in SG1.0	Comments
Voice (SCO-HV3)	Yes	See Section 4.2 for additional details
Various File/Data Transfer (OBEX, Serial port, DUN, Basic print, HCRP, PAN, BIP)	Yes	
Audio/Video streaming (AV)	Yes	Note issues may arise since data rate is reduced and packet latency increases due to coexistence mechanism. Will not be tested.
Video Conferencing (VC)	Yes	Note issues may arise since data rate is reduced and packet latency increases due to coexistence mechanism. Will not be tested.
Mouse, Keyboard, Pointing device, game controller (HID)	Yes	Supported up to Sniff mode limitations. See section 4.4 below.

2.2 Bluetooth Lower Level features support

The following table gives the BT features that are supported by Soft Gemini1.0.

Feature	Supported in SG1.0	Comments
SCO-HV3	Yes	See Section 4.2 for additional details
SCO-HV2	No	
SCO-HV1	No	Takes 100% of available bandwidth so coexistence is irrelevant
Sniff Mode	Yes	
Park Mode	No	This is a seldom-used feature. Can be replaced by Sniff mode.
Hold Mode	No	This is a seldom-used feature.
Master/Slave Switch	Yes	
Inquiry	Yes	
Inquiry scan	Yes	
Page	Yes	
Page scan	Yes	
ACL-DM1, DH1	Yes	
ACL-DM3, DH3	Yes	
ACL-DM5, DH5	Yes	

2.3 Bluetooth Connection build-up support

Soft Gemini supports BT connection build-up, and ensures no noticeable degradation in BT connection build-up time.

2.4 "Soft Gemini" Limitations

- In order to support BT Scan modes for fast BT connection buildup, WLAN data rate is limited during BT connection buildup period.
- In order to ensure no degradation in BT voice quality, WLAN data rate is limited during BT voice connection periods. In some cases while the BT voice connection is active, the device can experience a temporary loss of WLAN throughput Testing has shown that even in the case of a loss of throughput, the WLAN connection is still maintained. This could conceivably vary depending on the AP.
- In the BT-Voice scenario, WLAN is limited to 11Mbps to avoid rate fallback and longer packets (see **Figure 2**). This could limit the range of the device in this scenario, depending on the environment.

2.5 "Soft Gemini" Scope

"Soft Gemini" does not attempt to address the following:

- Doesn't handle other stations interference.
- Doesn't use BT's Adaptive Frequency Hopping.
- Introduce latency in WLAN data and BT data (configured through API by driver).
- Doesn't address RF/HW design issues (such as card layout problems).

2.6 "Soft Gemini" Operation modes

- Soft Gemini can be turned on/off.
    - On the WLAN side this is done via registry settings.
    - On the BT side, Soft Gemini needs to be initialised by the protocol stack.
- Notice that turning on Soft Gemini may require re-association to the WLAN AP.

3. Baseline Performance

This section defines a baseline for the WLAN and Bluetooth performance in the scenario outlined below. Note that this baseline assumes WLAN or Bluetooth are operating isolated from each other.

3.1 Data rate

In the following tables we give the baseline performance details of:

- WLAN Normal Data
- WLAN ELP Data
- BT Data

For the following case:

- Cisco AP 1200
- 1 WLAN STA in the BSS
- Distance from the AP: 4m
- BT Up is defined as transmitting DH5 packets and receiving DH1 packets
- BT Down is defined as receiving DH5 packets and transmitting DH1 packets
- BT Up+Down is defined as transmitting DH5 packets and receiving DH5 packets

3.1.1 WLAN-Normal-Data Baseline Performance

Test Scenario	Data Rate (Kbps)	
WLAN	Upstream	Downstream
Up	2636	N/A
Down	N/A	4082
Up+Down	2171	710

3.1.2 WLAN ELP-Data Baseline Performance

Test Scenario	Data Rate (Kbps)	
WLAN	Up	Down
Up	1487	N/A
Down	N/A	2805
Up+Down	1230	1210

3.1.3 BT-Data Baseline Performance

Test Scenario	Data Rate (Kbps)	
BT	Up	Down
Up	723.2	N/A
Down	N/A	723.2
Up+Down	433.9	433.9

3.2 Bluetooth connection build-up time

In the following table we give the baseline performance details of Bluetooth connection buildup time.
This is given for the following case:

- Distance between BT devices: 0.5m
- No WLAN interference

Percentage	**80%**	**90%**	**95%**
Connection buildup time [sec]	2.2	2.5	2.7

4. "Soft Gemini" Product Performance Specification

Note: This specification is based on theoretical analysis as well as thorough testing of Soft Gemini 1.0 in a wide range of scenarios. Still, different implementation specific aspects that are outside the scope of the product (such as WLAN Access point implementations) may have effect on the performance of this product in some scenarios.

4.1 Data rate specification in BT Data mode

In the following two tables we give the Soft Gemini product specifications for the cases of:

- BT Data + WLAN Normal Data
- BT Data + WLAN ELP Data

Data on WLAN and BT is given as percentage (%) of the baseline performance of each technology alone.

Note for reference that the baseline performance of WLAN for one scenario is given in **Section 3**. Also note for reference that the performance without coexistence is given in Appendix A (Section 5). Reference on the BT performance can be found in [1].

Refer to the test results for characterization of performance with each AP that was tested. Notice that AP rate fallback is dependant on:

- AP type
- Distance between BT/WLAN combo device and AP
- Isolation between WLAN and BT antennas

Also notice the following:

- The specification is applicable for distances of 2-25m between WLAN+BT combo module and the WLAN-AP.
- BT Idle is defined as standby state with inquiry scan, page scan (with default values).
- BT connected is defined as regular QoS (POLL, NULL).
- WLAN Up+Down performance numbers are averaged on the total Up+Down rate. Notice possible variation of the distribution between the two directions.

4.1.1 Bluetooth-Data / WLAN-Normal-Data scenario

Note that these numbers represent a percentage of baseline throughput performance. For example, a 4Mbps baseline would still yield a 400kbps throughput in the worst case (10%) scenario below. These percentages are not an indication of any reduction in signal strength quality.

For each scenario, two performance numbers are given for WLAN. The first is for the case where the AP does not initiate rate fallback. The number in parenthesis is for the case where the AP does initiate rate fallback independently.

Test Scenario		BT Throughput *(against baseline)*		WLAN Throughput *(against baseline)*	
BT	WLAN	Up	Down	Up	Down
Idle	Up	N/A	N/A	90%	N/A
Idle	Down	N/A	N/A	N/A	90%
Idle	Up+Down	N/A	N/A	90%	90%
Connected	Up	N/A	N/A	45% (30%)	N/A
Connected	Down	N/A	N/A	N/A	45% (10%)
Connected	Up+Down	N/A	N/A	45% (20%)	45% (20%)
Up	Idle	90%	N/A	N/A	N/A
Up	Up	40%	N/A	45% (30%)	N/A
Up	Down	35%[1]	N/A	N/A	45% (10%)

[1] Some performance degradation due to non-collocated interference

Up	Up+Down	35%[2]	N/A	45% (20%)	45% (20%)
Down	Idle	N/A	90%	N/A	N/A
Down	Up	N/A	40%	45% (30%)	N/A
Down	Down	N/A	15%[3]	N/A	45% (10%)
Down	Up+Down	N/A	15%[4]	45% (20%)	45% (20%)
Up+Down	Idle	90%	90%	N/A	N/A
Up+Down	Up	30%[5]	30%	45% (30%)	N/A
Up+Down	Down	30%[6]	15%[7]	N/A	45% (10%)
Up+Down	Up+Down	30%[8]	15%[9]	45% (20%)	45% (20%)

4.1.2 Bluetooth-Data / WLAN-ELP™ Data scenario

Note that these numbers represent a percentage of baseline throughput performance. For example, a 4Mbps baseline would still yield a 400kbps throughput in the worst case (10%) scenario below. These percentages are not an indication of any reduction in signal strength quality.

Relative performance with ELP active is on par or better than without ELP (3.1.1) due to TI's Dynamic-ELP™ enhancement and some ELP™-specific coexistence enhancements.

For each scenario, two performance numbers are given for WLAN. The first is for the case where the AP does not initiate rate fallback. The number in parenthesis is for the case where the AP does initiate rate fallback independently.

Test Scenario		BT Throughput *(against baseline)*		WLAN Throughput *(against baseline)*	
BT	WLAN	Up	Down	Up	Down
Idle	Up	N/A	N/A	90%	N/A
Idle	Down	N/A	N/A	N/A	90%
Idle	Up+Down	N/A	N/A	90%	90%
Connected	Up	N/A	N/A	45% (30%)	N/A
Connected	Down	N/A	N/A	N/A	45% (10%)
Connected	Up+Down	N/A	N/A	45% (20%)	45% (20%)
Up	Idle	90%	N/A	N/A	N/A
Up	Up	40%	N/A	45% (30%)	N/A
Up	Down	35%[10]	N/A	N/A	45% (10%)
Up	Up+Down	35%[11]	N/A	45% (20%)	45% (20%)
Down	Idle	N/A	90%	N/A	N/A
Down	Up	N/A	40%	45% (30%)	N/A
Down	Down	N/A	30%[12]	N/A	45% (10%)
Down	Up+Down	N/A	30%[13]	45% (20%)	45% (20%)

[2] Some performance degradation due to non-collocated interference
[3] Some performance degradation due to non-collocated interference
[4] Some performance degradation due to non-collocated interference
[5] Some performance degradation due to non-collocated interference
[6] Some performance degradation due to non-collocated interference
[7] Some performance degradation due to non-collocated interference
[8] Some performance degradation due to non-collocated interference
[9] Some performance degradation due to non-collocated interference
[10] Some performance degradation due to non-collocated interference
[11] Some performance degradation due to non-collocated interference
[12] Some performance degradation due to non-collocated interference
[13] Some performance degradation due to non-collocated interference

Up+Down	Idle	90%	90%	N/A	N/A
Up+Down	Up	40%	40%	45% (30%)	N/A
Up+Down	Down	35%[14]	30%[15]	N/A	45% (10%)
Up+Down	Up+Down	35%[16]	30%[17]	45% (20%)	45% (20%)

[14] Some performance degradation due to non-collocated interference
[15] Some performance degradation due to non-collocated interference
[16] Some performance degradation due to non-collocated interference
[17] Some performance degradation due to non-collocated interference

4.2 Data rate specification in BT Voice mode

In the following two tables we give the Soft Gemini product specifications for the cases of:

- BT Voice + WLAN Normal Data
- BT Voice + WLAN ELP Data

Data on WLAN is given as percentage (%) of the performance of WLAN alone.

Note for reference that the baseline performance of WLAN for one scenario is given in **Section 3**. Also note for reference that the performance without coexistence is given in Appendix A (Section 5). Reference on the BT performance can be found in [1].

In order to ensure no degradation in BT voice quality, WLAN data rate is limited during BT voice connection periods. In some cases this results in termination of the WLAN application, during the BT voice connection.

Also notice the following:

- The specification is applicable for distances of 2-25m between WLAN+BT combo module and the WLAN-AP.
- WLAN Up+Down performance numbers are averaged on the total Up+Down rate. Notice possible variation of the distribution between the two directions.

Note that these numbers represent a percentage of baseline throughput performance. For example, a 4Mbps baseline would still yield a 200kbps throughput in a 5% case below. These percentages are not an indication of any reduction in signal strength quality.

For each scenario in the tables, two performance numbers are given for WLAN. The first is for the case where the communication is maintained. The number in parenthesis indicated the case where no WLAN communication is maintained.

Also note that even in the case of a 0% throughput, TI's testing shows that the WLAN connection to the Access Point will still be maintained, eliminating the need for the user to re-authenticate after the BT-Voice call is completed. This ability could vary depending on the Access Point.

4.2.1 Bluetooth-Voice / WLAN-Normal-Data scenario

Test Scenario		WLAN Throughput *(against baseline)*	
BT	WLAN	Up	Down
Voice	Up	10% (0%)	N/A
Voice	Down	N/A	1% (0%)
Voice	Up+Down	5% (0%)	5% (0%)

4.2.2 Bluetooth-Voice / WLAN-ELP-Data scenario

Test Scenario		WLAN Throughput *(against baseline)*	
BT	WLAN	Up	Down
Voice	Up	10% (0%)	N/A
Voice	Down	N/A	1% (0%)
Voice	Up+Down	5% (0%)	5% (0%)

4.3 Bluetooth connection build-up time specification

The following table gives performance numbers for BT connection build-up time when BT is both in Master and slave mode.

Percentage	**80%**	**90%**	**95%**
Connection buildup time [sec]	2.5	2.8	3

4.4 Bluetooth sniff mode specification

The following table gives performance numbers for WLAN when BT is operating in sniff mode.
BT operation in sniff mode is supported by soft Gemini.
Sniff mode parameters that are supported are limited by Minimum sniff as defined below.

In the following two tables we give the Soft Gemini product specifications for the two cases of:

- WLAN Normal Data
- WLAN ELP Data

Notice that performance numbers for WLAN when BT is in Minimum Sniff mode are given for the case where BT is using DH1 packets.

Specification is given for three different sniff modes:

- Minimum Sniff – Tsniff: 30mS, Attempts: 1, Timeout: 0
- Default Sniff – Tsniff: 500mS, Attempts: 8, Timeout: 0
- Maximum Sniff – Tsniff: 2Sec, Attempts: 8, Timeout: 0

Refer to the test results for characterization of performance with each AP that was tested. Notice that AP rate fallback is dependant on:

- AP type
- Distance between BT/WLAN combo device and AP
- Isolation between WLAN and BT antennas

Note that these numbers represent a percentage of baseline throughput performance. For example, a 4Mbps baseline would still yield a 400kbps throughput in the worst case (10%) scenario below. These percentages are not an indication of any reduction in signal strength quality.

For the Minimum sniff mode, two performance numbers are given for WLAN. The first is for the case where the AP does not initiate rate fallback. The number in parenthesis is for the case where the AP does initiate rate fallback independently.

4.4.1 Bluetooth-Sniff / WLAN-Normal-Data scenario

Test Scenario		WLAN Throughput *(against baseline)*	
BT	WLAN	Up	Down
Minimum Sniff	Up	40% (30%)	N/A
Minimum Sniff	Down	N/A	25% (10%)
Minimum Sniff	Up+Down	35% (20%)	35% (20%)
Default Sniff	Up	70%	N/A
Default Sniff	Down	N/A	70%
Default Sniff	Up+Down	70%	70%
Maximum Sniff	Up	80%	N/A
Maximum Sniff	Down	N/A	80%
Maximum Sniff	Up+Down	80%	80%

4.4.2 Bluetooth-Sniff / WLAN-ELP-Data scenario

Test Scenario		WLAN Throughput *(against baseline)*	
BT	WLAN	Up	Down
Minimum Sniff	Up	40% (30%)	N/A
Minimum Sniff	Down	N/A	25% (10%)
Minimum Sniff	Up+Down	35% (20%)	35% (20%)
Default Sniff	Up	70%	N/A
Default Sniff	Down	N/A	70%
Default Sniff	Up+Down	70%	70%
Maximum Sniff	Up	80%	N/A

Maximum Sniff	Down	N/A	80%
Maximum Sniff	Up+Down	80%	80%

5. Appendix A: Performance without coexistence (informative)

In this section we give informative data on the performance of WLAN and BT without coexistence (or when coexistence is turned off):

- In BT Data mode when WLAN is in ELP: BT takes the whole bandwidth
  - No WLAN communication is possible (see example below)
- In BT Voice mode: BT voice is not protected.
  - This implies that no BT voice connection is possible during WLAN traffic.
- BT connection buildup is not supported.
  - This implies that BT devices may fail to connect when WLAN is active.
- BT sniff mode is not supported.
- In BT data mode when WLAN is in normal mode: The performance of both BT and WLAN cannot be guaranteed.
  - Performance may significantly vary depending on the location of the devices and the direction of communication.

These issues were validated by tests when the coexistence is turned off.
An example of performance without coexistence is given in the following table. This is for the following case:

- WLAN ELP Data
- BT Data
- Cisco AP 1200
- 1 WLAN STA in the BSS
- Distance from the AP: 10m
- Distance between the combo device and the other BT device: 0.5m

Test Scenario		BT [kbps]		WLAN [kbps]	
BT	WLAN	Up	Down	Up	Down
Idle	Up	N/A	N/A	1611	N/A
Idle	Down	N/A	N/A	N/A	3099
Idle	Up+Down	N/A	N/A	1312	1253
Connected	Up	N/A	N/A	1148	N/A
Connected	Down	N/A	N/A	N/A	590
Connected	Up+Down	N/A	N/A	493	668
Up	Idle	639	N/A	N/A	N/A
Up	Up	632	N/A	0	N/A
Up	Down	640	N/A	N/A	0
Up	Up+Down	642	N/A	0	0
Down	Idle	N/A	609	N/A	N/A
Down	Up	N/A	604	0	N/A
Down	Down	N/A	597	N/A	0
Down	Up+Down	N/A	598	0	0
Up+Down	Idle	380	372	N/A	N/A
Up+Down	Up	379	364	0	N/A
Up+Down	Down	378	355	N/A	0
Up+Down	Up+Down	379	360	0	0

6. References

[1] Bluetooth_11_Specifications_Book.pdf