



## The WLAN/Bluetooth coexistence range challenge

Why Voice-over-WLAN calls will cause consumers to experience unacceptable WLAN performance when Bluetooth is active -- and what can be done about it.

A signaling interaction between Wireless LAN (WLAN) Access Points (APs) and the WLAN device inside portable consumer devices, such as cell phones or smartphones, with a collocated and active Bluetooth solution, can radically reduce the system sensitivity and range of the WLAN link.

Careful testing and analysis by NXP Semiconductor has shown that in an office environment, range can be reduced to about 20% of its baseline distance (that is, when Bluetooth is not active).

The problem is a particularly significant one in terms of end-user experience when the WLAN station is a dual-mode cell phone that switches to WLAN when a WLAN or hot spot is available. Because the problem occurs only when Bluetooth is active, consumers will be acutely aware that the performance of their cell phone is highly unpredictable and in many cases unsatisfactory.

In terms of distance or range, there are three values to consider:

- ▶ Sensitivity when Bluetooth is not active is generally in the range of -95 dBm and the output power is in the range of 15-20 dBm.
- ▶ When the Bluetooth and WLAN collocation problem exhibits itself, link is lost at -65 dBm.

- ▶ When a corrective mechanism, invented and implemented by NXP Semiconductors in its Bluetooth and WLAN chips is introduced, connection is maintained @ -85 dBm sensitivity.

Actual range figures vary widely from application to application but an average improvement of about 50% of the baseline range can be expected.

### AP rate adaptation

The problem is made more difficult by some of the challenges inherent in Bluetooth and WLAN signaling. Both technologies utilize the same 2.4 GHz ISM band, but their respective engineering development processes did not take collocation scenarios into account because the applications seemed to be separate and distinct from each other at the point of inception.

WLAN was initially conceived as a data-only link between PCs -- simply an Ethernet LAN that worked without wires. Bluetooth was originally conceived as a short-distance, wireless connection for mobile phones.

Over the past few years, however, the introduction of WLAN hot-spots and a strong increase of WLAN Access Points in homes and its synergy with cell phones -- that is, to hand-off to a WLAN in poor coverage areas inside buildings -- has put it in the voice traffic business. Similarly, Bluetooth mono headsets are being utilized with cell phones and stereo

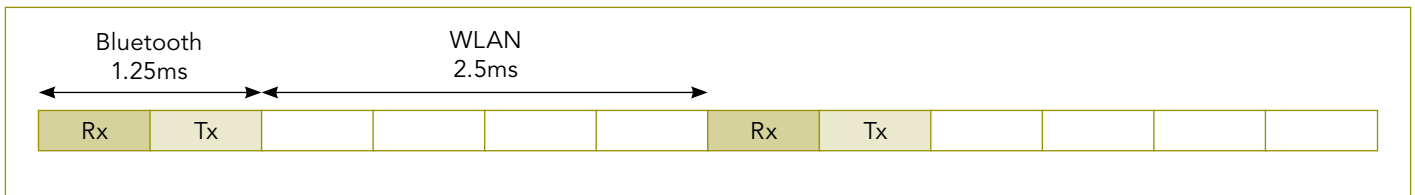


Figure 1. Bluetooth and the WLAN AP share a 3.75 ms window with the WLAN station

Bluetooth headsets with MP3 players and iPods, to name just the most prominent extensions of use case scenarios.

These new scenarios mean that Bluetooth and WLAN are operating in close proximity and the end-user experience depends on Bluetooth and WLAN operating simultaneously, transferring the same kinds of data sometimes with critical latency demands.

The core of the collocation problem lies in the AP rate adaptation mechanism that WLAN APs use to maintain a robust link with WLAN stations (WLAN enabled devices) such as smartphones.

It is best to begin exploring this mechanism by describing Bluetooth's operation. In voice transmission mode, Bluetooth establishes what is known as an SCO (Synchronous Connection Oriented) link. SCO links are used during voice mono transmission and they have a regular frame structure which allows for the exchange of voice data every 3.75ms for 1.25ms. This frame structure is shown in Figure 1.

This SCO frame structure is part of the Bluetooth specification and cannot be changed or altered.

The 1.25-ms receive and transmit interval required by Bluetooth leaves only a 2.5 ms interval during which the WLAN packets must be transmitted or received. Otherwise, they will be subject to collision and degradation by a Bluetooth packet.

If a frame transmitted by the AP falls inside of the Bluetooth Tx period it will most likely be destroyed by the ongoing Bluetooth transmission and the WLAN station will not transmit an acknowledgment to the AP. Similarly, if a frame transmitted by the AP falls too close to the end of the quiet period, the WLAN station will not be able to transmit an acknowledgment frame causing the AP to assume that the frame was not correctly received by the station. The number of non-acknowledged frames is used by many APs to determine the channel quality.

This type of channel assessment works very well if the WLAN channel is more representative of an Adaptive White Gaussian Noise (AWGN) channel, but it fails in the presence of a bursty interferer such as Bluetooth.

The type of interference Bluetooth generates is important because there are essentially two types of noise that could be present in the channel: AWGN and, bursty interference, which is very typical of the noise created by Bluetooth transmissions.

AWGN is typical of most environments where noise is random and more or less unvarying. Given the engineering assumptions at the time, WLAN APs were designed to operate in an AWGN channel.

As a result, the approach to maintaining robust communications links and lengthening range was simple and direct: When the sensitivity started to degrade, both the AP and the WLAN station reduced their transmission data rates to maintain their packet error rate targets.

Each device is responsible for its link. The amount of rate adaptation for the link from the AP to the WLAN station is determined in the AP. In order to maintain the target error rates between it and the station -- and by making the assumption that it is operating in a AWGN channel -- the AP falls back in its rate of data exchange according to the algorithm design engineers chose for the AP. However, the amount of information in the WLAN frame -- typically about 1500 bytes -- does not change, which means that the frame requires more time to be transmitted and received. NXP's WLAN implementation for the station does not have the same problems as it takes the collocated Bluetooth into account when adapting its data rate.

Taking more time to send the data, however, makes it all the more likely that the WLAN frame will not fit into the 2.5 ms window Bluetooth has left when it is operating in an SCO link mode. In fact, packets sent at WLAN rates of 1, 2, and 5.5 Mbit/s are so long that at least one Bluetooth transmission will impact them with a high probability of packet destruction. The lowest data rate where it is possible for WLAN to operate is 6 Mbits/s, which corresponds roughly to a sensitivity of less than -90 dBm. The coexistence range problem is that AP behaviour is not compatible with WLAN/Bluetooth collocation. APs send data packets when they like to and even if a packet is sent at a high enough rate so that it would fit in between Bluetooth traffic, there is still some statistical probability that WLAN data packets will collide with a Bluetooth transmission.

Three additional characteristics of APs make the problem even more difficult to solve:

- ▶ The WLAN station has very little control over the AP.
- ▶ Bluetooth coexistence mechanisms communicate with the station (STA) -- not the AP.
- ▶ Fall-back mechanisms and algorithms differ from manufacturer to manufacturer.

### **Towards a solution**

Because there are two types of links between WLAN stations and Bluetooth, a complete solution requires a slightly different procedure for each. We will look at the aforementioned SCO link first and then examine the ACL link scenario.

One of the few means the WLAN station has for controlling data transmission from the AP occurs in the system's power-save mode. This mode was created to extend the battery life of portable stations. In other words, it allows the stations to go into sleep mode and not be constantly listening for and responding to signals from the AP.

By using the signalling that controls this power-save mode, the WLAN station can decrease the probability of encountering interference from a collocated Bluetooth device.

Under normal operation, the AP sends a beacon to the WLAN station about every 100 ms to inform the WLAN station whether there is data pending in the AP for delivery to it. The time between beacons can vary and it is usually programmable in the AP. Ordinarily, when the WLAN station receives a message that it has data pending it will ask the AP to send the data. Clearly, if the station listens first for Bluetooth activity it can indicate to the AP that it is in sleep mode whenever Bluetooth is active.

Once the WLAN station goes into power save mode, the AP stops sending frames until the station requests them. The WLAN station initiates its request for data by sending a poll frame to the AP. By timing the poll frame strategically, the WLAN station can increase the probability that the response from the AP falls into the Bluetooth quiet period.

Referring to Figure 1, the procedure begins with the WLAN station having received a beacon from the AP indicating that information is waiting for it at the AP. The WLAN station then listens for its next Bluetooth transmission over an SCO link. Once that exchange begins, the WLAN station knows it has 1.25 ms to receive the Bluetooth information followed by a 2.5 ms interval to receive its information from the AP.

Increasing the probability of properly aligning the AP transmissions in-between Bluetooth transmissions is not, however, sufficient to create a reliable mechanism for extending WLAN range. Depending on the recent

transmission history, the AP may choose a data rate, for example, that makes it impossible for the frame to fit into the allotted 2.5 ms.

In any real-world situation, there are many opportunities for interference. Once that occurs, the AP will initiate the rate adaptation procedure that actually makes it less and less likely that a link can be established and data transferred between the AP and the WLAN station.

The most obvious alternative is to adjust the data rate of the AP. In many APs, this can be accomplished by having the WLAN station very briefly disconnect from the AP and then quickly reconnect. Usually, the AP will start over again with a high data rate and the interleaving of Bluetooth and WLAN packets process can be repeated.

Another possibility is to have the WLAN station disregard the priorities Bluetooth would ordinarily enjoy in its connection with the WLAN station. A priority line between the Bluetooth device and the WLAN station gives the WLAN station advance notice about Bluetooth transmissions. This priority can be ignored, which would cause the Bluetooth frame to be destroyed, that usually comes at the cost of degradation of the Bluetooth voice quality.

### **ACL links**

The discussion so far has addressed scenarios in which Bluetooth and the WLAN station have established an SCO link. But when Bluetooth is using the A2DP profile -- being used to listen to music on stereo headphones, for example -- it establishes an ACL (Asynchronous Connection Oriented) link. Here, the situation is less complicated because ACL links do not have the same rigid frame transmission structure as SCO links.

The Bluetooth connection, in fact, can be controlled by the WLAN station and longer gaps in-between Bluetooth transmissions can be arranged. A scheduling mechanism essentially ping pongs the medium back and forth between Bluetooth and WLAN. Considerable care must be taken, however, because Bluetooth applications must maintain average data throughput and low latency for the stereo headsets to work at all.

Bandwidth allocation algorithms can be written to manage the available bandwidth between Bluetooth and WLAN. The parameters are programmed into the Bluetooth chip at the Host Control Interface level.

The mechanisms and procedures described in this white paper are implemented in proprietary software created by NXP Semiconductors. Software must run on both the Bluetooth and the WLAN station chips, specifically NXP's BGB210S Bluetooth chip and the BGW211 802.11 b/g WLAN chip.

## Results

Integrating NXP chips into a design that involves Bluetooth-WLAN collocation can significantly improve system sensitivity performance and with it extend the range of WLAN systems.

Figure 2 illustrates the difference in WLAN range when three different coexistence solutions are used. The figure uses color coding to indicate the range of two cell phones containing competing solutions as well as the range of a solution with NXP's BGB210S Bluetooth chip and its BGW211 802.11b/g WLAN chip. The NXP chips are enhanced with the techniques described in this white paper to mitigate the effects of AP-initiated data-rate fallback.

In summary, this white paper has explored three main topics.

- ▶ NXP's WLAN and Bluetooth solutions' proprietary coexistence algorithms reduce the WLAN system sensitivity as experienced by the user
- ▶ NXP's WLAN and Bluetooth coexistence reduces WLAN system sensitivity during WLAN download to  $-65\text{dBm}$
- ▶ NXP's WLAN and Bluetooth coexistence improves WLAN system sensitivity to  $-85\text{dBm}$

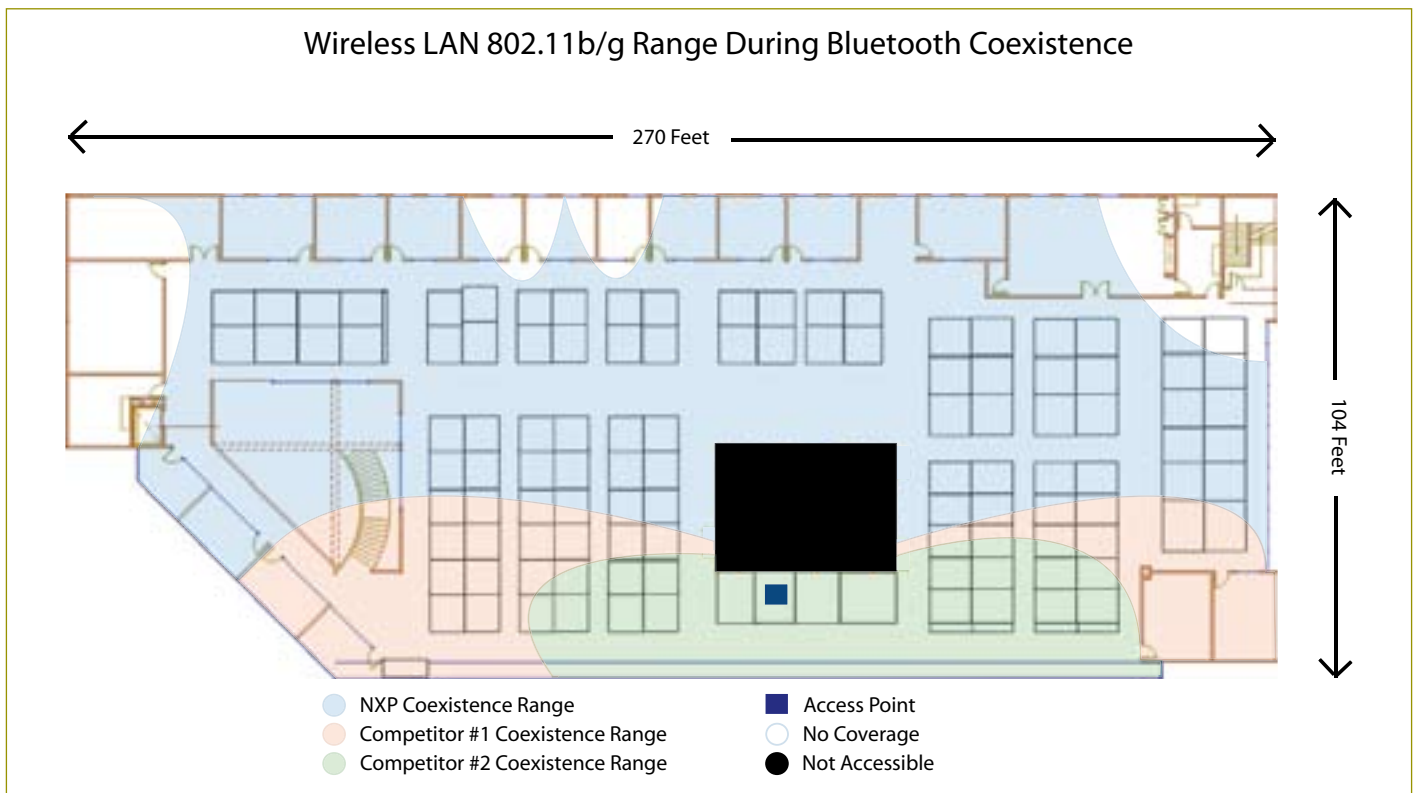


Figure 2. Improvements in range with NXP solution