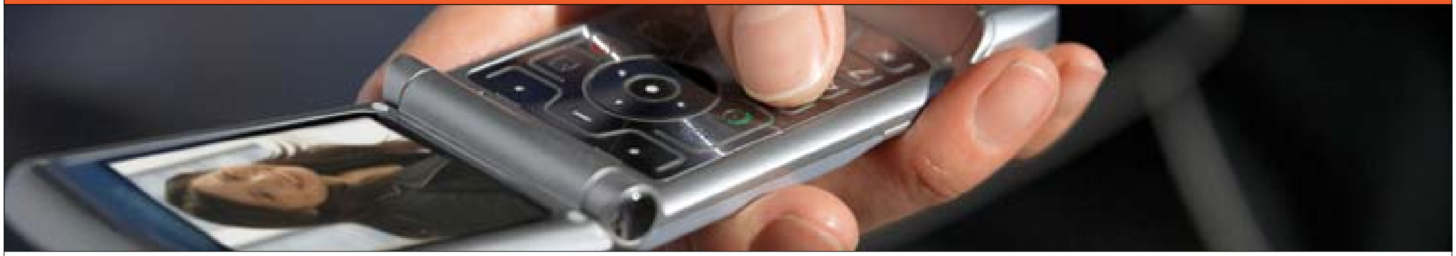
White Paper



Yes! Wi-Fi and Bluetooth Can Coexist in Handheld Devices

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Introduction

Imagine a room full of people talking. There may be a lot of noise, but as long as people are spread out and not conversing too loud, two people in close proximity can successfully carry on a conversation. However, if someone nearby started shouting, it would be very difficult to continue that discussion.

Similarly, when Wi-Fi and Bluetooth® are put into the same device—particularly a smaller handheld type—the signals transmitted can cause interference with each other, thereby disrupting the “conversation.”

As these two wireless technologies continue to permeate the consumer electronics market, people continue to ask “Can these Wi-Fi and Bluetooth coexist in a single device?” The answer is yes.

This white paper discusses the emergence of Wi-Fi and Bluetooth technologies on a single integrated circuit (IC) for use in today’s popular handheld devices. It explains the potential challenges of competing wireless signals, as well as innovative design techniques to help original equipment manufacturers (OEMs) overcome potential issues and rapidly develop cost-effective consumer devices. Finally, it expands on the advantages that Marvell’s Avastar® family of multi-functional radios (MFRs) have over competing devices available in the market today.

The Increasing Popularity of Wi-Fi and Bluetooth--Together

Wi-Fi and Bluetooth are two of the most widely used wireless technologies in consumer electronic devices. Although devices including these two technologies can use separate ICs on an embedded platform, with the latest advances in technology innovation, it is possible to co-locate Wi-Fi and Bluetooth devices on one IC, thereby reducing cost, size and time-to-market.

These technologies operate in the 2.4GHz Industrial, Scientific and Medical Device band (ISM) band, but are disparate from each other in almost every manner. Wi-Fi devices operate on an asynchronous protocol and access the wireless medium using the Carrier Sense Multiple Access / Collision Avoidance (CSMA/CA) mechanism. With Bluetooth devices, the medium access time is slotted. Also, the advent of 802.11n technology in handheld platforms poses the difficult challenge to accommodate the requirements of both Wi-Fi and Bluetooth links while ensuring optimal performance.

While it's generally acknowledged that Bluetooth and Wi-Fi can coexist in harmony, it's another matter to get them to work together while residing in the same device. Interference problems from collisions—since both use the same radio frequency (RF) band—causes dropped packets, which only cascades into other problems.

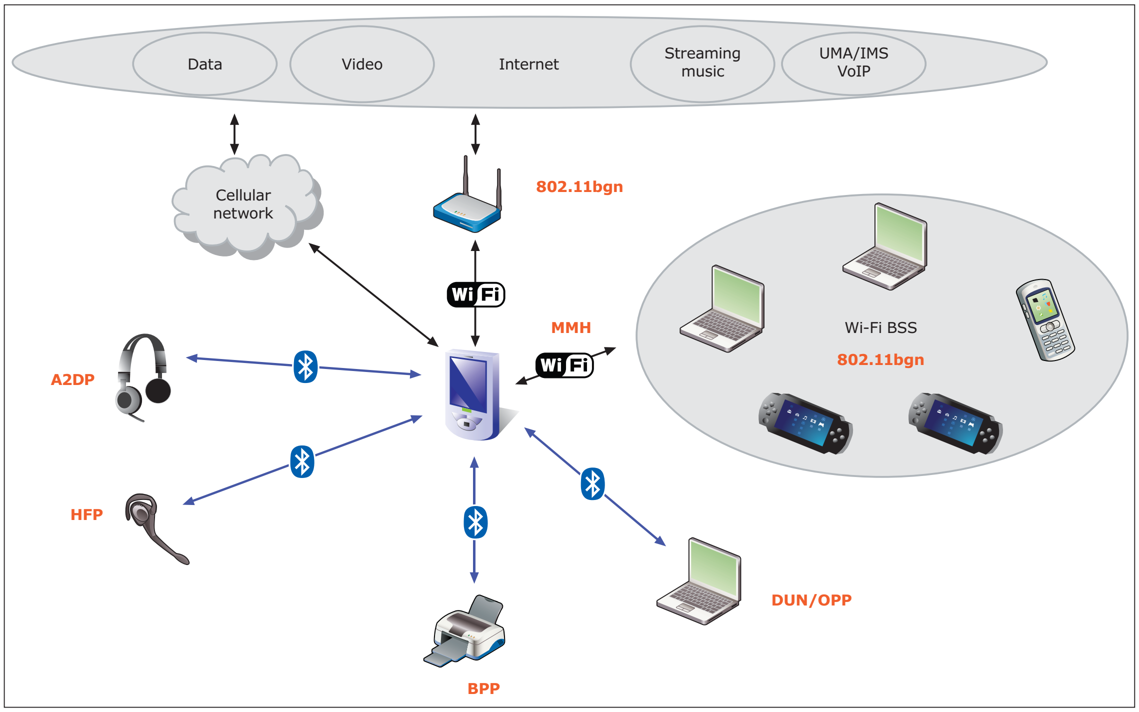
Despite this ambient RF interference, Bluetooth and Wi-Fi have gained increasing popularity with consumers in recent years, driven by the array of handheld devices available today. As both technologies are placed in close physical proximity, coexistence is a priority.

Below we outline the challenges of Wi-Fi and Bluetooth co-existence in small form-factor products, and then discuss detailed measures that can be implemented by OEM designers to counteract any interference.

Coexistence in Handheld Devices

More and more handheld devices, from personal digital assistants (PDAs) to smartphones, are being shipped with both Wi-Fi and Bluetooth technologies. With widespread use of these “dual-mode” devices, co-existence has become a complex challenge. Figure 1 illustrates the most common cases for simultaneous usage of Wi-Fi and Bluetooth technologies.

Figure 1: Typical Wi-Fi and Bluetooth use cases for smartphones.



The smartphone depicted at the center of the diagram is connected via Wi-Fi to an access point *and* via the cellular network. With built-in Bluetooth, the smartphone can also be used with a host of profiles such as Hands-Free Profile (HFP), Advanced Audio Distribution Profile (A2DP) for streaming stereo music, Basic Printing Profile (BPP), Dial-Up Networking (DUN), Object Push Profile (OPP) and so on.

Today's smartphones are also beginning to serve as embedded access points, whereby the phone creates a small Wi-Fi network that can handle a limited number of clients. (See White Paper - Marvell Mobile Hotspot technology.)

Depending on the intended use cases, Wi-Fi and Bluetooth devices can take up the medium time for an extended period—for example, a Wi-Fi client actively scanning or a Bluetooth device seeking a peer using page or inquiry mechanisms. In any such operation, the other co-located device suffers from acute starvation in accessing wireless medium, resulting in delays in getting its own data packet(s) through the airwave.

For OEMs seeking to develop new handheld devices that incorporate both Wi-Fi and Bluetooth on a single IC, there is a distinct requirement to optimize coexistence algorithms that enhance the performance of both technologies.

High Level Design Strategies for Optimal Performance

As both technologies have evolved, new techniques have been developed to enable Wi-Fi and Bluetooth to coexist easily with each other and other potential sources of interference.

As described below, designers can approach the coexistence challenge from both a "time domain" and "frequency domain" aspect:

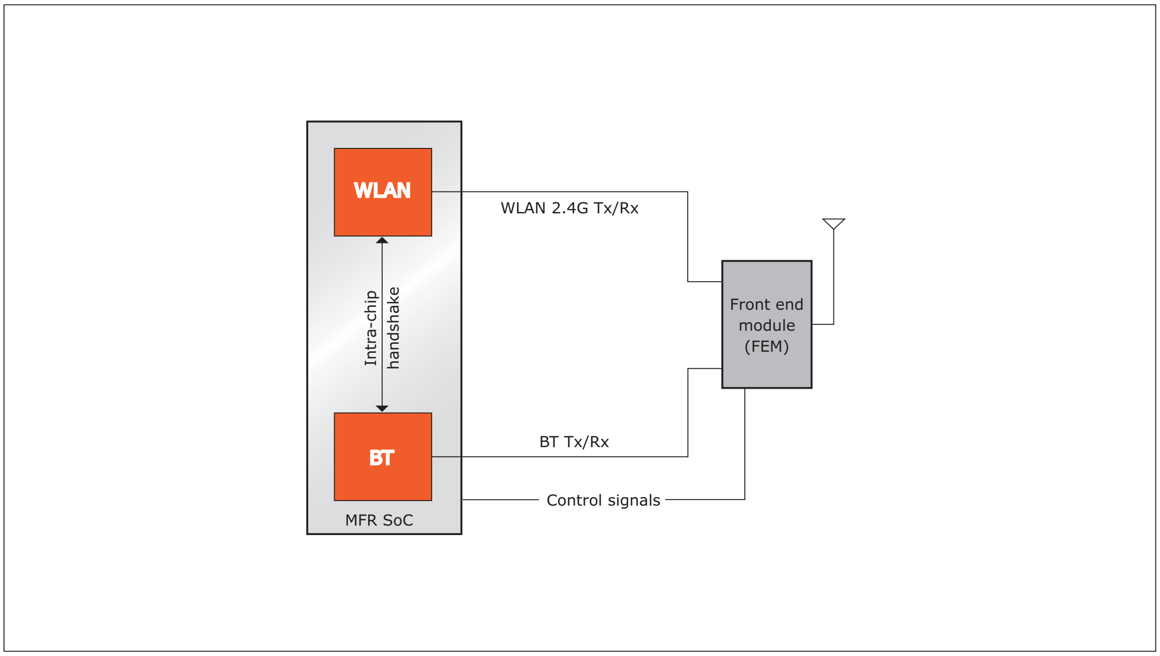
Time Domain

In most consumer devices, due to size and cost constraints, manufacturers tend to design systems that share a single antenna for both Wi-Fi and Bluetooth devices. As a result, Wi-Fi and Bluetooth transceivers have limited wireless access time to avoid packet collisions. Designers can address this issue by incorporating the following mechanisms:

- **Packet Traffic Arbiter (PTA).** PTA is a dedicated hardware System-on-Chip (SoC) block that controls access of Wi-Fi and Bluetooth devices to the antenna. It does this through pre-programmed priority of packet transmissions and receptions. In a discrete solution (i.e., separate Wi-Fi and Bluetooth SoCs), a unique set of protocols (e.g., 2-wire, 3-wire, 4-wire) is followed between the SoCs through hardware signaling.

  In an integrated Wi-Fi and Bluetooth SoC, however, there can be additional "handshakes" designed into this block. Marvell Wi-Fi/Bluetooth multi-function radio MFR devices, for example, are designed to optimize medium access time for maximum yield of Wi-Fi throughput and Bluetooth audio quality through packet arbitration. (See Figure 2 below.)

Figure 2: Example: Wire interface is a Wi-Fi/Bluetooth MFR solution.

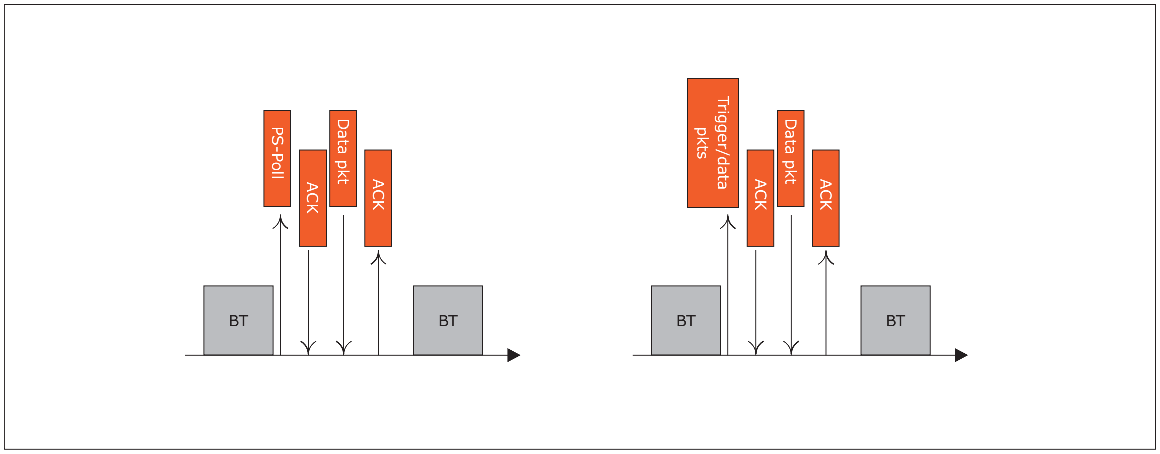


- **PS-Poll and WMM Trigger Frames.** One of the primary challenges with Wi-Fi and Bluetooth coexistence is controlling downlink traffic from the access point. Access points are usually unaware of ongoing Bluetooth traffic on the client Wi-Fi device. Downlink frames from an access point can arrive anytime, creating over-the-air collisions. This results either in very low Wi-Fi throughput or eventually leading to Wi-Fi link loss, depending on the type of access point. Therefore, it is important to control the downlink traffic from the access point.

  This can be accomplished either by using PowerSave-Poll (PS-Poll) frames or Wi-Fi MultiMedia (WMM) Trigger frames. (See Figure 3) The former polls the access point one data packet at a time, whereas the latter can be used to download multiple frames at a time, although in different modes of operation. The former is used in IEEE Power Save mode, whereas the latter is used when the Wi-Fi device operates in WMM Power Save mode. These enhancements are particularly helpful when the client Wi-Fi device associates with an aggressively rate-dropping access point.

  In an integrated Wi-Fi/ Bluetooth SoC, it is possible to line up these frames with the Bluetooth frames, as shown in the figure below, so that the audio quality does not suffer and the downlink Wi-Fi traffic is also sustained—thereby minimizing over-the-air collisions. This is quite challenging when a discrete set of Wi-Fi and Bluetooth SoCs are used.

Figure 3: PS-Poll and WMM Trigger frames.



Frequency Domain

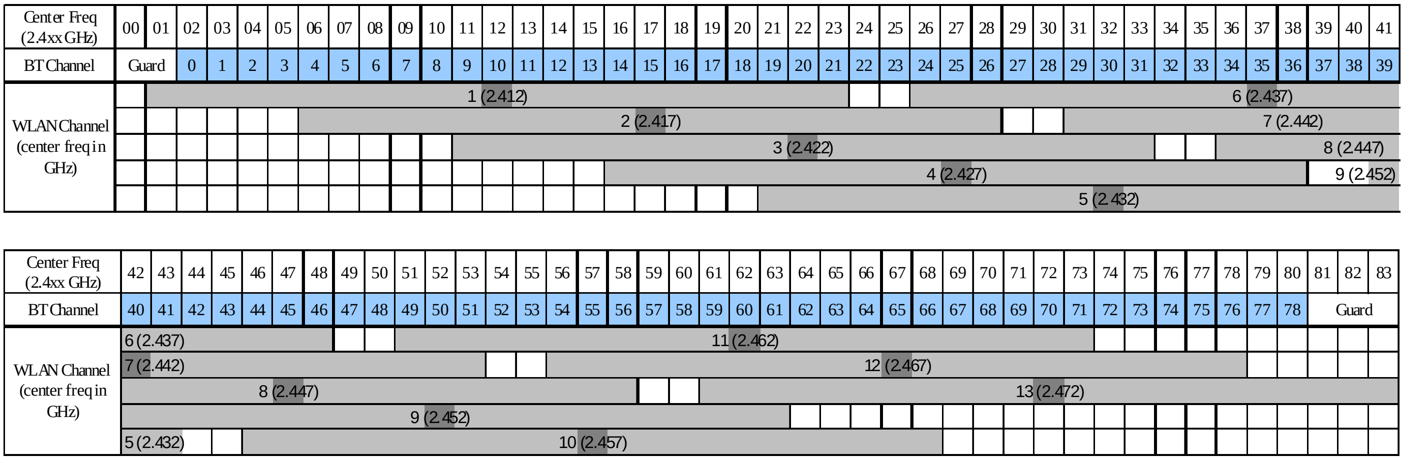
Since Wi-Fi and Bluetooth share the 2.4GHz ISM frequency band, each of these two technologies need to be partitioned to use a specific set of frequencies, thus providing enough RF isolation. This can be accomplished through the following design techniques:

- **Adaptive Frequency Hopping (AFH).** Starting from version 1.2 of the Bluetooth specification, all Bluetooth devices offered Adaptive Frequency-hopping (AFH) spread spectrum as a key enhancement. This enables the Bluetooth device to use only a certain (programmable) set of frequencies as part of its hopping sequence.From a Wi-Fi and Bluetooth coexistence perspective, this feature is very helpful. Based on the Wi-Fi channel, the Bluetooth device can be programmed to not use the frequencies around the Wi-Fi channel's center frequency. Hence, the Bluetooth device is programmed with a static (or adoptive) mask of channels that should not be included in the hopping pattern.

  The specifics of how many channels are required to be blocked should be governed by: 1) RF front-end components and isolation thereof, 2) transmit power level of the Wi-Fi and Bluetooth devices, 3) flexibility of allowing simultaneous transmit and receive activities on Wi-Fi and Bluetooth devices and 4) maximum adjacent channel rejection (ACR) of the Wi-Fi and Bluetooth devices.

  Figure 4 below depicts the channel map allocated for Wi-Fi and Bluetooth devices. There are a total of 13 Wi-Fi and 79 Bluetooth channels in this band. Wi-Fi channels have a center frequency and are approximately 23 MHz wide, while Bluetooth channels are only 1 MHz wide.

Figure 4: Wi-Fi and Bluetooth channel allocation.



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<tr><td rowspan="5">WLAN Channel (center freq in GHz)</td><td></td><td colspan="23">1 (2.412)</td><td></td><td></td><td colspan="16">6 (2.437)</td></tr>
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<tr><td colspan="16"></td><td colspan="23">4 (2.427)</td><td colspan="3">9 (2.452)</td></tr>
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<tr><td colspan="3">5 (2.432)</td><td></td><td colspan="23">10 (2.457)</td><td colspan="15"></td></tr>
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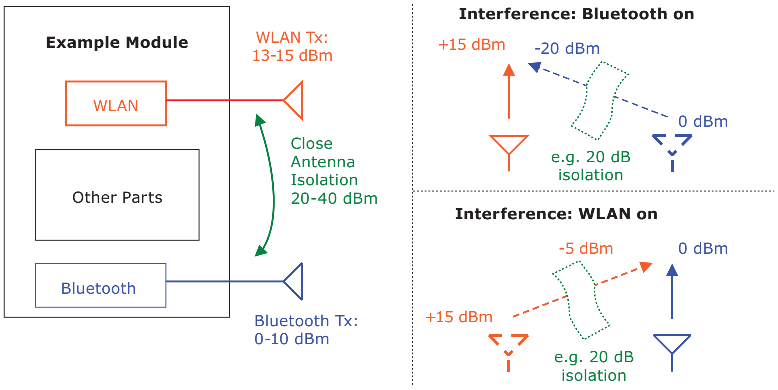
- **RF Isolation and Gain Adjustment.** Most Wi-Fi and Bluetooth implementations offer transmit power control algorithms where, according to the link conditions, the transmitting device either increases or decreases transmit power. The higher the transmit power from the Wi-Fi device, the more Bluetooth channels one needs to mask in order to ensure low packet error rate (PER).

  It is also observed that, if the RF isolation between the Wi-Fi and Bluetooth devices is not enough, transmissions from either of the two devices can saturate the receive path of the other device, assuming the transmit power to be considerably high. (See Figure 5 below.) This could result in a link disconnect or high PER and, therefore, detract from the overall user experience.

  There are two ways to resolve this problem: 1) adjust the maximum gain of the intermediate receiver stages of the individual Wi-Fi and Bluetooth devices or 2) adjust the transmit power of the two devices so that it is low enough to sufficiently maintain the individual links. These are particularly important in a design that uses shared antenna between Wi-Fi and Bluetooth.

Figure 5: Examples of RF Isolation.



Solutions Catering to Offer Best-in-Class Overall User Experience

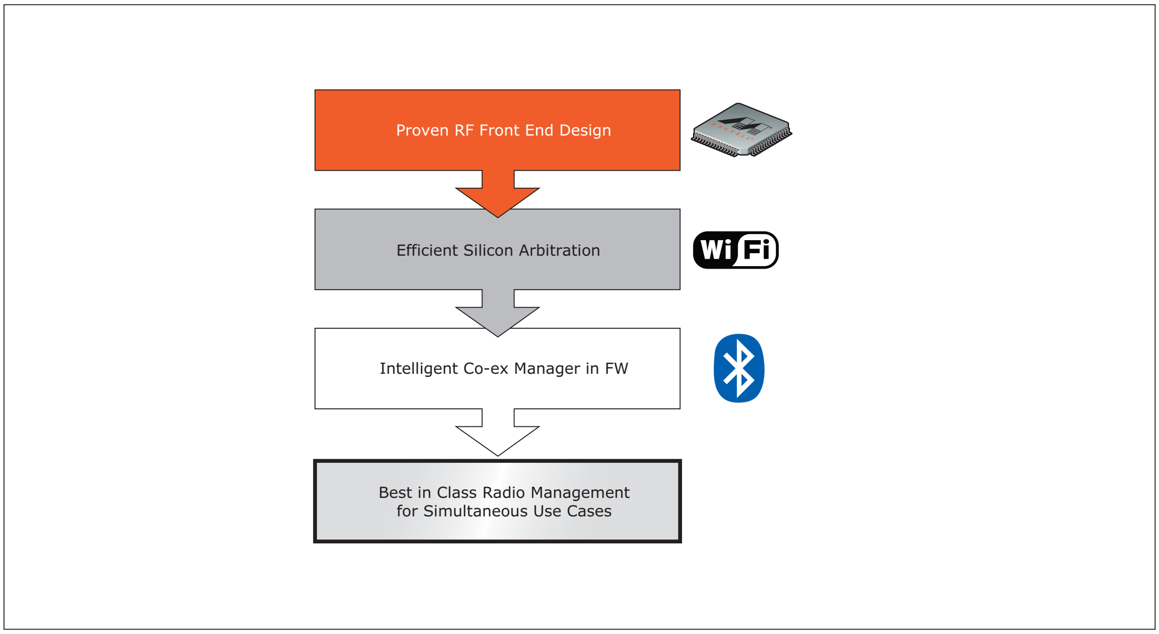
As Marvell has integrated the Wi-Fi and Bluetooth devices on a single silicon die, the Marvell's Avastar family of wireless connectivity solutions has mastered the coexistence technologies to offer world-class performance, leading to an overall user experience that simultaneously delivers maximum Wi-Fi throughput with optimal Bluetooth voice quality.

Among these coexistence technologies are:

- Alignment of PS-Poll / Trigger frames with SCO / eSCO slots to optimize Rx traffic, as mentioned in the section above
- Usage of larger Wi-Fi time window whenever available, especially during eSCO
- Dynamic Bluetooth-aware Wi-Fi rate adaptation scheme
- Interception of Bluetooth page/inquiry to yield for WLAN traffic
- Partition airtime between Bluetooth and Wi-Fi traffic to yield best performance possible
- Coexistence for a multi-profile usage scenarios, for example, running HFP (i.e., SCO/eSCO) and Personal Area Network (PAN)-over-Asynchronous Connectionless Link (ACL) simultaneously with Wi-Fi traffic
- Scheme to sustain the overall network throughput in a multiple-client scenario (e.g., multiple WiFi+Bluetooth enabled smartphones in a small conference room connected to the same access point and paired with their individual headsets)
- Wi-Fi and Bluetooth link-aware performance

- BT-aware 802.11n block acknowledgement streams
- Optimal number of aggregates versus Modulation and Coding Scheme (MCS) rate index in the transmit direction

Figure 6: Marvell Smart Radio Coexistence



Marvell’s Avastar family of MFR combo devices ensures:

- A Mean Opinion Score (MOS) of more than 4.0 for voice quality over the Bluetooth link at all times, with or without the Wi-Fi link being active
- Minimal impact in an on-going A2DP stream at all times, with or without the Wi-Fi link being active
- No Wi-Fi link loss between the client and access point, with or without the Bluetooth link being active
- Theoretical maximum Wi-Fi 802.11a/b/g/n throughput achievable while coexisting with collocated Bluetooth links.

Conclusion

The market for Wi-Fi and Bluetooth devices is growing rapidly, driving increased demand for integration and coexistence among these two technologies. Through its innovative design techniques and solutions, as part of its low power MFR devices, Marvell has found a way to limit interference between Wi-Fi and Bluetooth technologies in handheld devices. The techniques and technologies described above can help OEMs address the design constraints of Wi-Fi and Bluetooth devices and develop combined Wi-Fi/Bluetooth solutions in a small, cost-efficient design, with quicker time-to-market. This will also help successfully enhance the overall consumer experience.

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Ronak Chokshi is a technology professional with more than six years experience across the wireless and fabless semiconductor industries. After receiving his Master of Science degree in Information Networking (ECE) from Carnegie Mellon University in Pittsburgh, Pennsylvania, Ronak worked briefly at Honeywell Labs, where he was focused on the implementation of advanced aeronautical wireless technologies for NASA. Currently, as technical marketing engineer at Marvell, Ronak is responsible for the definition of technologies, product management and technical marketing across Marvell's complementary wireless product line.

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