

Motorola's Bluetooth Solution to Interference Rejection and Coexistence with 802.11

Application Note

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Abstract and Contents

Bluetooth™ is a low-cost and low-power wireless connectivity technology operating in the 2.4 GHz unlicensed ISM band. One of the important challenges to Bluetooth™ adopters is interference rejection and coexistence with other WLAN standards such as 802.11. This document describes Motorola’s Bluetooth solution that addresses these challenges.

Motorola’s interference rejection solution is achieved via high-performance signal detection algorithms. High-performance signal detection algorithms not only increase Bluetooth™ performance, but also reduce its interference to 802.11 due to the reduction of re-transmissions. The high-performance signal detection in baseband includes joint detection of the access code, timing, and carrier frequency. The maximum likelihood sequence estimation (MLSE) is used for symbol recovery and carrier tracking. Motorola’s interference rejection performance is not at the price of extensive processing that increases silicon cost and power consumption. The joint detection gate count is comparable with a conventional solution for the access code detection and timing sync and the MLSE gate count is negligible in current silicon technology. Motorola’s solution relies on its unique, powerful, and efficient algorithms.

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1 Introduction

Bluetooth™ is a low-cost and low-power short-range radio link that operates in the worldwide 2.4 GHz unlicensed ISM band. It may be used as a cable replacement technology or as an advanced personal wireless local area network. Because of the unrestricted access to the ISM band, Bluetooth devices are exposed to a high level of interference from unknown proprietary products, such as microwave ovens, cordless phones, and so on. Interference is also possible from WLAN products, such as 802.11, which coexist with Bluetooth products.

A frequency-hopping scheme is used to overcome interference and fading. Bluetooth uses Gaussian Frequency Shift Keying (GFSK) modulation on each hop with a 1 Mbit/s raw data rate. This frequency hopping technology helps mitigate interference to some extent. However, due to the fact that Bluetooth channels are spread over the entire ISM band and have a narrow channel spacing, interference from adjacent Bluetooth channels also presents a problem.

Motorola believes that the solution to interference rejection can be achieved via high-performance signal detection algorithms. High-performance signal detection not only increases Bluetooth's ability to survive in an interference environment, it also reduces interference to 802.11 by reducing the need for re-transmissions. This in turn not only enhances the user's experience, it also reduces the battery drain of the device. However, Motorola's interference rejection performance does not come at the price of extensive processing that would increase power consumption and silicon cost. Instead, it relies on its unique, powerful, and efficient algorithms.

2 Motorola's Bluetooth Solution

The Motorola Bluetooth solution is a two-chip solution as shown in Figure 1, where the baseband portion provides high-performance detection.

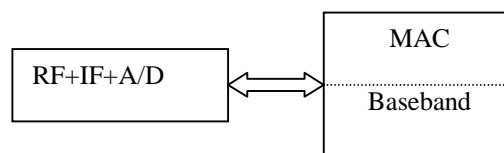


Figure 1. Motorola's Two-Chip Bluetooth Solution

The high-performance signal detection in baseband includes joint detection of the access code, timing, and carrier frequency. The maximum likelihood sequence estimation (MLSE) is used for symbol recovery and carrier tracking. The joint detection uses the 64 bits of the entire sync word to estimate the carrier digitally, instead of the 4 bits of the preamble in the conventional analog approach. Thus, the joint detection significantly improves the carrier estimation in the presence of interference, thereby enhancing the message recovery performance. The Bluetooth channel has unrecoverable Inter Symbol Interference (ISI) due to its GFSK modulation and narrow channel spacing. Conventional slicing detection is optimal only

Motorola's Bluetooth Solution

for zero-ISI channels and is a non-optimal solution for Bluetooth. The MLSE symbol recovery, however, can be an optimal solution for channels with ISI. MLSE detection is a packet waveform matching detector that tries all possible bit patterns. ISI has been included into its optimization. Thus, MLSE is expected to provide a significant performance gain over the conventional slicing detection in the Bluetooth channel environment. In addition, MLSE allows the use of an exceptionally narrow selectivity filter, thus providing additional interference and Additive White Gaussian Noise (AWGN) rejection.

Traditionally, sophisticated joint detection and MLSE symbol recovery require more processing power than other approaches, resulting in sub-optimal cost and operational power. However, the Motorola Bluetooth solution achieves a cost-effective and power-efficient solution. The joint detection gate count is comparable with a conventional solution for the access code detection and timing sync. The MLSE gate count is negligible in current silicon technology.

2.1 Joint Detection of Access Code, Timing, and Carrier

The Bluetooth packet structure is shown in Figure 2. Different from other communication protocols, the access code in Bluetooth serves not only for synchronization purposes, but also for user detection purposes. The access code changes from connection to connection and only the intended receiver knows the access code precisely. The access code is used by the intended receiver to derive the arrival timing and carrier. Non-intended receivers treat the access code as noise and switch to sleep mode at the end of the access code.

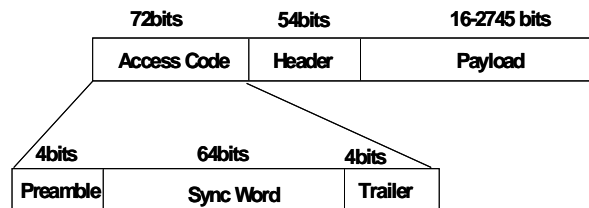


Figure 2. Bluetooth Packet Structure

The access code is constructed as shown in Figure 3 where the 24 LAP bits are the lower address portion (LAP) of the sending device's ID. The 34 parity bits are generated in such a way that any access code has a minimum distance of 14 bits from any other access codes with a different LAP. This ensures that a sufficient correlation magnitude difference exists between the intended receiver and non-intended receivers, allowing the intended receiver to reliably detect the message arrival while unintended receivers quickly fall into a power-saving sleep mode. Another important feature of the access code is its non-cyclic nature. This means that a time-shifted version of any access code will not be similar to another access code, thus avoiding potential false alarms for non-intended receivers.

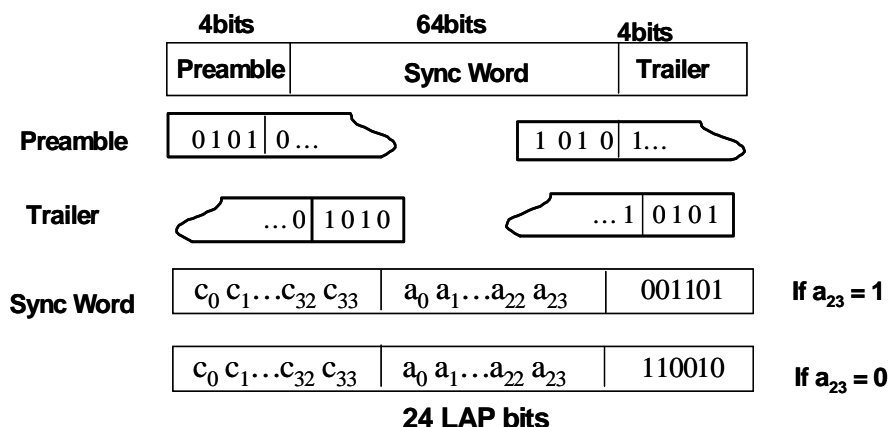


Figure 3. Access Code Structure

In a conventional approach, the 4 bits of preamble are used for carrier estimation. The estimated carrier is corrected for the following signal for the access code detection, timing synchronization, and symbol recovery. In the presence of interference, the 4 bits of preamble are not enough to estimate a reliable carrier, thus the performance of the access code detection and timing sync is affected, and so is the following symbol recovery.

With Motorola’s joint detection, the baseband signal of the 64 bits of the entire sync word is used for simultaneous carrier estimation, timing synchronization, and access code detection. The unique joint detection metric is designed so that it has a global peak for the intended receiver at the arrival time and correct carrier estimation, which is also achieved only at the arrival time. This joint detection is shown in Figure 4. Measurements indicate that this joint detection not only gives us improved carrier estimation accuracy, it also reduces the false alarm rate and increases the reliability of the access code detection, thus reducing the re-transmission. The reduced re-transmission and lower false alarm rate improves the battery life. The reduced re-transmission also lowers the interference to other devices operating in the ISM band, such as 802.11 devices.

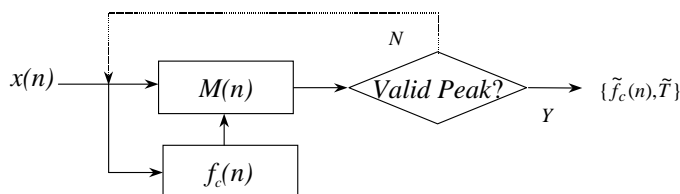


Figure 4. Motorola’s Joint Detection

2.2 MLSE Symbol Recovery with Carrier Tracking

The conventional approach to symbol recovery uses a slicing detector after the discriminator and Post-Detection Filter (PDF), as shown in Figure 5. With a slicing detector, a symbol is detected based on its signal value at its symbol center. The symbol recovery performance is controlled by the eye-opening of the channel or Inter Symbol Interference (ISI) of the channel, as shown in Figure 6. A slicing detector is optimal only if the channel has zero-ISI.

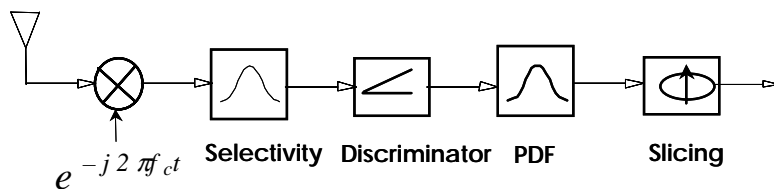


Figure 5. Conventional Receiver Architecture

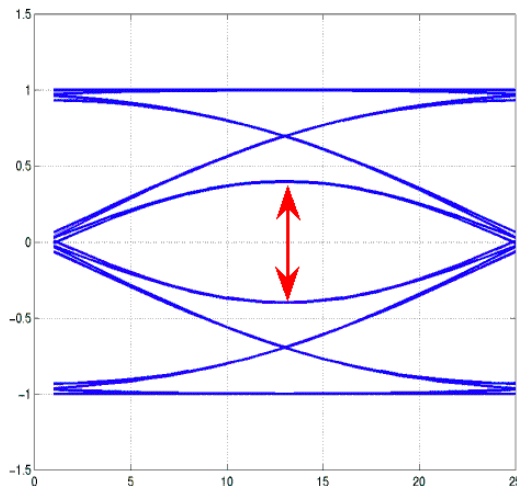


Figure 6. Slicing Detector Performance Determined by the Channel's Eye-Opening or ISI

In the Bluetooth channel environment, however, the received signal has unrecoverable ISI. Channel equalization cannot remove this ISI because of the Gaussian pulse shaping and the congestive Bluetooth channel structure. The congestive channel structure requires a selectivity filter that causes additional ISI and non-linear distortion.

To achieve a significant performance improvement for symbol recovery over the conventional slicing detector, Motorola uses the maximum likelihood sequence estimation (MLSE) for the symbol recovery. MLSE is a packet waveform matching detector that tries all bit patterns of the packet and selects the best bit pattern as the detected packet bits. With MLSE, the ISI is included into its optimization, which makes MLSE an optimal solution for channels with ISI. Because of this key feature, MLSE symbol recovery allows the use of an exceptionally narrow selectivity filter to reject interference and AWGN. The receiver architecture with MLSE is shown in Figure 7.

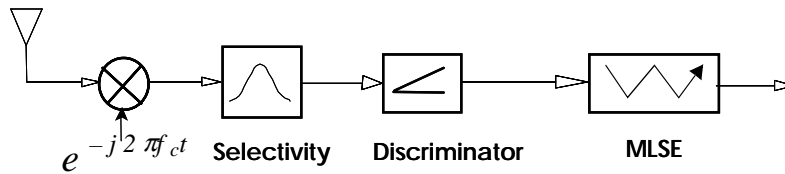


Figure 7. MLSE-Based Receiver Architecture

An intuitive explanation for the MLSE symbol recovery is shown in Figure 8. MLSE symbol recovery looks at the signal transition between two symbols. With Viterbi searching, as each new symbol is received, two surviving paths or two possible packets always remain. As the last symbol is processed, a final packet is chosen from the two.

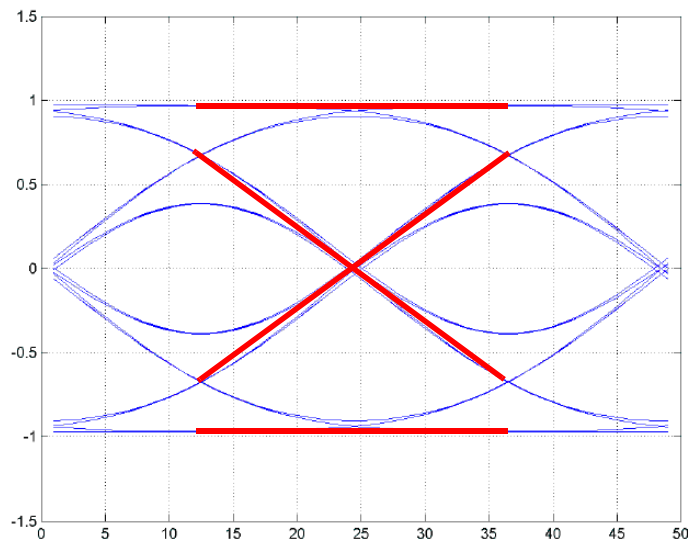


Figure 8. Signal Transition Used in MLSE

The Motorola Bluetooth solution is based on MLSE symbol recovery and includes carrier tracking to compensate for carrier drift over the message transmission.

3 Performance of Motorola's Bluetooth Solution

Figure 9 gives the performance comparison between the MLSE symbol recovery and the conventional slicing symbol recovery in AWGN. It is shown that the MLSE approach gives us at least 5 dB gain in AWGN. Table 1 summarizes the interference rejection performance and comparison with the performance specification of other vendors. It shows that the Motorola Bluetooth solution gives the best interference rejection performance on the market. In terms of user experience, the AGWN performance gain and interference rejection performance can be translated as coverage expansion, capacity increase, and quality improvement of service, as shown in Figure 10.

Performance of Motorola's Bluetooth Solution

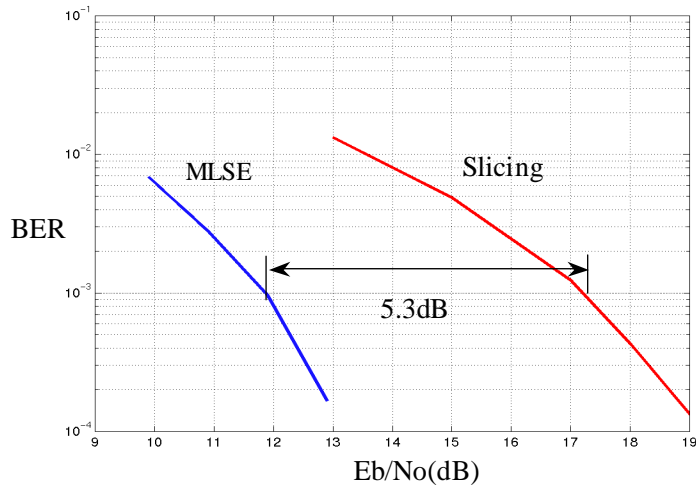
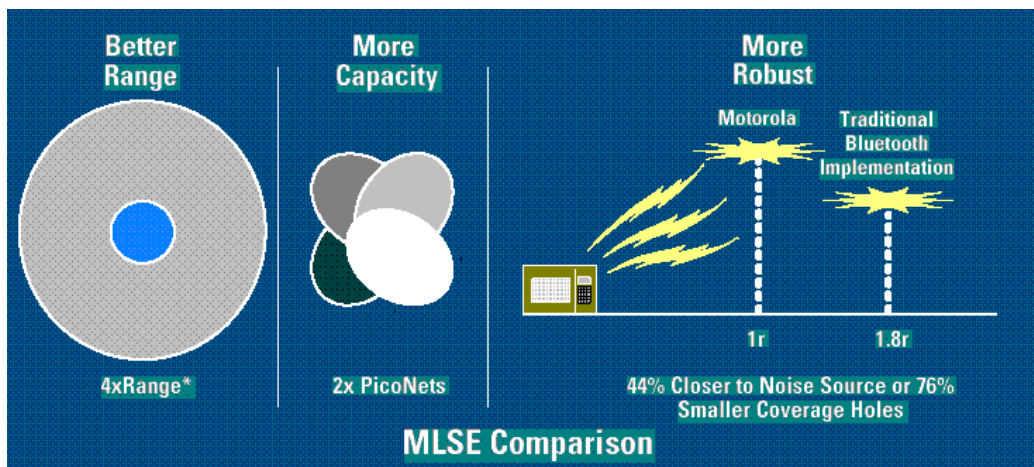


Figure 9. Performance Gain of MLSE Symbol Recovery

Table 1. Summary of Interference Rejection Performance

	Motorola	Vendor A	Vendor B	Vendor C
Co-channel	(7.5 dB)	12 dB	9 dB (10.6 dB)	9 dB
Adjacent Channel	(-10 dB)	4 dB	-6 dB (-4.5 dB)	-2 dB
Sensitivity	(-84 dBm)	-80 dBm	-85 dBm	-72 dBm

() = measured
 = specification sheet



* Compared to a Bluetooth Specification V1.1 compliant bit slicing radio

Figure 10. User Experience of the Performance Gain from MLSE versus Traditional Slicing Detector

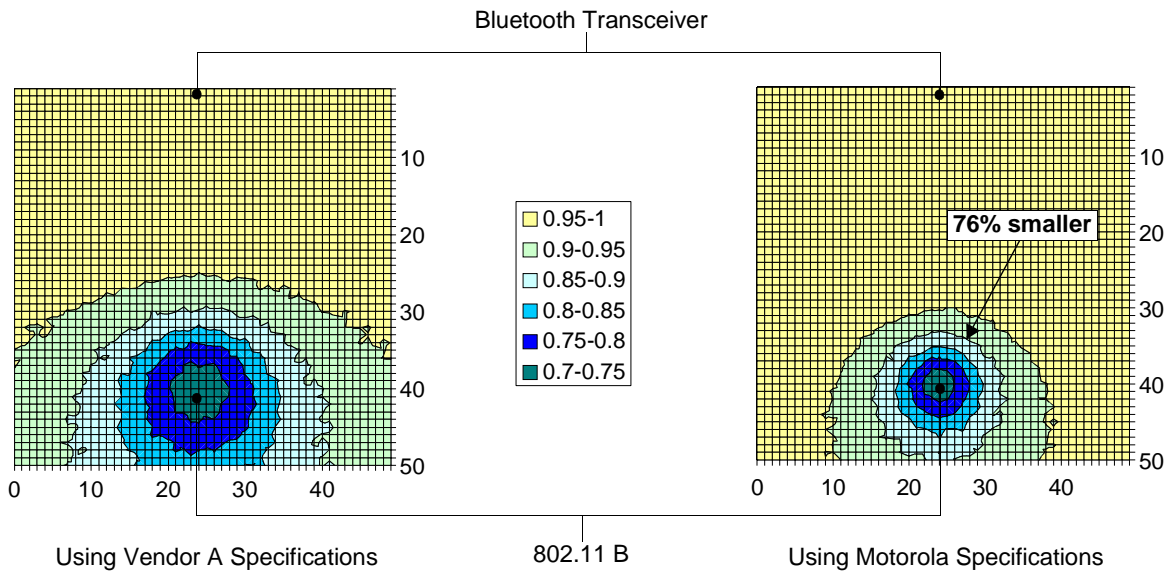


Figure 11. Coverage Map Showing Bluetooth Performance in the Presence of an 802.11 Interferer

Figure 11 shows how the interference rejection numbers in Table 1 impact the link performance of Bluetooth devices under 802.11 interference. The two graphs show Bluetooth packet reliability at various locations using Vendor A and Motorola devices respectively under identical 802.11 interference. It is shown that the Motorola solution provides a significant improvement in reception quality (76% smaller coverage hole). This improvement reveals itself in the form of increased throughput (for data applications) and better voice quality (for audio applications). Meanwhile, the improved Bluetooth performance also reduces the re-transmission for Bluetooth devices, thus further reducing interference to 802.11 devices.

4 Summary

The Motorola Bluetooth solution delivers to the Bluetooth market not only low-cost and low-power devices but also the best interference rejection performance as well.

Motorola has been involved with Bluetooth development since its beginning. Motorola is aware of the challenging issues of interference rejection and coexistence with 802.11. The engineers at Motorola put a heavy emphasis on interference rejection performance into the design of its platform solution.

The joint detection for access code, timing, and carrier provides high reliability and low false-alarm rate for the access code detection. It also provides robust carrier and timing synchronization in the presence of interference. The MLSE symbol recovery with carrier tracking is an optimal solution to message recovery in a Bluetooth channel environment that has unrecoverable ISI. In addition, MLSE symbol recovery also allows using exceptionally narrow selectivity that gives the Motorola solution additional interference rejection.

These sophisticated detection algorithms extend the battery life since they reduce the need for re-transmission. The sensitivity gain can be directly translated into better user experiences including coverage expansion, capacity increase, and quality of service. The reduced re-transmission can also improve the condition of coexistence with 802.11.

