Technical Brief

Bluetooth Radio Performance

- Class 1 vs. Class 2 Bluetooth

- Adaptive Frequency Hopping (AFH)

Cordless scanning in a typical warehouse environment with a Motorola LS3578-ER.

Background

Motorola's lineup of rugged cordless scanners employs the Bluetooth standard for transmitting information wirelessly. When a scanner is paired with a cradle or other device, the data is exchanged over a radio frequency link using the 2.4 –2.5 GHz unlicensed spectrum. Of great importance in nearly any cordless scanner application is the radio range, which is defined as how far apart scanner and cradle/BT device can operate without a loss of the radio connection. This brief discusses the technical details behind radio range and presents data on the radio range of Motorola's Class 1 and Class 2 Bluetooth architectures used in rugged scanners.

Bluetooth Radio Range Theory

Fundamentally, radio range is dependent upon the Bluetooth radio's transmitted radio frequency (RF) power and receiver sensitivity, and the absorption rate of the medium the RF waves travel through. When the medium absorbs enough of the transmitted energy to make the signal at the receiver lower than the receiver sensitivity, the connection is lost. An excellent analogy is human hearing. Transmitted RF power is analogous to how loud someone is speaking, and receiver sensitivity is analogous to a listener's hearing acuity. When two people are having a conversation in reasonable proximity to each other, it is easy for the listener to understand what the speaker is saying. However, if the speaker and listener are very far apart, or are in different rooms, it may be difficult or impossible for the listener to make out what the speaker is saying.

Dissimilar materials absorb RF energy at different rates. Therefore, it is very hard to accurately predict the amount of RF energy lost during transmission in a given environment. To make this prediction even more complicated, there are often multiple ways for the RF signal to get to the receiver. So, even if the direct RF path is blocked by a metal wall with a known absorption rate, there may be a way around or over the wall with enough signal strength for the receiver to correctly detect the signal. Due to these complications, radio range is best represented by approximations based on average assumed levels of RF power absorption. For the purposes of this paper, the discussion is limited to theory and experiments performed in open air environments.

Bluetooth radio range is primarily defined by the maximum allowable path loss, which is defined as the delta between the max RF power output and the maximum sensitivity of the radio. The formula for path loss is:

$$L_{total} = 20 * \log_{10}(f) + N * \log_{10}(d) + L_f(n) - 28,$$

where:

- N = Distance Power Loss Coefficient

- f = Frequency (MHz)
- d = Distance (meters) between nodes ($d > 1$)
- L_f = Floor Penetration Loss Factor (dB)
- n = Number of Floors Penetrated ($n > 0$)

The above equation assumes that the Bluetooth receiver and transmitter antenna provide no additional gain (0dB), which is typical in many applications. To simplify this equation to the open-air environment that is being discussed, the frequency should be set at 2,500 MHz (maximum frequency assigned for Bluetooth communication). Since we are limiting our discussion to open air environments, there is no RF transmission between floors. Therefore, $n = 0$. According to Shellhammer[1], the distance power loss coefficient in Free Space would be equal to twenty (N = 20). For the purpose of this exercise, we shall assume that the distance power loss for typical outdoor "line of sight" applications is equivalent to that of free space. Under these assumptions, the formula simplifies to:

$$L_{total} = 40 + 20 * \log_{10}(d)$$

Therefore, we can solve for the maximum allowable path loss, L_{total}, as the difference between the sensitivity of the Bluetooth radio and the RF output power. The maximum range, d, at which the Bluetooth radio can communicate is based on the maximum allowable path loss, and is independent of whether the radio is classified as Class 1 or Class 2 Bluetooth. Figure 1 is an example of a typical Class 1 Bluetooth (early design) compared to a typical Class 2 Bluetooth (current design). Although they both have different RF output power and receiver sensitivity, their maximum allowable path loss is equivalent at 85 dB. Therefore, both theoretical radio designs should have equivalent radio range. Based on the Path Loss Model presented above, the maximum distance that each design can theoretically operate at is 178 meters in free space. At these hypothetical RF power levels and sensitivities in a real open-air environment, the actual radio range would be less than 178 meters. This could be due to interference from physical objects and electromagnetic waves.

A key characteristic of a Bluetooth radio is the level of RF power it radiates when transmitting; the Bluetooth standard defines three classes of RF power output levels. Class 1 radios can emit a maximum of 20 dBm of RF power, while Class 2 radios are limited to 4 dBm and Class 3 radios capped at 0 dBm. In practice, Classes 1 and 2 make up the vast majority of Bluetooth radios. The range for Class 2 Bluetooth radios was 'defined' early on by the Bluetooth industry group as 10 meters.

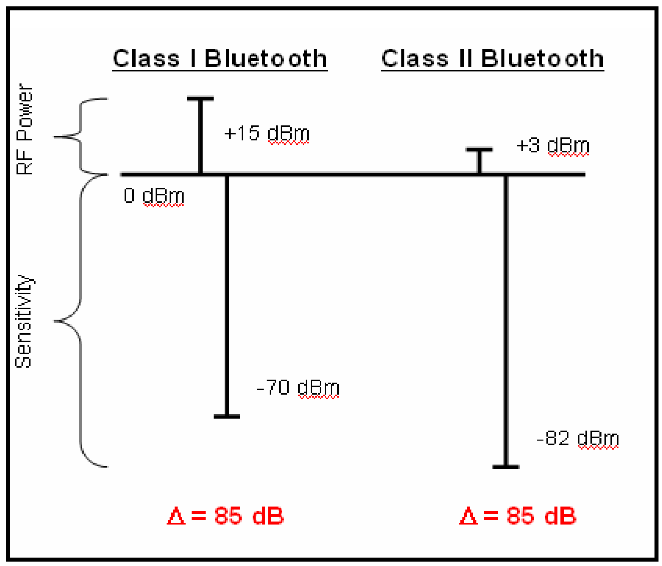

Figure 1. Example of equal performance between a Class 1 and Class 2 Bluetooth radio.

This value assumes a near-worse-case environment for radio range (N ~ 30), an RF power output of ~ 0 dBm and a receiver sensitivity of approximately -70 dBm, which was common among early Bluetooth radios. However, today's Bluetooth radios achieve sensitivities of -80 dBm or better, which increases radio range logarithmically. The benefit of increased receiver sensitivity is apparent in open air line-of-sight range estimations. Motorola's Class 2 Bluetooth scanners and cradles have receiver sensitivities less than -80 dBm.

Test Measurements

Open air measurements of Bluetooth radio range were recorded for the Motorola LS3478 (Class 1 Bluetooth) and Motorola LS3578 (Class 2 Bluetooth) scanners. The experiment included multiple LS3478 scanners and STB3478 cradles, as well as LS3578 scanners and STB3578 cradles. Each device was paired to a specific cradle and a 13 mil UPC barcode was scanned every three feet while the scanner was moved further away from the cradle, which remained in a constant position. The radio range was recorded at the last point that the scanner decoded the UPC barcode and transmitted the data back to the cradle. The cradle was connected to a laptop computer via a USB cable and the barcode information was recorded in a Word document to confirm the decode and transmission of the data. In all cases, both the LS3478 and LS3578 yielded similar radio range, with both products outperforming the Class 1 Bluetooth standard range of 100 meters. Therefore, the conclusion is that Motorola's Class 1 and Class 2 Bluetooth scanners have equivalent performance in an "open-air" environment and exceed the defined Class 1 Bluetooth radio range.

Independent Bluetooth radio range tests were conducted with the same Motorola LS3478 and LS3578 scanners in an indoor office environment. The result of the tests indicate that the performance between the Class 1 and Class 2 Bluetooth scanners is equivalent in a typical office environment, which consists of standard office cubicles and multiple Wi-Fi access points. However, this does not guarantee that the Bluetooth performance between the LS3478 and LS3578 will be identical in all indoor environments, since physical layouts, such as walls and shelving units, will affect the performance of the Bluetooth radio.

Coexistence with WLAN

Another fundamental attribute of Bluetooth is its use of the Frequency Hopping Spread Spectrum (FHSS) technique to avoid interference. Up to 1,600 times per second, the radio changes the frequency used for transmitting and receiving information[2]. All devices in a piconet (i.e. scanner and cradle paired together) are synchronized, so they are always changing frequency in lockstep. The frequencies used by the radios are not arbitrary; rather, the devices in a piconet randomly choose from one of 79 predefined frequencies in the 2.4 – 2.5 GHz spectrum called channels. The 'hopping' between frequencies is entirely handled by the radio itself, and is fully transparent to the user of the scanner.

The Bluetooth radios in the LS3578 scanner and STB3578 cradle utilize Adaptive Frequency Hopping (AFH), which is required for all version 1.2 Bluetooth radios. AFH is an algorithm which detects fixed sources of interference in the allocated Bluetooth frequency spectrum and excludes them from the list of available channels. Although multiple sources of interference exist, the most likely source is an access point or base station for an 802.11b/g wireless network (WLAN). 802.11b/g WLAN networks utilize the same frequency band as Bluetooth (2.4 – 2.5 GHz) and each access point in a WLAN network occupies 22 MHz of spectrum. Most WLAN networks optimized for capacity set their access points to occupy one of three equally-spaced channels within the available 80 MHz of spectrum to minimize interference. Therefore, a maximum of 66 MHz of spectrum can be occupied by the wireless network, if three access points are located in close proximity. A Bluetooth radio used in this environment is the worst-case situation for AFH. Even under these conditions, the AFH would detect or "sniff" interference on 66 of the 79 available frequencies, and operate on the remaining 13 available quiet channels. One main difference between WLAN and Bluetooth, is that the WLAN does not "hop" between frequencies. Rather, it will continuously occupy the same 22 MHz frequency band until the source has been powered down. Therefore, once AFH determines which channels in the frequency spectrum are currently being used, those channels are removed from the hopping sequence, leaving the available channels free to transmit packets of data cleanly.

Although earlier versions of Bluetooth (version 1.0 and 1.1) did not include AFH and had the potential to affect wireless networks working in the 2.4-2.5 GHz frequency spectrum, today's Bluetooth 1.2 radios and beyond are designed to sidestep this interference and allow the two standards to coexist peacefully.

Summary

The radio range achieved by the scanner and cradle is dictated by the path loss of the system, rather than it's classification as Class 1 or Class 2 Bluetooth. As shown in this paper, Motorola's use of a high-sensitivity Class 2 Bluetooth design in the LS3578 scanner and STB3578 cradle does achieve comparable radio range as the previous Class 1 Bluetooth design, utilized in the LS3478 scanner and STB3478 cradle. In addition, the integration of AFH enables the LS3578 scanner and STB3578 cradle to perform robustly in even the most demanding WLAN environments.

References

[1] Symbol Technologies, Inc., "Propagation Data and Prediction Methods for Planning of Indoor Radio Communication Systems and Radio LAN in the Frequency Band 900 MHz to 100 GHz," doc. IEEE 802.15-00/294r1, www.itu.int./itudoc/itu-r/rec/p/1238-1.html, P.1238

[2] Bluetooth Special Interest Group, "Specification of the Bluetooth System, Core Version 1.1," www.bluetooth.org.

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