

# Bluetooth and Wi-Fi coexistence schemes strive to avoid chaos

*Bluetooth and wireless LANs look for the comfort zone as deployment issues for both systems come on-line.*

**By Oren Eliezer and Matthew Shoemake**

**D**ave Rupp is trying to avoid what he calls “chaos-net.” As the worldwide manager of local area network (LAN) services for Texas Instruments (TI), he’s concerned about the coexistence of wireless RF systems. Specifically, he wants to avoid interference conflicts among devices trying to simultaneously access a Bluetooth personal area network (PAN) and a wireless Ethernet LAN (802.11b).

“It hasn’t happened yet because not enough Bluetooth devices are in use,” Rupp said. “Right now I’m trying to figure out when or if it will become a problem, and plan accordingly. My nightmare is that two years from now, a group of managers will

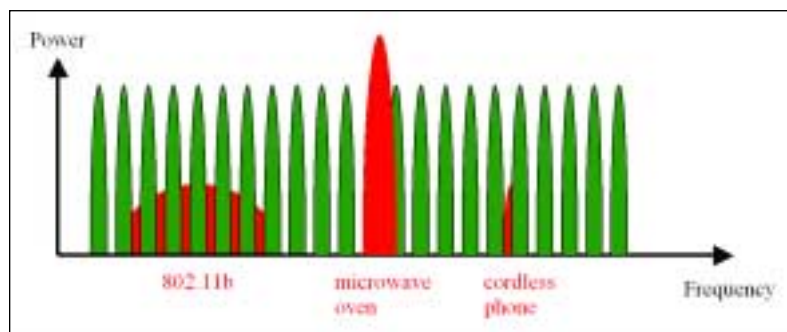


Figure 3a. FHSS channel spectrum power vs. frequency against competing devices.

be in a conference room and they’ll all try to use Bluetooth or access a wireless 802.11b network at the same time. I’m going to get a call that the network is down, but by the time the service technician reaches the site, the meeting will have ended and the network will be back up again. The temporary problem will be gone but it hasn’t been solved.”

Rupp is not the only one thinking about coexis-

tence issues. Formal and informal standards bodies, equipment vendors and component manufacturers are addressing the situation. Several potential solutions are being discussed, although no solution set has been adopted just yet. Still, the technical concepts that have been suggested offer Rupp and other LAN managers a glimmer of hope that Bluetooth, wireless Ethernet and other sources of RF signals can live together in harmony.

## Mutual coexistence

Both wireless Ethernet (802.11b), otherwise known as Wi-Fi, and Bluetooth operate in the unlicensed 2.4 GHz industrial, scientific and medical (ISM) band. This band is 83.5 MHz wide, beginning at 2.4 GHz and ending at 2.4835 GHz. Although the ISM band is unlicensed spectrum, the Federal Communications Commission (FCC) in the United States still regulates its use.

Because Wi-Fi and Bluetooth approach spectrum use in different ways, they can cause considerable interference for one another. 802.11 employs a direct-sequence, spread spectrum (DSSS) technology, while Bluetooth uses a frequency-hopping spread-spectrum (FHSS) technique.

An 802.11b device only occupies about a quarter of the 83.5 MHz bandwidth that’s available in the ISM band, and maintains usage of its frequency band only during the actual transmission of data. After the transmission has ended, the frequency band is available for other devices in the network, as well as other users of the band. In other words, 802.11b devices share the channel on a time-division, multiple-access (TDMA) basis. 802.11b defines 11 possible channels with center frequencies spaced at 5 MHz distances. There is some overlap among the 11 channels.

To avoid interference among co-located Wi-Fi networks, distinct LANs are typically operated on channels 1, 6 and 11 (see Figure 1a). With this configuration, three Wi-Fi networks co-located close to one another would not overlap in frequency and, therefore, would not interfere with each other.

As in 802.11b networks, Bluetooth devices in a PAN also share the Bluetooth channel on a TDMA basis. However, in contrast to 802.11b, the Bluetooth channel is not fixed in frequency because frequency hopping is employed. Bluetooth devices hop in a pseudo-random manner among 79 defined channels spaced at 1 MHz distances (see Figure 1b). In this way, Bluetooth occupies the entire band, but at any instant in time, only a small portion of the band is ever occupied. Bluetooth hops to a new channel in the ISM band about 1,600 times a second.

Typically, 802.11b devices are either incorporated into a PC (desktop or notebook) or act as access points for the Ethernet-wired backbone LAN and the Web. As a result, it is economically feasible and effective from the standpoint of data throughput that 802.11b devices have transmission power levels in the order of 100 mW. At this power level, 802.11b can support 11 Mb/s data transfers over significant distances on the order of 100 meters, depending on the construction

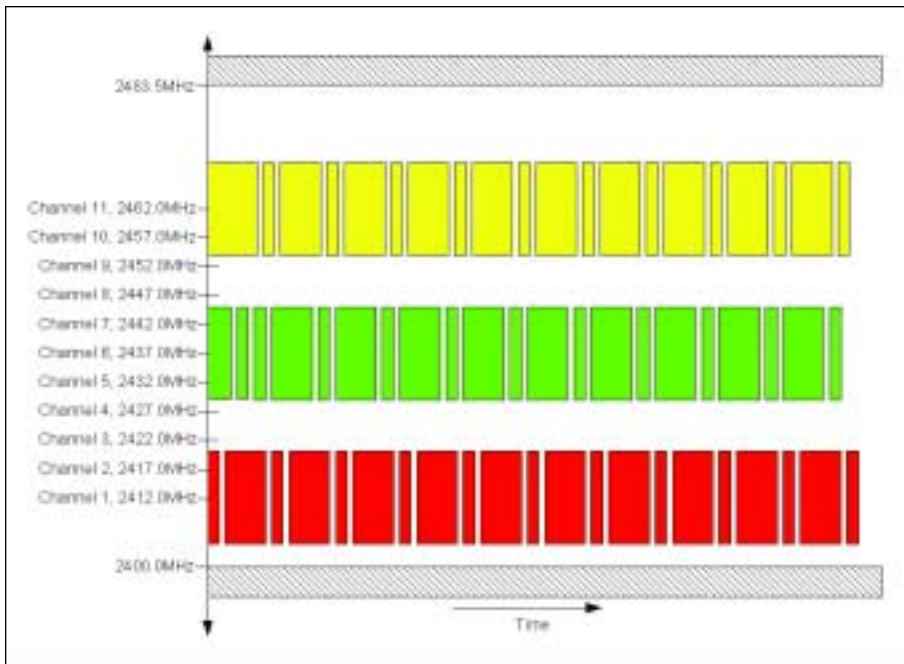


Figure 1a. Time slots and frequency allocation for Wi-Fi networks.

and other environmental factors where the network is installed.

Compared to 802.11b, Bluetooth is a PAN and was intended for short distance communications between devices in a room where a cable had been used. Examples of Bluetooth applications include wireless PDA synchronization and a wireless headset for a cell phone.

Because Bluetooth supports a lower data rate (1 Mb/s), and cost and current consumption must remain within the

range of various low-cost consumer applications, it typically transmits at levels closer to 1 mW. Bluetooth has an option to transmit at higher levels to 100 mW, and this may be found in applications where reaching an extended range to 100 meters is required.

These types of devices are defined as "class 1" devices in the Bluetooth radio specifications. By transmitting at the highest power level, class 1 devices would create more interference than

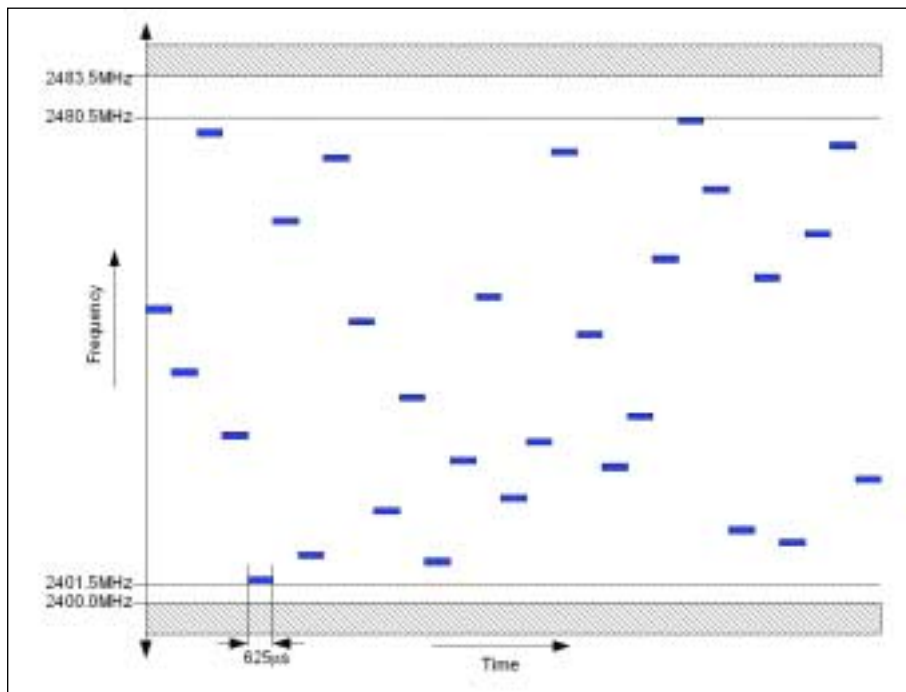


Figure 1b. Bluetooth's pseudo-random hops among its 79, 1 MHz channels.

Bluetooth's class 2 and class 3 devices, which transmit at lower power levels.

Overlaying the spectrum use techniques of Wi-Fi and Bluetooth shows that the two technologies have the potential to interfere with each other, depending on the relative location of the 802.11b and Bluetooth devices. Because each Bluetooth PAN will occupy the entire ISM band, two or more coexisting Bluetooth PANs will occasionally collide, possibly causing loss of data packets.

### Quantifying coexistence

Various experiments have been performed to measure the performance degradation for various coexistence scenarios. As a first step in such an experiment, baseline throughput rates must be established in a clear environment. To do this, a Wi-Fi station and an access point were placed in a room with a clear line of sight between one another and at various distances to 250 feet. The resulting performance was a consistent 5.5 Mb/s of data throughput over the entire range. A similar set-up was used with a Bluetooth master and slave unit to establish a baseline performance rate of about 550 kb/s.

Introducing interference into the experiment degraded these figures significantly. The first set-up established the effects of Bluetooth as an interferer with Wi-Fi. In this case, a Wi-Fi station and an access point were placed in the same positions as the baseline test, except Bluetooth master and slave devices were located within 10 cm of the Wi-Fi station. This clearly represented a worst-case scenario. To determine the effects of distance, the test set-up was changed by moving the Bluetooth devices 30 feet away from the Wi-Fi station. The Bluetooth devices transmitted at 100 mW, while the Wi-Fi devices used a 30 mW transmit power.

The results (see Figure 2-a) showed that the effects of Bluetooth interference on Wi-Fi performance are substantial when the Bluetooth devices are close to the Wi-Fi station. When the Bluetooth devices are moved 10 meters away, the effects of the interference are mitigated.

A similar test set-up was used to determine the effects of Wi-Fi interference on Bluetooth throughput. The Wi-Fi and Bluetooth devices exchanged locations and the results (see Figure 2-b) showed that Bluetooth performance was affected by Wi-Fi interference when the Wi-Fi devices were close to the communicating Bluetooth devices.

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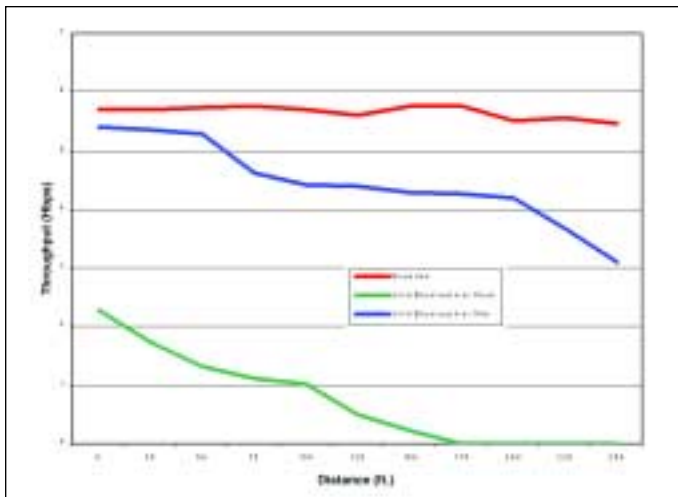


Figure 2a. Effects of Bluetooth interference on Wi-Fi performance (throughput).

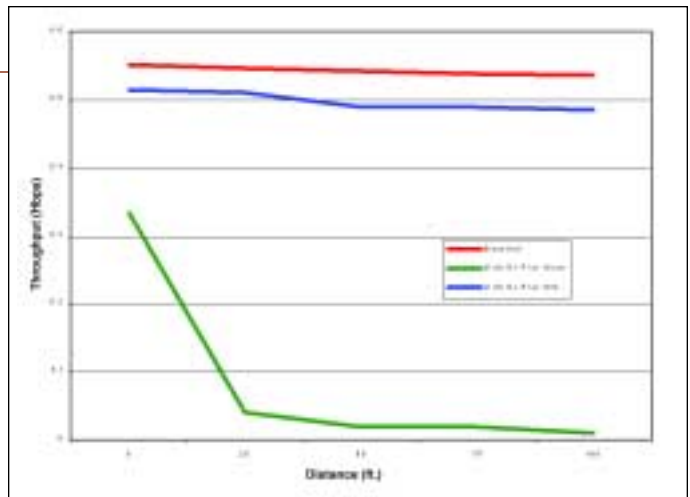


Figure 2b. Effects of Wi-Fi interference on Bluetooth performance (throughput).

When Wi-Fi devices were moved to 30 feet away, Bluetooth's performance was minimally affected, reaching about 90% of the baseline throughput.

These tests demonstrated that Wi-Fi and Bluetooth do interfere with each other. It was also shown that increasing the distance from the source of the interference does mitigate its effects. Unfortunately, in the real world and with the types of mobile applications envisioned for both Wi-Fi and Bluetooth, significant distance from an interference source cannot be ensured or predicted.

It should be noted that the performance measure in this experiment was the data throughput rate. In data communications applications, throughput would be indicative of the actual user-perceived performance or the user experience. However, with voice applications, for example, what may appear to be a slight reduction in data rate throughput may in fact be a significant degradation in voice quality.

Therefore, it is important when conducting experiments and when performing analysis using calculations and simulations, to define the performance measure and its relevance to the user-perceived or user-experienced performance.

### Adaptive Bluetooth solutions

To alleviate potential problems with coexistence interference in the ISM band, various standards bodies, including the IEEE 802.15.2 committee and the Bluetooth special interest group (SIG), are discussing several adaptive technologies.

- *Adaptive frequency hopping*

One such solution, known as adaptive frequency hopping, would involve a change in the Bluetooth frequency-hopping sequence to allow for more flexibil-

ity in the use of the ISM band.

Currently, Bluetooth devices must hop through all 79 channels, regardless of whether another technology, such as 802.11b, a cordless phone or even a microwave oven, is already occupying a segment of the band (see Figure 3a on page 66).

Adaptive frequency hopping would introduce some degree of intelligence into the process, so that a Bluetooth device would analyze the available spectrum and steer the transmission to those channels where interference would not be encountered, or where the Bluetooth device would not cause interference for other users already occupying portions of the band (Figure 3-b).

- *Transmission power control*

Another technique involves adapting the transmit power used by various devices in the ISM band. The reasoning behind the notion of adaptive power control is based on common sense. Transmitting data at a power level above the minimum needed to meet a predetermined level of acceptable data integrity unnecessarily causes interference to other users in the band.

For example, if a Bluetooth device could determine the minimum power level it needs to transmit packets with a certain acceptable received bit error rate (BER), then nothing is gained by transmitting at a higher power level. Exceeding that minimal power level only increases the possibility of interference with other devices in the area, including Bluetooth devices, 802.11b devices and cordless phones.

The current Bluetooth standard calls for a poor receiver sensitivity level of -70 dBm. Most manufacturers have actually reached higher sensitivity levels of -80 dBm without adding unnecessarily to the cost to the system. More

sensitive receivers would allow for a reduction in the transmit power level while maintaining an acceptable signal-to-noise ratio. This would indirectly enhance the system's coexistence performance by making it more "environmentally friendly" in terms of interference caused to others.

Aside from improving the interference conditions in the band, adaptive power control could also reduce the overall power consumed by a Bluetooth device, especially if it is a Class 1 device operating at high power. This would be particularly critical for battery operated mobile or hand held devices because reduced power consumption would extend battery life.

- *Adaptive selection of packet type*

The type of Bluetooth packet being transmitted can also affect coexistence performance. Bluetooth packets can carry various payloads, depending on the number of "slots" in the packet. Packets can occupy anywhere from one to five time slots, according to the Bluetooth specifications. While carrying more than 10 times as much data, a Bluetooth packet with five slots will remain on a certain channel at a certain frequency five times longer than would a one-slot packet, increasing both the vulnerability of this packet to interference, as well as increasing the chance that the transmission will interfere with others sharing the frequency.

A transmitter capable of dynamic packet type selection would determine where and when interference is present in the environment and adapt the Bluetooth packet type accordingly. For example, when little interference is present at the frequency currently reached by the hopping transmitter, longer packet types can be used, so that once a channel has been acquired, more data can be

transmitted. If the interference in the surrounding area reaches a point where packet corruption is unacceptable, an adjustment to a shorter packet type could help ameliorate the conditions.

Reducing the packet type to one slot, for instance, would reduce the vulnerability of any one packet to interference because the packet would have a shorter duration. This would improve the

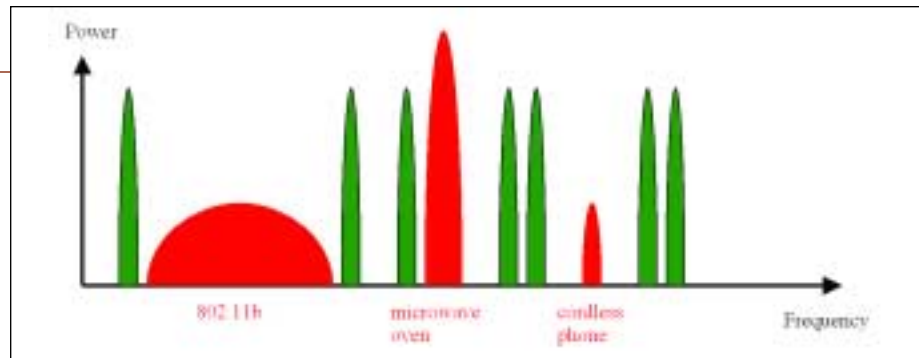


Figure 3b. Adaptive frequency hopping intelligent spectrum usage.

chances that a particular packet would be accurately received.

Research has shown that shorter Bluetooth packets can improve data throughput in an environment with interference. A throughput tradeoff arises from the higher level of overhead that must be processed with shorter packets, including additional address and packet header processing, and the dead time between hops that is needed for synthesizer and transmit/receive switching. A point of diminishing returns is reached where the overhead of processing a greater number of smaller packets counterbalances the performance improvements of the shorter packets.

#### Factors affecting coexistence

Aside from adaptive solutions that act as coexistence performance-enhancement mechanisms, a number of factors will affect the interference present in a given environment and the degree to which this interference will affect the user-perceived performance of the wireless communications.

The most dominant factor in determining performance in a coexistence environment will be the applications that are operating in that environment. For example, the quality of a voice conversation over a Bluetooth link is more susceptible to coexistence interference than a data transmission.

When compared with the short PDA sync. session, for example, the duty cycle or duration of the transmission of a voice conversation will make it more likely to cause interference with other applications existing in the same area. But even then, the interference level for a voice conversation should not be seen as a problem until it reaches a level in which a typical user perceives degradation in performance. Measures of performance used by designers, such as BER and signal-to-noise (S/N) ratios, should be of less concern than whether the quality of a typical user conversation is compromised by poor performance.

Several groups in the industry have

suggested application-specific coexistence improvements. Because of the importance of voice as a primary application for Bluetooth, Proposals for enhancement to the Bluetooth protocol to better facilitate voice conversations over Bluetooth have been introduced by one or more players.

One proposal suggests an adaptive algorithm could be used to select transmission slots best suited to a voice conversation at a reasonable quality level. Other existing proposals would improve the interference resistance of Bluetooth and Wi-Fi in certain applications.

### 802.11b solutions

Coexistence solutions for 802.11b have also been discussed in the industry, and these solutions are similar to the adaptive Bluetooth techniques.

As was previously described, many Wi-Fi installations try to avoid coexistence interference by configuring multiple 802.11b channels. In the example cited previously (see Figure 1-b), three channels centered on channels 1, 6 and 11 were configured. An 802.11b access point would typically be assigned to a certain channel, and this would not change without intervention by the LAN administrator.

Dynamic channel selection would allow the access point itself to determine which channel is best suited for communications at any point in time. An intelligent access point could evaluate any of several criteria to determine which 802.11b channel to use. For example, when Wi-Fi devices communicate, packet error rate measurements are compiled on each channel. A high packet error rate on a certain channel could cause the dynamic selection of an alternative channel. By detecting interference on Wi-Fi channels, a channel with high noise content can be avoided. Likewise, multipath propagation and intersymbol interference are monitored and can form the basis for dynamic channel selection.

Without having to communicate with other Wi-Fi devices, an 802.11b access point can measure the signal strength of the interferers on the channels. This can be determined by monitoring the setting of the automatic gain control on each channel. When the interferers on a channel rise above a certain level, the access point can dynamically select another channel with conditions more favorable to communications.

Another technique that has been put forward to help Wi-Fi networks cope with coexistence interference is adap-

tive packet fragmentation. Because the length of 802.11b packets need not be the maximum length for each transmission, fragmented or shortened packets can be used to overcome the effects of coexistence interference. With shorter packet lengths, less data must be retransmitted when a packet transmission fails because of interference.

Experiments have shown that in an interference-challenged environment, shorter packet lengths will increase data throughput. Of course, adaptive 802.11b packet fragmentation comes with the same sort of performance tradeoff that occurs with shorter Bluetooth packets. Shorter packets cause added overhead processing and this eventually counterbalances the performance gained by using the shorter packets.

Similar to what has been described for Bluetooth, transmission power control can minimize the interference caused to other users while 802.11b communications are taking place. Here too, the optimal transmission power would be the minimum level necessary to maintain a predefined level of data integrity.

In practice, power control may not be able to operate at the rate at which channel conditions fluctuate, especially when rapid physical movement is involved. When this happens, it would be necessary to maintain some reasonable fading margin above the minimal level, and this power margin would be wasted or unnecessary when transmitting devices were not moving rapidly through the environment.

### Collaborative solutions

Coexistence interference problems are exacerbated when 802.11b and Bluetooth transmitters and receivers are placed close to one another. A prime example of this, and one that will soon have profound effects on the market, is a laptop PC equipped with both Bluetooth and 802.11b. The laptop might use Bluetooth for wireless connections to an external mouse, printer or other peripheral devices, for example, while the 802.11b link would provide access to the enterprise LAN. Because 802.11b and Bluetooth would be housed inside the compact confines of the same laptop PC, the likelihood of coexistence interference is almost assured.

But having Wi-Fi and Bluetooth in the same computer also allows for collaboration between the two networks. The computer itself can supervise the

operations of the two wireless systems. For example, a communications management subsystem could operate a reservation system for transmit and receive slots in the channel access timing. The laptop could also be equipped with a simple scheme that would establish virtual connections for those instances when conflicting communication reservations between Wi-Fi and Bluetooth came about.

The objective of any collaborative coexistence scheme must be to maximize the throughput of both Bluetooth and Wi-Fi, while prioritizing them based on the sensitivities of the applications they are serving at a given time. For example, voice communication would typically have a high priority in terms of the instances its transmissions must access the channel. At the same time though, fair access to communication channels must be maintained, while avoiding long and intolerable delays in transmitting or receiving packets.

### Rising to the top

The many suggestions, recommendations and proposals for 802.11b and Bluetooth coexistence solutions have come out of much in-depth discussion and research by ad hoc and formal industry groups, such as the IEEE 802.15.2 coexistence task group and the Bluetooth SIG. Undoubtedly, the development work and research will continue until the optimum solutions rise to the top in the near future. Then that glimmer of hope for coexistence harmony will have become a bright reality.

**RF**

### About the author

Oren Eytan Eliezer is chief engineer of Texas Instruments' Short-Distance Wireless Business Unit. He has 13 years of wireless experience. Eliezer received a master's degree in electrical engineering from Tel Aviv University in Israel. Currently, Eliezer is an active contributor in coexistence related industry bodies.

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