SPLY005 – November 2003
White Paper

The Effects of Adjacent Channel Rejection and Adjacent Channel Interference on 802.11 WLAN Performance

The escalating deployment of wireless networking technology as well as other wireless technologies in the same unlicensed spectrum is rapidly increasing the radio frequency (RF) interference for Wi-Fi® (802.11) products, threatening the data throughput performance of wireless local area networks (WLAN). At the same time, the market is demanding higher data throughput rates for new WLAN applications like multimedia audio and video, streaming media, voice over WLAN, and others that require quality of service (QoS) capabilities and low packet error rates. As a consequence of an increasing amount of in-band and adjacent band interference in the environment for WLAN equipment, the design of radios and digital filtering has become critical. This white paper analyzes the sources of adjacent channel interference (ACI) and the radio design practices that can improve a WLAN's adjacent channel rejection (ACR) for better overall performance.

Overview

The problem of ACI and a need for improved RF receiver performance for Wi-Fi and WLAN technology in both the 2.4 GHz and 5.x GHx unlicensed bands has come to the attention of manufacturers, system designers, integrators and the Federal Communications Commission (FCC). In fact, when the FCC released an additional 250 MHz of spectrum for 802.11 WLANs starting at 5.4 GHz, it noted that regulatory changes soon may be needed in WLAN's crowded band of the spectrum. The FCC may soon issue a "Notice of Inquiry" (NOI) that would gather information on the possibility of establishing a governmental standard for radio receiver design in this spectrum.

What's at Stake?

Future WLAN market growth could be adversely affected unless the interference problem is addressed. Currently, the performance of a WLAN access point (AP) or client station can be interfered with by other WLAN APs and stations in close proximity to it and other non-802.11 devices which operate in the same unlicensed band. The situation is similar to that which the cellular telephone industry faced and solved with channel frequency reuse solutions. As the 802.11 market grows and the density of WLAN technology increases, the problem will be exacerbated in applications such as the following:

- Corporate/enterprise deployments
- Dense commercial hot-spot deployments (strip malls, etc.)
- Residential apartment building deployments
- High density urban deployments

The performance of WLANs can be hampered by a number of sources of interference, including the following non-802.11 equipment:

- Cordless phones (2.4 or 5.x GHz)
- Bluetooth™ personal area networking devices (2.4 GHz)
    - Bluetooth wireless headphones are a special case
- Pulse radar (Using the 5.4 GHz band for pulse radar is under review in the U.S.)
- Microwave ovens (50 percent duty cycle creates pulse jamming in the 2.4 GHz band.)
- Low energy RF lighting sources (2.4 GHz)

- Spurious RF noise in integrated devices, handsets and PDAs with multiple wireless technologies including cellular, Bluetooth and WLAN
- Wideband 5 GHz equipment for the emerging "world band" requirements

Interference can also emanate from adjacent channels. When this is the case, the design of an 802.11 system's RF sub-system and digital filtering can greatly affect the performance of the AP or station. Moreover, the physical design of a WLAN network can overcome many of the repercussions of in-band interference. The performance of a WLAN is often determined by the signal-to-interference ratio (S/I or SIR), which is defined as the ratio of the data signal to the interference signal. SIR is usually more critical to WLAN performance than the signal-to-noise (SNR) ratio. Figure 1 below illustrates this concept.

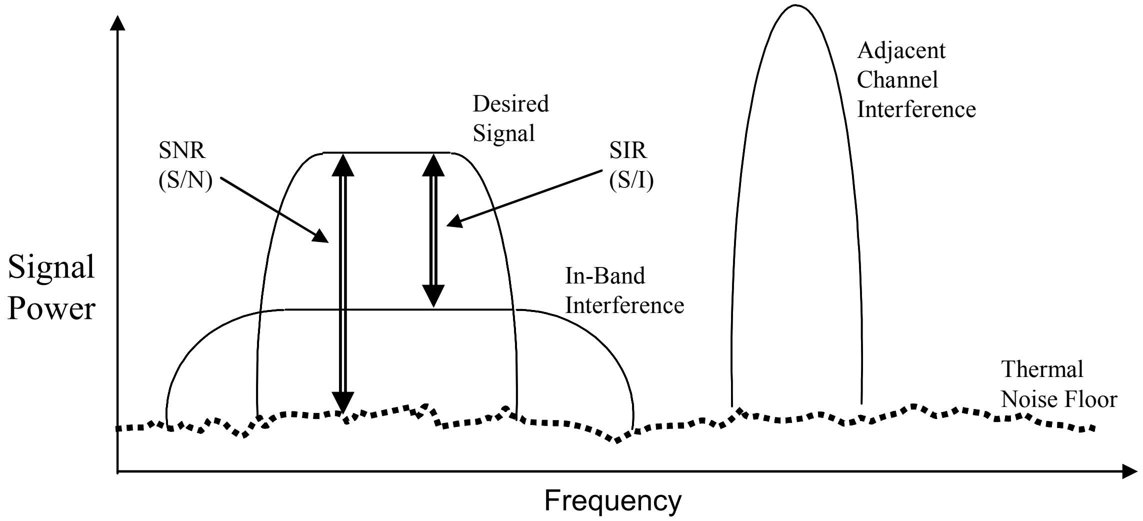


Figure 1 -- Interference Patterns

Obviously, the signals generated by commercially available wireless equipment are by no means perfect. Indeed, the signals from 802.11 radios generate some amount of energy outside of their approved spectrum band. This is called side band emissions. This also is true of other wireless devices, such as Bluetooth, cordless telephones and others which occupy the same band as 802.11. Although filtering is usually done to minimize RF interference from adjacent channels, this interference also generates side lobe energy that falls into the pass band of 802.11 WLAN signals. If the ACI is much stronger than the 802.11 signal, side band energy from the ACI can dominate the channel's noise floor. This is shown in Figure 2.

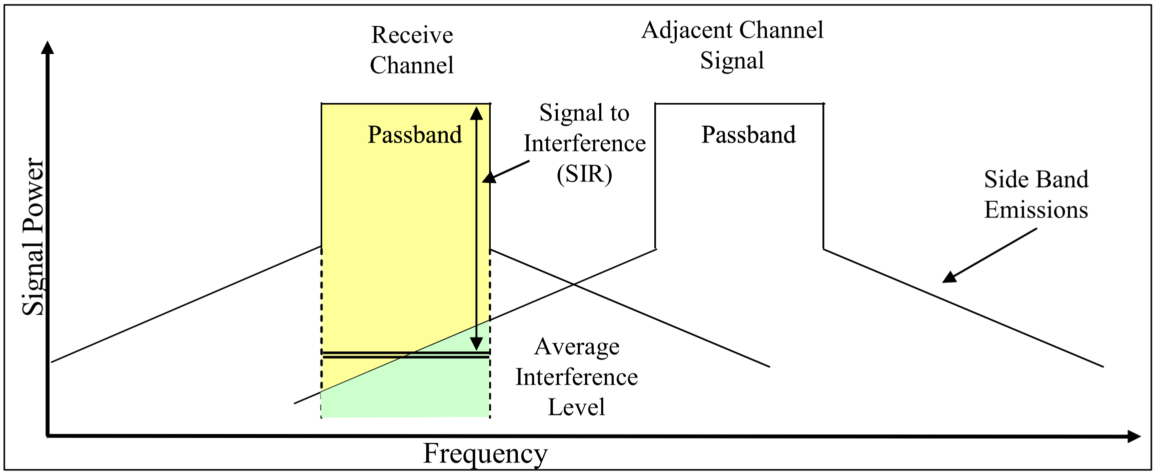


Figure 2 -- Dominating Side Band Interference

WLAN RF receivers can be designed with effective ACR for narrow band signals which are approximately 0.10 the bandwidth of 802.11 signals. These narrow band signals include cordless phones and Bluetooth signals. However, wide band ACI generates significant side band energy which falls into the pass band of an 802.11 receiver. Under these conditions, the amount of link margin, or the size of the SIR, will have a decisive effect on the data throughput of the WLAN.

There is a growing trend in the wireless industry to provide 5.x GHz radio architectures that span all of the possible frequencies in the unlicensed band around the world. The following diagram (Figure 3) shows how these so-called "world band" radios operate from 5.150 GHz to 5.875 GHz. This range can be expanded to 4.9 GHz to 5.875 GHz if the Japanese allocation, which will be available in 2007, is included. Given certain sources of high-power interference in this band, such as radar and navigation systems, a world band radio will need some level of filtering for channel selectivity to avoid any performance degradation caused by these sources of high-energy interference.

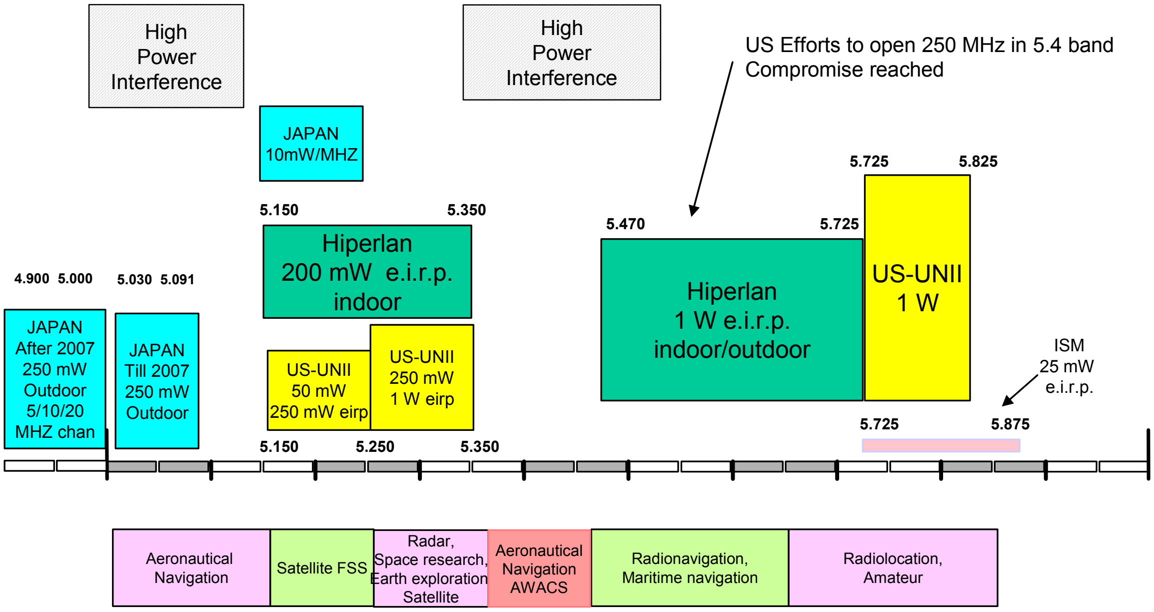


Figure 3 -- World Band Spectrum

With the previous discussion as background, the remainder of this white paper will address the following:

- RF receiver designs for adjacent channel rejection (ACR) of interference.
- ACR filtering techniques that can be implemented in embedded applications where Bluetooth and 802.11 technology coexist in the same product platform. Special emphasis will be given to problems that are encountered in wireless headsets.
- In-band interference that is generated from adjacent 802.11 cells in dense subscriber environments.

Receiver Design for ACR

The ability of an RF system to reject interference emanating from adjacent channels is highly dependent upon the receiver architecture. Several receiver architectures are in use, but, because the direct conversion (DC) and dual conversion or super heterodyne (super-het) architectures are the most prevalent in WLAN systems, this white paper will limit its analysis to these two architectures.

To design effective ACR into a WLAN receiver, two critical points in the receiver chain must be considered. These two points are the following:

- The input signal saturation level of the low noise amplifier (LNA) and IP3
- The signal level presented to the analog-to-digital (A/D) converter in the system's digital baseband processor

The input level of most LNAs in 802.11 systems saturates at around -20 to -30 dBm. In the presence of strong input signals above this level, the LNA will cease providing gain and actually inject non-linear distortion into the signal. A well-designed LNA can operate up to an input level of -10 to -15 dBm. Some systems are able to bypass the LNA when the input signal exceeds -10 to -15 dBm. This allows input signals up to +4 dBm, but the tradeoff is lower receiver sensitivity.

At the other end of the RF processing chain from the LNA is the input to the system's A/D converters. These converters have a limited dynamic range. As a result, failure to filter out ACI will cause the digital noise floor to dominate the received signal. Assuming that the WLAN radio is designed with at least 20 dB of digital filtering, the ACI noise and the 802.11 signal should be the same in terms of signal power (equal power point) at the A/Ds.

Table 1 below contains examples of the sources of interference in the 2.4 GHz band. The effective interference figures in this table (column 5) illustrate why the saturation point of the LNA is so critical.

Interference Source	Frequency	Interference PWR (dbm)	Interference Isolation/ Loss (db)	Effective Interference (dbm)	Modulation	BW (MHZ)	ACR for -80 dbm WLAN
BT 1.2 (adaptive Hopper) Controlled	2.4 ISM	0 to +4	By control & isolation -15 to -19	-15 Possible LNA saturation	GFSK	1	65 dB
BT 1.2 adaptive) No Control	2.4 ISM	0 to +4	By control & isolation ~-10 dB	-10 to- 6 LNA Saturation (note 1)	GFSK	1	65 dB (15 dB sens. loss)
Cordless Phone (CT2)	2.4 ISM 5.1-5.3 5.8	+20	Distance > 0.5 meter -34	-14	GFSK	1	66 db
Legacy 802.11 FH (Adaptive)	2.4 ISM 5.8 GHz	+20	Distance > 0.5 meter -34	-14	GFSK	1	66 dB
Cordless Phone (DSSS)	2.4 ISM 5.1-5.3 5.8	+ 20	Distance > 0.5 meter -34 (note 2)	-14	DSSS	~5 MHz	66 dB
Microwave oven and other misc. ISM Sources	2.4 GHz	+20	< 0.5 meter -34	-14	arbitrary	arbitrary	66 dB

Table 1 -- Interference Sources in the 2.4 GHz Band

Most of the sources in Table 1 are narrow band devices such as cordless telephones or Bluetooth products. In many cases, these sorts of products can be operating within a meter or less of a WLAN client device. Even with propagation losses, these sources of interference can provide signal levels as high as 0 dBm to the LNA at the end of an 802.11 receiver chain, but their signals typically are in the -15 to -20 dBm range.

802.11 Receiver Architectures

Figure 4 below contrasts the differences between a super-het and DC receiver architectures. This example assumes strong adjacent narrow band interference of -15 dBm from a cordless phone and a goal of -80 dBm for the received WLAN signal level. That's a difference of nearly 65 dBm in received power between the interference and the WLAN signal. This type of scenario could readily occur. For example, someone could be working on a portable computer connected to the local WLAN while talking on a cordless telephone.

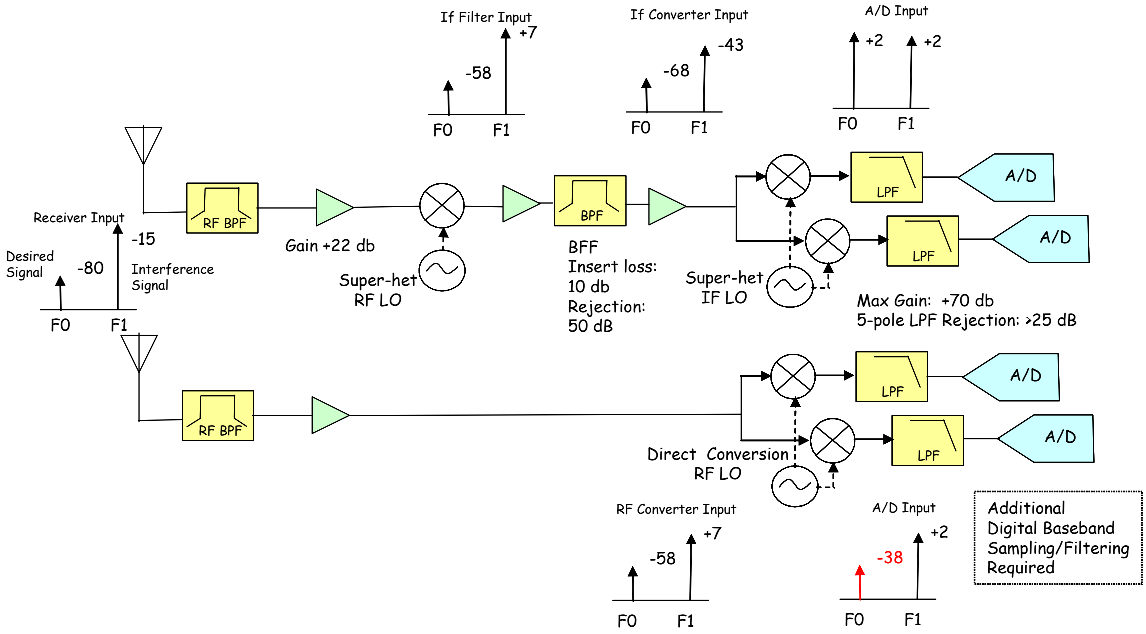


Figure 4 -- Super-het vs. DC Architectures

Figure 4 shows that the filtering of the super-het receiver architecture reduces ACI to an acceptable level. Under conditions with at least 20 dB of digital adjacent channel filtering, the super-het receiver should be able to receive an 11 megabits per second (Mbps) CCK or 22 Mbps PBCC 802.11 Wi-Fi signal with no increase in packet error rate.

With the DC architecture, the surface acoustic wave (SAW) filter at the intermediate frequency (IF) is removed, resulting in an interference signal at the A/D converter in the receiver chain that is 40 dB stronger than the acceptable level. With over sampling at the A/D and recursive decimation filtering, the 802.11 signal still could be recovered. For example, GSM receivers use DC architectures and provide nearly 80 dB of ACR by over sampling the approximately 300 KHz bandwidth GSM signals at around 26 MHz. Unfortunately, over sampling by a factor of almost 100 is possible for narrow band signals like those of GSM, but it is impossible for wider band signals like those of 802.11 because of limitations in technology and low power consumption as dictated by battery-operated products.

Figure 5 below shows the effects of strong ACI at the A/D converter. The high level of ACI results in a noise floor that dominates the 802.11 channel's SIR, reducing WLAN signal strength by causing processing artifacts and quantization.

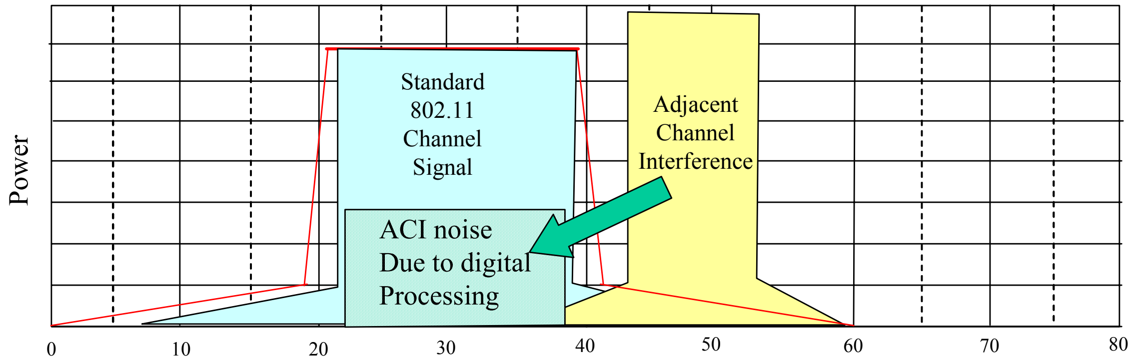
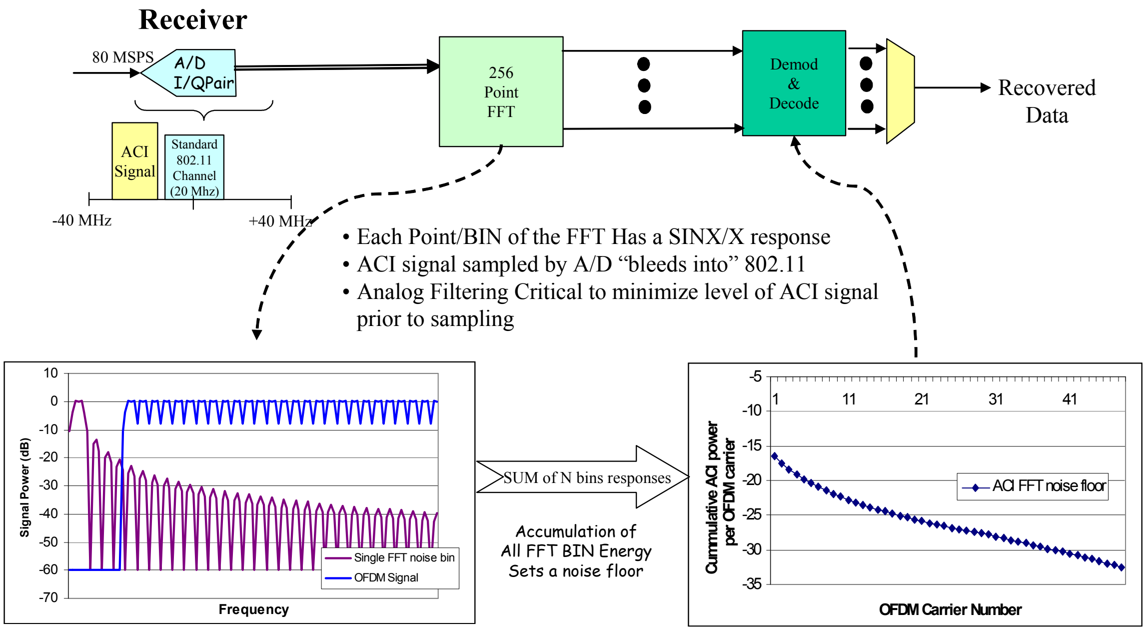


Figure 5 -- ACI-induced High Noise Floor

For WLANs that have implemented the OFDM modulation scheme, the fast Fourier transform (FFT) in the receiver chain typically has leakage from one frequency bin into the others and vice versa. This results in an average out-of-band rejection floor of around 25 dB. Figure 6 illustrates the SinX/X response of each FFT bin.



- Each Point/BIN of the FFT Has a SINX/X response
- ACI signal sampled by A/D "bleeds into" 802.11
- Analog Filtering Critical to minimize level of ACI signal prior to sampling

Figure 6 -- 802.11 Receiver Chain with OFDM Demodulation

While beyond the scope of this white paper, it is noteworthy to point out that ACR filtering in an 802.11 receiver chain reduces power consumption because the sampling rate of the A/Ds in the baseband processor can be reduced. Instead of sampling at a higher rate, the burden is placed on additional analog filtering to meet the requirements of anti-aliasing. This anti-aliasing issue is particularly critical in so-called world band radios in the 5 GHz band because the front end for these radios is a signal nearly 1 GHz wide. That means that hundreds of megahertz of spectrum is presented to the A/D converter in the receiver chain. Included in this signal can be high-power pulse radar signals, which will dominate the receiver chain.

Bluetooth and WLAN Coexistence Issues

Convergence has been a major trend in electronics for some time now. In the cell phone and PDA markets this means converged handsets, smartphones, wireless PDAs and multimedia devices which include three wireless technologies: cellular telephony, 802.11 Wi-Fi WLAN and Bluetooth. Many experts predict the availability of cost-competitive converged devices such as these as early as 2004. This new breed of mobile handheld devices will emphasize multimedia applications such as MP3 music, streaming video and others. To provide a compelling user experience, these new devices must be able to take advantage of the increased data rates provided by next-generation cellular protocols and infrastructure, as well as high-speed WLAN connections. Wireless Bluetooth headsets and other types of peripherals will add to the convenience and ease-of-use of these devices.

Figure 7 below illustrates how these types of devices may be used in a WLAN hotspot. In this scenario, the user could be communicating over a voice-over-IP (VoIP) connection via the WLAN or might be downloading an MP3 or streaming video file through the device's 802.11 modem. In addition, the converged device might be connected to a Bluetooth headset for private listening.

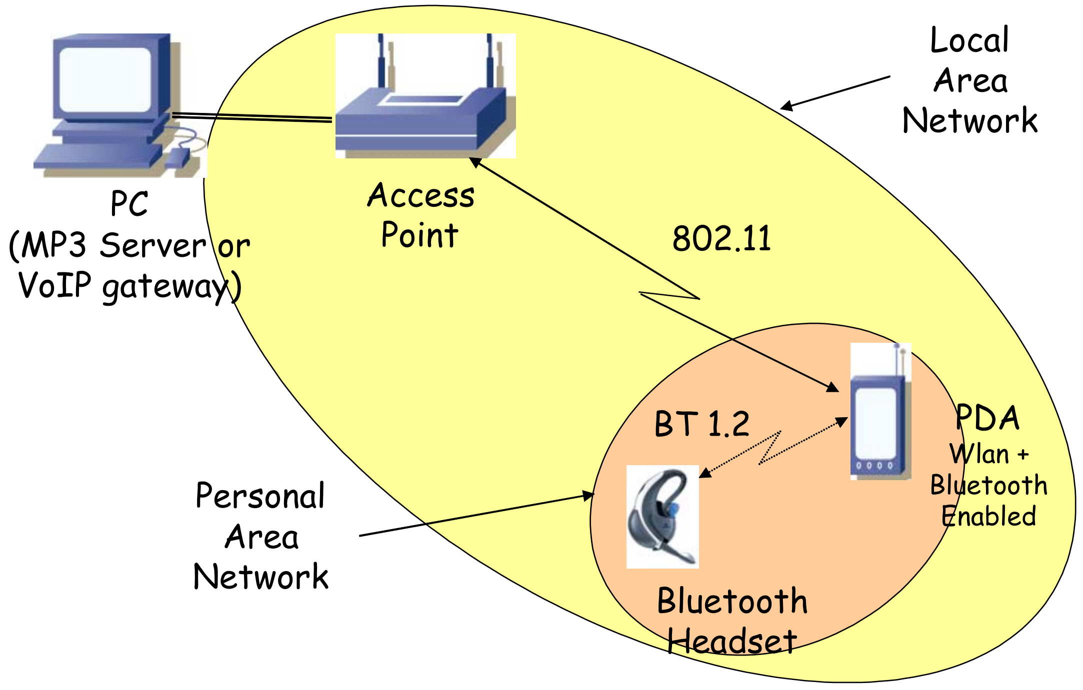


Figure 7 - A Typical Scenario for Next-Generation Converged Mobile Devices

The type of scenario portrayed in Figure 7 soon will be played out in the marketplace, but coexistence solutions will be needed for users to take full advantage of all of the wireless technologies in this application. Because they operate in the same unlicensed band, Bluetooth and WLAN modems in a converged cell phone/PDA device could interfere with each other. In addition, other 802.11 client devices in the area will be contending for access to the same WLAN access point as the converged cell phone/PDA.

The only coexistence solution prescribed in the current 1.0 generation of the Bluetooth standard would require that Bluetooth and a WLAN share the system's media access controller (MAC) function so that when either WLAN or Bluetooth were transmitting, the other would be idle. After monopolizing the MAC for a predefined period of time, Bluetooth or WLAN would give up control of the MAC to the other technology.

In an environment where traffic on the WLAN is light and there is minimal QoS activity, this sort of MAC time-sharing arrangement could avoid co-existence interference problems between the WLAN and Bluetooth while providing acceptable performance. In this type of environment, WLAN access points could implement aggressive auto-request protocols to re-transmit lost or delayed packets. Unfortunately, as advanced power savings techniques are deployed and demand for QoS services increases, the performance within a WLAN's access point (AP) cell will deteriorate rapidly.

Exacerbating the coexistence situation between WLAN and Bluetooth is the fact that an 802.11 AP cannot sense that associated clients are experiencing any non-WLAN interference from Bluetooth devices or cordless telephones, for example. Programming the AP with queuing algorithms or scheduling routines for applications requiring QoS capabilities would not alleviate the problem of in-band interference because APs do not realize that interference is present and as a result can not schedule around it.

Even if the AP is equipped with 802.11's automatic response queue (ARQ) capability, the link would only be able to tolerate errors on the order of five percent. As this point is approached and exceeded, packet queues at the AP must increase in size so they can store and re-assemble packets that arrive sporadically. Typical multimedia applications which require QoS capabilities like high-quality audio or MPEG2 video would quickly violate the 802.11 standard's definitions for QoS. As an alternative, ARQ could be dropped from the links requiring QoS, in which case voice performance would be somewhat acceptable with a packet error rate of less than two percent, but the performance of any type of streaming media would be unacceptable.

It must be remembered that a WLAN client in transmit mode uses only a small portion of the bandwidth of an 802.11 WLAN. A typical rule of thumb is that 80 percent of a client's active WLAN time is spent receiving, while only 20 percent is spent transmitting. When transmitting, the client typically sends short acknowledgement packets to the AP. File transfers from clients are the exceptions to this rule, but these are always broken into packets no larger than 1,500 bytes and they are transmitted at the 'available bit rate' (ABR).

By applying this information and other characteristics of 802.11 operations to the example of the converged WLAN/Bluetooth PDA illustrated in Figure 7, the conclusion is reached that simultaneous WLAN and Bluetooth operations is required in an environment where the WLAN APs are moderately loaded. The analysis substantiating this statement is as follows.

The Bluetooth headset connected to the wireless PDA shown in Figure 7 has a maximum link bandwidth of 700 Kbps with no protocol overhead. If the PDA's user is playing a streaming MP3 audio file from a server on the Internet, this application will require approximately 128 Kbps of the total Bluetooth bandwidth of 700 Kbps. The Bluetooth signal will be on the air 18 percent of the time. In contrast to this, this same application will only consume 128 Kbps of the PDA's WLAN bandwidth of 11 Mbps. In addition, 802.11 operations will involve the transmission of acknowledgements (ACK) while receiving the MP3 stream. These ACKs will amount to about 1/16th of the bandwidth of the WLAN. In other words, the client will spend less than 0.1 percent of the time performing 802.11 transmissions.

If WLAN and Bluetooth transmissions block or interfere with each other, then Bluetooth will interfere with WLAN transmissions 18 percent because Bluetooth is on the air for that much of the time. Conversely, WLAN transmission will interfere with Bluetooth transmission less than one percent of the time. This leads to the conclusion that with a moderate amount of AP loading, Bluetooth transmissions must be able to take place while WLAN signals are being received -- or, simply stated, the PDA's Bluetooth and WLAN capabilities must be able to operate simultaneously.

The question then becomes: in a converged device with WLAN and Bluetooth, can the WLAN capability continually receive downloads from an AP regardless of the operating mode of the device's Bluetooth subsystem? With careful design, planning and deployment decisions for the Bluetooth implementation, the answer is yes. First, designers must take advantage of both the power control (Class 3 device) features of Bluetooth 1.2 as well as Bluetooth's adaptive frequency hopping (AFH). Figure 8 below shows how AFH avoids direct in-band interference with WLAN operations.

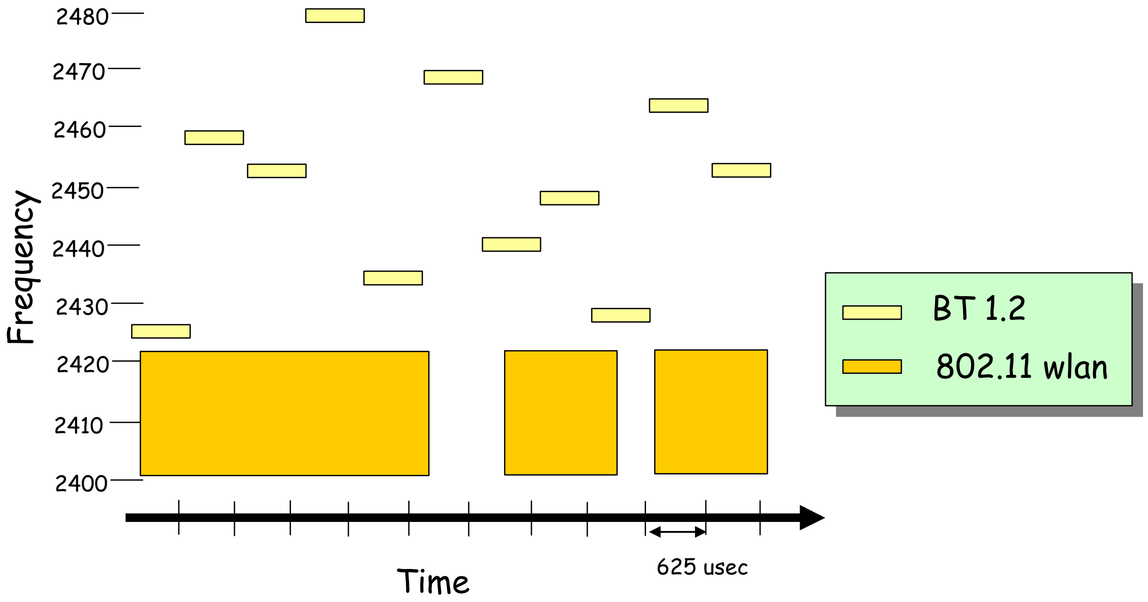


Figure 8 -- Bluetooth's AFH Avoids Interference with WLAN Operations

If the system were to deploy power control techniques, the Bluetooth power at the LNA in the receiver chain will be proportionately lower, as will the level of Bluetooth's side band energy that falls into the 2.4 GHz band regardless of the ACR filtering. Propagation losses of -40 to -50 dBm could be expected for the Bluetooth signal. This would result in Bluetooth transmitted power in the range of -25 dBm to -15 dBm in order to maintain a low error rate in the link. Figure 9 illustrates how power control techniques can reduce spectrum emissions in a Bluetooth channel.

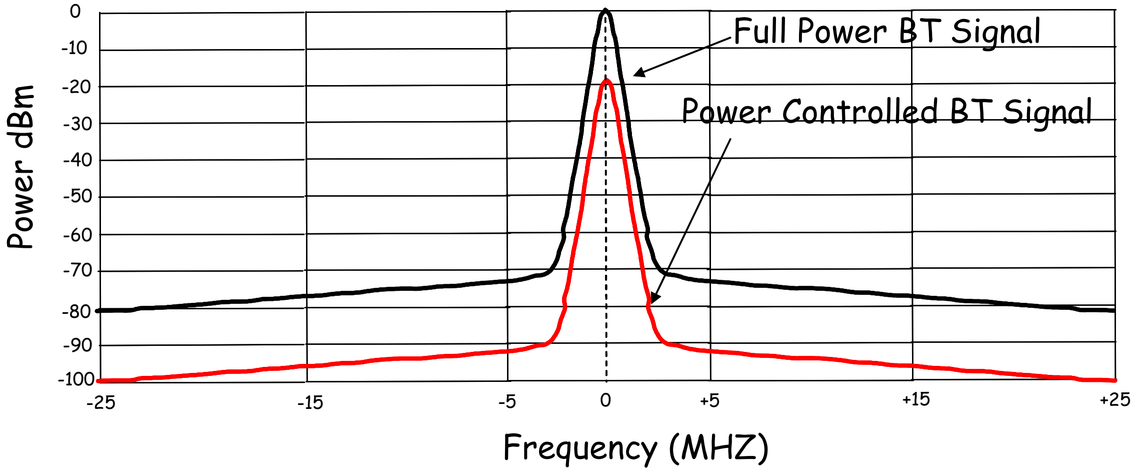


Figure 9 -- The Effects of Power Control on Bluetooth Signaling

An examination of a handheld device with both Bluetooth and 802.11 and certain other operating characteristics further illuminates the question of coexistence. In this example, the assumptions are that the handheld device has a 0 dBm Bluetooth transmitter and a 802.11 receiver with either of the following qualities:

1.) Power control techniques can provide 20 dB of isolation between Bluetooth and WLAN.
2.) There is 0 dB of isolation between Bluetooth and 802.11, but the system has the ability to switch out the LNA in the RF receiver chain. The system does not have power control capabilities.

For the sake of simplicity, this discussion is limited to a receiver design with the super-het architecture. Figure 10 shows that in either case, the receiver can operate. In the first case listed above, where there is 20 dB of isolation between the device's Bluetooth and WLAN, the receiver must have at least 15 dB of digital filtering. In the second case, where there is no isolation between Bluetooth and WLAN, 30 dB of filtering and digital gain must be present. An alternative for this second case would be to limit the receiver to 802.11 signals greater than around -60 dBm, where there would be no requirement for special filtering.

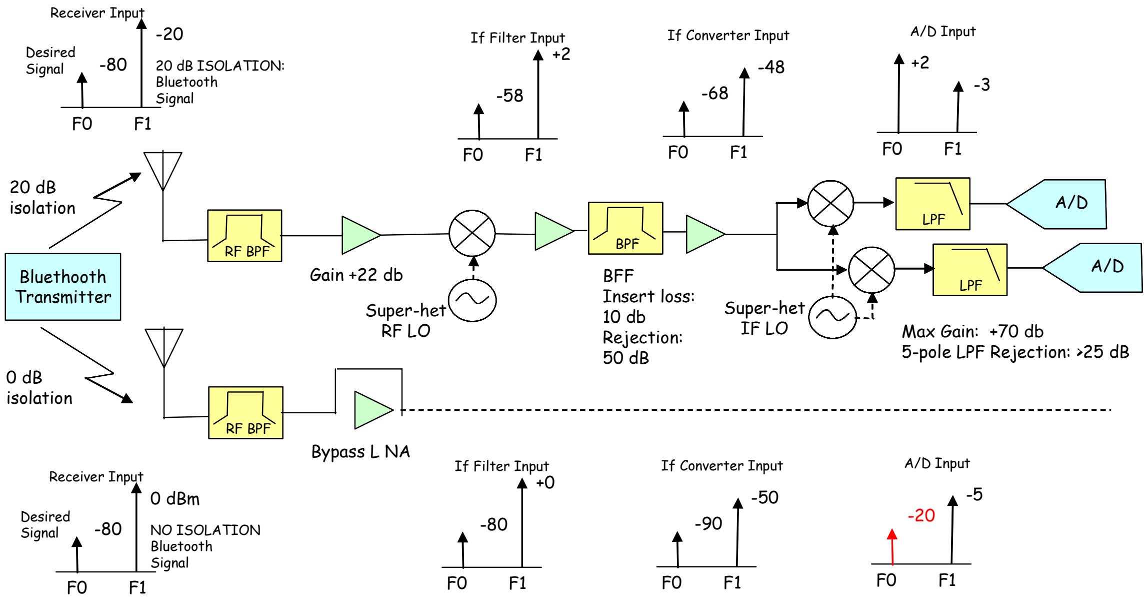


Figure 10 -- 802.11 and Bluetooth Coexistence Requirements for a Super-het Receiver

This example shows that a super-het receiver with 20 dB of isolation derived from power control techniques can achieve continuous operation of 802.11 and collated Bluetooth. If MAC-level time coordination between Bluetooth and 802.11 were added to the system, WLAN transmission interference could have minimal effects on the Bluetooth transmitter. This would allow for nearly flawless simultaneous Bluetooth and WLAN operations with practically any traffic load or coverage demands on the WLAN cell.

In-Band Interference and Link Budgets

In-band interference and the effect it has on limiting a WLAN's RF links is discussed in this section. For illustrative purposes, the interference caused by two 802.11 access points is briefly described, but this analysis could just as well be applied to in-band interference from Bluetooth, cordless telephones or microwave ovens.

The signal propagation losses for an 802.11 AP will depend on the environment, but, generally speaking, signal loss is a function of distance from the AP to the user. Under ideal line-of-sight conditions, signal loss is proportional to the square of the distance (R^2). More typical in real-world environments, signal loss can be described as the cube of the distance (R^3). Under adverse conditions, signal loss is usually equal to the distance raised to the fourth power (R^4).

The range of a particular 802.11 AP also is a function of several other factors, including the AP's transmit power, which is typically 20 dBm, antenna gain and the sensitivity of the receiver for a certain modulation. For the purposes of this example, the antenna gain is assumed to be 0 dB as it would be for a typical omni antenna. More complex modulation schemes require a stronger signal-to-noise (SNR) ratio for an 802.11 signal to be received at a certain bit error rate (BER). To achieve a higher SNR, the receiver must have greater sensitivity and/or the range of the transmitted signals must be proportionally shorter.

Table 2 below shows how the different modulation schemes for 802.11g and 802.11b affect SNR, receiver sensitivity and signal range. Note that 802.11b with CCK modulation has the equivalent SNR as 802.11b with PBCC modulation.

			Link distance at 20 dbm TX power (m)		
Modulation	SNR, dB	Sensitivity, dbm	R^2 loss	R^3 loss	R^4 loss
54 MBPS QAM OFDM	26	-68	251.2	39.8	15.8
48 MBPS QAM OFDM	25	-69	281.8	43.0	16.8
36 MBPS QAM OFDM	21	-73	446.7	58.4	21.1
24 MBPS QAM OFDM	17	-77	707.9	79.4	26.6
12 MBPS OFDM	12	-82	1258.9	116.6	35.5
11 MBPS CCK (PBCC 22)	10	-84	1584.9	135.9	39.8

Table 2 -- The Effects of Modulation Schemes on SNR, Receiver Sensitivity and Signal Range

This table shows that if R^3 is typical for signal propagation losses in a real-world setting, then the resulting range of an 11-Mbps AP using CCK modulation or a 22-Mbps AP using PBCC modulation is around 400 feet. Given that typical suburban lots are around 200 feet wide, house-to-house interference from contiguous residential APs will be very likely as the deployment of 802.11 becomes denser. In a worst case scenario for single dwelling units, two APs in side-by-side homes could be separated by as little as 10 feet of air space and two walls. The in-band interference is even more challenging in apartment complexes where all that separates two or more APs might be the width of a wall or a floor. The width of a typical apartment is 100 feet or less, half the width of a suburban housing lot.

It is noteworthy to point out that the average data throughput across an 802.11 cell with a 22-Mbps AP using the TI-developed PBCC modulation scheme is quite good. Table 3 shows the average data throughput rates with different modulations and at different levels of signal propagation losses. Once again, R^3 is assumed to be the signal loss typically found in most contemporary settings. Most importantly, Table 3 points out that PBCC nearly doubles the average data rate over CCK modulation across the entire cell. PBCC has the same sensitivity and, therefore, the same range as CCK. In addition, these average data rate figures point out a subtle five to 10 percent improvement in throughput when more than one modulation scheme is deployed in a cell. With more than one modulation scheme available, clients can be provided the optimal data rate and range.

	Average data rate across the cell (MBPS)		
Modulations	R^2 loss	R^3 loss	R^4 loss
OFDM 54 & 36, CCK 11	13.4	12.6	12.3
OFDM 54 & 36, PBCC 22	23.6	21.5	20.2
OFDM 54 PBCC 22	22.8	20.1	18.5

Table 3 -- Average AP Data Rates

In-Band Signal-to-Interference Analysis

Figure 11 illustrates how two contiguous APs can cause interference problems for each other. When two sources of RF signals, such as two APs, are placed in close proximity to one another, thermal noise and path losses become secondary considerations because in-band interference will have a dominant impact on the effective range and data rates of the APs. As the drawing shows, in-band RF interference can render an AP ineffective over a large portion of its coverage area.

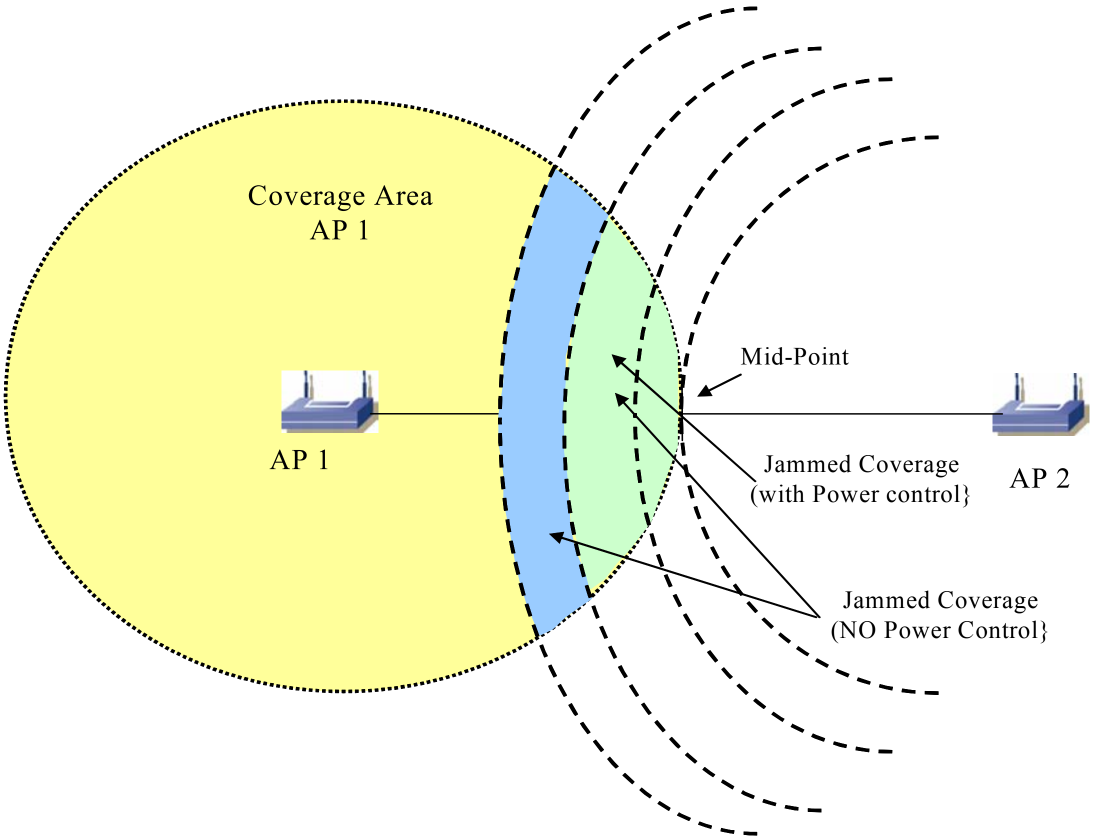


Figure 11 -- In-band Interference Between Contiguous 802.11 APs

Table 4 quantifies the in-band interference problem for the two APs shown in Figure 11. This analysis assumes that no techniques such as power control have been implemented to alleviate some of the problem. The data in Table 4 were derived from a typical urban deployment of two 802.11 APs. Both APs were transmitting at 20 dBm power, they were spaced 25 meters (approximately 75 ft.) apart, and they both experienced signal propagation losses of R^3. SIR was analyzed from each AP to the midpoint between them. Table 4 shows the SIR at various distances as well as the modulation and data rates supported at each SIR level.

	Distance from Access Point 1 (meters) with R^3 loss									
No Power control	1.25	2.5	3.75	5	6.25	7.5	8.75	10	11.25	12.5
RX power AP1 (dbm)	-22.9	-31.9	-37.2	-41.0	-43.9	-46.3	-48.3	-50.0	-51.5	-52.9
RX power AP2 (dbm)	-61.3	-60.6	-59.8	-59.0	-58.2	-57.3	-56.3	-55.3	-54.1	-52.9
SIR (db)	38.4	28.6	22.6	18.1	14.3	11.0	8.1	5.3	2.6	0.0
Modulation support	54 OFDM	54 OFDM	36 OFDM	PBCC 22	PBCC 22	PBCC 22	NO LINK	NO LINK	NO LINK	NO LINK

Table 4 -- The Effects of In-Band Interference on SIR

This analysis points out the devastating effects of in-band interference. For example, an AP using PBCC modulation typically would have an effective range of more than 135 meters, but in-band interference reduces that to just 7.5 meters. And an 802.11g AP using 54 Mbps OFDM modulation should have a range of nearly 40 meters, but its coverage is limited to just 2.5 meters as a result of in-band interference.

Today with the relatively low deployment of 802.11 WLANs, in-band RF interference from one AP to another is rarely noticed because most applications require little WLAN bandwidth and errors during transmissions can be recovered very quickly. But, as WLAN technology becomes more pervasive and higher bandwidth applications requiring QoS capabilities increase in popularity, in-band interference will increase as well. Indeed, in-band interference generated by 802.11 technology could become acute in high-density offices and dwellings like town homes, condominiums and apartments.

The Effects of Power Control on In-Band Interference

In the past, sophisticated power control techniques in a mobile device were needed to reduce power consumption and extend the life of the battery. Now, another benefit of power control has emerged. In a system or device with 802.11, power control can lower in-band interference. For example, assuming open loop power control with 1 dB accuracy, the average interference between two APs on the same RF channel and relatively close to each other can be reduced by 6 dB. Power controls can reduce interference even further in smaller 802.11 cells.

Table 5 shows the effects power control techniques can have on SIR for an AP at various distances and the corresponding modulation supported by each SIR level.

	Distance from Access Point 1 (meters) with R^3 loss									
Power Control	1.25	2.5	3.75	5	6.25	7.5	8.75	10	11.25	12.5
RX power AP1 (dbm)	-22.9	-31.9	-37.2	-41.0	-43.9	-46.3	-48.3	-50.0	-51.5	-52.9
RX power AP2 (dbm)	-67.3	-66.6	-65.8	-65.0	-64.2	-63.3	-62.3	-61.3	-60.1	-58.9
SIR (db)	44.4	34.6	28.6	24.1	20.3	17.0	14.1	11.3	8.6	6.0
Modulation support	54 OFDM	54 OFDM	54 OFDM	36 OFDM	PBCC 22	PBCC 22	PBCC 22	PBCC 22	NO LINK	NO LINK

Table 5 -- The Effects of Power Control on an AP's SIR at Various Distances

Even though the signal is still limited by in-band interference, power control techniques are able to reduce in-band interference by an average of 6 dB, improving the range of the AP by 25 percent. In practice, several strategies, including power control, automatic frequency selection and multiple bands (2.4 GHz and 5.x GHz) will likely be deployed to increase the RF channel options as more and more WLANs are deployed and as high-bandwidth QoS applications become the norm.

Anticipating Interference Issues

In the years ahead as wireless local area networking becomes increasingly popular in residential and office settings, two potential problems necessitate careful receiver design considerations on the part of equipment manufacturers. These two concerns are:

1. Non-WLAN interference from RF sources in channels adjacent to the unlicensed band of 802.11. This could come from Bluetooth devices, cordless phones or microwaves.
2. In-band interference caused by one 802.11 AP or client for another. This will certainly be exacerbated as the deployment of WLAN technology increases and becomes denser.

By following careful design practices, 802.11 receivers can be developed with adequate adjacent channel rejection (ACR) in order to overcome much of the adjacent channel interference (ACI) encountered in WLAN deployments. In addition, power control and other strategies can be designed into WLAN receivers and transmitters to drastically improve the data throughput and range performance of APs and clients in the presence of in-band RF interference.

Ultimately, those 802.11 WLAN equipment suppliers that provide a satisfying and compelling user experience will succeed in the marketplace. Considering the quality of the design of the WLAN chipsets implemented in their WLAN equipment will play an important role in ensuring satisfied users.

For more information, visit the Texas Instruments Web site:
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