Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of:	)	
Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems	)	CC Docket No. 98-153

REPLY COMMENTS OF INTEL CORPORATION

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REPLY COMMENTS OF INTEL CORPORATION

Intel Corporation hereby respectively submits a reply to the comments in response to the Notice of Proposed Rule Making ("NPRM")[1] concerning the use of ultra-wideband (UWB) technology. Intel has been a leader in the design and development of wireless communications devices and is currently involved in standardization efforts for Bluetooth, HomeRF, IEEE 802.11 Wireless LAN, IEEE 802.15 WirelessPAN™, and IEEE 802.16 WirelessMAN™ systems, which occupy some of the bands that may be impacted by UWB devices. We are also a leader in bringing new technology to the marketplace to foster the proliferation of the Internet and enable more people to have access to the numerous social, economic, and educational benefits it provides. Intel believes that UWB is a very promising technology for enabling short distance, high data rate connections that can support new and innovative applications, and Intel supports the FCC in the formation of regulations for UWB transmissions in order to bring these benefits to the marketplace in a timely manner. As part of Intel's business strategy for promoting new technologies that support the growth of the PC and Internet markets, Intel Capital has invested in Fantasma Networks and is considering similar investments to support the growth and utility of the Internet. On the other hand, we have a strong interest in ensuring that UWB devices do not cause unacceptable interference levels that would significantly impact the performance of some of our current offerings at 2.4 GHz, including Bluetooth, HomeRF, and WLAN devices. With this perspective in mind, Intel supports the FCC in their process to allow the use of UWB devices under the Part 15 rules, and provides the following comments to support some of the emission limits that are proposed in the NPRM.

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[1] "Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems, ET

Emission limits: Interference Impact on co-located PAN/LAN devices

Intel believes that the greatest potential use for UWB devices is for short-range communications in the home or business: replacing wires to add mobility to devices that do not currently have this capability, allowing for high data rate links for sharing information between devices (*e.g*. downloading video frames to a computer from a hand held video camera), and a host of other applications. By overlaying several frequency bands, it makes very efficient use of the available spectrum and offers a competitive alternative to other PAN type devices. Therefore, we have primarily focused on coexistence scenarios between UWB transmitters and other short/medium range transmission systems, including Bluetooth and WLAN devices, which are expected to be located in the same geographical areas. The appendix shows some straightforward link budgets that consider the impact a UWB transmitter located nearby has on other Bluetooth and WLAN systems.

The UWB transmitter is modeled as white, Gaussian noise interference for simplicity, which should be valid for a pulse repetition frequency that is much greater than the bandwidth of the narrowband system. The effects of discrete spectral lines in the power spectrum[2] are not taken into account, but it should be noted that Bluetooth and WLAN systems were originally designed for the challenging indoor environment that is shared with many other Part 15 devices (*e.g.*, PCs), and therefore have mechanisms for mitigating narrowband interference (*i.e.*, Frequency Hopping Spread Spectrum (FHSS), Direct Sequence Spread Spectrum (DSSS),

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Docket No. 98-153, Notice of Proposed Rule Making, Released May 11, 2000.

[2] For example, see Multispectral Solutions, Inc., "Response to FCC Notice of Proposed Rule Making ET Docket No. 98-153 'Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems'", 12 September 2000.

Orthogonal Frequency Division Multiplexing (OFDM), and automatic repeat/request (ARQ) in the MAC layer).

The challenge of introducing a new technology that potentially impacts current products is to determine an acceptable level of interference to allow this new technology to prove itself in the marketplace. In this respect, it is worthwhile to look at a "typical usage scenario", which will help to determine whether or not UWB transmitters allow co-location with these other devices in a fair sharing of the available bandwidth. Initially, we consider low volume deployments of UWB systems that are not specifically designed to be co-located with Bluetooth or WLAN devices. In this case, it would be desirable to have a Bluetooth device operate with a range of at least 10 meters when transmitting at the lowest power setting, and to have a WLAN device operate with a range of at least 50 meters when transmitting at the highest power setting, when a UWB transmitter is located 2 meters away, approximately corresponding to an adjacent cubical in an office. The following table illustrates this scenario and shows the maximum ranges that result from having a UWB transmitter located at a 2-meter separation distance. The UWB transmit power is based upon the limits described in the NPRM for frequencies greater than 2 GHz. Further details regarding the generation of this table are provided in the appendix.

Transmit Power	**Distance between UWB device and victim receiver**	**Max. Distance between BT/WLAN devices**
Bluetooth		
20 dBm	2 m	51 m
4 dBm	2 m	15 m
0 dBm	2 m	11 m
802.11b WLAN		
30 dBm	2 m	62 m
20 dBm	2 m	28 m
802.11a WLAN		
29 dBm	2 m	65 m
23 dBm	2 m	41 m

16 dBm	2 m	24 m

This table suggests that a small number of UWB devices could be co-located with other PAN/LAN products without disrupting service. Of course, as the UWB transmitter is moved closer to the victim receiver, the performance of the receiver will be degraded. However, this is the same problem that all Part 15 devices, operating in an unlicensed band, must face without further coordination.

Assuming that UWB products eventually migrate towards high volume productions, then further transmission requirements may need to be imposed on UWB systems in order to allow for a reasonable coexistence with other PAN/LAN devices. Typically, standards organizations, such as the IEEE 802 group or Bluetooth SIG, help to enable these large volume product deployments by standardizing systems for specific applications. For example, if a UWB system for PAN applications is to be used in a laptop computer at the same time an 802.11a WLAN card is to be used for LAN applications, then the design of such systems must be done carefully in order to allow for these devices to coexist. Intel believes that this type of coexistence work is best handled by a standards body or industry SIG, which can carefully take into account the functional requirements, cost impacts, implementation complexities, and market requirements. Note that there is currently work underway to improve the coexistence between 802.11b and Bluetooth devices within IEEE, which can cause significant interference to each other in the 2.4 GHz band, so there is precedence for the industry to work towards peaceful coexistence. Accordingly, Intel supports the emission limits proposed in the NPRM, which allow for UWB transmissions to meet the current FCC Part 15.209 limits for frequencies above 2 GHz.

Emission Limits: Impacts on UWB Performance

Based on the current emission limits proposed in the NPRM, UWB could offer a variety of throughputs at a number of useful ranges, which will enable new applications to be used over the wireless medium. Intel agrees that emission limits below 2 GHz should be carefully selected in order to adequately protect the GPS bands, and looks forward to the test results that are being done to address this issue. Intel recommends that the FCC proceed with regulations above 2 GHz in order not to slow down the introduction of these new products into the marketplace, and possibly delay any recommended emission limits for UWB devices below 2 GHz until adequate testing is done. We believe that the current recommendations for devices operating above 2 GHz are adequate for allowing competitive equipment to come to the marketplace in a timely manner. Including a further 12 dB reduction of power for the frequencies greater than 2 GHz, as suggested by Motorola[3], could potentially limit the competitiveness and usefulness of UWB devices for PAN type applications. As shown in the previous table, this is not necessary. Note that, if the majority of the applications for UWB are for indoor PAN type connections, then the interference to outdoor systems, an area of concern that has been voiced by Motorola, Cisco, and others, could be significantly reduced. The following table compares some possible throughputs that could be supported by UWB systems with the current emissions limit defined in the NPRM and those same limits with a 12 dB reduction. These results assume that the UWB waveform occupies 2 GHz of bandwidth (occupying, for example, 2-4 GHz) and a pulse period of 1 nsec, with other parameters defined in the appendix.

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[3] R. C. Barth and L. M. Chinitz, Comments of Motorola, Inc., September 12, 2000.

Distance between UWB devices (m)	Possible Throughput (Mbps) without 12 dB power reduction	Possible Throughput (Mbps) with 12 dB power reduction
1	1000	250
3	500	32
5	167	12
10	45	3
15	14	< 1

This table shows both the potential for UWB in supporting very high throughputs at short range as well as the impact a 12 dB further reduction in power would impose. Intel recommends using the emission limits that are currently defined in the NPRM for frequencies greater than 2 GHz without any additional attenuation. With these emission limits, the interference caused by UWB with other PAN/LAN devices was shown to result in an acceptable level of interference for initial deployments, as discussed previously.

Interference Mitigation Techniques

There are many methods that can be utilized to mitigate the interference that UWB might cause to other devices, which occupy the same spectrum. One method is for the FCC to impose emission limits that try to alleviate the worst-case interference scenario, but this may have a negative impact on the capabilities of UWB systems. Other methods include the use of intelligent power control, notches in the frequency domain to protect certain frequencies, or even a time-sharing protocol to reduce interference when many other users of the spectrum are in the same area. The FCC could either mandate one or more of these concepts or allow the industry to regulate itself based upon specific system requirements for various applications. For example, an indoor PAN application of UWB for businesses may wish to further protect the 5 GHz band in order to allow UWB devices and IEEE 802.11a devices to be co-located. Alternatively, an indoor PAN application of UWB for the home may wish to further protect the 2.4 GHz band in order to allow UWB devices and Bluetooth/HomeRF devices to be co-located, or maybe both the 2.4 GHz and 5 GHz bands may wish to be further protected.

As long as the FCC imposes reasonable limits to protect these other wireless systems against an occasional, unregulated UWB transmitter, Intel believes an industry standards body should determine how UWB will peacefully coexist with other wireless systems, due to the large number of potential applications for UWB. The Part 15.209 emission limits provide this reasonable level of protection for other wireless PAN/LAN systems operating at frequencies greater than 2 GHz. Additionally, the FCC should mandate the following rule to help further mitigate interference from UWB transmissions, following the recommendations of the U-NII 5 GHz bands (from FCC Part 15.407c):

> *The UWB device shall automatically discontinue transmission in case of either absence of information to transmit, operation failure, or absence of receiving devices. These provisions are not intended to preclude the transmission of control or signaling information or the use of repetitive codes used by certain digital technologies to complete frame or burst intervals. Applicants shall include in their application for equipment authorization a description of how this requirement is met.*

This requirement could prevent, for example, a continuous video broadcast transmission for distribution of television channels to televisions located in a house or building, when the televisions are not on. We expect that UWB devices would need to operate in a Time Division Duplex fashion, and therefore, would have the capability of turning on and off transmissions, so the cost impact of this requirement should be minimal. Also, this requirement should help to reduce the overall interference presented by multiple UWB transmitters, and represents good spectrum etiquette for a shared environment.

Conclusion

Intel Corporation commends the FCC for taking the first steps towards allowing UWB communications devices to be deployed in the marketplace. Intel believes that UWB technology could generate numerous benefits, including the efficient use of the spectrum so more people can enjoy the benefits of wireless technology, the possibility for low power operation for longer battery life in mobile devices, capability for high throughput enabling many new applications over the wireless media, and the potential for low cost devices that would make UWB systems affordable to a large portion of the population. Intel appreciates the concerns that several commentors made with regard to the potential interference impacts for existing systems, and shares many of those concerns. However, we believe that the FCC has taken the right approach and that the interference that will be generated by UWB devices, based upon the FCC recommendations, should be manageable with both FCC regulations and industry cooperation in the future.

Respectfully submitted,

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Appendix

Overview

Ultra-wideband (UWB) technology is based on the use of transmitting very short pulses, which occupy a wide bandwidth based upon the design and duration of the pulse. In the recent NPRM, the FCC has defined UWB signals as those that occupy a bandwidth >= 25% of the center frequency or > 1.5 GHz of spectrum. As a result, this waveform will potentially interfere with other systems operating in either unlicensed or licensed spectrum. Since Intel views UWB as a potential technology to significantly enhance personal area networks (PANs), the following study focuses on the impacts that UWB transmitters could potentially have on other PAN/LAN devices that may be co-located with a UWB system. For simplicity in this initial evaluation, the effects of UWB transmissions on other devices are modeled as additive, white, Gaussian noise (AWGN). Due the broadband nature of UWB transmissions compared to the relatively narrow bandwidths of most other applications, as well as the typically flat spectral characteristics of UWB waveforms, this assumption was deemed reasonable. As a result, the interference from the UWB transmitters is assumed to simply add in power to the already present AWGN coming from the receiving antenna. Depending on the modulation, spectral lines may appear in the power spectrum and potentially cause greater interference than AWGN with the same power, but this effect is not considered here. Many systems that operate in frequency bands below 10 GHz typically employ mechanisms for dealing with frequency selectivity in which the interference level in different frequency bands varies, typically due to multipath fading or other co-channel interference (*i.e.*, CDMA or OFDM type systems). These methods often provide some protection against narrowband interference and should help protect against these discrete spectral components. However, it should be noted that, if the majority of the available power is contained in these spectral lines, which is measured over a 1 MHz resolution bandwidth, then the interference shown to systems with bandwidths less than 1 MHz (including OFDM systems with narrowband carriers) could result in worse performance than has been analyzed here. Therefore, UWB systems should be designed to limit the power in these spectral lines.

Interpretation of NPRM Rules on Emission Limits for UWB devices

The FCC Part 15 rules place emission limits on intentional and unintentional radiators in unlicensed bands. These emission limits are defined in terms of uV/m, which represents the electric field strength of the radiator. The FCC is recommending the emissions of UWB devices to be regulated by the current emission limits described in the Part 15.209. For the cases studied here, we use the limits defined for frequencies greater that 2 GHz, which is 500 uV/m measured at 3 meters. This results in a power spectral density of –41.25 dBm/MHz, based upon the 1 MHz resolution bandwidth for measuring the power.

Indoor Path Loss Model

There are many factors which affect the propagation loss model for the indoor wireless channel[4, 5], including the floor layout of the building, the number of walls/dividers between the transmitter and receiver, and the type of material present in the obstructions (concrete, metal, etc.). In order to provide some initial results, we chose the below model as our base indoor

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[4] See T. S. Rappaport and S. Sandhu, "Radio-Wave Propagation for Emerging Wireless Personal Communication Systems," IEEE Antennas and Propagation Magazine, Vol. 36, No. 5, pg. 14-24, Oct. 1994 and the references therein.

[5] K-W Cheung, J. Sau, and R. Murch, "A New Empirical Model for Indoor Propagation Prediction," IEEE Trans. On Vehic. Tech.,Vol. 47, No. 3, pp. 996-1001, Aug. 1998.

propagation loss model, based upon the information in previous studies.[4, 5]. The same model is also used for UWB transmission, since some measurement results provided in another study[6] suggest similar path loss exponents. The approach taken separates the distance between a transmitter and receiver into two regions, each of which have a different path loss exponent (n_1 and n_2). For distances less than 10 meters, the free space path loss model is used (n_1=2), and for distances greater than 10 meters, a path loss exponent of n_2=3 is used. This results in the following path loss model:

$$L(d) = \begin{cases} L_0 + 10\log(d)^{n_1} \text{ for } d \le 10 \text{ meters} \\ L_0 + 10\log(10)^{n_1} + 10\log(d/10)^{n_2} \text{ for } d > 10 \text{ meters} \end{cases}$$

where $L_0 = 20\log(4\pi/\lambda)$ is the distance loss at 1 meter in free-space, and λ is the carrier wavelength.

Impacts of UWB transmitters on Bluetooth devices

First, we consider an environment that has both a Bluetooth (BT) device and a UWB transmitter nearby. According to the Bluetooth standard [Specification Volume v1.0B, December 1st 1999], some relevant transmitter and receiver characteristics are given by the following:

- Carrier frequency: 2.4 GHz
- Equivalent Noise BW = 1.5 MHz
- Noise figure of BT receiver assumed to be 6 dB.
- Resulting receiver noise floor = –106.2 dBm/MHz
- Antenna gain assumed to be 0 dBi.

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[6] J.M. Cramer, R.A. Scholtz, and M.Z. Win, “On the analysis of UWB communication channel,”

The following table represents the potential increase in the noise floor of the BT receiver due to the presence of a UWB transmitter near by.

UWB Power (dBm) in 1.5 MHz	UWB Power (mW) in 1.5 MHz	Distance of UWB Tx (m)	Interference power of UWB Tx (mW)	BT (N+I) including NF	BT Noise floor increase (dB)
-39.48857741	0.000112497	1	1.11312E-08	1.1155E-08	26.7137785
-39.48857741	0.000112497	2	2.7828E-09	2.80658E-09	20.72085712
-39.48857741	0.000112497	5	4.45249E-10	4.69022E-10	12.9510194
-39.48857741	0.000112497	10	1.11312E-10	1.35086E-10	7.545176178
-39.48857741	0.000112497	15	1.46584E-11	3.84318E-11	2.085993257
-39.48857741	0.000112497	20	3.4785E-12	2.72519E-11	0.593055668
-39.48857741	0.000112497	25	1.13984E-12	2.49132E-11	0.203388528
-39.48857741	0.000112497	30	4.58075E-13	2.42315E-11	0.082885483
-39.48857741	0.000112497	35	2.11935E-13	2.39853E-11	0.038544882
-39.48857741	0.000112497	40	1.08703E-13	2.38821E-11	0.019812744

In order to see how a nearby UWB transmitter effects the useful range of the BT device, the following assumptions are made:

- Minimum required C/I = 14 dB (includes a minimum required C/I of 11 dB with a 3 dB implementation loss)
- Additional link margin of 10 dB is desired in order to allow room for fades, interference, or other propagation losses. The frequency hopping and ARQ capabilities of BT help to further reduce the impacts of multipath fading and time varying interference levels.

In this case, we shall consider the following usage model for coexistence, in which it is desirable to have a BT device able to communicate up to 10 meters at the lowest transmit power when a UWB device is within 2 meters from the BT receiver (corresponding to an adjacent cubical in an office building, for example). The following table shows the different operating distances capable for BT devices with a near-by UWB transmitter.

Proceedings of MILCOM 1999, Vol. 2, pp. 1191-1195, 1999.

BT Output Power	Distance between UWB device and BT device	Max. Distance between 2.4 GHz BT devices	Resulting Link Margin
20 dBm	2 m	51 m	10.2 dB
4 dBm	2 m	15 m	10.2 dB
0 dBm	2 m	11 m	10.2 dB

Since BT was designed as primarily a wireless replacement technology, the distances given above are deemed reasonable from a coexistence perspective. If UWB devices are desired to be co-located with a BT device (*i.e.*, located less than 2 meters or in the same laptop), then the design of the UWB device must be able to notch out, through filter or antenna designs for example, the frequencies used by the BT system in order to allow for acceptable communications. In our opinion, this type of design is best left up to an industry standards organization which can specifically design for this type of market use, rather than have the FCC regulations accommodate "worst-case" uses.

Impact of UWB transmitters on 2.4 GHz IEEE 802.11b WLAN devices

As another example, we considered the 2.4 GHz WLAN application (based on the high rate IEEE 802.11b specification) with a UWB transmitter in the same area. A similar analysis could also be done for an 802.11 frequency hopping spread spectrum system (FHSS) as well as a HomeRF system operating in the 2.4 GHz band. Since the conclusions would be similar for all these cases, only the 2.4 GHz WLAN system, based on the IEEE 802.11b specification, is studied here. The following table shows the impact on the WLAN noise floor due to the UWB transmitter. The following assumptions were used:

- Equivalent noise BW=11 MHz.
- Noise figure = 6 dB

- Resulting noise floor of receiver = -97.5861 dBm
- Reference carrier frequency = 2.4 GHz
- 0 dBi antenna gain on the transmitter and receiver

UWB Power (dBm) in 11 MHz	**UWB Power (mW) in 11 MHz**	**Distance of UWB Tx (m)**	**Interference power of UWB Tx (mW)**	**WLAN (N+I) including NF**	**WLAN Noise floor increase (dB)**
-30.83556315	0.000824981	1	8.16289E-08	8.18032E-08	26.7137785
-30.83556315	0.000824981	2	2.04072E-08	2.05816E-08	20.72085712
-30.83556315	0.000824981	5	3.26516E-09	3.43949E-09	12.9510194
-30.83556315	0.000824981	10	8.16289E-10	9.90627E-10	7.545176178
-30.83556315	0.000824981	15	1.07495E-10	2.81833E-10	2.085993257
-30.83556315	0.000824981	20	2.5509E-11	1.99847E-10	0.593055668
-30.83556315	0.000824981	25	8.3588E-12	1.82697E-10	0.203388528
-30.83556315	0.000824981	30	3.35921E-12	1.77697E-10	0.082885483
-30.83556315	0.000824981	35	1.55419E-12	1.75892E-10	0.038544882
-30.83556315	0.000824981	40	7.97157E-13	1.75135E-10	0.019812744

Clearly, as the UWB device is moved closer to the WLAN receiver, the noise floor will be correspondingly raised. This will have the impact of either reducing the range of the WLAN device and/or reducing the allocated link margin available. In order to determine how UWB interference affects the usefulness of 2.4 GHz WLAN systems, the following assumptions are made (in addition to the assumptions made above):

- Minimum required C/I = 13 dB (this corresponds to a minimum C/I of 8 dB plus a 5 dB implementation loss).
- Due to the use of CCK modulation and the potential use of RAKE reception, a reasonable link margin for this example is assumed to be 10 dB. Note that additional margin could be gained at the expense of range, and vice versa.
- Maximum Tx powers = 30 dBm and 20 dBm (within occupied bandwidth).

We are interested in a possible coexistence scenario in which there is a UWB device about 2 meters away from a WLAN receiver (corresponding to an adjacent cubical in an office building, for example), while the WLAN device is still able to operate with at least a 50 meter range when transmitting at maximum power. The following table illustrates this particular interference model.

WLAN Output Power	**Distance between UWB device and WLAN device**	**Max. Distance between 2.4 GHz WLAN devices**	**Resulting Link Margin**
30 dBm	2 m	62 m	10.0 dB
20 dBm	2 m	28 m	10.4 dB

These numbers suggest that UWB devices can be co-located with 2.4 GHz WLAN devices with a reasonable range and link margin. Again, WLAN systems operating in the unrestricted bands will more likely be limited by interference from other devices sharing the band, rather than the interference from UWB transmitters. Of course, as the UWB transmitter is moved closer to another receiving device, the impact becomes more noticeable and will either impact range and/or link margin. In addition, if the UWB devices use transmit power control and stop transmitting when there is no data present, then the interference level caused by UWB devices could be further reduced.

Impact of UWB transmitters on 5 GHz IEEE 802.11a WLAN devices

As another example, we considered the 5 GHz WLAN application (based on the IEEE 802.11a draft specification) with a UWB transmitter in the same area. The following table shows the impact on the WLAN noise floor due to the UWB transmitter. The following assumptions were used:

- Equivalent Noise BW=16.6 MHz.
- Noise figure = 6 dB

- Resulting noise floor of receiver = -95.7989 dBm
- Reference carrier frequency = 5.15 GHz
- 0 dBi antenna gain on the transmitter and receiver

UWB Tx Power (dBm)	UWB Tx Power (mW)	Distance b/w UWB and WLAN device (m)	UWB Interference power (mW)	WLAN (N+I) including NF	WLAN Noise floor increase (dB)
-29.04840912	0.001244971	1	2.67527E-08	2.70158E-08	20.11509414
-29.04840912	0.001244971	2	6.68817E-09	6.95126E-09	14.21955699
-29.04840912	0.001244971	5	1.07011E-09	1.3332E-09	7.047871378
-29.04840912	0.001244971	10	2.67527E-10	5.30619E-10	3.046748248
-29.04840912	0.001244971	15	3.52299E-11	2.98322E-10	0.545774066
-29.04840912	0.001244971	20	8.36021E-12	2.71452E-10	0.135857332
-29.04840912	0.001244971	25	2.73948E-12	2.65832E-10	0.044987543
-29.04840912	0.001244971	30	1.10093E-12	2.64193E-10	0.018135531
-29.04840912	0.001244971	35	5.09363E-13	2.63602E-10	0.008400078
-29.04840912	0.001244971	40	2.61257E-13	2.63354E-10	0.004310505

In order to determine how a UWB transmitter would impact the usefulness of a 5 GHz WLAN system, the following assumptions are made (in addition to the assumptions made above):

- Minimum required C/I = 9.5 dB (includes a minimum of 4.5 dB for BPSK with a rate ½ convolutional code for a BER = 10e-4 and a 5 dB implementation loss. Note that these parameters will allow for the minimum 6 Mbps throughput rate).
- Due to the presence of interleaving, convolutional coding, and OFDM modulation, a reasonable link margin is assumed to be 10 dB to compensate for imperfect interleaving, frequency correlation, and any additional propagation losses. Again, additional margin could be gained at the expense of range, and vice versa.
- Maximum Tx powers = 29 dBm, 23 dBm, and 16 dBm (within occupied bandwidth of 16.6 MHz).
- All calculations are based on the 6 Mbps mode of operation (BPSK with a rate ½ code).

The use of higher data rates will reduce the possible distance between WLAN devices. Again, we are interested in a possible coexistence scenario in which there is a UWB device about 2 meters away from a WLAN receiver (corresponding to an adjacent cubical in an office building, for example), while the WLAN device is still able to operate with at least a 50 meter range when transmitting at maximum power. The following table illustrates this particular interference model.

WLAN Output Power	**Distance of UWB device**	**Max. Distance between WLAN devices**	**Resulting Fade Margin**
29 dBm	2 m	65 m	10.0 dB
23 dBm	2 m	41 m	10.0 dB
16 dBm	2 m	24 m	10.0 dB

These numbers suggest that 5 GHz WLAN systems will still have a reasonable range, even when a UWB device is operating in an adjacent office, for example. The low power WLAN system with a UWB transmitter operating within 2 meters will certainly have a reduced range. Again, co-locating a UWB device and a WLAN device into the same platform, like a laptop computer, would need to be specifically designed not to interfere with each other and, in our opinion, is best left up to the industry. The use of power control in the UWB devices, the restriction of transmitting only when there is data to send, and the time variability of the data could further reduce the interference caused by UWB devices. Note that systems operating in these bands must also expect interference from other WLAN devices as well as other Part 15 devices. The interference from UWB transmissions is not necessarily the only impairment that WLAN devices encounter, and therefore, performance may not always be limited by the UWB interference.

Aggregation of UWB devices

The aggregation of several UWB devices in the same area could have the potential of further increasing the noise floor of operating devices in the same frequency. If these devices are assumed to add non-coherently (assuming that different UWB transmissions operating in the same geographical area are not synchronized), then the aggregated average interference power will simply add. This additional interference will either reduce the acceptable operational distances of other wireless devices or impact the available link margin and potentially impact the perceived performance levels. However, interference of this nature is typically dominated by the closest interferer, especially for PAN type applications, assuming that the location of these UWB devices are randomly located in a geographical area and the relative numbers of these devices are small (i.e., as would be the case for a residential application, for example). To reduce the potential aggregated interference, the cessation of transmitting when it is not necessary (either no data present or no receivers present) could be used. These ideas should help to further reduce the interference caused by UWB devices on other co-located systems and result in a more efficient use of the shared spectrum. In addition, the random locations of these devices, the random data arrival rate of different devices, and the possible mobility of these devices should help to reduce the possible aggregation effect.

Potential Applications for UWB devices

In order to get an understanding of whether or not the FCC emission limits will impact the applicability and competitiveness of UWB devices, some straightforward link budgets can be used to show some trade-offs between possible transmission distances and data rates. For this example, we assume the following:

- The pulse width is assumed to be 1 nsec, and the shape of the pulse is assumed to occupy about 2 GHz of spectrum (this is based upon the 10 dB bandwidth of a pulse shape that is the derivative of a Gaussian).
- It is assumed that the pulse has been shaped and/or filtered to occupy the 2-4 GHz spectral region, so that the FCC part 15.209 rules apply without addition power reductions. As a result, the average center carrier frequency is 3 GHz, which is used to calculate the average path loss.
- The pulse repetition frequency (PRF) can be varied in order to reduce the effects of multipath. By separating the pulses in time by a sufficient amount (greater than the delay spread of the channel), the multipath effects could be made negligible. However, the wider the pulse repetition time is, the greater the peak-to-average power ratio and the lower the possible peak data rate (assuming one bit is transmitted per pulse). For the table below, we assume that the nominal PRF = 1 GHz (1/pulse time), which can easily be generalized to different PRF by using a generic "system processing gain". In particular, a system processing gain of N corresponds to a PRF of 1/N GHz and a peak power that is N times the nominal transmit power (resulting the in same average transmit power, as allowed in the FCC recommended rules). Note that, a system processing gain of N could also be interpreted as a spread spectrum processing gain, where the transmit power is

divided into multiple chips, and the receiver is able to capture and combine this energy in order to yield a greater received SNR per bit.

- A 0 dBi antenna gain is assumed.
- A 6 dB Noise Figure is assumed.
- The required C/I was chosen to be 13 dB, which includes an 8 dB minimum C/I threshold (assuming some FEC is applied to the symbols) and a 5 dB implementation loss.
- Since UWB transmissions are less affected by multipath fading, a 5 dB link margin was deemed reasonable for these comparisons.

UWB Tx Power (dBm)	**Distance b/w UWB devices (m)**	**UWB Rx Power (dBm)**	**System Processing gain**	**Throughput (Mbps)**
-8.239190043	1	-50.22338732	1	1000
-8.239190043	3	-59.76581242	2	500
-8.239190043	5	-64.20278741	6	166.6666667
-8.239190043	10	-70.22338732	22	45.45454545
-8.239190043	15	-75.5061251	72	13.88888889
-8.239190043	20	-79.25428719	169	5.917159763
-8.239190043	25	-82.16158758	329	3.039513678
-8.239190043	30	-84.53702497	569	1.757469244
-8.239190043	35	-86.54542865	903	1.107419712
-8.239190043	40	-88.28518706	1348	0.741839763
-8.239190043	50	-91.19248745	2632	0.37993921
-8.239190043	60	-93.56792484	4549	0.219828534
-8.239190043	70	-95.57632852	7223	0.138446629
-8.239190043	80	-97.31608693	10781	0.092755774
-8.239190043	90	-98.85066261	15350	0.06514658
-8.239190043	100	-100.2233873	21056	0.047492401

The above calculations suggest that UWB transmitters will likely be limited to relatively small distances for reasonable processing gains and available throughputs. Also, the above throughputs for a given processing gain are for a single user in the system. Overall capacity can be improved by multiplexing several users with the same throughput (possibly through the use of orthogonal code sequences and/or orthogonal separation of users in time). Therefore, Intel believes that UWB technology can provide significant benefits in terms of available throughputs at useful distance separations that are not currently available.

The impact of reducing the emissions limit to be 12 dB below the current emissions limit (as suggested by Motorola) for frequencies greater than 2 GHz is shown in the following table.

UWB Tx Power (dBm)	**Distance b/w UWB devices (m)**	**UWB Rx Power (dBm)**	**System Processing gain**	**Throughput (Mbps)**
-20.23919004	1	-62.22338732	4	250
-20.23919004	3	-71.76581242	31	32.25806452
-20.23919004	5	-76.20278741	84	11.9047619
-20.23919004	10	-82.22338732	334	2.994011976
-20.23919004	15	-87.5061251	1127	0.887311446
-20.23919004	20	-91.25428719	2670	0.374531835
-20.23919004	25	-94.16158758	5215	0.191754554
-20.23919004	30	-96.53702497	9011	0.110975474
-20.23919004	35	-98.54542865	14308	0.06989097
-20.23919004	40	-100.2851871	21358	0.046820863
-20.23919004	50	-103.1924875	41714	0.023972767
-20.23919004	60	-105.5679248	72082	0.013873089
-20.23919004	70	-107.5763285	114463	0.008736448
-20.23919004	80	-109.3160869	170860	0.005852745
-20.23919004	90	-110.8506626	243275	0.004110574
-20.23919004	100	-112.2233873	333710	0.002996614

Comparing the previous 2 tables at a 10 meter separation distance, the throughput of a UWB system would be reduced from 45.5 Mbps to 3 Mbps (a factor of about 15 or roughly 12 dB) if the transmit power is further reduced by 12 dB, for this example. Intel believes that this will significant reduce the effective use of UWB technology and recommends that the FCC consider keeping the current proposed limits for frequencies greater than 2 GHz.

Conclusion

The above link budget calculations are based on several assumptions, which include antenna gains, receiver noise figure, required fade margins, implementation loss, etc., that effect the results. However, the numbers that were chosen were deemed reasonable and somewhat generic (*i.e.*, not based on a specific implementation) in order to shed some light on possible deployment and interference scenarios for UWB systems. Slight modifications to these numbers should not change the overall conclusion that UWB does, in fact, cause interference to other devices in the same geographic area. However, Intel believes that this interference is acceptable in small volumes and can be manageable both through proper emission limits provided by the FCC as well as through industry cooperation and standards development.