# Potential of UWB Technology for the Next Generation Wireless Communications

*(Invited Paper)*

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***Abstract*— This paper discusses the potential deployment of ultra-wideband (UWB) radio technology for next generation wireless communications. Firstly, the state-of-art in UWB technology is reviewed. Then, the current status of worldwide regulatory efforts and industrial standardization activities is discussed. Various technical challenges that remain to be solved prior to the successful deployment of UWB systems as well as the possible technical approaches are also reported. Specifically, we envisioned the potential of location awareness capabilities to provide new applications and usage models for future mobile terminals. An overview of the existing ranging and localization techniques is presented and some technical aspects as well as design trade-offs in terms of device complexity and ranging accuracy are highlighted. Finally, since UWB systems operate as overlay systems, issues of coexistence and interference with existing narrowband systems are presented.**

## I. INTRODUCTION

Ultra-wideband (UWB) radio is an emerging technology that has attracted a great deal of interest from academia, industry, and global standardization bodies [1]–[8]. UWB technology has been around since 1960, when it was mainly used for radar and military applications. A measurement metric appropriate for UWB signals is the fractional bandwidth $B_f$, defined as [9]:

$$B_f = 2\frac{f_{\rm H} - f_{\rm L}}{f_{\rm H} + f_{\rm L}} \tag{1}$$

where $f_{\rm H}$ and $f_{\rm L}$ are the higher and lower $-3$ dB bandwidth, respectively. Defense Advanced Research Project Agency defined UWB signals as signals with fractional bandwidth greater than $25\%$ [9]. This is much wider than any existing communications system. On the other hand, narrowband signals are defined as signals with fractional bandwidth less than $1\%$, while wideband signals are between $1 - 25\%$ [10]. Since the 1990's, interest in commercial applications has increased due to several advantages UWB communications systems offer, such as:

i) *High data rate transmission* – Current UWB systems can support more than 500 Mbps data transmission within 10 m, which enables various new services and applications [3]–[7].
ii) *Fading robustness* – UWB systems are immune to multipath fading and capable of resolving multipath components (MPCs) even in dense multipath environments. Resolvable paths can be combined to reduce the fading margin and enhance system performance [11], [12].
iii) *Security* – Since UWB systems operate below the noise floor, they are inherently covert and extremely difficult for unintended users to detect [10], [13].
iv) *High precision ranging* – UWB systems have good time-domain resolution and can promise sub-centimeter resolution capability for location and tracking applications [14]–[17].
v) *Low loss penetration* – UWB systems can penetrate obstacles and thus operate under both line-of-sight (LOS) and non-LOS (NLOS) conditions [18]–[23].
vi) *Low power spectra density* – UWB systems have low power spectral density that allows them to coexist with other services such as cellular systems, wireless local area networks (WLAN), global positioning systems (GPS), etc. [24], [25].
vii) *Single chip architecture* – UWB systems can be implemented nearly all-digitally with small-size, low cost and low power on a single chip architecture (e.g., CMOS) since the RF carrier can be eliminated [26]–[28]. Such architecture is essential for handheld devices such as a mobile terminal (MT).
viii) *Scalability* – UWB systems are very flexible because their common architecture is software re-definable so that it can dynamically trade-off high-data throughput for range [28]–[31].

In the recent years, short-range wireless applications and ad-hoc networking have become increasingly important in line with the vision to achieve ubiquitous communications. UWB radio is foreseen as one of the most promising technologies for such applications. Due to the convergence of wireless connectivity, the next generation of the wireless world will most likely be an integration of heterogeneous networks including wireless regional area networks, wireless wide area networks, wireless metropolitan are networks, WLAN, and wireless personal area networks (WPAN). Ultimately, these wireless technologies may intersect with each other as shown in Fig. 1. It is also widely anticipated that new wireless technology based on UWB radio can complement other wireless technologies and has the potential to realize seamless connectivity with other

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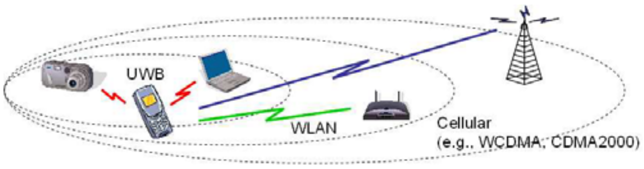



Fig. 1. Intersection of various wireless technologies.

communication infrastructure (i.e., provide users with their desired information on any devices anywhere and at anytime). The advantages of UWB technology as described above are important even to cellular operators, as UWB technology may play a key role in the future 4G network solution by providing enhancement and add-on functionality to next generation MTs such as high-data rate applications (e.g., audio/video multimedia data exchange, file sharing, etc.) and low-data rate applications with localization capabilities (e.g., sensor networks, information services, inventory tracking, etc.).

The remainder of this paper elaborates the above discussion and is organized as follows: Section II describes worldwide regulatory and standardization efforts; Section III gives an overview of technical challenges and approaches for UWB systems; Section IV focuses on ranging and localization; Section V discusses coexistence and interference issues; and finally, in Section VI some future perceptions of UWB technology and appropriate conclusions are drawn.

## II. Worldwide Regulation and Standardization

Generally, worldwide UWB regulatory efforts can be categorized as international, regional or national. At the global level, the International Telecommunications Union Radio Sector (ITU-R) plays the major role in providing recommendations. In July 2002, ITU-R Study Group 1 established Task Group 1/8 (TG1/8) to study the compatibility between UWB devices and radio communication services, comprising four Working Groups (WGs): (i) WG1 – UWB characteristics, (ii) WG2 – UWB compatibility with other radio services, (iii) WG3 – UWB spectrum management framework, and (iv) WG4 – UWB measurement techniques [32].

### A. UWB Regulation in the USA

In February 2002, a US Federal Communications Commission (FCC) issued the First Report and Order (R&O), which permitted unlicensed UWB operation and commercial deployment of UWB devices. There are three classes of devices defined in the R&O document: (i) imaging systems (e.g., ground penetrating radar systems, wall imaging systems, through-wall imaging systems, surveillance systems, and medical systems), (ii) vehicular radar systems, and (iii) communications and measurement systems. The FCC allocated a block of unlicensed radio spectrum from 3.1 – 10.6 GHz for the above applications where each category was allocated a specific spectral mask as described in [33]. Note that the FCC only specified a spectral mask, and the bandwidth limitations of a UWB device, but not the type of signal and modulation scheme. According to FCC rules, a signal is defined as UWB if its *absolute bandwidth*, $B$ is at least 500 MHz or the *fractional bandwidth*, $B_f$ is greater than $20\%$ [33]. According to (1), $f_H$ and $f_L$ are now defined as the higher and lower $-10$ dB bandwidth, respectively. In general, the spectral mask associated with the FCC UWB regulation was designed to protect other spectrum users from undesirable levels of interference caused by UWB transmissions. For wireless communications, the FCC regulated power levels are very low (i.e., $-41.3$ dBm/MHz), which allows UWB technology to overlay with available services such as the GPS and the IEEE 802.11 WLAN. Additionally, the FCC prohibits UWB communications in toys, aircraft or satellites. The flexibility provided by the FCC ruling greatly raised the interest of many large establishments in forming industry alliances such as WiMedia [34] and the UWB Forum [35] to deploy UWB technology.

### B. UWB Regulation in Europe

The European Telecommunications Standards Institute (ETSI) and European Conference of Postal and Telecommunications Administrations (CEPT) have been working closely to establish a legal framework for the deployment of unlicensed UWB devices. Within ETSI, there are two TGs to develop UWB regulation and standards for the European Union. The ETSI TG31A is responsible for identifying a spectrum requirement and developing radio standards for short-range devices using UWB technologies [36], while the ETSI TG31B is responsible for developing standards and system reference documents for automotive UWB radar applications [37]. Lastly, CEPT SE24 is responsible for regulatory issues and spectrum management e.g., studying spectrum sharing for $< 6$ GHz [38].

### C. UWB Regulation in Asia-Pacific

The Asia-Pacific Telecommunity is responsible for facilitating regional coordination with regard to the UWB regulations. Currently, UWB regulatory efforts are underway in China, Japan, Korea and Singapore. On 27 March 2006, Japan's Ministry of Internal Affairs and Communications (MIC) issued a preliminary approval for UWB emissions policy in Japan [39]. The UWB unlicensed spectrum allocation consists of two bands i.e., a lower band between $3.4 - 4.8$ GHz and an upper band between $7.25-10.25$ GHz for indoor devices only. For the lower band, implementation interference mitigation techniques such as detect and avoid (DAA) mechanisms are required. This is to protect current and future services from potential interference as well as ensure coexistence with incumbent systems and new services like WiMAX, 4G and digital broadcast. However, between $4.2-4.8$ GHz of the lower band, interference mitigation techniques can be waived until the end of December 2008. The emission limits for both bands are $-41.3$ dBm/MHz i.e., the same as those approved by the US FCC. According to Japan's MIC rules, a UWB signal must have a minimum absolute bandwidth of $450$ MHz (instead of $500$ MHz) or a fractional bandwidth greater than $20\%$. Additionally, systems using frequency hopping or chirping

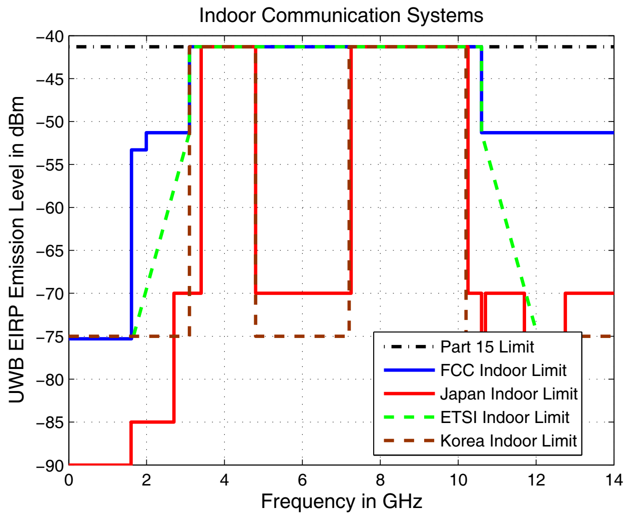



Fig. 2. UWB emission limits for indoor communications systems in the US, Europe, Japan, and Korea.

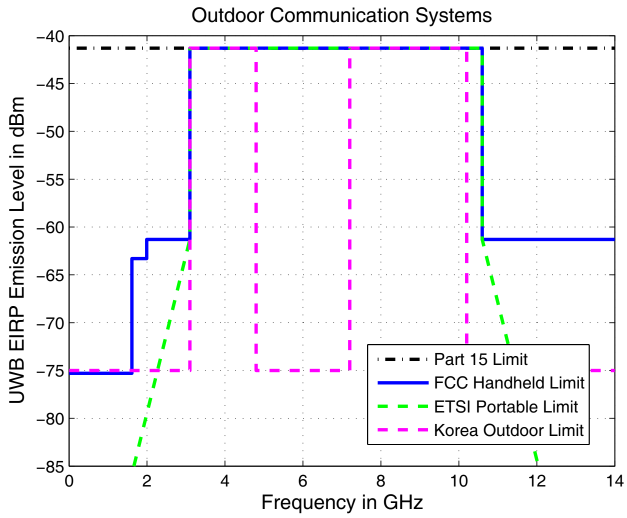



Fig. 3. UWB emission limits for outdoor communications systems in the US, Europe, and Korea.

as UWB systems are regarded as such if their instantaneous bandwidths meet the UWB bandwidth definition.

In the recent Korea UWB public hearing session, Korea's Ministry of Information and Communication announced a plan on Korean UWB spectrum allocation [40]. According to the hearing, the target UWB spectrum will be allocated from $3.1-4.8$ GHz for the low band and from $7.2-10.2$ GHz for the high band. For the low band, DAA mechanisms are mandatory in order to protect existing services and IMT-Advanced systems. However, for $4.2-4.8$ GHz the DAA mechanisms can be exempted until June 2010. The emission power level from UWB devices is allowed up to $-41.3$ dBm/MHz and the usage of the target band will be allowed for both indoor and outdoor communication systems. It is anticipated that the official UWB spectrum allocation will be announced by the end of June 2006 after the review of questions and comments from various sectors.

Fig. 2 and Fig. 3 show the proposed UWB emission limits for indoor and outdoor communications systems, respectively, in the US, Europe, Japan, and Korea. Table I shows the summary comparison of US, Japanese, and Korean UWB regulations.

### *D. Current Standardization Status*

Within the IEEE 802 standard, the UWB standardization activities take place in the IEEE 802.15 WGs for WPAN. The IEEE 802.15.3a (TG3a) and IEEE 802.15.4a (TG4a) are two TGs within 802.15 WG that develop their standards based on UWB technology. The TG3a was formed in January 2003 with the objective of providing a higher speed physical layer (PHY) enhancement amendment to the IEEE 802.15.3 [7]. The group aimed to develop PHY standards to support data rates between $110-450$ Mbps over short ranges (i.e., $< 10$ m). In March 2003, 23 companies responded to the Call for Proposals. However, after approximately three years of deadlock between two merged proposals, namely, multi-band orthogonal frequency division multiplexing (MB-OFDM) and direct sequence UWB, TG3a decided to disband the group in January 2006. The official termination will be effective in July 2006.

The TG4a was formed in March 2004 with the objective of providing an amendment to IEEE 802.15.4 for an alternative PHY [8]. The aim is to offer both communications and high precision ranging capability (i.e., 1 m accuracy and better). In January 2005, 26 companies turned in proposals to be considered in the standard and in March 2005, all proposals were merged and the baseline specification was selected without enacting the down-selection procedures. The baseline is based on two optional PHYs consisting of a UWB impulse radio (operating in unlicensed UWB spectrum) and a chirp spread spectrum (operating in unlicensed 2.4 GHz spectrum), where the former will be able to deliver communications and high precision ranging. The group is aiming to finalize the standard by first quarter of 2007.

Industry's first commercial UWB standards were released by ECMA International in December 2005 [6]. ECMA-368 standard for high rate UWB defines PHY and medium access control (MAC) layers for a decentralized complex system. The standard employs unlicensed $3.1-10.6$ GHz UWB spectrum and mandatory support of at least 53.3, 106.7 and 200 Mbps. This standard is based on the MB-OFDM specifications supported by the WiMedia alliance, which includes companies like Intel, Texas Instruments, Philips, Hewlett-Packard, Samsung, Sony, etc. [34] and currently applies to the US only.

## III. Technical Challenges and Approaches

As described in Section I, UWB technology has many advantages that make it very attractive for future wireless communications and many other applications. However, there are some technical challenges and open issues that remain to

TABLE I
SUMMARY COMPARISON OF THE UNITED STATES, JAPAN, AND KOREA UWB REGULATORY.

| | United States | Japan | Korea |
|---|---|---|---|
| Approval date | 14 Feb 2002<br>15 Dec 2004 (Amendment) | 27 Mar 2006 | Jun 2006 (Expected) |
| Frequency bands | $3.1 - 10.6$ GHz | Lower band: $3.4 - 4.8$ GHz<br>Upper band: $7.25 - 10.25$ GHz | Lower band: $3.1 - 4.8$ GHz<br>Upper band: $7.2 - 10.2$ GHz |
| Transmission power | $-41.3$ dBm/MHz | $-41.3$ dBm/MHz | $-41.3$ dBm/MHz |
| Operating bandwidth | $B_f = 20\%$ or<br>$B = 500$ MHz | $B_f = 20\%$ or<br>$B = 450$ MHz | $B_f = 20\%$ or<br>$B = 500$ MHz |
| Operation limitation | Indoor and handheld systems | Indoor systems only | Indoor and outdoor systems |
| Interference mitigation technique | Optional | Mandatory at lower band by Dec 2008 | Mandatory at lower band by Jun 2010 |

be solved prior to the successful deployment of UWB systems. These challenges have opened up many research opportunities in various areas, which will be discussed throughout this section.

i) *Antenna design* – Portable devices like MTs require small antennas that can be integrated into the device. The design of UWB antennas is more challenging than narrowband antennas due to the very large signal bandwidth and linearity requirements [41], [42]. The antenna must be linear to avoid signal distortion, because any signal distortion in the frequency domain will cause similar distortion in the time domain. This will eventually increase the complexity of the detection mechanism at the receiver (RX). Therefore, designing a small-size, low-cost, and efficient UWB antenna is a major challenge.

ii) *Propagation channel* – UWB propagation introduced a large number of MPCs that were not resolvable in narrowband communication systems. Though MPCs undergo less fading in UWB propagation channels, the average total received energy is now spread over a large number of paths [19]–[22]. For reliable detection, UWB RXs must capture a sufficient amount of multipath energy, which eventually increases the complexity of the RX system design. Furthermore, multipath dispersion can cause inter-symbol-interference if UWB pulses are too closely spaced. Thus, in order to design robust UWB systems, greater understanding of propagation characteristics is highly desirable.

iii) *Timing acquisition and synchronization* – Timing acquisition and synchronization is a critical challenge in UWB systems due to the very short-pulse duration and low transmit power. These imply that timing requirements at both the transmitter (TX) and RX are very high, necessitating a long search time in order to obtain a reliable timing. This area has received a great deal of attention from the UWB community with the most current research focusing on efficient search strategies and reducing the searching space or time [43]–[48].

iv) *Coding and modulation* – Coding and modulation is one way to improve UWB systems capacity. In choosing an appropriate coding and modulation scheme, a number of aspects have to be considered, such as the trade-off between implementation complexity and system performance. A substantial amount of work has been done [2], [30], [31], [49]–[52], however, more advanced modulation and coding schemes are required in order to design robust and reliable UWB communication systems.

v) *Integrated circuit (IC) and digital signal processing (DSP) design* – The excessive bandwidth of UWB systems requires fast analog-to-digital (ADC) converters and very high-speed sampling rates DSP in order to satisfy the Nyquist criteria. However, most commercialized low-cost ADC have relatively small analog bandwidth (e.g., $< 1$ GHz) [26], [27], [53]. Recently, the use of high performance ADCs and DSPs has been proposed, but this will tend to increase the complexity and cost. A new solution is required in order to yield small size, low-cost, and low complexity IC.

vi) *UWB networking* – UWB based networks such as MAC layer protocol, optimum routing algorithms, and resource and mobility management are still in their infancy. For example, there is an open issue whether the single-hop or multihop network is more suitable for indoor networking applications [54]. These remain important for further investigations. Recently, an increasing amount of work related to this area has been reported in the literature [55]–[59].

## IV. RANGING AND LOCALIZATION

### A. Application Scenarios

Location awareness is one of the fundamental problems in tomorrow's wireless networks. With the advent of GPS, localization has found application in many different fields. In areas where there is a clear LOS to GPS satellites, this technique provides a good estimate of the user's location on the earth. However, in indoor and dense urban environments the GPS signal is typically unavailable, and localization becomes a more challenging problem. UWB technology is capable of providing highly accurate ranging in the harshest environments, owing to its inherent high delay resolution and ability to penetrate obstacles. Therefore, it is the technology of choice for range-based localization, especially in dense cluttered environments, and can be used to infer the position of a moving agent. It has been identified that location awareness applications will be important for future MTs, and accurate ranging and localization capabilities can provide new usage models. Furthermore, UWB technology possesses both *ranging* and *communication* abilities. This leads to network nodes with low complexity and low power consumption. UWB localizers implemented on an MT can provide various important add-on applications in the future such as:

i) *Object location* – Drivers could easily locate their cars in large parking structures if both MTs and cars are integrated with UWB technology.
ii) *Personal location* – Rescuers could find people in a variety of situations, including civilians in a burning building, injured skiers on the slopes, or hikers in a remote area, if these people were carrying an MT with integrated UWB technology (note that an MT is a device that almost every individual will soon own).
iii) *Smart homes and offices* – Home or office appliances with integrated UWB technology (e.g., TV, lamps, PC, etc.) can enable technologies that turn the desired appliances on or off, by knowing the location of both the appliance and the individual that carries an MT with integrated UWB technology [60], [61].
iv) *Ad-hoc networking* – The ad-hoc network has no infrastructure and consists of several MTs that can communicate with each other without fixed routers. Each MT can act as a terminal as well as a router. So, it can find and maintain a suitable route to other nodes in the network dynamically. Such a feature provides a remarkable increase in the level of autonomy compared to the traditional fixed communication infrastructure. However, the location of the MT, the strict power consumption constraints on a battery-powered MT, and multipath interference are the main concerns in ad-hoc networks. When using UWB radio technology, two MTs inside the network can determine their distance within centimeters. Thus, ad-hoc networking using UWB technology can overcome the main limitations associated with traditional multi-hop solutions, such as power constraints, multipath propagation, and location of the MT, and can provide invaluable add-on features for future MT usage models.
v) *Smart highways* – Positioning devices could be used to assist autopilots in automobiles. Vehicles (e.g., cars, motorcycles) could be guided along a highway by integrated UWB technology along the road. UWB devices placed inside the vehicles or on the MT enable them to communicate and, thus, provide real time local intelligence in order to avoid accidents [62].

### B. Technical Approaches and Challenges

Generally, there are two phases towards realization of highly accurate location awareness applications. Firstly, through accurate *ranging* i.e., an action of estimating the distance between two nodes, and secondly, through *localization* (a.k.a. positioning) i.e., an action of determining the exact location of an unknown node from known nodes (anchors) by means of the intersection of three or more measured ranges from known nodes. In this section, a brief overview of existing ranging and localization techniques will be given. The four commonly used techniques to perform ranging are as follows [63]:

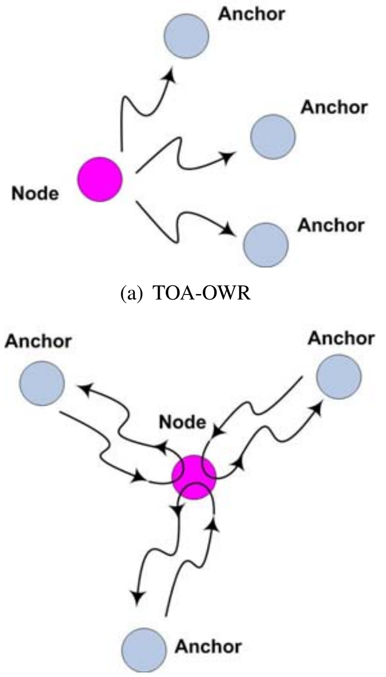
i) *Time-of-arrival (TOA) technique* – Distance information is extracted from the propagation delay between TX and RX. This technique can be further classified into TOA one-way-ranging (TOA-OWR) and TOA two-way-ranging (TOA-TWR). The former requires perfect synchronization between TX and RX, while the latter does not require synchronization between TX and RX. Fig. 4 illustrates these two classes of TOA techniques.
ii) *Time-difference-of-arrival (TDOA) technique* – The difference between TOAs in several RXs is used to reconstruct a TX's position. This requires highly precise synchronization between the RXs, but not precise synchronization between TX and RXs.
iii) *Received-signal-strength indication (RSSI) technique* – Distance is measured based on the attenuation introduced by the propagation of the signal from TX to RX. Since the relation between distance and attenuation depends on channel behavior, an accurate propagation model is required for reliable distance estimation. MT mobility and unpredictable variations in channel behavior can occasionally lead to large errors in distance evaluation. Thus, the RSSI technique is not an accurate method, and its adoption is confined to applications that require coarse ranging. Furthermore, this technique does not exploit the fine time resolution of UWB signal.
iv) *Angle-of-arrival (AOA) technique* – Distance between terminals is reconstructed from the angle between them; this technique requires adoption of expensive antenna arrays, and the results are highly sensitive to multipath, NLOS conditions, and array precision.

The *TOA localization* and the *TDOA localization* are the two well-known techniques frequently used to perform positioning. The former requires a common time reference available to agent and all anchors; while the latter requires an accurate common time reference between the anchors, but does not rely on precise synchronization between anchors and the agent. However, ranging and localization accuracy could be limited by the presence of multipath, NLOS conditions and extra propagation delay due to the presence of obstacles (e.g., walls). Hence, suitable ranging and localization techniques have to be investigated and analyzed, especially in NLOS conditions. In addition, many applications pose constraints on device complexity and consumption, so a suitable trade-off between complexity and ranging accuracy has to be analyzed.

## V. Coexistence and Interference Issues

### A. Basic Problem

The strength of UWB systems lies in the use of extremely large transmission bandwidths. Since UWB signals occupy such a large bandwidth, they operate as an overlay system with other existing narrowband (NB) radio systems as shown in Fig. 5. The increasing penetration of heterogeneous communication devices sharing the same frequency band makes mutual




(a) TOA-OWR



(b) TOA-TWR

Fig. 4. Two classes of TOA ranging techniques.

interference a key issue for investigation, in order to ascertain whether their coexistence is possible. Therefore, to ensure the successful deployment of UWB systems, it is important to assess the potential coexistence of UWB systems with existing and next generation wireless systems. Coexistence requires that both NB and UWB systems do not interfere with one another. UWB devices must then be designed to account for two fundamental aspects:

- UWB devices must not cause harmful interference to licensed next generation wireless services and existing NB systems (e.g., GPS, GSM/GPRS, UMTS, Bluetooth, IEEE 802.11 WLAN, etc.)
- UWB devices must be robust and able to operate in the presence of interference caused by both NB systems and other UWB-based nodes.

There are many parameters that can influence the way a UWB system would interfere with a NB system, or vice versa, such as the number and distribution of the interferers, the relative power of the interferers, the UWB modulation, the pulse repetition frequency, the center frequency of the NB system, and the type and structure of the NB and/or UWB receiver being used. Thus, it is interesting to study the impact of NB interferers on UWB receivers and vice-versa, taking different receivers into account, such as coherent, differential-coherent and non-coherent systems.

### *B. Technical Approaches and Challenges*

In order to realize UWB technology on MT for future wireless services, the first step is to ensure the coexistence of UWB systems with existing and future wireless network technologies

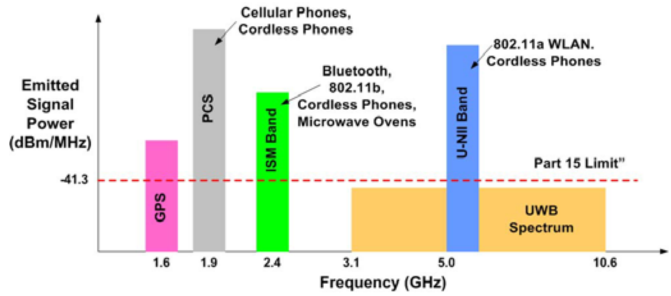



Fig. 5. UWB systems overlay with other existence NB systems.

such as WLAN, GSM, UMTS, 3G, etc. Such coexistence is not straightforward since wireless systems often use the same unlicensed frequency bands. Interference problems must be thoroughly examined so they can be controlled or eliminated in order to preserve the overall system's throughput, performance and quality of service. Parallel operation is of great importance since it allows UWB devices the opportunity to offer add-on services like personal and object tracking, high-rate data transfer, short-range communication, etc.

Currently, only a very preliminary analysis on the possible interference of UWB signals with cellular systems has been studied such as [24], [25], [64]–[66]. Furthermore, many results have been obtained starting from some unrealistic assumptions, leading to pessimistic conclusions about the impact of UWB on cellular systems. Main misleading assumptions deal with the selection of the free-space channel model for both indoor and outdoor propagation and with the procedure used to evaluate UWB interference on the cellular receiver [67], [68]. In addition, some work reported in the literature assesses UWB interference by assuming that every UWB terminal continuously emits at its maximum power, which is not the case for a practical UWB system.

So far, no investigation has been carried out to study the interference of current 3G and future 4G on UWB systems and vice-versa. The dual-model MT, which incorporates both cellular (i.e., 3G) and WLAN (i.e., WiFi) technologies, has been released by NTT DoCoMo Japan in November 2004 [69]. Since the WLAN spectrum overlays with UWB spectrum, a thorough understanding of the coexistence of cellular/WLAN and UWB systems is important to ensure robust communications.

Although the individual UWB device must satisfy emission limits imposed by regulatory agencies, the cumulative interference from multiple UWB emitters is not regulated. The impact of such aggregate interference on victim NB systems, as well as on other UWB systems, can be significant. Although this is a very important issue, the effect of aggregate interference on both NB and UWB systems has not been investigated thoroughly. Limited results and the lack of an in-depth analysis on the UWB/NB coexistence may lead to RF pollution in the licensed band and/or cause delay in the widespread deployment of UWB-enhanced MTs.

Various coexistence strategies can be deployed. The more conventional approach is based on *static control* in which UWB devices are pre-configures so they will not use a particular band (based on geographic region or device usage). The more intelligent method is based on *dynamic control* (a.k.a DAA mechanisms). Based on this, UWB devices will need an algorithm that can detect the presence of NB interference and then avoid it upon detection of its presence. One way to perform dynamic control is based on cognitive radio or software define radio. Additionally, some UWB device manufacturers will design a notch filter in such a way to avoid UWB devices operating in the WLAN band.

## VI. Conclusion

In this paper, an overview of UWB radio technology is presented. This new technology offers significant benefits, making it a suitable candidate to complement other wireless technologies to achieve ubiquitous communications. However, various technical challenges remain as open issues need to be confronted to ensure the successful deployment of this technology. One of the main constraints is the lack of harmonization of worldwide regulations. At this point, only the US and Japan have approved the commercialized usage of the UWB spectrum, with Korea expected to announce their UWB spectrum allocation in June 2006. However, in other countries, especially in Europe, UWB regulation is still premature. It is widely anticipated that location awareness applications will become more important for the future wireless world. Although various ranging and localization techniques are available, TOA based techniques are best suited for UWB systems due to fine delay resolution. However, current TOA schemes have various limitations such as the high sampling rate required to achieve good ranging accuracy, which eventually increases the system complexity. Thus, sub-optimal systems with lower complexity should be investigated. Furthermore, in order to ensure a robust communication link, the issue of coexistence and interference of UWB systems with current and future wireless systems must be considered.

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