Unlicensed reuse of licensed spectrum: case UWB

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Abstract

In this paper, unlicensed reuse of licensed spectrum is discussed from the regulatory point of view. This issue concerns the regulator by the possibility of interference to existing services, and also the increase of spectrum efficiency. Ultrawideband (UWB) technology is an interesting subject for this matter and here, the topic of the paper is discussed through a case study of UWB.

1. Introduction

Unlicensed reuse of already licensed spectrum to increase the spectrum efficiency is relevant topic in today's regulation. The regulator has significant interest in this field, since its task it to make sure the existing allocated radio systems are not interfered by new allocations. On the other hand, the regulator is interested in the increase of social welfare, and therefore also the increase of spectrum efficiency.

Ultrawideband (UWB) technology provides an interesting case to view of this topic. From regulatory point of view, UWB needs some alternative regulatory actions to consider, since the implementation of the system differs greatly from the traditional radio systems. The implementation of UWB needs the use of already licensed radio spectrum in an unlicensed manner, i.e. without a licensing cost or control. Therefore, it is essential that the existing services are not interfered while implementing new systems.

The interest of UWB radio access systems have grown rapidly over past few years. The use of broadband radio access is today familiar to users and equipment manufacturing costs are low enough to support it to become general. Also in home usage, the need for cables running all over the house has become frustrating and people are anxious to use wireless systems for this reason also. In many promotion texts of UWB, something like this is said to motivate people: "*In the digital home of the not-too-distant future, people will be sharing photos, music, video, data and voice among networked consumer electronics, PCs and mobile devices throughout the home and even remotely. For example, users will be able to stream video content from a PC or consumer electronics (CE) device -- such as a camcorder, DVD player or personal video recorder -- to a flat screen HDTV (high-definition television) display without the use of any wires*." [1]

The discussion of UWB mainly consists of communication opportunities of the system, and this is also the focus of this paper. However, also imaging services, e.g. radar systems operating in a 24 GHz band, are also being developed using UWB technology [2].

2. Overview of UWB

UWB is a personal area network (PAN) that is intended for short range radio transmission as mentioned above. UWB is a high-rate connectivity that complements other wireless technologies in terms of link ranges, as shown in Figure 1 [3].

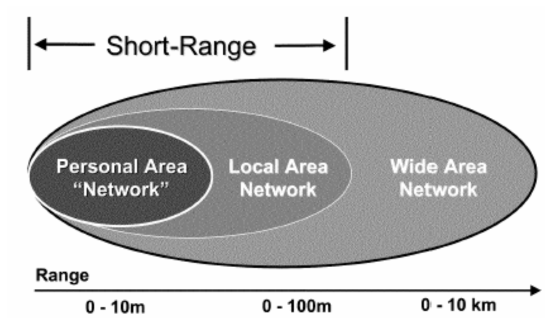

Figure 1 WPAN, WLAN, and cellular networks and their typical ranges

UWB is not a new invention, but it is has been developed back in the 1980's [4], although the research started already in the 1960's. Traditionally UWB (or impulse radio) transmitter operates by transmitting billions of pulses across a very wide spectrum of frequencies several GHz in bandwidth. The receiver then translates the pulses into data by listening for a familiar pulse sequence sent by the transmitter. UWB is defined as any radio technology having a spectrum that occupies a bandwidth greater than 20 percent of the center frequency, or a bandwidth of at least 500 MHz.

The development of UWB has been conducted for many years in the laboratories, and this now it has moved to standardization. Current status in the standardization process, while writing this paper, is that there are two competing physical layer specifications available; one that is based on direct sequence spread spectrum (DS-UWB), and the other that is based on multiband orthogonal frequency division multiplexing (OFDM). These two alternatives are currently under consideration by the IEEE 802.15 Task Group 3a (TG3a) [5].

The latter alternative is heavily supported by the industry; there are now over 170 companies (inc. Intel, Nokia, Texas Instruments, etc.) involved in the MultiBand OFDM Alliance (MBOA), a consortium formed in June 2003 [6].

2.1. Motivation for UWB

The concept of a UWB radio spans many different applications, as also mentioned previously. UWB along with the convergence layer becomes the underlying transport mechanism for different applications, some of which are currently only available in wired networks. Example of interesting applications that would operate on top of the common UWB platform would be wireless universal serial bus (WUSB), wireless IEEE 1394 (FireWire), the next generation of Bluetooth, and Universal Plug and Play (UPnP). This vision is illustrated in Figure 2 [1]. This concept has a lot of potential applications since it creates the first high-speed wireless interconnects.

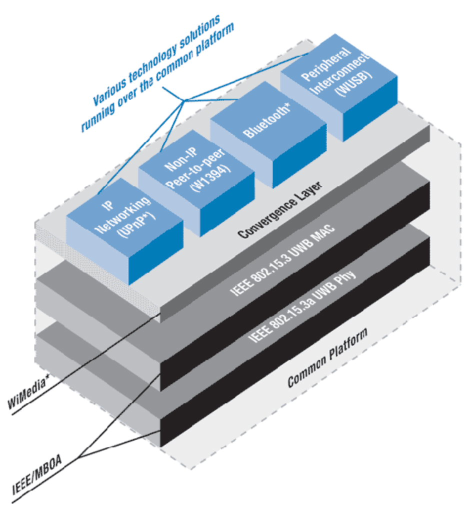

Figure 2 Vision of UWB as common platform under "convergence layer"

An example application for UWB would be to use it for downloading content to a mobile device like a portable media player (PMP) from the content source like a PC, laptop or external hard disk drive. Once authentication and authorization is established the device and PC can perform bulk data transfer of video files. Within the consumer electronics industry, there is demand for wireless connecting various devices such as DVDs, HDTVs, stereos, camcorders, digital cameras and other devices.

Also for aesthetic reasons, UWB can be applicable for example for a wall-mounted TV display where users prefer not to have cables visible. A variation on this example is the ability to stream content to multiple devices simultaneously. This would allow picture-in-picture functionality or viewing of the same or different content on multiple viewing devices.

2.2. Technical characteristics

The definition for UWB, according to the FCC, is any radio technology with a spectrum that occupies more than 20 percent of the center frequency or a minimum of 500 MHz. Today, UWB operates on an unlicensed radio spectrum from 3.1 GHz to 10.6 GHz, which is allocated by the FCC in 2002. Regulation issues are dealt in more detail in following chapter.

However, UWB does not use the entire 7.5 GHz band, or even a large portion of it, but the minimum bandwidth of 500 MHz defined by the FCC. This FCC regulation expands the design options for UWB communication systems. System designers are free to use a combination of sub-bands within the spectrum to optimize system performance, power consumption and design complexity. UWB systems can maintain the same low transmit power as if they were using the entire bandwidth by interleaving the symbols across these sub-bands. [7] Figure 3 illustrates the operation principle of UWB compared with GSM and UTMS [8].

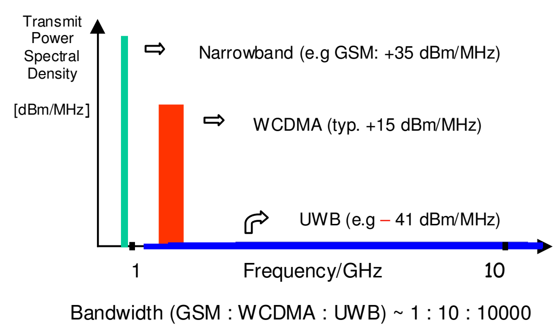

Figure 3 Operation principles of GSM, UMTS, UWB

For such multiband system, information can either be transmitted by the traditional pulse-based single carrier method or by multicarrier techniques. Pulse-based single carrier systems transmit signals by modulating the phase of a very narrow pulse. Advantage of this method is a very simple transmitter design, but there still exist several disadvantages, e.g. to collect enough signal energy in a typical usage environment (with many reflecting surfaces); switching time requirements can be very strict; the receiver signal processing is very sensitive to group delay variations; and, spectral resources are potentially wasted in order to avoid narrowband interference. Multiband OFDM transmits data simultaneously over multiple carriers spaced apart at precise frequencies. With this method the transmitter complexity is only slightly increased. Advantages of multiband OFDM include high spectral flexibility, resiliency to RF interference and multipath effects, and better efficiency. OFDM modulation techniques have been successfully applied to several other high-performance popular commercial communications systems including WLAN 802.11a/g and WiMAX 802.16a [7].

Dividing the available spectrum into several smaller bands allows the selective implementation of bands at certain frequency ranges while leaving other parts of the spectrum unused. The dynamic ability of the radio is important because it can adapt to regulatory constraints. The band plan for the MBOA proposal has five logical channels, as shown in Figure 4 [1]. In the current MultiBand OFDM Alliance's proposal, bands 1–3 are for mandatory mode, while the other remaining channels (2–5) are optional. There are up to four time-frequency codes per channel, thus allowing for a total of 20 piconets with the current MBOA proposal [1].

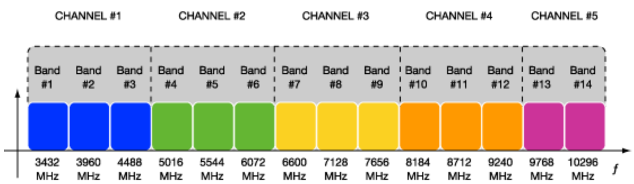

Figure 4 The MultiBand OFDM frequency band plan

Based on existing CMOS technology geometries, use of the spectrum from 3.1 GHz to 4.8 GHz is considered optimal for initial deployments. Limiting the upper bound also avoids interference with the U-NII band (around 5 GHz) where 802.11a resides as well as simplifies the design of the radio and analog front end circuitry. The frequency band from 3.1 GHz to 4.8 GHz is sufficient for three sub-bands of 528 MHz, as illustrated in Figure 5 [7].

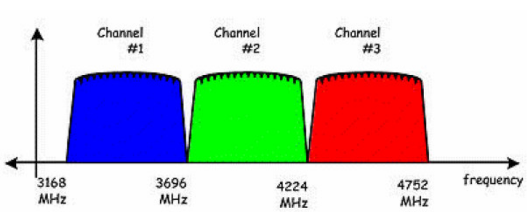

Figure 5 Frequency allocation of sub-bands

3. Current regulation state

The frequency bands that UWB operates were mentioned above to consist of 528 MHz bands in frequency range of 3.1 to 10.6 GHz. However, an obvious problem for UWB usage can be identified here; these frequencies are already in use, at least partly in every corner of the world. It is well-known that frequency spectrum is limited resource, and it should be efficiently in use. Figure 6 illustrates the situation of frequency allocations in the USA in frequencies from 3 kHz to 300 GHz [9]. It can be clearly seen, even though that the figure is from 1996, that the spectrum is rather full.

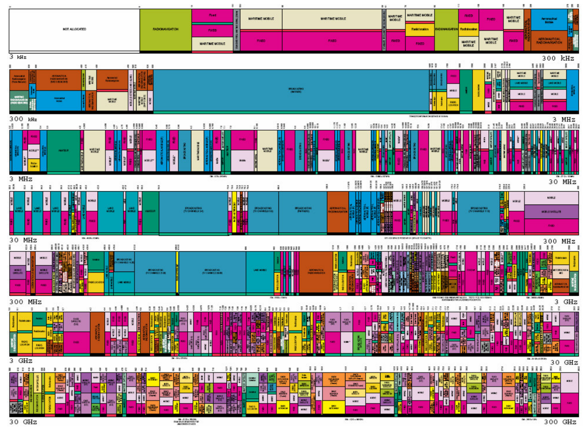

Figure 6 Frequency allocation in USA, 3 kHz - 300 GHz

The close-up from Figure 6 on frequencies from 3.1 to 4.8 GHz, which is presented as the obligatory frequency band for UWB is shown in Figure 7.

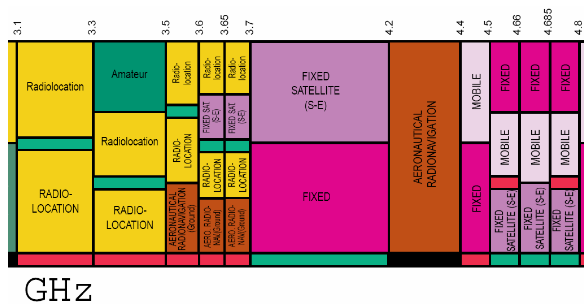

Figure 7 Frequency allocation in USA, 3.1 – 4.8 GHz

The situation is basically the same in other countries as well, even though the allocated radio systems differ from country to country. These figures illustrates the problem with introduction of UWB, since it goes without saying that existing systems should not be interfered by new systems operating at the same frequency. Therefore it is also clear that strict regulation is needed for UWB, before it could be commercially launched. The regulation can also have significant effect of UWB system characteristics, as well as its commercial potential.

3.1. Regulation is USA

Prior to the regulation of UWB by the FCC, there was debate over how much interference UWB would pose to existing radio services. Services such as the GPS location service, which operates around 1.9 GHz frequency band were thought one of the most vulnerable to UWB interference. The debate started to look neverending, as the UWB front kept on stating that the interference is minimal, while GPS front argued against the interference. Nevertheless, the FCC ended the speculation by publishing a technical report indicating that "ultrawideband (UWB) is no more of an interference threat to the Global Positioning System (GPS) than a laptop or hairdryer [10]."

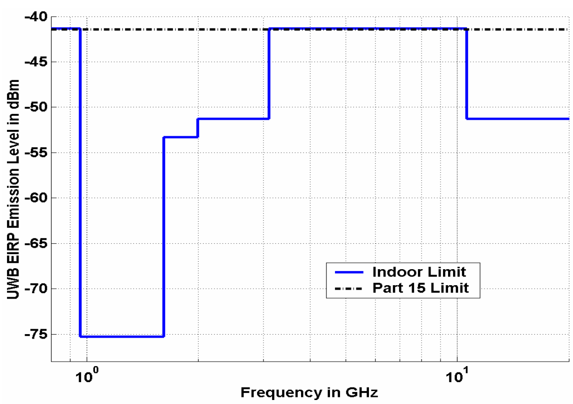

Figure 8 Spectrum mask of UWB for indoor environments

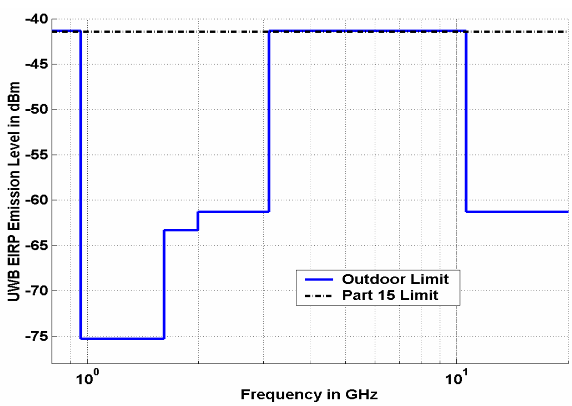

Figure 9 Spectrum mask of UWB for outdoor environments

The FCC approved the deployment of UWB on an unlicensed basis in the 3.1–10.6 GHz band in 2002. The essence of this ruling is to limit the power spectral density (PSD) measured in a 1 MHz bandwidth at the output of an isotropic transmit antenna to a spectrum mask, which is shown in Figure 8 and Figure 9 for indoor and outdoor environments, respectively [11].

The above spectral mask allows UWB devices to overlay existing systems while ensuring sufficient attenuation to limit adjacent channel interference, i.e. the UWB Effective Isotropic Radiated Power (EIRP) emission level is restricted to -41dBm/MHz constant PSD over a 7.5 GHz bandwidth, which implies approximately 0.55 mW average transmit power. Additional PSD limits have been placed below 2 GHz to protect critical applications such as global positioning system (GPS) as shown (there exist bands for digital cellular at 1.9 GHz and GPS band at 1.5 GHz in the USA). Because of the shape of this spectral mask, it is needed to use additional transmit filtering of baseband pulse to limit the out-of-band emission spectra.

Since the UWB spectrum has the unlicensed nature all wireless devices sharing the spectrum must coexist. In other words the interference should be kept as low as possible, regardless of present or future spectral allocations and emissions restrictions in various regions of the world. According to MBOA, multiband OFDM is capable of complying with local regulations by dynamically turning off certain tones or channels in software, which speaks to their favor. However, it is still worth of pointing out that the physical layer characteristics are not standardized yet.

In summary, UWB communications is allowed at a very low average transmit power compared to more conventional (narrowband) systems that effectively restricts UWB to short ranges. UWB is, thus, a candidate physical layer mechanism for IEEE 802.15Wireless Personal Area Network (PAN) for short-range high-rate connectivity.

3.2. Regulation in Europe

In Europe, the regulation of UWB is still in progress. The process begun later than in the USA, and while the FCC regulation was published, European Conference of Postal and Telecommunications Administrations (CEPT) were finalizing a report on UWB spectrum sharing. Individual European regulators were supposed to base their regulations on the report. In October 2004, Electronic Communication Committee (ECC) published a draft of a new ECC Report 64 on the protection requirements of radio communication systems below 10.6 GHz from generic UWB applications [12]. This report still needs to be reviewed by the ECC TG-3 meeting on 10-14 January 2005, so in other words the regulation is taking place while writing this paper.

In [12], a spectrum mask of UWB for indoor and outdoor usage is proposed and it is shown in Table 1

Table 1 Maximum UWB band-edge mask for average power density

Power type	Frequency, GHz f < 3.1 dBm/MHz	3.1 < f < 10.6 dBm/MHz	f > 10.6 dBm/MHz
Type I. (Indoor)	–51.3 + 87* log (f/3.1)	–41.3 dBm/ 1 MHz	–51.3 + 87* log (10.6/f)
Type II. (Outdoor)	–61.3 + 87* log (f/3.1)	–41.3 dBm/ 1 MHz	–61.3 + 87* log (10.6/f)

Figure 10 and Figure 11 illustrates the differences between the FCC and the ECC spectrum mask [13].

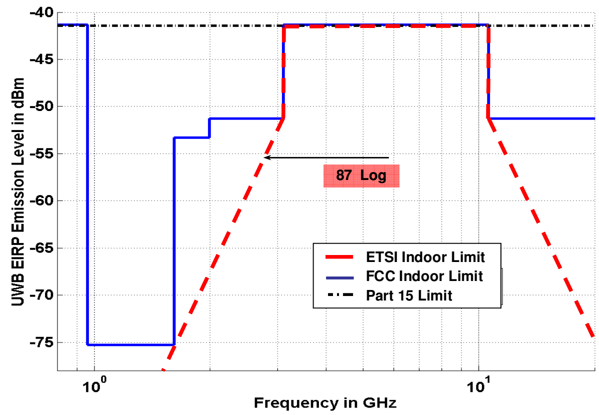

Figure 10 FCC and ECC spectrum mask for indoor UWB

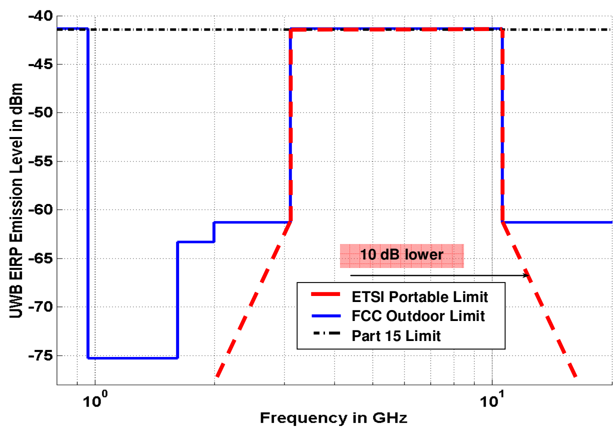

Figure 11 FCC and ECC spectrum mask for outdoor/portable UWB

The response for the differences between the FCC and the ECC mask when the first draft was published in 2002 were rather pessimistic. In [13] it is pointed out that that from 5 dB to 30 dB more protection at specific frequencies is needed over the FCC in-band limit for in-door devices. This "European limit" of 30 dB lower than set by the FCC, was feared to make UWB useless for consumer and PC applications. Also a rather pessimistic forecast for UWB usage in Europe was stated by a single manufacturer in [13]: "*UWB may become a US only technology for 3 to 5 years. Afterwards successful deployment in the US, the regulations can be changed in Europe and Japan (Japan may "play it safe" and follow strict European rules).*"

Later there have been more optimistic approaches for the matter, (e.g. [14]), and it seems that manufacturers are convinced to try to overcome the difficulties.

4. Conclusions

The allocation of such a large range of spectrum for unlicensed use, as in the case with UWB, indicates a significant shift away from a regulatory viewpoint that has up till now been dominated; the licensed spectrum usage philosophy. This action has been significant enough to raise many concerns from several directions, particularly regarding UWB's ability to coexist with existing radio services such as IEEE 802.11a wireless local area networks (WLANs), radar systems, etc. During the commentary period of the Notice of Proposed Rule Making (NPRM), the FCC received a large number of responses to the docket, many from concerned licensed service providers, indicating the intense interest that UWB has generated [3].

However, a wider perspective based on total spectrum utilization viewpoint reveals the potential for achieving more efficient spectrum utilization (i.e. acceptance of impacts on existing systems with the greater common net good obtained by introducing such new overlay-friendly technologies such as UWB). Studies of licensed bands have shown that a significant percentage of spectrum remains unused, averaged over time, contributing to this spectral inefficiency [3]. The commercial success of WLAN technologies, particularly 802.11, has led to need for increasing globally harmonized allocations of unlicensed spectrum. However, it is worth pointing out that the use of unlicensed spectrum for sure can have its own problems, regarded more generally as the tragedy of commons [15]. Therefore, it is likely that addition of such new spectrum for unlicensed use will require a sort of "an etiquette" for sharing of common resources via mechanisms e.g. such as dynamic spectrum management. Hence, the ability of UWB to fill-in unused/underused spectrum at any time promotes opportunistic communications can contribute to both greater spectral efficiency and aggregate network throughput assuming a suitable multiple accessing network architecture for UWB is identified.

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