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Requirements for UWB mitigation techniques for IR UWB and OFDM UWB

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Abstract

This deliverable presents the requirements of interference mitigation techniques for both Impulse Radio and OFDM-based UWB systems that, in the context of cognitive radio (CR), can be exploited to increase coexistence. Focusing on the four scenarios considered in the project, the home theatre, automotive, airborne systems, and the heterogeneous networking, several interference mitigation techniques are proposed.

Keywords

Ultra-WideBand, Impulse Radio, Orthogonal Frequency Division Multiplex, Interference Mitigation, Coexistence.

Table of Contents

List of Figures

Abbreviations

BEP	Bit Error Probability
BPAM	Binary Pulse Amplitude Modulation
CR	Cognitive Radio
DAA	Detect And Avoid
DAB	Digital Audio Broadcasting
DoA	Direction-of-Arrival
DS	Direct-Sequence
DVB-T	Digital Video Broadcasting-Terrestrial
EUWB	CoExisting Short Range Radio by Advanced Ultra-WideBand Radio Technology
FCC	Federal Communication Commission
IR	Impulse Radio
MF	Matched Filter
MIMO	Multiple-Input Multiple-Output
MUI	Multi-User Interference
SDR	Software Defined Radio
OFDM	Orthogonal Frequency Division Multiplex
PPM	Pulse Position Modulation
QoS	Quality of Service
SSA	Soft Spectrum Adaptation
TH	Time-Hopping
ToA	Time-of-Arrival
UWB	Ultra-WideBand

1 Executive summary

For both Impulse Radio and OFDM-based UWB systems we identify the requirements of interference mitigation techniques that, in the context of cognitive radio, can be exploited to increase coexistence.

The aim of this deliverable is to define interference mitigation techniques that adopt the cognitive radio principles. In particular, focusing on the four scenarios considered in the project, the home theatre environment (HT), automotive environment (Auto), airborne systems (AirB), and the heterogeneous networking environment (HetG), a number of suitable interference mitigation techniques have been proposed. Such techniques include: DAA (detection-and-avoidance), identification and adaptive classification of interference, suppression of interference, spectrum-agile UWB waveforms generation, cooperative modulation and coding strategies, array beamforming to reject interference.

2 Introduction

The formidable development of wireless communication systems in recent years has led to a progressive definition of rules for accessing to the radio spectrum, posing several tasks in the organization and in the sharing strategies for such a precious resource.

Traditionally the radio spectrum can be divided in two categories: licensed and unlicensed bands. In unlicensed bands, users can freely transmit. However, the amount of interference introduced by a transmission system operating in those bands must be limited in order to avoid impairments to other users' communications. Thus, some limitations on the power spectral density are usually introduced. Nevertheless, a too high number of users transmitting on the same unlicensed band (in the same area), can be responsible of a high overall aggregated interference, sufficient to prevent communications. Licensed services are instead designed to efficiently utilize the spectrum, with the aim of guaranteeing a quality of service (QoS) to primary users.

To overcome some of the weaknesses of the traditional approach for the spectrum usage, a new paradigm known as Cognitive Radio (CR) is emerging [3]–[7]. Cognitive radio aims to provide a more efficient and flexible usage of the radio spectrum, starting from the basic fact that the spectrum is largely underutilized in space and time. The licensed spectrum is not used for instance in some geographical areas; there are also many applications for emergency were the use of the spectrum has a very low duty cycle (e.g., services that use the spectrum only occasionally, but with high priority). By investigations on the radio spectrum usage including some revenue-rich urban areas, it has been observed that some frequency bands are largely unoccupied most of the time, that some other frequency bands are only partially occupied, and that the remaining frequency bands are heavily used [4]–[7]. From such observations, the concept of spectrum holes has been introduced. A spectrum hole is a band of frequencies assigned to a primary user, that, at a particular time and specific geographic location, is not utilized by that user [4]. In other terms, a spectrum hole is a frequency band that is "locally" (in the space/time domain) not used. In order to improve spectrum utilization, these spectrum holes could be utilized by secondary users at the right time and location.

Cognitive radio permits in principle to greatly improve the efficiency in the radio spectrum occupation. In order to exploit the locally available spectrum, a CR terminal must first sense its environment and then must adapt some of its features (as power, frequency, modulation, etc.) allowing a dynamical reuse of the available spectrum. This could in theory lead to a multidimensional reuse of spectrum in space, frequency and time, exceeding the severe limitations in the spectrum and bandwidth allocations that have slowed down broadband wireless communications' development.

Cognitive radio systems are also strongly related to software-defined radio (SDR). With SDR, the definition of some parameters of the communication is allowed by a software embedded in the radio terminal, permitting a high level of reconfigurability of signalling technique and spectrum occupation. Cognitive radio is smarter than SDR, since the aim is to have a radio that can sense and is aware of its environment and that can learn from its environment for the best spectrum and resources usage. In [8], four application scenarios are introduced as possible targets for CR systems:

- First, a licensee can employ cognitive radio technologies internally within its own network to increase the efficiency of use.
- Second, cognitive radio technologies can facilitate secondary markets in spectrum use, implemented by voluntary agreements between licensees and third parties. For instance, a licensee and third party could sign an agreement allowing secondary spectrum uses made possible only by deployment of cognitive radio technologies. Ultimately cognitive radio devices could be developed that "negotiate" with a licensee's system and use spectrum only if agreement is reached between a device and the system.

- Third, cognitive radio technologies can facilitate automated frequency coordination among licensees of co-primary services. Such coordination could be done voluntarily by the licensees under more general coordination rules imposed by Commission rules, or the Commission could require the use of an automated coordination mechanism.
- Fourth, cognitive radio technologies can be used to enable non-voluntary third party access to spectrum, for instance as an unlicensed device operating at times or in locations where licensed spectrum is not in use".
The cognitive radio approach poses several tasks, regarding for instance the radio environment sensing (with the purpose of detecting spectrum holes and to estimate interference effects), dynamic spectrum management, estimation of the channel state information and of the available channel capacity, the cooperation and the competition among users for the wireless medium access, etc.
Ultra Wide Bandwidth (UWB) communication systems represent a first example of technology suitable for the implementation of cognitive radio. UWB systems are appealing for their large bandwidth, their low-power noise-like signalling, which can be exploited in the transmission over (licensed) bands producing a controlled level of interference on existing communication systems. Thus recent researches has been focused on the investigation of coexistence issues related to the UWB technology, assuming that such systems will operate in an environment characterized by the presence of heterogeneous interfering users. In the following sections, we will focus on some coexistence and interference-related issues dealing with UWB systems, discussing how ultra wide bandwidth communications constitute a first step towards cognitive radio.

In the context of the EUWB project, and in particular within WP.2, the research tasks will be aimed at enhancing the current UWB radio technology, by enabling Cognitive Radio functionalities, namely:

- Spectrum sensing and monitoring;
- Interferers identification and classification;
- Spectral sculpting and adaptation;
- Interference mitigation;
- Network cooperation/negotiation.

as illustrated schematically in Figure 1, where the Cognition Engine is implementing the cognition cycle at the device level and governing the application of the cooperation/negotiation policies at the network level.

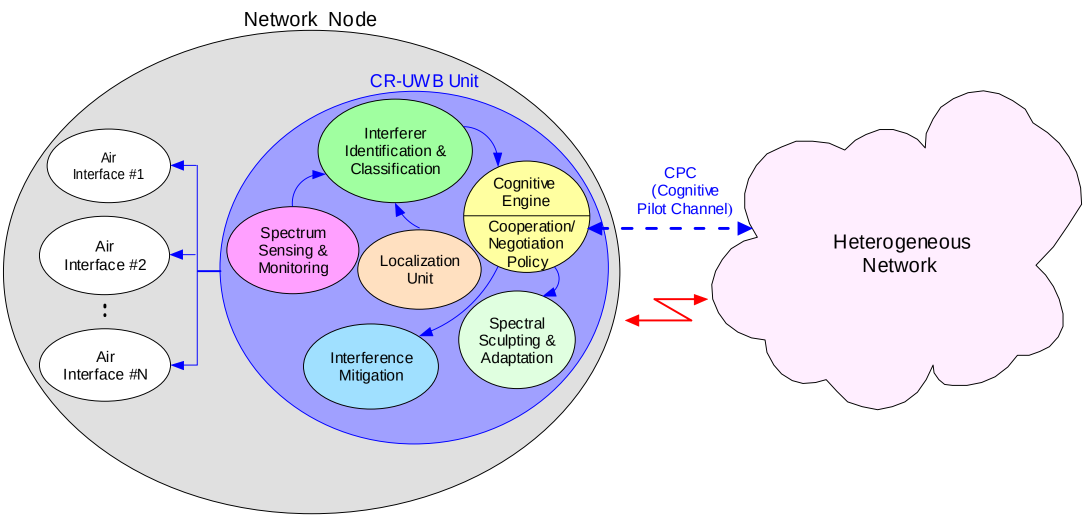

Figure 1: Schematic representation of the basic Cognitive Radio.

The spectrum sensing functions will perform a multi-dimensional (e.g. frequency, time, space, code) sensing and monitoring of the spectrum, during the initial setup phase and normal operation of the network, respectively. Correspondingly, whenever applicable, identification and classification algorithms will classify the potential interferers according to the known existing wireless standards and systems (e.g. WiFi), possibly leveraging on shared databases. Moreover, the localization capabilities offered by UWB devices and systems, can be exploited for deriving the spatial distribution of radio resource and interference for network optimisation purposes. In general, the latter task may be greatly simplified wherever the concept of Cognitive Pilot Channel (CPC), as a way to coordinate among heterogeneous networks to ensure coexistence, is supported. The research work will also address the development of novel interference mitigation and coexistence techniques including adaptive coding and modulation, spectrum-agile waveform generation, and smart beamforming techniques. Coexistence studies will be carried out regarding both intra-network interference (e.g. UWB-UWB), and inter-network interference (e.g. UWB-WiMAX).

3 Interference mitigation techniques

For both Impulse Radio and OFDM-based UWB systems we identify the requirements/functionalities of interference mitigation techniques that, in the context of cognitive radio, can be exploited to increase coexistence.

The aim of this deliverable is to define interference mitigation techniques by cognitive radio principles.

Interference mitigation techniques at the receiver end will include **DAA (detection-and-avoidance)** techniques, **adaptive classification**, **channel estimation**, and **suppression of interference**. The interference needs to be classified by means of the parameters estimated, and subsequently suppressed. Specific **spectrum sculpting** for impulse based system and OFDM based system is proposed.

Relying on impulse radio-like techniques such as **SSA (soft-spectrum adaptation)**, **UWB waveform generation** is proposed, in which spectrum-agile UWB waveforms achieving adaptation features and their associated modulation, coding and multiple-access techniques is considered.

Specifically, **bi-orthogonal multiple-tone schemes** will be developed, which give more design freedom and spectrum shaping capabilities. In the scheme, a given set of OFDM-based orthogonal waveforms can be used at the transmitter and a different set of orthogonal waveforms at the receiver.

Cognitive UWB devices will opportunistically use the spectrum, while their local resource management choices, e.g. selecting the transmission rates, transmission powers, coding schemes, etc., will greatly influence the performance of all the other users. **Cooperative modulation and coding** strategies for dynamic spectrum access and increased spectrum utilization will be investigated, with a view to minimize control information in the feedback channel. Another important aspect is to investigate radio parameters adaptation based on node locations. For example, in a network there are devices that are using orthogonal codes to code their transmission. If the location of the nodes is known a priori, it may be possible to exploit different degrees of codes orthogonality for nodes in the network depending on their relative distance. In this way, we can construct a mapping between spatial diversity and code diversity. A bigger challenge would be for the case of mobile terminals, which would require on-the-fly spatial-code sets adaptation.

The use of **multiple antennas** can improve the robustness of UWB system to interference, and/or can be used to reduce the amount of UWB interference towards non-UWB devices. On the other hand, once the interferer is located through the discovery of the spatial distribution of interferers, it is possible to perform **array beamforming** to reject the interference coming from a particular direction. The location of the node, a prediction of its movement, together with the information of the radio interference map can then be used to design an efficient “virtual” multiple-input multiple-output (MIMO) beamforming**,** with the cooperation transmission amongst the multiple radiating nodes oriented to one direction, which also represents an original research direction in the context of UWB.

3.1 Detect and Avoid (DAA) techniques

The DAA techniques are used to mitigate the interference, in order to avoid the performance decay of possible victim systems (primary users), operating in the same spectrum portions.

These techniques are mainly composed by two phases. The aim of the first phase is to perform some sort of detection on whether a primary user is present or not in the time, frequency and spatial domains. If there are one or more active primary users in some band portions, the second phase is started, which utilizes techniques able to protect the primary users performances in those portions of the transmission resource.

The UWB device will therefore have to effect periodical sensing cycles, in order to detect the activity of possible victim systems, by working autonomously, with no cooperation from them.

3.1.1 Sensing phase

Based on the a-*priori* information on the presence of a primary user and its transmission signal structure we may deploy different techniques, concerning the first phase of the DAA, to detect the primary users. We propose to look into the following techniques, given any or no a-priori knowledge of a primary users in the environment.

3.1.1.1 Energy Detection

Energy detection [9] - [11] is the simplest method to detect the presence of a user in the event of no a-*priori* information. The detection criteria for this case can be mathematically expressed as,

H^D_0: $y(n) = w(n)$

H^D_1: $y(n) = s(n) + w(n)$

where we decide on the null hypothesis H^D_0 when the received signal y(n) is only given by the noise w(n), and decide on the alternative hypothesis H^D_1 when a signal s(n) is present. D is the observation domain being either time space or frequency. The test statistic used for the decision is the energy of the received signal given by,

$\Lambda = \sum | y(n) |^2$

The test statistic is then compared to a threshold λ in order to make the decisions. In WP2 it will be important to identify the values of the decision threshold based on the statistical characteristics of the noise w(n) for the four different application clusters that we are interested in, namely, the home theatre environment (HT), automotive environment (Auto), airborne systems (AirB), and the heterogeneous networking environment (HetG). The statistical properties of the noise and other interference sources for the given application clusters are to be experimentally found and modeled by performing measurements in the real world scenario.

3.1.1.2 Waveform Sensing

Given a complete knowledge of the transmission signal structures of the primary users present in the environment, the cognitive radio terminal can identify and detect the primary users by sensing the waveforms [11] and detecting its structure corresponding to the particular user. In such case the test statistic is given by,

$$\Lambda = \mathrm{Re} \left\{ \sum | y(n)\, s^*(n) | \right\}$$

where, s*(n) is the complex conjugate of the transmitted signal s(n). The performance of such DAA techniques for the identified narrowband primary users for the given application clusters HT, Auto, AirB and HetG will be considered in WP2.

3.1.1.3 Cyclostationary Feature Sensing

Another technique for DAA is to use the cyclostationarity properties of the transmitted spectrum. The data transmission statistics of a primary user in general has a cyclostationary characteristic and the cognitive radio terminal can utilize such characteristics to detect the primary user [12] – [15]. In WP2 such DAA methods for interference mitigations in UWB- cognitive radios using the cyclostationary spectral properties will be investigated.

3.1.2 Protection phase

Once terminated the sensing phase, if the presence of active primary users has been detected, the UWB device will activate a protection mechanism so as not to damage their performances.

The easiest and most immediate protection mechanism consists in avoiding or ceasing the transmissions in the frequency bands used by the victim services. Generally speaking, other protection mechanisms exist, besides the above mentioned, such as:

- reduction of the emission power in the implied bands and adaptive power control;
- notch filters;
- turning off transmission of the implied OFDM sub-carriers (for OFDM-UWB);
- AIC (Active Interference Cancellation, for OFDM-UWB) [17].

Keeping in mind also the location capability of the UWB device and the opportunity of collaboration between different UWB devices, new protection mechanisms can be thought.

The UWB device will have to be able to support these functionalities and obtain, at the same time, the best trade-off between the resulting use of resources and its own performance in terms of communication.

3.1.2.1 Adaptive Power Control

The transmission on frequency bands occupied by primary users without causing harmful interferences requires to decrease the transmission power until a protection level. In this situation, the simplest and most immediate solution is to set a fixed value ($P_{protection}$), which has to be assigned to the emitted power when a primary user is detected, in order to avoid, in whichever situation, the arise of harmful interferences to the primary user. Therefore, an UWB device will have to transmit with a certain power level, until it will detect an active primary user. Once the primary user is detected, the UWB device decreases its own transmitted power down to the established power level ($P_{protection}$), regardless of its geographical location in relation to the primary user and considering the maximum interference level that can be tolerated.

Together with the simple mechanism described above, we propose to analyse and evaluate other power control mechanisms, which have greater complexity, but are able to exploit more efficiently the spectral resources without affecting the performance of the primary communication. In particular, an UWB device that uses these power control techniques will be able to extract, from the sensing procedure and from other possible a-priori data, the useful information to adapt, from time to time, the emission power level, in order to ensure, in any situation, the desired protection level and, at the same time, to exploit to the utmost the available resources. If an UWB device works, at the same time, on more than one frequency band, each band will be affected by a different level of fading and interferences, and it could be occupied by a primary user or not. In this context, the UWB device shall be able to dynamically allocate its power on the different frequency bands, considering their conditions and accordingly to the different protection levels required in the occupied bands.

Finally, power allocation mechanisms can be analyzed also in a cooperative context. In fact, in such a context, the decisions, concerning which power level has to be used and on which frequency bands, does not come from the optimisation process that involves the single UWB device performance, but instead they come from an optimisation process that involves the whole UWB network. The power control techniques that presupposes cooperation need for coordination and control that can be centralized or distributed. The choice of centralized or distributed power control is an important aspect that has to be evaluated based on different factors, among which, the features of the UWB system adopted and the propagation environment.

3.2 Interference identification and classification

If a radio system should coexist with primary users, it must be able, on the one hand, to decay their performance the least and, on the other hand, to exploit the spectrum the most, to ensure a reliable communication and an adequate level of QoS.

From this point of view, the distinction and the classification of the various kinds of signals, together with their detection, of course, become critic operations for the cognitive radios which have to adapt to the radio environment.

UWB devices must then be able to identify and classify all signals belonging to potential victim systems. Such a devices will carry out a first sensing phase, during which they will collect a sufficient statistic allowing them, firstly, to detect the possible presence of signals and, secondly, if any signal is detected, to extract a series of features which are significant for their identification (some potential parameters could be operating frequency, bandwidth, bit rate, chip rate, etc.) [18].

Starting from these parameters and from the observations, it will be possible to obtain further information relating to detected signals, such as, for instance, the type of modulation, if it is a single or multi-carrier signal, frequency hopping or direct-sequence signal, etc.

This set of information will represent the starting point to effect a classification of detected signals, on the basis of a comparison between their features and the features of a series of signals known a priori [19].

Once the detected signals have been recognized, the UWB device will be able to apply the most suitable mitigation techniques and, at the same time, to exploit the spectrum resources to the utmost, also through algorithms of prediction of the victim systems behavior.

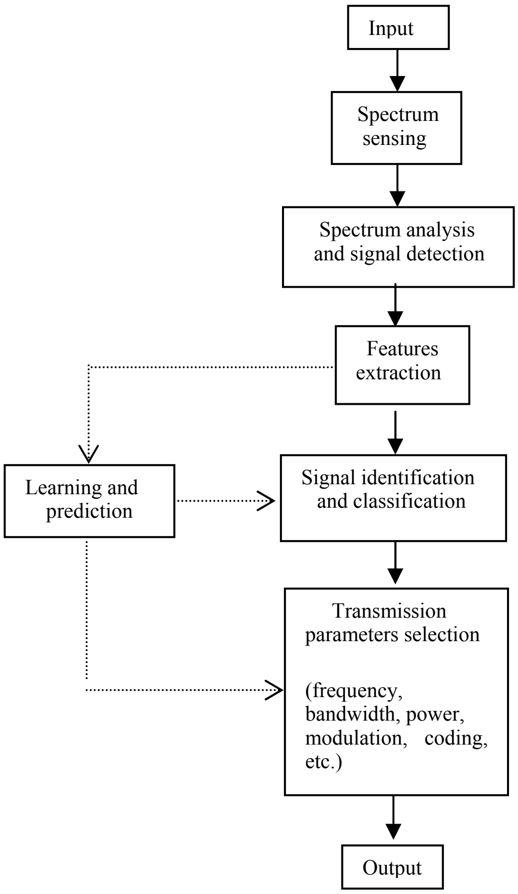

Figure 2: Interference identification and classification.

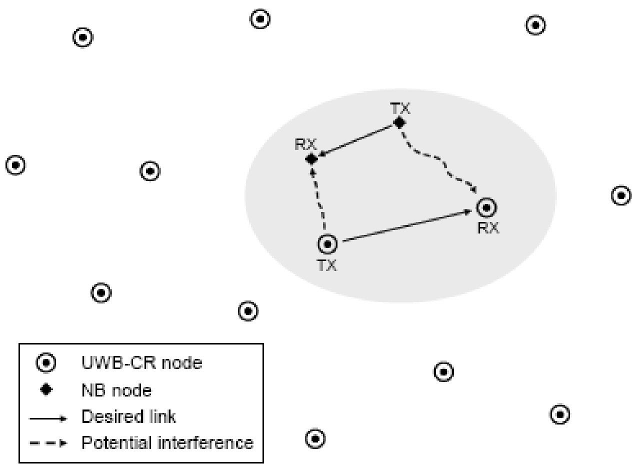

Figure 3: CR scenario

3.3 Narrowband interference mitigation in UWB IR through DS and TH codes

A possible coexistence scenario that we encounter in CR is represented in Fig. 3, where a network of UWB-CR nodes operates in the same area where a NB communication is present. Thanks to the location capability of the UWB technology, the CR network identify the region (represented with a grey oval) where the coexistence represents an important issue. Therefore, the location of those nodes that belong to that region may help in assigning them the right resources to drastically reduce the mutual interference. In Fig. 4, a sketch of the scenario inside the critical area identified, is depicted. In particular, the figure highlights the coexistence problem where a UWB-CR communication contends the radio spectrum already occupied by a NB one that does not have CR capabilities. In this scenario, we have to determine first the impact of NB interference on the UWB system and then adapt the UWB transmission (e.g., spectrum) to guarantee a possible coexistence.

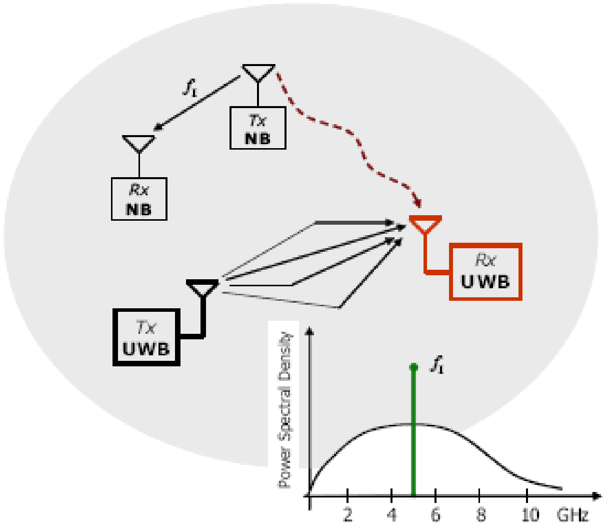

Figure 4: Coexistence between UWB and narrowband systems.

In this regard, it is necessary to study the mutual interference between wideband SS signals and existing wireless systems in order to evaluate a possible coexistence. In the literature, there are some studies devoted to the analysis of UWB systems in the presence of NB interference. The coexistence between UWB systems and systems as GSM, UMTS/WCDMA, and GPS, is investigated by means of simulation in [20], while the performance of time-hopping UWB systems in the presence of a single-tone interferer without additive noise is proposed [21].

A unified framework for the analysis of the coexistence between wideband wireless systems (either TH or DS) and NB interferers in frequency-selective channels is developed in [22]. In the same paper it is shown that the analytical results derived are useful in assessing the possible coexistence of UWB systems with existing NB wireless systems. An extension of this study to Rice fading and frequency-hopping interference is derived and analyzed in [23].

The use of Orthogonal Frequency Division Multiplex (OFDM) transmission scheme spans many wireless systems such as Digital Audio Broadcasting (DAB), Digital Video Broadcasting–Terrestrial (DVB-T), IEEE802.11a/g and IEEE802.16. To this regard, in [24] a closed-form bit error probability (BEP) expression for binary coherent UWB systems by approximating the multi-carrier interference as sum of tone interferers is derived. Simulation results prove that the assumption of sum of tone interferers is a good approximation for the multi-carrier interference. Furthermore, in the same paper it is shown that the approach developed is useful in assessing the possible coexistence between TH-PPM/BPAM systems and OFDM based systems such as IEEE802.11a/g.

In [25], the effect of aggregate NB interference on UWB communication systems is studied when the interferers are spatially located according to a Poisson distribution. Under this scenario, the authors derived a closed-form expression for the BEP of a general binary coherent system with Rake reception, subject to both noise and NB interference.

The presence of interference coming from interferers in a coexisting region may considerably degrade not only the communication reliability but also the range estimation performance. In this regard, it is important to assess the impact of interference on ranging in UWB systems. In [26] a method that performs nonlinear filtering on the received signal energy samples to mitigate wide bandwidth interference (multiuser interference, MUI) in a time-of-arrival (ToA) estimation, is developed. The analysis of performance of practical ToA estimators for UWB ranging systems in the presence of narrow and wide bandwidth interference is proposed in [21] where the impact of the interference is evaluated by considering realistic multipath environments and for different system parameters. In the following, we show a possible solution to the coexistence problem that can be faced with the CR paradigm in UWB-IR systems.

As an example of possible interference mitigation technique for UWB-IR systems a direct-sequence binary pulse amplitude modulation (DS-BPAM) UWB system in the presence of NB interference with frequency f_I = 5.003 GHz is considered. The DS-BPAM system adopts two possible spreading sequences $\{c_1\}$ ={+1, +1, –1, –1, +1, +1} and $\{c_2\}$ = {+1, +1, –1, –1, –1, +1} of length N_s = 6. In Fig. 5, the matched filter (MF) transfer function of the UWB coherent receiver is reported in a frequency range around f_I for the two possible sequences. As can be seen, the potential impact of the NB interferer is strongly dependent on the MF frequency response which in turn is dependent on the spreading sequence used. In this example, for the UWB-IR system considered in the presence of the NB interferer, it is better to adopt the sequence $\{c_2\}$ which guarantees a lower level of interference at the output of the MF. This is the case in which the interference is filtered by the receiver transfer function.

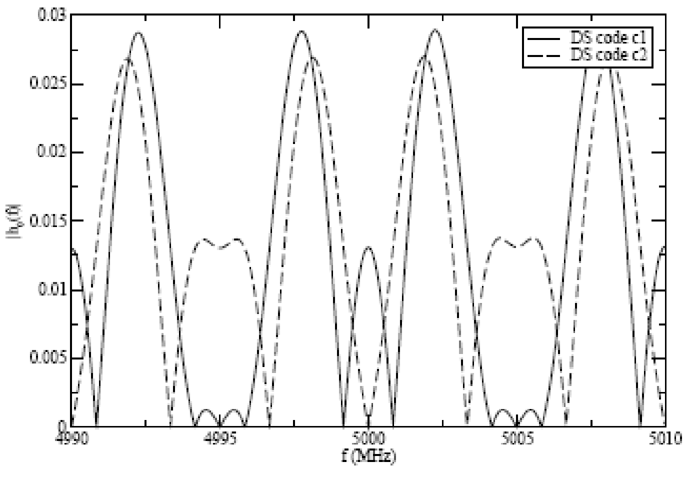

Figure 5: The MF transfer function of the UWB-IR receiver for different sequences adopted.

3.4 Soft spectrum adaptation and UWB waveform generation

Designing waveforms for Impulse Radio based UWB (IR-UWB) signals is important in order to maintain the spectral masking properties according to the standards specified by the FCC. The purpose of this requirement is to avoid possible interference to other users within the UWB frequency band. In such cases, sophisticated UWB signal generation techniques are required to perform adaptive signal generation in order to match the spectral masking requirements and also to avoid interference to the other primary users operating within a specific frequency band, especially for the cognitive radio based IR-UWB systems. One of the aim of WP2 it to look into several spectrum adaptation techniques for UWB waveform generation and explore the possibilities of some of the exiting techniques such as [27] – [29] as well.

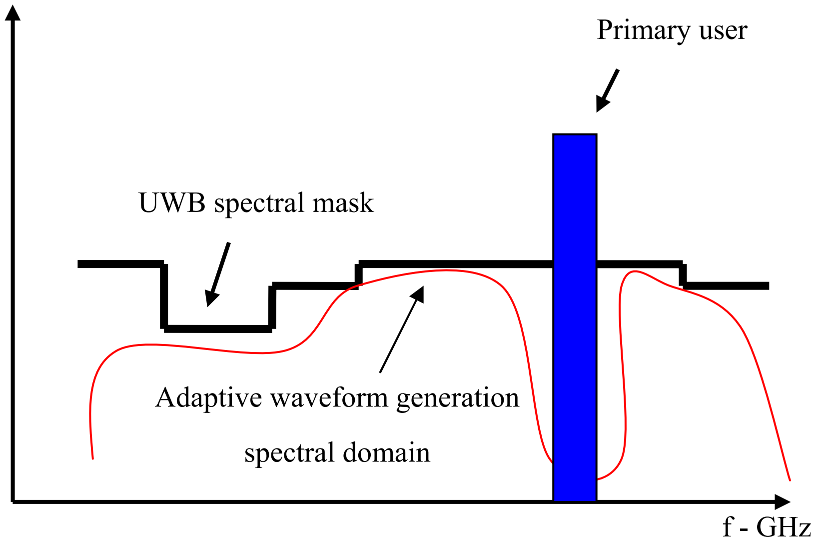

Figure 6: Shaping the spectral content of the waveform by performing adaptive techniques at the transmitter.

3.5 Bi-orthogonal multiple-tone schemes for OFDM

Similar to the IR-UWB waveform generation described in the previous section, to attain the spectral properties abiding the FCC standards, the bi-orthogonal multiple tones scheme [30] also can be used to generate signals. A classical example is depicted in Fig. 6. Such schemes allow more flexibility in shaping the spectrum in OFDM systems to avoid potential interference to other users. This technique will be investigated for the given set of scenarios.

3.6 Beamforming for interference rejection

Array beamforming is considered an appropriate way to actively mitigate interference in UWB. The deployment of smart antenna techniques in UWB systems has been considered in [31]. It has been shown that smart antennas facilitate an increased system throughput by e.g. spatially reducing the interference using adaptive beamforming [32], [33]. Adaptive beamforming is relatively new in UWB systems, usually beamforming has been considered for narrowband systems only. The expression “narrowband system” can have different meanings, namely,

- a communications system using a transmission bandwidth which is lower than the coherence bandwidth of the transmission channel,

- a communications system with a relative bandwidth, i.e. the ratio of the transmission bandwidth and the center frequency, much lower than 1,

- a communication system with a transmission bandwidth that is much smaller than the product of the speed of light and the distance between adjacent array antenna elements divided by the number of array antenna elements minus one.

Since UWB does not comply with any of these definitions, adaptive beamforming must consider the effect of the wideband nature of UWB explicitly. Beamforming can be accomplished either in the time domain or in the frequency domain [33]. Time domain realizations lend themselves for the application in impulse radio systems which have e.g. been treated in [32], [33]. The frequency domain realization is beneficial for multicarrier systems like e.g. ECMA-368 (WiMedia) [34].

Most currently known adaptive beamforming techniques for UWB systems have assumed the requirement to generate a single beam which physically means that e.g. all waves are received from a single direction of arrival (DoA). In what follows, the existence of several DoAs is considered to allow a more realistic assumption of the transmission environment.

When combining multicarrier techniques with adaptive beamforming, subcarrier specific weighting to realize the beamforming is an appropriate scheme. In the case of narrow band transmission, it is sufficient to use the same weighting factor per array antenna element for each subcarrier. However, owing to the wideband nature of UWB, the weighting factors per array antenna element vary from subcarrier to subcarrier, even in the case of a single tramsmitter-receiver pair communicating over a single beam. An extension to a multi-user scenario is also conceivable.

3.7 Interference mitigation techniques in Multiband-OFDM platforms

Multiband (MB) OFDM is one of the candidates for UWB communications based on multiple OFDM bands. The main advantage here is that, once a user has been detected in a particular band, the use of the individual bands in MB-OFDM allows to avoid interference to the primary users by conveniently avoiding that particular band. In the EUWB project we propose to look at MB-OFDM based interference mitigation techniques [35-38]. The MB-OFDM uses fourteen different frequency bands with a bandwidth of 528 MHz each as shown in Figure 7. Recently there has also been a 6^{th} band group additional to the ones shown in the figure, in order to harmonize the band groups around the world, by merging band-9, band-10 and band-11 together. The total number of subcarriers used is 128, of which 100 are allocated as data tones, 12 as pilot tones, 10 as guard tones, and 6 as null tones. Such an approach of having different spectral bands is a convenient way to monitor the spectrum in cognitive radios, detect the primary users, and avoid interference to them by adopting the transmission accordingly, avoiding the primary user's spectrum band. The power in the band groups can also be controlled to reduce the interference levels to the primary users according to specific standards. The interference avoiding process after detecting a primary user can be performed using notch filters and/or band stop filters at the transmitter.

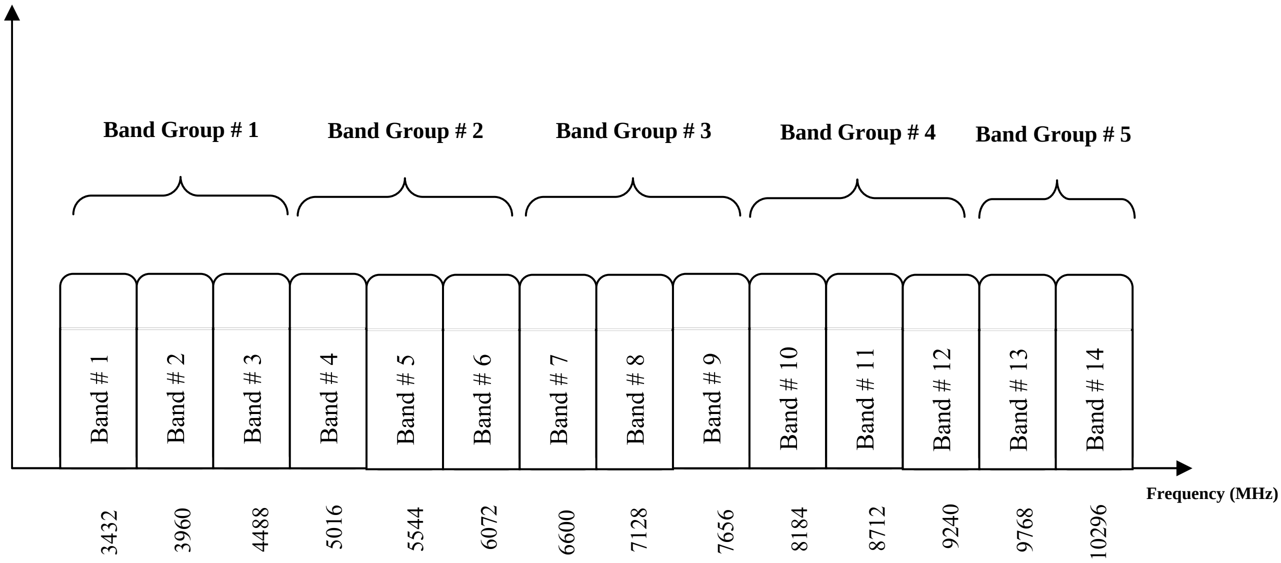

Figure 7: MB-OFDM band group organization

4 Conclusions

In this deliverable we identify the requirements of interference mitigation techniques for both Impulse Radio and OFDM-based UWB systems that, in the context of cognitive radio, can be exploited to increase coexistence. A review of requirements of different interference mitigation techniques that can be used at the transmitter and/or the receiver to reduce the mutual interference has been presented. In particular, focusing on the four scenarios considered in the project, the home theatre environment (HT), automotive environment (Auto), airborne systems (AirB), and the heterogeneous networking environment (HetG), a number of suitable interference mitigation techniques has been proposed.

References

[1] S. Zeisberg, V. Schreiber, "EUWB - Coexisting Short Range Radio by Advanced Ultra-Wideband Radio Technology," ICT Mobile and Wireless Communications Summit, Stockholm, June 2008.
[2] URL of EUWB consortium: http://www.euwb.eu
[3] Federal Communications Commission, "Spectrum Policy Task Force," Rep. ET Docket no. 02-135, Nov. 2002
[4] P. Kolodzy et al., "Next generation communications: Kickoff meeting," in Proc. DARPA, Oct. 17, 2001
[5] M. McHenry, "Frequency agile spectrum access technologies," in FCC Workshop Cogn. Radio, May 19, 2003.
[6] G. Staple, K. Werbach, "The end of spectrum scarcity," IEEE Spectrum, vol. 41, no. 3, pp. 48–52, March 2004.
[7] S. Haykin, "Cognitive Radio: Brain-Empowered Wireless Communications," IEEE J. on Select. Areas in Commun., vol. 23, no. 2, pp. 201–220, Feb. 2005.
[8] Federal Communications Commission, "Notice of Proposed Rulemaking and Order," Rep. ET Docket no. 03-322, Dec. 2003.
[9] H. Urkowitz, "Energy Detection of Unknown Deterministic Signals," Proc IEEE, vol.55, pp. 523–531, Apr. 1967.
[10] D. Cabric et al., "Implementation Issues in Spectrum Sensing for Cognitive Radios," Asilomar Conf. on Signals, Systems and Computers, vol. 1, pp 772–776, Pacific Grove, California, USA, Nov. 2004.
[11] H. Tang, "Some Physical Layer Issues of Wide-band Cognitive Radio Systems," IEEE In Sym. on New Frontiers in Dyn. Spec. Access Networks (DySPAN), pp151–159, Baltimore, MD, USA, Nov 2005.
[12] W. Gardner, "Exploitation of Spectral Redundancy in Cyclostationary Signals," IEEE Signal Processing Magazine, vol.8, no. 2, pp. 14–36, Apr. 1991.
[13] M. Ghozzi et al., "Cyclostationary – based test for detection of vacant frequency bands," IEEE CrownCom, Mykonos Island, Greece, pp. 1–5, Greece, June 2006.
[14] A. Fehske et al., "A New Approach to Signal Classification Using Spectral Correlation and Neural Networks", IEEE In Sym. on New Frontiers in Dyn. Spec. Access Networks (DySPAN), pp. 144–150, Baltimore, MD, USA, Nov 2005.
[15] M. Oner et al., "Cyclostationary based air interface recognition for radio systems," IEEE Radio and Wireless Access Conference, pp. 263-266, Atlanta, GA, USA, Sep. 2004.
[16] V. S. Somayazulu, J. R. Foerster, R. D. Roberts, "Detect and Avoid (DAA) Mechanisms for UWB Interference Mitigation," IEEE International Conference on Ultra-Wideband, pp. 513–518, Sep. 2006.
[17] H. Yamaguchi, "Active interference cancellation technique for MB-OFDM cognitive radio," 34th European Microwave Conference, vol. 2, pp. 1105–1108, Oct. 2004.
[18] E. C. Real, "Feature Extraction and Sufficient Statistics in Detection and Classification," ICASSP, vol. 6, pp. 3049–3052, Atlanta, GA, USA, May 1996.
[19] R. O. Duda, P. E. Hart, D. G. Stork, "Pattern Classification," Wiley Interscience, 2001.
[20] M. Hämäläinen, V. Hovinen, R. Tesi, et al., "On the UWB System Coexistence with GMS900, UMTS/WCDMA, and GPS," IEEE J. on Selected Areas in Commun., vol. 20, no. 9, pp. 1712–1720, Dec. 2002.

[21] L. Zhao, A. M. Haimovich, "Performance of Ultra-Wideband Communications in the Presence of Interference," IEEE J. on Selected Areas in Commun., vol. 20, pp. 1684–1691, Dec. 2005.

[22] A. Giorgetti, M. Chiani, M. Z. Win, "The Effect of Narrowband Interference on Wideband Wireless Communication Systems," IEEE Trans. on Communications, vol.53, no. 12, pp. 2139–2149, Dec. 2005.

[23] A. Giorgetti, "Coexistence of UWB and Narrowband Systems in Nakagami/Rice Channels," Eight Int. Symposium on Wireless Personal Multimedia Comm. (WPMC'05), Aalborg, Denmark, Sep. 2005.

[24] A. Giorgetti, D. Dardari, "The Impact of OFDM Interference on TH-PPM/BPAM Transmission Systems," Proc. IEEE Vehicular Tech. Conf. (VTC2005-Spring), Stockholm, Sweden, May 2005.

[25] M. Z. Win, P. C. Pinto, A. Giorgetti, M. Chiani, L. A. Shepp, "Error Performance of Ultrawideband Systems in a Poisson Field of Narrowband Interferers," Proc. IEEE Int. Symp. On Spread Spectrum Tech. & Appl. (ISSSTA), pp. 410–416, Manaus, Brazil, Aug. 2006, Invited Paper.

[26] Z. Shainoglu, I. Guvenc, "Multiuser Interference Mitigation in Noncoherent UWB Ranging via Nonlinear Filtering," EURASIP J. Wireless Communications and Networking, vol. 2006, pp. 1–10, 2006.

[27] N. C. Beaulieu, S. Niranjayan, "New UWB receiver designs based on a Gaussian-Laplacian noise plus MAI model," IEEE ICC, pp. 4128–4133, Glasgow, Scotland, June 2007.

[28] H. Zhang, R. Khono, "Soft Spectrum Adaptation in UWB Impulse Radio," IEEE PIMRC 2003, vol. 1, pp. 289–293, China, Sep. 2003.

[29] L. Yin, Z. Hongbo, "UWB Pulse Design Using the Approximate Prolate Spheroidal Wave Functions," IEEE Int. Sym. on Mic., Antenna, Propagation and EMC Tech for Wireless Comms, 2005, vol. 1, pp.450–453, China, Aug. 2005.

[30] C. Zoran., "OFDM with Bi-orthogonal De-multiplexing," IEEE ICASSP, Vol.5, pp. 2517–2520, Istanbul, Turkey, June 2000.

[31] W. P. Siriwongpairat, W. Su, M. Olfat, K. J. R. Liu, "Multiband-OFDM MIMO Coding Framework for UWB Communication Systems," IEEE Transactions on Signal Processing, vol. 54, no. 1, pp. 214–224, Jan. 2006.

[32] L. C. Godara, "Applications of antenna arrays to mobile communications, part I: Performance improvement and feasibility and system considerations," Proceedings of the IEEE, vol. 85, no. 7, pp. 1031–1060, July 1997.

[33] L. C. Godara, "Applications of antenna arrays to mobile communications, part II: Beam-forming and direction-of-arrival considerations," Proceedings of the IEEE, vol. 85, no. 8, pp. 1195–1245, Aug. 1997.

[34] http://www.wimedia.org/en/resources/index.asp?id=res#presentations

[35] A. Bastra, S. Lingam, J. Balakrishnan, "Multi-band OFDM: A Cognitive Radio for UWB," IEEE International Symposium on Circuits and Systems (ISCAS 2006), pp. 4, Island of Kos, Greece, 21-24 May 2006.

[36] M. P. Wylie-Green, "Dynamic Spectrum Sensing by Multiband OFDM Radio for Interference Mitigation," First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN 2005), pp. 619–625, Baltimore, MD, USA, Nov. 2005.

[37] K. Ohno, T. Ikegami, "Interference Mitigation Study for the Coexistence of Bi-phase UWB Multi-Band OFDM," International Conference on Ultra-Wideband 2005 (ICU 2005), pp. 707–712, Zurich, Switzerland, Sept. 2005.

[38] J. Lansford, Presentation Slides, "DAA for Multi-band OFDM UWB," Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs), 22 Sep. 2005.

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