Regulatory and Policy Implications of Emerging Technologies to Spectrum Management

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Spectrum policy: what next?

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Regulatory and Policy Implications of Emerging Technologies to Spectrum Management

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Abstract: This paper provides an overview of the policy implications of technological developments, and how these technologies can accommodate an increased level of market competition. It is based on the work carried out in the SPORT VIEWS (Spectrum Policies and Radio Technologies Viable In Emerging Wireless Societies) research project for the European Commission (FP6)

Key words: spectrum, new radio technologies, UWB, SDR, cognitive radio.

This paper surveys new and emerging radio technologies and their relevant characteristics with regard to spectrum management and the economics of spectrum, an analysis of the challenges facing existing radio technologies, spectrum usage, management and existing mechanisms for spectrum allocation. It also assesses the possible consequences of these technical evolutions for spectrum management from different perspectives and the way spectrum management can support innovation and economic efficiency.

Scope

Within the survey made in this study the focus will be on technology innovations in fixed, mobile (including nomadic) and broadcasting systems. At certain points connections and dependencies with other forms of spectrum use may be observed (such as radars, navigations systems, astronomy etc). Only the effect on the technology developments in radio communications of these other forms of spectrum use will be mentioned.

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The focus is on frequencies below 6 GHz that is considered the prime frequency range for fixed, mobile and broadcast services.

Spread spectrum technologies

In this chapter we discuss the group of radio technologies with spread spectrum properties, but not just in the classical sense. The classical spread spectrum technologies such as Direct Sequence and Frequency Hopping are shortly described but only for tutorial reasons. Recent and emerging technologies like OFDM and Ultra Wide Band and corresponding standards are of more interest.

The spread spectrum class of signals as we define it here is confined to those technologies which generate a (ultra) wide spectral profile, either instantaneously or within a longer period of time. This property makes this class suitable for spectrum underlay and/or overlay techniques [1].

Legacy spread spectrum technologies

Classical spread spectrum technology is based on the concept that the narrowband and modulated RF signal is manipulated (scrambled) prior to transmission in such a way that its profile in the frequency domain changes significantly, i.e. the signal occupies a much larger part of the RF spectrum, either instantaneously or over a certain time. Nowadays, 3G mobile communication systems use spread-spectrum mainly to improve system efficiency and flexibility within licensed bands, but the technique is even more powerful when used for underlay or in unlicensed bands. Ultra Wide Band (UWB) can also be regarded as a spread spectrum technique.

Direct Sequence Spread Spectrum (DSSS)

The direct sequence approach (DSSS) is based on multiplication of the original signal with a wideband pseudo noise spreading code, which results

[1] Spectrum underlay technique is a spectrum management principle by which signals with very low spectral power densities can coexist as secondary users in channels with primary users deploying systems with higher power density levels. Spectrum overlay technique is based on 'intrude and avoid' where a secondary user uses a primary channel only when it is not occupied.

in a wideband time continuous scrambled signal. DSSS significantly improves protection against interfering signals, especially narrowband. It also provides a multiple access capability, when the several different (orthogonal) spreading codes are being used simultaneously. It can provide transmission security if the spreading codes are not published (in case of 802.11 they are). Direct Sequence is also used as a technique to generate UWB signals.

Frequency Hopping Spread Spectrum (FHSS)

In case of frequency hopping spread spectrum (FHSS) the time continuous scrambling code is used to quickly change the RF frequency of the narrowband transmission within a certain range. Hence, a hopping pattern can be observed in the spectrum. Like DSSS, FHSS also provides a multiple access capability by using orthogonal hopping codes for different (logical) communication channels. It can also provide transmission security if the hopping codes are not published (in case of 802.11 they are).

Time Hopping Spread Spectrum

In case of time hopping a train of short duration pulses is transmitted which is derived from the narrowband information carrying signal through scrambling with a pseudo random modulated impulse train. The short pulse duration generates the spread spectrum profile. Time Hopping is used as a technique to generate UWB signals.

OFDM

Description and characteristics

OFDM stands for Orthogonal Frequency Division Multiplexing. Nowadays it is often the modulation type of choice in systems for mobile and short range wireless (WLAN) communications, digital audio/video broadcasting and fixed wireless access (particularly non-Line Of Sight). Hence OFDM is a legacy technology, but none-the-less it deserves treatment in this report for two reasons. There are some interesting spectrum management aspects related to its use.

The principle of OFDM is that a data symbol is transmitted using a certain number N modulated sub-carriers which form a comb in the spectrum. The key advantage is that the symbol transmission is made resilient to frequency dependent propagation effects (outages, multi-path) because an array of (sub-) carrier frequencies is used for its transmission rather than a single frequency. The sub-carriers should be chosen orthogonal to prevent adjacent channel interference.

Spectrum Management issues

The principle spectral shaping capability of OFDM raises the issue as to what this means from a spectrum management perspective. Should wideband OFDM be considered as a serious candidate for spectrum overlay arrangements?

Ultra Wide Band Technology

Description and characteristics

Ultra-Wide Band (UWB) is a technology developed to transfer large amounts of data wirelessly over short distances, typically less than ten metres. Unlike other wireless systems, which use spectrum in discrete narrow frequency bands, UWB operates by transmitting signals over wide portions of spectrum (up to several GHz). For example, the US regulator FCC has defined a radio system to be a UWB system if it has a spectrum that occupies a bandwidth greater than 20% of the central frequency or an absolute bandwidth greater than 500 MHz. Under FCC rules, UWB devices are subject to certain power, frequency and operational limitations including being limited to the 3.1 to 10.6GHz frequency band. The main characteristics of UWB and other short range wireless standards are presented in table 1.

UWB has a variety of possible applications. Those that are estimated to bring most economic benefits to consumers are likely to be in the PAN [2] environment, which includes homes and offices. Other potential applications for UWB include ground probing radar, positioning location systems, wireless sensors, asset tracking and automotive systems. It is generally

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2 PAN: Personal Area Network

assumed that the majority of UWB applications will fall into the category of consumer communications and high speed networking within PAN environments.

Table 1 - Comparison between UWB and other short range wireless standards (data)

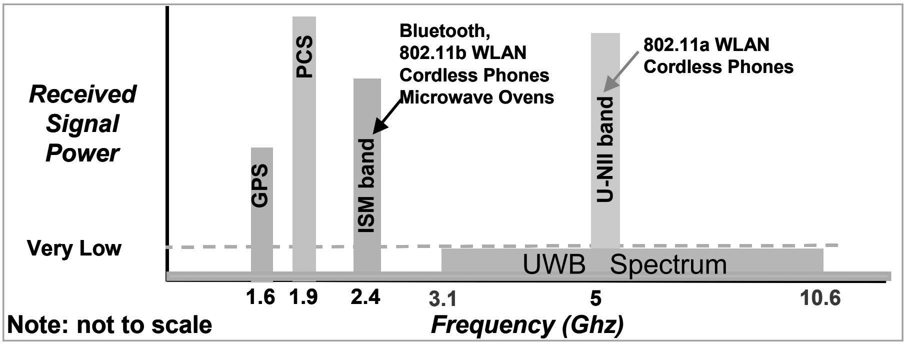
Technology	*Data rate*	*Range*	*Cost*	*Power*	*Spectrum*	*Issues*
UWB	50-100 Mbps	150 m	Low	Low	3.1-10.7 GHz	High data rate for short range only
Bluetooth	0.8-1.0 Mbps	10 m	Low	Low	2.4 GHz	Speed and interference issues
802.11a	54 Mbps	30 m	High	High	5 GHz	High power consumption, high costs, bulky chipset
802.11b	11 Mbps	100 m	Medium	Medium	2.4 GHz	Speed and signal strength issues for more range
802.11g	54 Mbps	30 m	High	High	2.4 GHz	Connectivity and range problems. High cost
HIPERLAN	25 Mbps	30 m	High	High	2.4 GHz	Only European standard. High cost
Home RF	11 Mbps	50 m	Medium	Medium	2.4 GHz	Speed issues
Zigbee	0.02-0.2 Mbps	10 m	Low	Low	2.4 GHz	Standard still under consideration, very low communication range, low data-rate

UWB is a potential alternative to other local area wireless technologies, such as Bluetooth, WiFi and other WLAN technologies. The principal advantage of UWB over existing wireless alternatives is that it should offer much faster data transfer rates (100 Mbps up to 1Gbit/s) over short distances thereby using frequency spectrum in stealthy fashion (hardly noticeable).

Spectrum usage and regulatory aspects

One of the important issues of UWB communication deployment is the protection of incumbent and future spectrum users. Due to the implicit use of a very wide spectrum range, UWB systems are not planned to operate under any specific allocation but there are lots of existing and planned wireless systems operating under allocated bands within the UWB signal band. The figure below shows how UWB uses already allocated radio spectrum.

Figure 1 - underlay-example of the UWB band in the USA



Source: Intel

If UWB can be deployed without undue interference to other allocated services then it effectively increases the availability of spectrum. It would not do this in the conventional sense of making more frequencies available, but by more efficiently using spectrum already allocated.

Spectrum Management issues

Today, Ultra Wideband systems represent an opportunity for the development of consumer and PAN (Personal Area Network) applications. The different spectrum masks adopted by the USA and Western Europe are likely to slow down the penetration of UWB equipment.

The main question surrounding the introduction of UWB systems is the question of interference caused to existing spectrum users. Mobile operators generally warn regulatory bodies about the potential consequences of introduction of UWB in Europe. CEPT is carrying out studies in order to precisely evaluate the potential interferences generated by UWB systems.

In order to prevent interference over the wide frequency range that UWB utilizes their application will probably be limited to short range. Therefore, they are not seen as potential candidates for mobile applications offered today by cellular systems.

They will probably be used in the framework of unlicensed systems in "commons" type frequency bands in Europe.

■ Dynamic spectrum access technologies

In this chapter we will describe various radio technologies that provide ways of dynamic spectrum access. "Dynamic Spectrum Access" (DSA) is any form of spectrum usage that is flexible, which implies that the set of transmission parameters is not fixed beforehand, but can be chosen and changed dynamically. This involves the selection of the appropriate band, channel, bandwidth, transmission power, modulation and coding scheme, and access method. The added value of this type of adaptivity is to be able to operate and maintain system or network performance under different and dynamic (spectrum) environmental conditions.

The technology that allows flexibility in the transmitted waveform exists today and is continuously improved and extended. A key research topic is the concept of smart or cognitive radio systems. These systems must be able to sense and interpret their (spectral) environment, make decisions on how to adapt their own spectral behaviour and evaluate the effect of their decisions (learning aspect).

Legacy dynamic spectrum access mechanisms

Automatic frequency selection mechanisms can be seen as early forms of flexible spectrum access. Several examples can be given:

- The automatic frequency selection principle can be found in modern car radio sets.
- DECT [3] cordless communication systems for use in residential and business environments apply the dynamic channel allocation mechanism (DCA).
- Dynamic Frequency Selection is a (mandatory) feature incorporated in IEEE 802.11h compliant WLAN devices operating in the 5 GHz frequency band where these devices have a secondary status. The DFS mechanism facilitates the avoidance of radio channels already in use by primary users (e.g. radar systems) or by other WLAN systems.

The listed examples have in common that:

[3] DECT stands for Digital Enhanced cordless telecommunications.

- The systems' behaviour is based on predefined pre-programmed algorithms and thresholds and is therefore predictable and reproducible;
- They are examples of unilateral coordination: the decisions and actions of a radio system are not based on information provided by systems with peer or higher status that coexist in the band.

Software Defined Radio

Description and characteristics

The essence of a Software Defined Radio (SDR) is that the functionality of the radio physical transmission level (physical layer) is almost completely implemented in software. This is a major technological advancement away from traditional radios, which operate with a predetermined built-in waveform, which is produced at the time of manufacture and cannot subsequently be modified. In a fully SDR based radio system, nearly all (except for the antenna) physical layer functions are implemented in software which creates the possibility for the radio to generate a wide variety of possible waveforms and associated settings. The radio architecture will be layered where the bottom layer comprises generic (but powerful) digital signal processing hardware and the top level the parameterised waveform applications. A middleware layer takes care of the abstraction of the hardware into software objects evocable from the application layer.

SDR technology is a logical step in the evolution of wireless systems. The following benefits of SDR can be identified:

- *Cost reduction:* "Every new IC process generation has higher initial costs, so the minimal production volume to be cost-effective becomes higher and higher.
- *Patchable devices:* design flaws can be repaired.
- *Prolonged lifetime:* support of new technology standards can be implemented in a radio through software updates.
- *User convenience:* several radio services are provided by a single device.
- *Adaptability:* through its software a SDR can be made to operate on multiple channels and communication standards, using multiple modulation

schemes and access methods. Thus, it is able to adapt to its spectral environment.

The specific benefits as well as the SDR design choices are very much application domain specific. In the 3G/4G domain, there is an interest in network reconfigurability.

Spectrum Management issues

The spectrum management related recommendations produced by E²R, based on the E²R regulatory questionnaire are summarized here because they cover quite well the set of issues that SDR raises in terms of spectrum management:

- harmonisation of standards (standards for reconfigurable hardware),
- certification of reconfigurable equipment,
- global circulation of reconfigurable equipment,
- development of new harmonised standards for reconfigurable equipment (i.e. pre-condition for the applicability of R&TTE directive).

To this list of issues, the question can be added how the regulator can exploit the existence of SDR technology, i.e. new instruments to regulate frequency bands.

Cognitive Radio

Description and characteristics

A Cognitive Radio (CR), as its name readily implies, is a radio that is capable of cognitive behaviour. In the description of CR-pioneer Mitola, a CR's cognitive abilities form a six-phase cognition cycle "Observe, Orient, Plan, Learn, Decide, Act".

We describe a CR as a radio that is aware of its environment (with characteristics such as vacant frequencies, user preferences, prevailing spectrum rules, and operator tariffs), and employs this acquired information in a reasoning process, that leads it to decide on its transmission behaviour. Additionally, it is capable of learning, through an evaluation of its own behaviour and experiences.

An important consequence of a CR's cognition is that, unlike other forms of "thinking radios"[4], the radio's behaviour may become unpredictable.

Generally, a radio system's cognitive behaviour is not strictly limited to its spectrum usage; it may show cognitive features in a multitude of other functions. However, given our focus on spectrum policy, we will primarily address the consequences of cognition for a radio's spectrum usage, and not take cognitive behaviour at higher system levels [5] into account. Software Defined Radio is widely regarded as an important enabler for Cognitive Radio.

Main obstacles

In the evolution of Cognitive Radio, numerous technical challenges still remain. Related to a CR's awareness of its spectral environment, the main issues are the following: Wideband sensing, Opportunity identification, Interference prevention, Dynamic coordination, Spectrum policy compliance, Software challenges and Hardware challenges.

In addition to these technical issues, the same authorization-issue that was discussed in the context of SDR plays a role for CR: how to prevent an unauthorized system modification that could harm radio communication by other spectrum users?

Spectrum Management issues

We have described the working principles of Cognitive Radio, and its relevance for spectrum usage. In summary, Cognitive Radio has the potential to improve spectrum utilization as follows:

- dynamic Spectrum Allocation,
- allow multiple, independent communications devices to coexist within shared spectrum,
- enable secondary markets and spectrum leasing,
- multi-mode terminals: overcome incompatibilities among communication services.

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4 These include adaptive and aware radios, i.e. radios that are aware of their spectral environment and are able to adjust their behaviour in a pre-determined manner.

5 An application of higher level cognitive behavior would be the CR as a member of an *ad hoc* Network. It communicates with another radio by, for every specific situation, creating its own transmission path involving several hops of other radios. Such advanced forms of information networks are discussed in section 2.5.2.

Like SDR, CR offer flexibility in their use of spectrum. SDR delivers this through its re-programmability: it makes it possible to modify the transmission parameters dynamically. Still, such modifications would require a lot of user intervention. CR – probably built on SDR-technology - takes re-programmability a step further by bringing intelligence to the radio, so that it is able to decide on its transmission parameters autonomously.

Given the advances in SDR-technology (enabler for CR), and the many initiatives in CR-research, CR-technology may develop rapidly over the coming years. Even though it will take several years at least, within the span of ten years the major technical obstacles may be removed. Spectrum regulators will then play a big role in shaping the eventual use of CR-technology.

On one hand the flexibility in spectrum utilization by these new technologies poses a challenge to the spectrum regulator: a significant amount of control over the spectrum use is lost. The amount of parties to divide the spectrum over increases drastically: whereas first there were only network managers to divide spectrum among, now in principle each individual radio-terminal forms a party of its own as it is free to determine its own spectrum use. Also, the flexibility of hardware renders certification difficult (certification issue).

Yet, on the other hand the flexibility has the potential to induce a much more efficient use of spectrum. The emerging CR/SDR-technology may deliver flexible forms of spectrum sharing, allow negotiation of frequency use between users, access of unlicensed users when the spectrum is not in use, and it may overcome incompatibilities among existing communication services.

Intersystem control

Description and general characteristics

Multiple radios making use of the same frequency band requires some form of coordination. Within a single radio system this is relatively easy to implement. For instance, in the GSM-system, there is a pilot channel through which radios can announce their intention to access the spectrum, and through which the GSM-network allocates a sufficient share of the available spectrum. Coordination between different radio systems is a more challenging task, since a network "administrator" – in the GSM-case: the operator – is not naturally present.

As radio designs and systems attain higher levels of intelligence, it becomes possible to fill holes in the spectrum, through spectrum sharing. Therefore, in the context of the perceived brimming of spectrum, and the progress in radio technology, inter-system coordination becomes ever more relevant.

The coordination process may involve the negotiation of many parameters: technical (frequency, location, time, transmission power, modulation, etc.), financial (price, payment options, etc.), and service quality (interference protection, signal-to-noise ratio, etc.).

The various forms of coordination that have been suggested in recent years fall into two categories: one in which the coordination is provided by some central controller or database, and one in which coordination is delivered by the radio systems themselves, without such a central entity.

Spectrum Management issues

The clear benefit of intersystem control for spectrum management is that under-utilized spectrum can be taken into use while interference can be prevented.

Central coordination provides a way for the regulator to remain in control over the spectrum access, also when there are multiple licensees of varying status and a wide range of transmission equipment. Thus, through implementing central coordination the regulator can safeguard against interfering spectrum use.

Distributed coordination has other advantages. Not only does it provide a more lightweight form of spectrum management, it also stimulates innovation incentive to coordinate their spectrum access. An example of this is the creation of IEEE 802.16's task group "h" following the FCC's decision to open a piece of spectrum under the condition of implementation of a coordination protocol.

■ Mesh and ad hoc networks

Description and characteristics

Mesh networks are radio communication networks in which radio nodes provide retransmission capabilities to neighbouring nodes, allowing end-to-end connectivity in the network based on multi-hop routes. There are two main categories of mesh networks:

- 'structured mesh networks': in which the radio nodes have fixed positions;
- '*ad hoc* mesh networks': in which the radio nodes act as mobile terminals.

Structured mesh networks

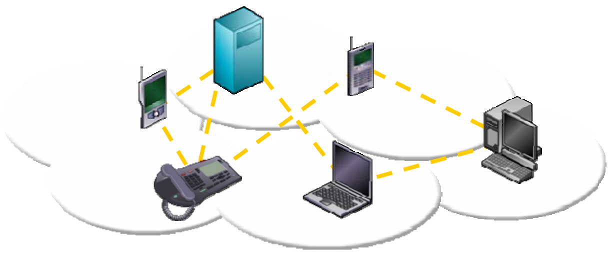
The term 'mesh network' (in the meaning of structured mesh network) is often used in relation to Fixed Wireless Access (FWA) systems which are applied to provide access services to small and medium enterprises, home offices and residential users.

Common FWA systems are based on a Point-to-MultiPoint (P-MP) architecture, in which a base station serves several fixed terminal stations within its service area. Each base station can be equipped with a single omni-directional antenna or, more usual, multiple antennas each serving a separate sector (e.g. 90º or 60º wide). To each base station one or more frequency channels are assigned (depending on the number of sectors). By installing multiple base stations a larger area can be covered, in a similar way as is done with cellular networks for mobile communications.

Ad hoc mesh networks

Ad hoc mesh networking is based on mobile terminals and/or devices which form an autonomous network as they come into each others vicinity. *Ad hoc* networking functionality pursues a high level of self management and self healing functionalities and minimal requirement for intervention of the users or a network operator. Within the *ad hoc* networking framework several network management protocols are defined e.g. to admit additional terminals which come in range of the other network nodes protocols, to optimise transmission power levels, and update route selection algorithms to improve the overall transmission efficiency. A schematic example of *ad hoc* mesh networking is schematically represented.

Figure 2 - Schematic representation of an ad hoc network (Nortel Networks)



The self organising and automatic network management features make *ad hoc* networks easy to use and convenient in many applications:

- personal area networks (PAN): interconnection of devices in the home environment such as TV, PC, organiser, mobile phone, video recorder;
- (temporary) local area networks: for instance at conferences, exhibitions or business meetings;
- mobile communications;
- sensor networks: communication between intelligent sensor devices;
- robotics: swarms of wirelessly interconnected robots or similar 'mobile autonomous systems';
- communications for military and public safety operations: fast connection establishment in areas where no communication infrastructure is present or communication means are damaged;
- communication between vehicles: for intelligent transport systems, safety increasing applications or to provide road-side information.

Benefits of mesh networks

Mesh networking can offer benefits compared to the more commonly applied cellular network topologies based on the deployment of base stations en central network management. The most important benefits of mesh networks are listed below.

Benefits of mesh networks:

- no single point of failure,
- robustness due to alternative routing possibilities in the network,
- range extension and coverage enhancement;

Benefits specifically related to ad hoc mesh networks:

- no fixed relay for installed infrastructure,
- networks are self organising,
- there is no need for network planning.

Technical challenges in mesh networking

The dynamic network topology (terminals moving within, joining and leaving the network) and realising efficient and reliable multi-hop communication are the basic challenges for mesh *ad hoc* networking. An additional complicating factor is the distributed nature of mesh *ad hoc* networks, where there is no central management entity controlling the network, but networking functionalities are distributed among the nodes. Nowadays research is aimed at solving these challenges for mesh *ad hoc* networking and optimising communication possibilities offered by these networks.

Besides the benefits that can be offered by (*ad hoc*) mesh networking there are also a number of issues to be resolved. The most important issues are:

- transmission delay in the network when in case of routing along multiple hops,
- optimisation of routing protocols,
- scalability,
- security,
- information security,
- increased terminal costs,
- willingness to relay.

Spectrum management implications

Contrary to what is often claimed, mesh networks do not provide improvement of spectrum efficiency compared to cellular network topologies. Pure mesh networks do not scale well, since in mesh networks with large numbers of nodes the relaying of transmissions will significantly reduce efficiency. For the reason of spectrum efficiency the mesh networking concept does not have any important implications for spectrum management.

Ad hoc meshed networks are in general operating autonomously with little or no intervention of users or a network operator. To enable this autonomous operation generally low power devices or cognitive functionalities are used to avoid interference. *Ad hoc* and mesh networking is an implementation of these technology developments that does not introduce spectrum management implications other than those that are treated in the specific chapters.

Ad hoc and mesh networking however provides some practical benefits over cellular networks and also offers new communication possibilities and services. Therefore (*ad hoc*) mesh networking finds employment in various applications e.g.: mobile communications, local area networking, sensor networks, machine-to-machine communications. The new possibilities that *ad hoc* and mesh networking offer may lead to an increase in wireless communications which could result in a corresponding spectrum requirement.

■ Low power devices and advanced antenna technologies

Low Power Devices (also indicated with the term Short Range Devices) and advanced antenna technologies are not covered in this paper. For more details, please refer to the SPORT VIEWS project (www.sportviews.org).

■ Spectrum management implications overview - Conclusion

Findings regarding spectrum management implications of recent and coming technological developments are gathered in the table on the following pages.

In this report the most important innovations in radio technology have been surveyed. It is concluded that many new radio technology developments attribute to increased spectrum efficiency and system performance. Also these innovations form the enabling technology for better frequency utilization or flexible access to the spectrum.

Technology	*Characterisation*	*Implications for Spectrum Management*	
OFDM **Multi Carrier - CDMA**	Modern efficient transmission technologies Robust / Adaptable Improvement of radio performance	Opportunities Spectrum Shaping Adaptive to local temporal environment characteristics (regulations) Enhanced Spectrum Efficiency Clever multiple-access schemes Throughput optimization	*Enabling technology*
Ultra Wide Band	Spreading signal power over ultra wide bandwidth Low power / short range New application possibilities high data rates radar applications indoor location determination	Opportunities New applications Enhanced spectrum utilization through 'underlay' Issues UWB does not fit in current spectrum allocation regime Doubts about 'underlay' use interference aggregation effect Discussion about spectral masks for UWB transmission	*Disruptive technology*
Software Defined Radio	Radio functionality implemented in software Flexibility in: radio signals radio transmission standard frequency utilization	Opportunities Adaptability to spectral environment. Adaptability to new transmission standards. Re-configurability. Enhanced flexibility of spectrum use. Basis for dynamic spectrum allocation systems. Might help solving interoperability difficulties and legacy issues. Issues Risk of unintended behavior. Equipment certification / standardization. Distributions of responsibilities.	*Enabling technology*
Cognitive Radio	Flexibility of SDR Awareness of the environment (sensing) Autonomous decisions on its radio transmission behavior Ability to learn from its behavior, observations and feedback	Opportunities Dynamic spectrum allocation / access Opportunity based spectrum use Autonomous coexistence in shared spectrum Issues Guaranteeing interference free coexistence sensing capabilities preventing undesirable behavior Declining control of the regulator Similar issues as SDR	*Disruptive technology*

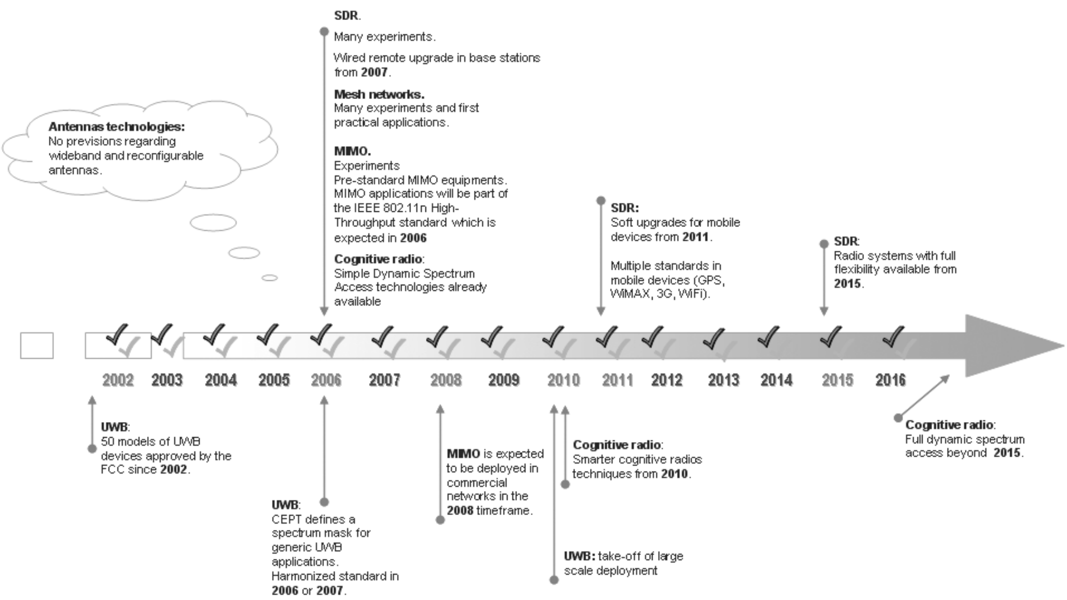
Intersystem Control *Note: Intersystem control is in some cases seen as a variant of cognitive radio*	Central spectrum coordination over: multiple networks multiple radio technologies multiple operators multiple spectrum users Central automated spectrum resource controller (Spectrum Policy Server) Transmission protocols to share spectrum control information (Common Spectrum Coordination Information Exchange)	Opportunities Dynamic spectrum allocation / access Optimize overall spectrum resource allocation Enhance spectrum utilization Enable economic mechanisms on a 'real-time' basis Issues Implementation of the new concept Forming a regulatory framework Establishing policies and rules for dynamic spectrum allocation Acceptance by operators	*Disruptive technology*
Mesh / Ad hoc networks	Terminals have relay functionality Capabilities to autonomously form a network of relaying nodes Independence of infrastructure (no base stations) Regulation / extension of unlicensed frequency bands Most of the available radio link capacity is used to relay data transmission Different applications of meshed and *ad hoc* networks may require separate spectrum allocations Low power devices or cognitive radio technology challenges	*Opportunities* Enhanced capabilities Optimization of transmission power levels Enhanced coverage (overcome line of sight issues) Robustness due to alternative routing possibilities in the network Autonomous operation with no or very little operator intervention Independence of infrastructure Robustness New application opportunities Issues Pure mesh networks do not provide enhanced spectrum efficiency (mesh networks do not scale) Manageability of autonomous radio nodes License free (low power or cognitive radio) implementations of autonomous operating radio nodes in mesh networks Willingness of nodes to relay Large variety of applications may result in additional (exclusive) spectrum requirements	*Enabling technology*

There are three innovations in radio technology identified that are disruptive in the sense that the current spectrum management frame work requires amendments to enable further development and introduction of these technologies. These innovations in radio technology are:

- ultra Wide Band,
- cognitive radio (with SDR as important enabling technology),
- intersystem control.

The estimated technology roadmap for these technology innovations is shown in the next figure. Here it can be seen that UWB is a development currently coming up and resolving the spectrum management issues for this technology is urgent at this time. For cognitive radio and intersystem control the time line is longer and the urgency is not so high yet. Implementing possibilities for these last technological innovations is a process that can be started now to keep up with the developments that are expected.

Figure 3 - Technology roadmap estimation



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