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Assessment of Spectrum Utilization in Dynamic Spectrum Access systems

A project thesis submitted in partial fulfillment for the degree of M.Sc. in Telecommunication and Information Systems

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DEDICATION

To my family

To my teachers,

To my husband

ACKNOWLEDGEMENT

I am very grateful to my supervisor Dr.Mohammed Ali Hammed Abbas for his guidance, assistance and his helpful advice. I am also endebted to Alneelain University for sposering me during my M.Sc. study.

last but not least, I’m extremely grateful to my family for their patience, support and encouragement.

ABSTRACT

The limited available spectrum and the inefficiency in the spectrum usage necessitate a new communication paradigm to exploit the existing wireless spectrum opportunistically. This new networking paradigm is referred to as Dynamic Spectrum Access (DSA). The current thesis concerned with the dynamic spectrum access, where useful multiple access techniques (CDMA) with spreading spectrum technologies to achieve high efficiency with large capacity is explained in detail. More specifically, a brief overview of the software defined radio technology is provided and parameter of different systems that use DSA techniques is introduced.

Moreover, DSA functions such as spectrum management and spectrum sharing are explained in detail. Finally, the performance and efficiencies of these systems that uses for comparison were discussed and compared by a MATLAB program.

ملخص

محدوديه الطيف المتاح وتدني الكفاءة في إستخدام الطيف تتطلب نمطاً جديداً لاستغلال الطيف اللاسلكي حسب الفرص المتاحه.

هذا النمط الجديد يعرف بالوصول المتغير للطيف (Dynamic Spectrum Access) .(DSA)
هذا البحث يركز على الوصول المتغير للطيف مع تقنية الوصول المتعدد للطيف بواسطة تقسيم الشفرة(CDMA) وأيضا مع تقنية نشر الطيف للحصول على كفاءة وسعة أفضل. تدرس هذه الكفاءة بواسطة معادلات رسومات بيانية.
إضافة إلى ذلك وضح البحث وظائف نظام الوصول المتغير للطيف (DSA) مثل إدارة الطيف وإستخدامه المشترك. نوقش الأداء والكفاءة لهذه الأنظمة وقورن بواسطة برنامج مستخدم MATLAB لتوضيحها بيانياً.

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Glossary

ABC	Always Best Connected
AP	Access Point
BLAST	Bell-Labs Layered Space Time
CDMA	Code Division Multiple Access
CEPT	Conference European of Postal and Telecommunications
DARPA	Defense Advanced Research Projects Agency.
DSA	Dynamic Spectrum Access.
ECC	Electronic Communications Committee
FWA	services (Fixed Wireless Access)
FCC	Federal Communications Commission.
FSM	Flexible Spectrum Management.
FSA	Fixed spectrum allocation
IMT-2000	International Mobile Telecommunication 2000 year.
ITU	International Telecommunication Union
ISM	Industrial, Scientific, Medical band
IRU	Indefensible Rights of Use
JRRM	Joint Radio Resource Management
MEA	multi-element antenna array

OFDM	orthogonal frequency division multiplexing
PAN	Personal Area Network
PSK	Phase shift keying
PoP	Point of Presence
QAM	Quadrature Amplitude Modulation
RAN	Radio access network
SAB	Services Ancillary to Broadcasting
SDR	Software Defined Radio
SMA	Spectrum Management Authority
SME	Small and Medium size Enterprises
TCAM	responsible body
V-BLAST	Vertical Bell-Labs Layered Space Time
VSF-OFCDM	Variable Spreading Factor Orthogonal Frequency and Code Division Multiplexing.
WLAN	Wireless Local Area Networks
EU	European Union
UWBWG	Ultra Wideband Working Group

1. INTRODUCTION

1.1 STATEMENT OF THE PROBLEM

The currently used mechanisms for spectrum management are a contributing factor to the long lead times from innovation to market in wireless technologies and systems. This has in turn been a major contributing factor to the dominance of the large telecom companies in the European and World markets, whereas very few innovative enterprises have exhibited consistent growth Alternative spectrum management regimes, such as the introduction of "unlicensed bands" have proven very effective in lowering entry thresholds for smaller companies (e.g. the WLAN business). In addition, experts claim that the spectrum requirements for communication purposes will increase by as much as 200-300 % up to 2010. At the same time the actual usage of the electromagnetic spectrum is very inefficient.

Here we can studying new more, flexible, efficient dynamic spectrum allocation which, in combination with new technologies, such as software defined radio and spatial techniques (e.g. multiple access techniques with spreading schemes) have the potential of lowering the entry thresholds for new actors and provide radical improvement to the efficiency of spectrum usage. The results will provide input to more efficiency in spectrum usage.

1.2 BACKGROUND

1.2.1 Background & Rationale

The development of the telecommunication industries was dramatic in the last decades. The Nordic countries have managed to seize a dominating role in this field. The currently used mechanisms for spectrum management with their very slow and consensus based processes have driven market actors into lengthy and complex standardization procedures. The consequence was long lead times from innovation to market in wireless technologies and systems. This has been a major contributing factor to the dominance of the large telecom companies in the European and World markets, whereas very few innovative enterprises have exhibited consistent growth. Most emerging SMEs (Small and Medium size Enterprises) are either quickly assimilated into the larger companies or become highly integrated sub-contractors and thus heavily dependent on the dominating actors in the arena.

A trend that has the potential to change the current industrial structure is the emergence of alternative spectrum management regimes, such as the introduction of so called "unlicensed bands", where new technologies can be introduced if they fulfill some very simple and relaxed “spectrum etiquette” rules to avoid excessive interference on existing systems. The most notable initiative in this area is the one of the FCC (Federal Communications Commission) (the regulator in USA) in the early 90’s driving the development of short range wireless communication systems and WLANs. (Wireless Local Area Networks)

Although it is not obvious if such spectrum allocation regimes are indeed scalable and efficient in the long run, some of them have proven very effective in creating business opportunities and lowering entry thresholds for smaller companies (e.g. the WLAN business).

In the US, with its entrepreneurial industrial tradition, the FCC is determined to actively use spectrum policy to further stimulate the wireless industry and the innovation system. During a number of years the commission has studied alternatives to the traditional spectrum management regime with this purpose. ”Free” spectrum trading becomes the preferred mechanism and technical systems that allow for the dynamic use and re-use of spectrum becomes a necessity. This may introduce a secondary market for spectrum licenses, hoping this market itself would arrive at more effective resource allocation. These secondary markets could arise if trade, lease and rent of licenses were possible without incurring excessive administrative procedures and overhead costs.

In the US (united state), the development toward a more dynamic spectrum management has thus already started. American companies may soon get competitive advantages in the US market, which will not be able to create a home market for products with dynamic spectrum management.

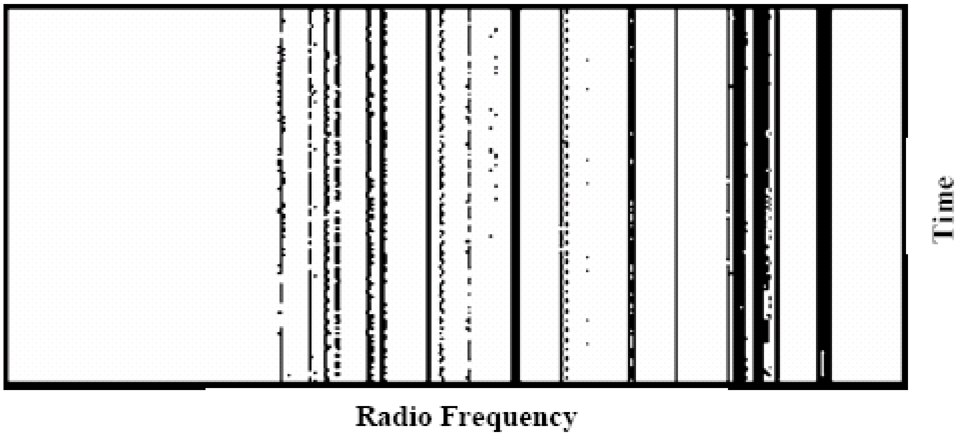


Figure 1.1. Spectrum usage of approximately 700 MHz below 1 GHZ during 1 hour in Atlanta in June 2002. A black dot denotes “in use”.

The Swedish innovation system with its high-level competence in wireless systems should be able to do well in this new technology field, provided that effort is spent in building competence in this area, both regarding technology as well as the regulatory and economic implications of more dynamic spectrum management. The other important rationale for investigating dynamic spectrum access regimes is large potential demand for wireless devices and services in the near future. Most future scenarios contain an ever-growing plethora of wireless devices, where every household appliance, every consumer electronics device is communicating wirelessly. In addition, experts claim that the spectrum requirements for communication purposes will increase by as much as 200-300 % up to 2010. At the same time the actual usage of the electromagnetic spectrum, as a result of traditional spectrum management is not very efficient. The current regulatory framework has as its primary target not only to reduce interference between different users and devices using different technical standards, but also to some to extent guarantee a low interference level to the primary users of the spectrum. Since real-time coordination and day-to-day policing of interference between users has this far been costly, fixed allocation of non-overlapping frequency segments (“bands”, “channels”) to each system/user has been the preferred method. Such an exclusive allocation guarantees low interference from other users but becomes very rigid and difficult to change. The reason for this is two-fold: Firstly, older wireless equipment was typically of fixed frequency type which means that using some other frequency band for a certain service meant replacing large number of transmitters/receivers (e.g. TV broadcasting). Secondly, interference management is a truly global activity since radio-waves (and thus interference!) propagate irregardless of national border. Reaching agreements regarding changing the use of a certain frequency band requires international negotiations and consensus based solutions – processes that operate on, typically, a 10-year time scale. The result is that existing systems and services are well protected and guaranteed interference-free operation, whereas new systems and services experience high entrance barriers and in, from a propagation perspective, attractive frequency ranges, severe spectrum shortage.

This combination of a slow (re-)allocation process and strict interference guarantees is fatal when it comes to efficient utilization. This is verified by measurements conducted by the FCC and others that show the actual occupancy/use of licensed spectrum in fact is quite low over time and in different geographical areas. Even in the most dense population centers and busy hours less than typically 1/3 of the frequency spectrum seems to be used. We have thus reason to believe that the poor utilization of existing spectrum is a more severe problem than the creation of "new" frequency bands (preferably at higher frequencies).

On the other hand, in the "unlicensed" bands the situation is very different. Anyone can design and use equipment in the band, as long it adheres to some simple etiquette rules typically governing transmitter behavior, power and emission limits.

The obvious advantages of this is the unlimited access for new and innovative technologies and the utilization of the spectrum under this regulatory regime is likely to be very high The drawback, however, is that existing (commercial) systems and services are not guaranteed any explicit protection from interference, in particular not from systems not yet known that may be introduced into the band later.

The term (spectrum) efficiency has a widespread use but it is often misused and not very well defined. To complicate matters even further the meaning of the term is dependent on the context. When discussing technical details of a system it may refer to how well the system manages to move data bits and when discussing business matters it may refer to how well the market manages to bring new services to the users.

In this thesis we define some efficiencies of some public systems that use some spreading modulations and coding for more utilization. From a systems operator's point of view, it is also a matter of rolling out new products and services meeting end-user demands and quickly making use of new technology. This can be done without the delays usually associated with the traditional spectrum allocation process. with the advent of more flexible radio systems and terminals, having a significantly higher degree of frequency agility and interference environment measuring ability, together with a much higher signal processing ability than traditionally and the flexibility of adapting its waveforms to whatever spectrum available and interference situation possible, we see a great potential in the combination of software defined radio, reconfigurable, radios and dynamic spectrum access communication systems. It is not the scarcity of spectrum that is the problem, rather it is the lack of ability to dynamically access spectrum that is holding development of services back.

1.2.2 Previous and ongoing work

How regulation and etiquette rules should be designed to strike a commercially interesting balance between the high efficiency of the unlicensed regimes and the interference protection of the fixed allocation schemes is very much in the focus of ongoing, in particular in the US and in the UK. Research and systems design activities towards a more efficient use of the spectrum have already started.

Dynamic frequency management is in itself not a new research field. The area has been under intense investigation during the last two decades in the development of cellular telephony systems. Here in this thesis, however, the problems investigated here can be labeled as cooperative resource management problems, i.e. there is a single operator that controls all entities, i.e. base stations and mobile telephones/terminals in the system, inside a fixed allocated frequency band, well protected from “outside” interference. The operator has the objective to provide a service to the users and looks for solutions that maximize the resource utilization (i.e. his revenues) with some constraint on the quality-of-service (QoS) perceived by the user. The latter is usually related to the interference level experience by the users. Implementations of such resource management schemes may be distributed over the various terminals and base stations in order to avoid excessive exchange of control information but there is no conflict of interest involved. What we are focusing on is the more general spectrum management problem, which is a non-cooperative resource management problem. In these problems we have multiple entities using the spectrum, each with their (potentially selfish) objective. In this emerging research area, not very much has been published.

Previous work has shown that the technology enabling dynamic spectrum access is almost there. An inherent feature of Dynamic Spectrum Access interesting in military rapid deployment scenarios is that it drastically reduces the requirement of advance planning of communication networks. Non-cooperative DSA and so-called “cognitive radios”, are therefore integral parts of the XG-concept [3].

1.2.3 Regulatory aspects for the DSA concepts

When it comes to the regulatory aspects for the proposed DSA concepts it is important to realize that there are more hinders to the introduction than the pure regulatory issues. In many cases the introduction of DSA systems is hindered not only by rules and regulations, but the general policy in spectrum management and the “way things work”, such as processes and guidelines that will need to be changed.

There are three distinct levels of the regulatory pyramid. On the global level there is the ITU (international telecommunication union) with the Radio Regulations and the framework of global regulations which have the status of international treaties.

On regional level there are different regional organizations such as the CEPT (Conference European of Postal and Telecommunications) in Europe, CITEL in the Americas, etc. On national level it is the Spectrum Management Authority, SMA (Spectrum Management Authority), which is responsible for the assignment and management of the spectrum, in Sudan NTC (national telecommunication corporation). The national responsibility can in many cases be split between the government and a national regulator.

The regulatory changes that might be needed to introduce DSA-systems can be mapped into a matrix with the geographic parameter on one axis and the type of change needed on the other axis.

Regarding the timeframes for changes to the regulatory framework under the current
regime an indication for the different levels are:

- ITU – global allocation of spectrum 5 – 10 years
- CEPT – recommendations and decisions 1 – 3 years
- EU - harmonization decisions 1 – 5 years
- National – change of frequency plan 0,5 – 2 years

1.3 OBJECTIVES

- To provide a qualitative assessment of the potential benefits of dynamic spectrum access regimes for more efficiency.
- Provide radical improvement to the efficiency of spectrum usage. System and regulatory proposals will be investigated. The work has not been limited to technology issues but has spanned over comparison between

different systems and their modulation schemes to utilize spectrum more efficient. Most importantly the question on how various unlicensed spectrum allocation may utilize by different systems has been investigated.

1.4 APPROACH

1.4.1 CONVENTIONAL APPROACH

The radio frequency spectrum is a naturally limited resource of extraordinary value, as the key to the provision of important communication and information services. Traditionally, spectrum has been allocated first to specific access technologies, and then sub-allocated to specific access networks, on very long term basis (up to decades). The traditional scheme can be very inefficient when demand patterns ("loads") exhibit high temporal and spatial variations.

1.4.2 PROPOSED APPROACH AND HOW IS IT DIFFERENT FROM THE CONVENTIONAL ONE

As we proposed here, dynamic spectrum allocation (DSA) improves radio spectrum efficiency by adjusting the allocation as demand changes in time and/or space. The scheme can be work with many radio-access technologies. But our analysis only considers a code-division multiple access (CDMA) technology.

A scarce and highly valuable resource needs to be managed very efficiently. However, traditional spectrum management can be very inefficient. Current practice is to allocate a segment of the spectrum to a specific radio access technology (e.g., TV broadcast, 2nd-generation digital telephony (GSM), UMTS, etc.) on a long-term basis. The fraction of the spectrum allocated to an access technology is further divided among individual licensees, who commercialize services based on the specific technology.

Dynamic spectrum allocation (DSA) seeks to exploit the variations in the "loads" of various networks to allocate the spectrum efficiently, as needs change with time and/or space.

We introduce a scheme to differentiate some systems and more efficient one to access dynamically to the spectrum.

1.5 ROADMAP

The report is organized as follows. First, in chapter introduction and objectives, the 2nd chapter describes the methodology and concepts used to assess the potential of new DSA schemes. This involves the investigation of a large number of candidate spectrum management concepts, among which 5 concepts are chosen for more detailed study. In chapter 3 are then describe SDR technology with respect to technical, regulatory and economic issues and a number of critical issues and research problems are identified, and different direct sequence types (legacy & new one) . In chapter 4, define problem for efficiently and dynamic access to the spectrum using CDMA to access to spectrum with different modulation schemes. In chapter 5 described system performance, in chapter 6 we calculate our results and simulate a program to mention these results clearly. Finally the conclusion of research and comparison of different system is shown.

2. LITERATURE REVIEW

2.1 Dynamic Spectrum Access (DSA)
Spectrum management, DSA methodology & concept

2.1.1 Spectrum management

The growing demand for wireless services has led to a worldwide reconsideration of established methods of spectrum management. The potential flaws of the dominant administrative licensing process are known and include rigidity, long delays, and patterns of over- and under-allocation of spectrum to uses. Spectrum management influences the evolution of the wireless communications industry.

2.1.1.1 The legacy regulatory framework

The regulatory framework for management of the radio spectrum resource can in many ways be seen as a historical description of the development of radio. The international regulations as found in the ITU (International Telecommunication Union) Radio Regulations have traces from the earliest days of radio. Over time the national and international frameworks have been amended to enable new use of the radio spectrum. As a result of history and the technical evolution, the national and international frameworks are an organized patchwork of different generations of regulation and solutions. One of the prevailing thoughts is that allocations on international level are made for infinity or at least for a very long time. This makes it more and more difficult for new generations of radio technologies to enter the stage.

In some instances the “refarming” tool has been used to free up underused or unused spectrum for new applications. The situation has over history been fairly successful since radio applications have been designed for a specific frequency band, often in close relation between national regulators, international organizations, equipment manufacturers and the monopolistic operators in each national market. When discussing the regulatory framework for radio spectrum it is important to describe the difference between two main processes in spectrum management, namely ***allocation*** and ***assignment.*** ***Allocation*** is the process of allocating a piece of spectrum to a specific use or service, ***assignment*** is the process of assigning licenses to use the spectrum to a specific user. The allocation of spectrum is mainly done in the international arena, whilst the assignment of licenses is mainly a national concern.

The regulations of the radio spectrum can be seen as a three layered pyramid, where the three layers are ***global, regional*** and ***national***. At the global level, the framework is governed by the Radio Regulations (RR) which is under the control of the International Telecommunications Union's Radiocommunications Sector (ITU-R). The Radio Regulations provide an overall global framework for the use of spectrum. In the RR, the radio spectrum is allocated to certain use or services, examples are fixed, mobile, broadcasting or radio navigation. The RR has status of international treaty, thus the national administrations are required to comply with the terms. The main application of the RR is in national border areas to ensure that the use of radio spectrum in one country does not cause interference to users in another country. Given this, there is an element of flexibility in the use of radio spectrum as long as interference is not caused in another country. At the regional level, there are in Europe two main paths for spectrum management, The European Union (EU) and the European Conference of Postal and Telecommunications Administrations (CEPT).

On the EU-level, initiatives are taken under the Spectrum Decision and other directives under the EU Framework for Electronic Communications. In some cases, specific harmonization measures may constrain national authorities in how spectrum is used through harmonization of frequencies. The Electronic Communications framework has been, or is being integrated into national legislation in all EU member states. Directives and decisions from the EU based on the directives are mandatory for member states. The CEPT has set up the ECC (Electronic Communications Committee). The ECC brings together the radio and telecommunications regulatory authorities of the CEPT member states. The ECC makes decisions and develops recommendations on the use of radio spectrum in the member states, the national adoption and implementation of decisions and recommendations is optional.

Nationally there are a number of national rules, laws and regulations regarding the use of spectrum that govern the national allocation and assignment of licenses. Apart from the regulatory framework for the allocation and assignment of spectrum there is also regulation on different levels when it comes to the placing on the market and the use of equipment using the spectrum.

2.1.1.2 Current trends and initiative in spectrum management

Over the last decade the markets for electronic communication have been opened up to competition and the relation between regulators, operators and developers of equipment is no longer as close as it has been. The technical development is generally heading in the direction of smarter and more adaptable systems and solutions. One of the main drivers behind this development is the perceived scarcity of spectrum for new technology.

The general development in the spectrum management world is towards increased flexibility and a more liberalized approach to the assignment and management of spectrum. This said, the processes are slow and the hurdles are high. Some of the hot topics in spectrum management at the moment are:

- **Flexibility** – how can licenses be made more flexible. There are two different flavours of flexibility currently on the agenda, namely the market oriented approach and the technical liberalization. The two flavours can be seen as two sides of the same coin, and in many cases the one requires the other.
- **Market oriented approach** – in the market oriented approach to flexibility lies the aim to make licenses and the values of licenses visible, and to create a market for the natural resource spectrum. One potential goal of a market oriented approach is the property rights model, whereby a license holder actually owns the spectrum. The license is indefinite in tenure and the spectrum can, under a limited interference and power level rulebook, be used for whatever purpose the license holder wants.
- **Technical liberalization** - the technical aspect of flexibility includes the removal of unnecessary restrictions on licenses to enable a wider use. Such restrictions can include non-radio related obligations, references to services, standards and systems etc.

\- The topic of flexibility includes a number of different dimensions;

- **Secondary trading** – the possibility to sell, buy, rent or lease a license. Secondary trading can be introduced under an ex ante (beforehand) approval regime or under an ex post (after the fact) regime. The ex-post regime would in most cases be equal or similar to general competition law.
- **Reconfiguration** – the possibility to reconfigure a license in time, geography and frequency. With reconfiguration a licensee can for example sell unused spectrum in a region or buy additional spectrum for popular services.
- **Change of use** – the possibility to change the use of a license outside the limitations given in the license. This could include the changing from fixed services to mobile services, from broadcasting to mobile use etc.

- **Digitalization** – more and more services are being digitalized. To name a few, mobile services have gone from 1G analogue systems to 2G digital systems, Digital television is being introduced, etc. Digitalization is interesting since many old legacy systems are being replaced by standardized systems with known interfaces. One interesting example of the results of digitalization is the potential to free up spectrum for new areas of use. This is a major discussion in the digitalization of broadcasting. As a result of the potential to free up spectrum through the digitalization of broadcasting, the so called digital dividend has been identified. The planning of digital broadcasting will to some extent be made technology neutral and thus enable the use of non-broadcasting solutions in broadcasting bands.
- **Technology neutrality** – in recent year's technology neutrality has become an important aspect of assigning licenses. Under previous regimes, spectrum for new services has very often been pinpointed to a system, a technology, a standard etc. Rather than allocating a piece of spectrum internationally for e.g. GSM which was made through an EU-directive, spectrum is allocated to enable different types of services.
- **License exemption** – in recent years, the proliferation of services using license exempt frequencies is apparent. The success of license except spectrum is one of the major trends in spectrum management.
- **Harmonized flexibility** – the notion of harmonized flexibility is to some extent driving the international discussions on increased liberalization. The boundaries of harmonization are being explored and harmonization will in the future become more open and technology neutral. In order to maintain some level of harmonization, to achieve economies of scale and to avoid complete fragmentation the methods and framework for flexibility will have to be harmonized in some way.

2.1.1.2.1 The commons model ("unlicensed spectrum")

Over the last couple of years there has been an explosion in the use of the so called free frequencies, or more rightly labeled license exempt spectrum. The model of setting a minimum set of rules for a piece of spectrum has attracted developers of equipment and users of many different applications, such as WLAN and Bluetooth to name a few. This trend has led to initiatives to open up more spectrum for license exempt use. Generally license exempt use is very well suited for short range devices (SRD) that are inexpensive and large in numbers. Within the commons model there are a number of different flavours which are described below.

2.1.1.2.2 The market model

In the market model the assignment and use of spectrum should mainly be decided by the market players. Thus the key elements of the market model are liberalization through secondary trading and flexibility. Secondary trading of licenses has become one of the main topics of liberalization of spectrum management regimes over the last couple of years. It is thought that the introduction of secondary trading will not reach its full benefit without the introduction of a more flexible policy regarding change of use and reconfiguration of licenses.

2.1.1.2.3 Relaxations in the command and control model

The model used for most of the radio spectrum today is known as licensed spectrum. Under this so called command and control model some relaxations have been made and most of the incremental changes to the regulatory framework will initially be part of the command and control model. One example of such relaxations is the increased use of block assignments. In frequency bands where assignment and planning of the networks has been performed by the national regulator the trend is towards block assignments, whereby the users of radio are given the possibility to coordinate and design their own networks. A block assignment can be made with very few restrictions on the use, as long as out of band interference is under control.

2.1.2 Methodology

The methodology used here is study and define some concepts spectrum space.

2.1.2.1 Concept selection procedure

One of the objective is to identify key research issues in current but mainly in future spectrum efficiencies and the impact of the these efficiencies on the innovation system and on regulation policies. This is a somewhat difficult task since these future management regimes and efficiencies are not well defined and in some cases even unknown.. For this purpose we have developed a number of study system concepts as the common basis for our analysis. Such a system concept describes a technical solution and the environment the system is placed in.

From a regulatory and management point of view, the system proposals should cover and stress aspects that are not so critical in today's exclusive-use policies.

- **Access –** Licensing, auctions, purchase and lease of spectrum.
- **Management** – Government, owners or brokers.
- **Transferability** – Approvals, aggregation and subdivision.
- **Use** – Flexibility and change of use.

In particular, we foresee many interesting principal research issues regarding spectrum as a property versus the primary policy of today, i.e., command-and control.

Since we do not know which system concepts will actually become reality (or at least serious candidates) the design and selection of study concepts is a non-trivial task. The selected concepts should both reveal interesting research issues and also point to problems that must be solved in order to enable dynamic spectrum usage.

A systematic search through a number of possible spectrum management regimes was done in the following way.

First, we identified what we believe are the five most important features of spectrum management. These features where

- Transferability of spectrum usage rights
- Exclusiveness of spectrum usage rights
- Strictness of spectrum regulation
- Centralized/Decentralized management of spectrum access
- Time-scale of management

The features in the list play the role “dimensions” than span the space of possible spectrum management concepts. In a systematic manner we go through all the 32 extreme points of this space along with some interior points and developed short descriptions of the corresponding system concepts. Many of these in total 40 concepts make very little sense, were very similar to others or had very limited practical application. Anyhow, five study concepts were selected for further studies. Two of these were reference cases, corresponding to existing spectrum management regimes, and three were “novel” approaches, with interesting properties and the capability to reveal interesting research problems as well as substantially improving spectrum usage efficiency. Note that the three “novel” approaches have some qualities and methods already in use today. Some of them are also in line with current trends in spectrum management.

It should be noted that we do not see any specific system concept as the most *probable* candidate for future spectrum use. Another important limitation that we have made in the definition of the system space is to leave out changes over time in the spectrum management regime. All system concepts represent a quasi-static situation. Changes in spectrum management regime would correspond to moving around in the system space.

2.1.2.2 Some assumptions and definitions

In an emerging field like the DSA area, there is bound to exist different and confusing terminology used by different researchers and organizations.

A *license* is the right to transmit on specific frequency on a specific geographic position for a specified time. There may also be a number of other *rules* coupled to the license. As a minimum there are rules about out of band emissions.

The spectrum resource is ultimately governed by a national regulator. Its interest is usually to ensure the most efficient use of radio spectrum to the benefit of society, i.e. the nation. The regulator has ultimate power over the spectrum in the same sense as a government has the ultimate power over a nation. Of course there are laws and rules to follow, but these can be changed in the long run or by certain unexpected events.

2.1.2.3 Key concept features – "Dimensions"

The key concepts used in this work are not usually seen in other DSA studies. We believe that this is the result of the rather wide scope used to span spectrum efficiencies.

2.1.2.3.1 Transferable – Non-transferable transmission rights

In the **transferable** end of this dimension, a license (right to transmit) can be transferred between actors without explicit consent of the regulator. In addition, the use of spectrum can be changed, i.e. the rules in the license do not state the use. Note that this makes is possible to sublet parts of the spectrum controlled by the license.

With **non-transferable** spectrum access, a license cannot be transferred and its use cannot be changed without intervention of the regulator. However here we assume that the regulator can not, or is not willing to, make changes except in some extreme cases.

Note that in the really long term perspective, it is possible for the regulator to change both owner and usage. However, in practice this time is so long that it, within the scope of this work, can be regarded as infinite.

2.1.2.3.2 Exclusive spectrum use – Shared spectrum use – Commons

With **exclusive use**, there is only one license to the spectrum band. The licensee should not experience any intersystem interference.

For **shared use**, there are a few license holders. Depending on the co-operation ambition among licensees, there may be intersystem interference.

In the **commons case**, an infinite number of users can access the spectrum band and there is no guarantee that signals will not be interfered with.

2.1.2.3.3 Strict spectrum rules – Etiquette

This "dimension" captures the number of rules specified in a license. With **strict rules** we mean a thick rulebook. There are few degrees of freedom. For **etiquette**, the rulebook is thin and there are many degrees of freedom.

In general the license rules can specify if use of the spectrum can be changed or not. However here that aspect is covered in the transferable, non-transferable dimension and not covered by this dimension.

There are different entities that the rules apply to. Some are tied to the transceivers used. These rules may specify output power, modulation methods used or protocol details. Other rules apply to the users, for example what information is sent, or how payment for services is to be extracted. Depending on which part of the system the rules apply to, their implementation will be different. There is also the aspect of ensuring that rules are followed. That may either be done by a strict certification procedure or it may be enforced by strict control of how the spectrum is actually used.

2.1.2.3.4 Short term – Long term spectrum usage rights

This dimension describes the lifetime of the rights to use spectrum. The scale ranges from milliseconds to several decades.

2.1.2.3.5 Centralized – Decentralized technical solutions

This dimension describes the technical implementation aspects. In the **centralized** case all decisions are made at a central point where all information is available. In the **decentralized** case decisions are made by the users of the spectrum themselves based on local information. As long as the end user equipment will take its own decisions, e.g. which part of the spectrum to operate in or what waveform to use, a solution is considered decentralized.

Note that other things than the technical implementation can be centralized or distributed, e.g. markets can also have this property. However it is in the technical domain that the difference is most notable and thus we have limited this dimension to the technical aspects to avoid confusion and complexity. Specifically it is the spectrum access mechanisms that we focus on in this key feature.

2.1.3 Possible DSA concepts

2.1.3.1 Open spectrum access

2.1.3.1.1 Overview

Government spectrum agencies allocate a certain spectrum for “any-kind” of equipment meeting just a few requirements such as maximum allowed emitted power and in-band as well as out-of-band interference handling requirements (very relaxed etiquette rules). The spectrum usage is not constrained to a specific service but could be used in any fashion. Note that spectrum trading is a non issue. Since the spectrum is free to use for anyone it is unlikely that there will be any buyers.

The concept of unlicensed or open access operation is very close to the very successful use of license exempt spectrum. This concept is however based on an even thinner rulebook, and a set of etiquette rules. These rules will have to be agreed upon entering the spectrum. The rules that can and should be imposed for the concept frequencies include out of band emissions, power and emission levels.

Furthermore there might be a need to include other general rules such as listen before talk, automatic power level corrections, etc. in order to enable the highest possible use without risking that systems become greedy and only increase the noise floor.

This system concept relies on etiquette, but the central institutions could still imply inclusion of some rules controlled by these institutions. Interference rules included, but few other rules (or etiquette) in the licenses. In order for this concept to have a significant effect, more spectrum will have to be assigned to the commons model. The spectrum assigned will have to be of the same nature as the 2.4 GHz band, i.e. without any constraints as to the service or to the technical nature of the use. Limitations will still have to apply regarding out of band emissions and output power.

- The commons case makes the spectrum usage transferable or nontransferable a non-issue but still governed by etiquette and equipment use also governed by etiquette.
- Usage of spectrum is down to milliseconds, typically a few seconds/minutes/tens of minutes, thus, the system concept is short term (ms).

- End terminal access to the channel is governed by each terminal in a distributed fashion, thus, the system concept is a decentralized one.
- Regardless of from whom the telecom equipment is bought, that specific equipment can be used. No telecom operator is required to be involved in the loop of providing services. No fee for usage is necessary. Thus, this is truly a commons system concept. However, there might be a need for policing of spectrum use, and coupled with that, a fee might be appropriate to finance that policing need.

Key regulatory aspects of the unlicensed or open access operation concept include;

- More spectrum for license exempt use
- Surveillance of power levels and usage
- Avoiding the tragedy of the commons

2.1.3.1.2 Examples of similar contemporary systems

The 2.4 GHz band hosts a number of very successful applications such as WLAN and Bluetooth.

2.1.3.1.3 Impact on the innovation process

By opening up for spectrum use, and not by regulating/licensing equipment, the time to market for new products is potentially reduced. This, in turn, yields an improved speed in the innovation process. Also, multitude and competition is encouraged.

2.1.3.2 License exempt operation - (reference)

2.1.3.2.1 Overview

The main issue with this system concept is that a few industrial actors join efforts and create a standard for a certain kind of equipment. Alongside with creating the standard, an effort is made to have government bodies controlling spectrum usage to allocate a certain part of spectrum in as many nations as possible. Dependent on what end-user value is targeted, and the estimated potential in what the end-users are willing to pay for that specific value, different degrees of complexity is designed in the system.
- Large traditional telecom equipment suppliers push government bodies to initialize a portion of the spectrum to be used for “standardized” equipment on a consumer market. This makes the spectrum usage transferable or

nontransferable a non-issue but still governed by strict rules and equipment use also governed by strict rules.

- Little effort may go into handling in-band interference problems as transmitters/receivers conceptually might be operating not too densely.
- Strict rules support that a greater effort can be made for handling in-band interference. Nevertheless the rule book may be rather thin.
- Strict rules also support tougher requirements on out-of-band operational aspects.
- Usage of spectrum is down to milliseconds, typically a few seconds/minutes/tens of minutes, thus, the system concept is short term (ms).
- End terminals access to the channel is governed by each terminal in a distributed fashion, thus, the system concept is a decentralized one.
- Regardless of from whom the telecom equipment is bought that specific equipment can be used. No telecom operator is required to be involved in the loop of providing services. No fee for usage is necessary. Thus, this is truly a commons system concept.

The commercial success for systems that, to some extent like WiFi-systems, conform to this concept makes this particular concept ideal as a reference case.

2.1.3.2.2 Examples of similar contemporary systems

Short range devices (SRD) for instance the European DECT concept is one place holder for this concept in our work. Note that other examples, Bluetooth, remote control devices (car port opener), IEEE802.11x, WiFi, WiMax…

The main difference is that there are more rules in this concept. Here 2.4 GHz WLAN has been taken as an example of a type of system, not an example of rulebook for the use of a specific piece of spectrum.

The commons model has very successfully been introduced already in the 2.4 GHz band for WLAN type applications, furthermore the 5GHz has been allocated as spectrum suitable for license exempt use. The 5 GHz band has more limitations than the 2.4 GHz band when it comes to the technical domain. For example due to the existence of radar systems in the 5 GHz band all equipment must use DFS-technology (Dynamic Frequency Selection).

Currently three bands are available for license exempt use, namely 2.400 - 2.483 GHz, 5.150 - 5.350 GHz and 5.470 - 5.725 GHz, furthermore there are a number of frequency bands where equipment generally can be used without a license.

2.1.3.2.3 Impact on the innovation process

Large industrial corporations are well supported in this concept, non-established, small and medium sized businesses have a hard time entering the market. New systems with high development costs and/or high introduction/deployment costs and/or long pay-off times on the investment are perhaps better supported in this concept.

2.1.3.3 Shared spectrum access

2.1.3.3.1 Overview

In this case a (fairly small) number of permissions to use a specific band are allocated to a number of licensees.

Allocating a limited number of licenses to a piece of spectrum may be a middle way between the dynamic behavior seen in the license exempt bands and the control of QoS that is possible in exclusive spectrum. Also knowing who the competitors are makes it easier to agree on how to cooperate.

The shared concept allows dynamic spectrum sharing, but without risking a complete breakdown, which could be the case with the commons. It is up to the licensees how to cooperate in the band.

One way is to simply split the spectrum among the licensees. This case is very similar to the traditional licensing schemes, but the licensing procedure is in some sense decentralized.

Obvious solution is to build one network that all licensees use. This method is superior in capacity. But there are problems as well it becomes more difficult for the users of the network to differentiate service offerings. The issues here are similar to the issues for infrastructure sharing in the UMTS networks.

The licensees may also choose to cooperate through a central instant spectrum manager, or access broker. The task of this may range from fairly simple frequency assignments to complicated real-time radio resource management regimes. The methods for achieving this are not completely new, but there are obviously unresolved issues.

The licensees may also choose not to cooperate and use the available technologies available for license exempt spectrum. For example frequency hopping, dynamic channel allocation, ad-hoc networking, adaptive antennas, software defined and agile radios and mesh networks etc. may be used. In this case the issues are similar to the unlicensed spectrum.

Key regulatory aspects of the shared spectrum concept include;

- New definition of shared spectrum, how many users in one frequency band
- Develop an interference management framework

One example of this is the discussions in the US regarding the use of FWA-services in broadcasting bands (IEEE 802.22) where intelligent equipment is allowed to use broadcasting spectrum for FWA services. This type of secondary non-exclusive use can make good use of many of the white spots as displayed in chapter one in Fig.1.1.

This concept can be viewed as a mix of the other concepts presented here. Thus many problems and opportunities are similar in this and the other concepts.

2.1.3.3.2 Examples of similar contemporary systems

The case of shared spectrum is not new, to take an example most taxi radio dispatch systems are using shared spectrum. So in a very simple case shared spectrum could be realized for a mobile data system as long as the different users are using technologies and etiquette rules that are relatively similar, as the case is for taxi radio.

Another example of current sharing of spectrum can be seen in broadcasting industry is using wireless microphones in broadcasting bands.

These “Services Ancillary to Broadcasting” (SAB) is a very good example of sharing based on different services, or use of “interference rights”.

2.1.3.3.3 Impact on the innovation process

Since there are few rules for the use of the spectrum it may be relatively easy to introduce new technology. However depending on the agreements between the licensees there may be a resistance to use technological advances.

Rules can be formulated to encourage co-operation which may improve spectrum use. How this should be done or how large the gains are is an open issue. A drawback with a very strict rule policy is less of dynamics and lower degree of innovations.

The whole description of this system concept is that there is a lot to gain by cooperating. However it is not trivial and the possible gains should be investigated. This will also affect how agreements are made.

2.1.3.4 Real time spectrum exchange

2.1.3.4.1 Overview

The concept represents the full realization of a market model for spectrum management. The concept as such implies that spectrum should be treated as the property of its holder, and that the license holder has a large number of degrees of freedom regarding the use of the license.

In this system concept, conventional exclusive licenses are initially sold out by the regulator (e.g., in a license auction) or given out by a beauty contest etc. The spectrum usage is not constrained to a specific service but could be used in any fashion by the spectrum usage rights holder with no, or within some very relaxed, etiquette rules. The licenses thus acquired can be resold fast by means of electronic trading mechanisms. The trading can be done through the regulator, through some central "license exchange" actor or by bilateral agreements.

The degree of decentralization is naturally interesting here. Although the trading is decentralized, a central register for responsibility is probably required. Information processes are becoming too complex and varied to be run in any other way as through decentralized decision processes.

Any DSA system may include real-time trading mechanisms enabling trade with the limited spectrum resource. This could be done either with a third party entity, i.e., broker, or directly between telecom operators with rights to use certain parts of spectrum and interested in selling and buying these rights to use them. From a technical point of view, the implementation of such mechanisms could either be of central control or with local control.

By a central control, we mean that any telecom operator engaged in such real-time trading of spectrum usage rights have one, and only one, central point where decisions are made whether or not that operator itself should keep the right to use a specific spectrum, during a specific time frame, or if they should sell its rights to an other operator. Furthermore, traditional telecom systems such as GSM and the like, and UMTS need little change, mainly in the telecom control plane, to support secondary use trade. It is mainly a matter of keeping track of how to debit or we could say roaming in all national networks as we do while out-of-nation use.

A local control is define by that the end user terminals themselves have authority to buy spectrum usage rights, and use them instantly, and where network access points, e.g., base stations, have authority to sell spectrum usage rights and provide service instantly.

Key regulatory aspects of the real time spectrum exchange concept include;
- Fully implemented secondary trading without prior consent from the regulator
- Liberalization of license restrictions enabling change of use
- Full reconfiguration of licenses in frequency, geography and time
- Establishment of a trading place, centralized or decentralized The regulatory framework must in this concept be very light when it comes to restrictions in use. However, the restrictions that can be associated with a license under this concept can be relatively strict when it comes to boundary conditions such as maximum power and out of band emission levels.

This system concept relies on etiquette, but the central institutions could still imply inclusion of some rules controlled by these institutions. We will probably see interference rules, but few other rules in the licenses.

In regulatory terms, one of the possible solutions for implementing the concept is through the introduction of a “spectrum manager”. A spectrum manager holds the license and manages the use of the spectrum. The potential interference between users is a business issue between the spectrum manager and the users, restrictions and obligations can be part of the business arrangement. The (SMA) will only hold the spectrum manager responsible for interference outside the license. Whatever the operation is within the license held by the spectrum manager it is part of the business arrangement between the spectrum manager and the users.

2.1.3.4.2 Examples of similar contemporary systems

The typical example is roaming in GSM. Here it is not the frequency spectrum that is traded, but rather capacity. However the trading mechanisms are similar.

In this system concept the original license holder could then be seen as a "reseller", perhaps charging also others on a “pay as you go" format. Extra high prices for short-term peak leases, lower prices for those willing to make a commitment for say 3 years. This principle has been used for decades in the context of reselling of capacity on satellite transponders, or IRUs on intercontinental cables.

2.1.3.4.3 Impact on the innovation process

Opportunities for easier trading with spectrum licenses should lower entry barriers for newcomers. This should encourage trials with new services and uses of spectrum.

2.1.3.5 Traditional licensing – (reference)

2.1.3.5.1 Overview

In this concept an application for a license is made to the regulator who grants exclusive use for an extended period of time. However there are a number of conditions connected to the license. For example a 3G license requires that equipment adhering to a specific standard should be used and coverage everywhere must be ensured. The license cannot be transferred to another party and if the license holder does not fulfill the requirements the license may be revoked.

2.1.3.5.2 Examples of similar contemporary systems

This is the traditional regime for licensing and there are many examples. GSM spectrum may be one that many know of.

2.1.3.5.3 Impact on the innovation process

Since the license process is quite slow, the standards that must be followed are kept for a long time. This makes innovation slower since it is not possible to take advantage of new technical developments. The slow timescale for licenses makes it possible to create complex standards that only large companies can handle. This excludes small companies.

2.2 Software Defined Radio (SDR) & Spread Spectrum

In this chapter we discuss the group of radio technologies with spread spectrum properties that uses in SDR technologies that uses in physical layer to facilitate transmission of multiple channel without interfering others.

2.2.1 SDR Technology

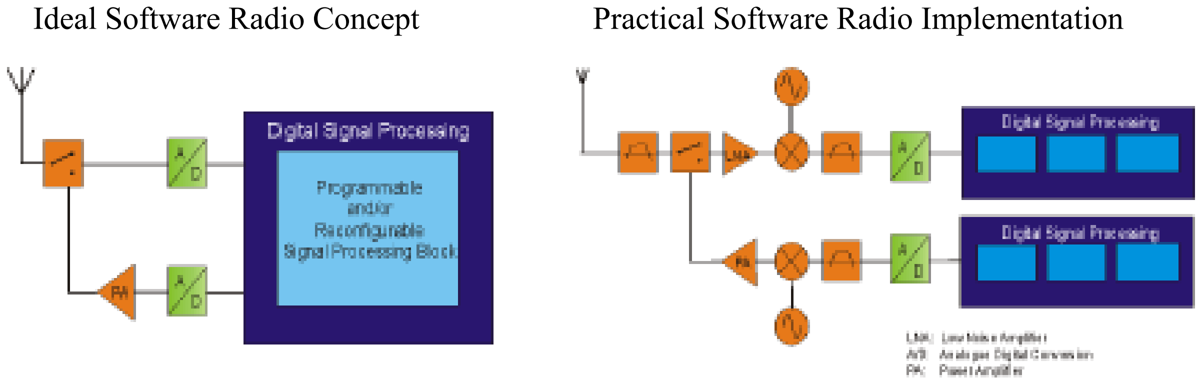
2.2.1.1 Definition

Figure 2.1 SDR structure

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. If a manufacturer can make fewer chip designs by using for example SDR technology, manufacturing costs could be reduced due to higher volumes. Moreover, SDR could reduce the number of ICs in a radio which also reduces costs."
- **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. Also, the radio can minimize power usage of the transmitter and the modulation.

SDR Hardware


Ideal Software Radio Concept

Practical Software Radio Implementation

Figure 2.2: Software radio: Ideal concept and Practical implementation

2.2.1.2 SDR requirements and challenges

The shift away from hard-wired communication terminals towards software defined and configured communication devices will introduce new ways for existing and future technologies to bind terminals and networks in entirely different business models. The reconfigurable nodes (terminals or base stations) will have the possibility to download any type of software from any possible type of software source, this includes not only the databases of manufacturers and network providers, but it enables also third party software (configuration, application and services) provision and downloads. However, such customizability will not remain limited to the application layer only, but will stretch to the lower layer and radio implementations of communication devices. In addition, it will extend to telemetric services such as automotive management and control where engines may obtain control software updates, washing machines may dynamically download new washing programs, electronic toys may install updated programs, etc. Customized and personalized applications require many more dynamic features for application development platforms than those which are currently available in small consumer devices. The capabilities of a widely used, extensible programming environment such as the Java™ platform or the implementation of comparable virtual machines, which will simplify the development of highly flexible and reconfigurable applications, services and finally configurable communication platforms.

2.2.1.2.1 Wireless Technologies

The roadmap for wireless technologies depends on a number of aspects and the actual evolution may be based on the desire for increased availability, usability and reliability of services. This requires some degree of interworking between the different technologies of the radio but, in addition, also impacts the networking and system layers. Looking at the availability of radio access networks, in densely populated areas, the radio environment tends to be rather diverse, i.e. many, separate, wireless technologies are available. Using a more flexible approach, based on the enhancements that reconfigurable SDR technology has to offer, the services of one wireless technology or system may be achieved using resources from another. There are many different approaches of how flexible interworking may be achieved, some are based on network integration and coupling, while others assume more reconfigurable terminal technology capable of interacting and providing services via any available network.

The classical delivery mechanisms for services may not always be the most efficient (e.g. DVB broadcast for only a few active users would be less resource efficient than using UMTS Multicast or even individual point-to-point connections). Coupling of these technologies and coordinated or common resource management could be used to increase the overall efficiency evaluation of the available resources. While the mere coupling on the network side already faces some obstacles, the radios that have to cope with service provision via different air interfaces are even more challenged.

2.2.2 SDR Deployment areas

While SDR Technology continues to evolve and the first commercial products have been deployed, the wide spread application of SDR equipment is yet to come. There are still many technical hurdles to be overcome, including: the completion of the reconfigurable Baseband, modularization of all hardware blocks, higher power efficiency, implementation of a digital front-end, new radio design methodologies, smart antennas, reconfigurable physical layer, integrated radio execution platform and finally reconfigurable radio hardware (possibly MEMS based).

The main gain for the operator is that the roll out of this reconfigurable access network allows them to dynamically alter the network configuration depending on the actual load situation (e.g. change the number of carriers, cell size, transmission power, etc.) and eventually, it will allow the exchange of the air interface without need to change the base station hardware. Additionally, if regulation would permit, a small operator could use their reconfigurable equipment to implement short and medium term spectrum sharing with other services (e.g. using temporally available bands), see figure below.

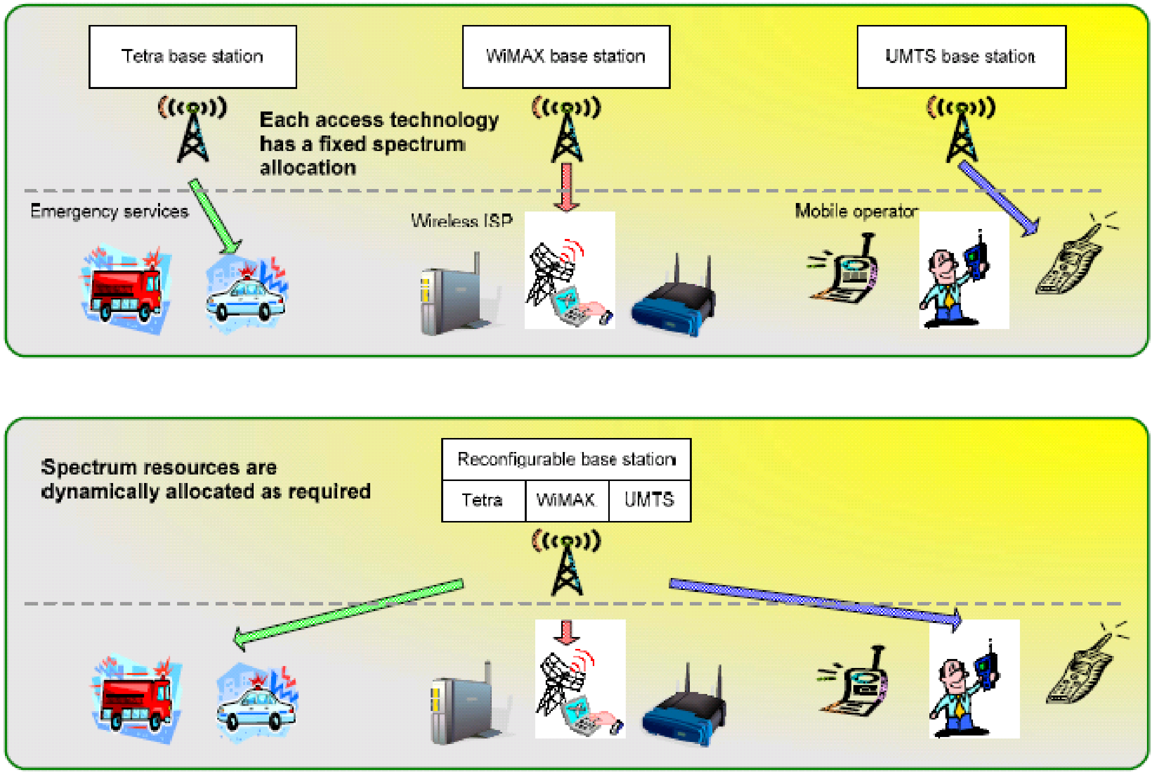


Figure 2.3 Small operator could use their reconfigurable equipment to implement short and medium term spectrum sharing with other services (e.g. using temporally available bands)

However, there are a few basic, mostly regulatory but also commercial, restrictions that prevent the widespread application of SDR equipment. In the first instance, most (regulatory) restrictions relate to the fact that radio wave emitting equipment (including both base stations as well as terminals) requires certification/conformance testing and usually some form of type approval before it can be used (or even distributed to users). While a global solution for regulation would be desirable, history has shown that this will be next to impossible to realize.

SDR Technology may be perceived as providing a rather costly alternative to current day solutions since the technology will cause (initially) higher platform costs and will further increase the complexity of the corresponding systems. The advantages of SDR Technology can be grouped into two main categories: on one hand deployment security and on the other hand are the operational advantages (such as system flexibility, extensibility and performance)[4]. SDR technology as part of a reconfigurable communication system will affect all parts of the communication network; table 3-1 outlines the advantages and disadvantages of SDR deployment

SDR Technology	
Advantages	Disadvantages
User	
portability	complexity increase
flexibility	restriction to basic control
Compatibility	security vulnerability
“AAA” (anything, anyplace, anytime) service	complex billing
interoperability	problems in provision of services
openness to configure as wanted	
increased service availability	
Operator (Network and Service Provider)	
better control of systems	additional provision of services
easy problem fixes	possible diversification of clients roles
Mass upgrade	
utilization of the network efficiently	
Manufacturer (Network and Terminal Equipment Provider)	
easy to maintain the equipment	more competition from 3rd party software providers when using open architectures
easy to develop and support systems	
concentration on the software side	
single platform	

Table 2-1: SDR Technology: deployment advantages-disadvantages

There is a dependency between the technology development/deployment and some areas where regulatory changes or clarification may be needed in order to speed up the development process.
SDR stand-alone will be merely another enabling technology towards the next generation of systems and terminals; it can only unfold all its features and possibilities when used in a suitable context.
The general view in Europe could be summarized as that:
SDR technology will enable the cost effective integration of legacy and future Radio networks and it is expected that it will facilitate the implementation of a more flexible spectrum assignment scheme.

2.2.3 Spread spectrum technologies

2.2.3.1 Introduction

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.

2.2.3.2 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. The manipulation requires a pseudo random code which is, in the original concept, only known to the parties at each end of the radio connection. Nowadays, 3G mobile communication systems use spread-spectrum today 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.

2.2.3.2.1 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 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.

2.2.3.2.2 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. As the instantaneous signal is still narrowband, spectral power density levels are comparable to classical narrowband systems. In terms of spectral coexistence with other systems, FHSS is an avoidance technique, i.e. if the hop coincides with someone else's transmission on the same channel, the collision will take only the duration of the hop, which is typically in the order of milliseconds or even less. Thus frequency hopping would in principle be suitable for spectrum overlay. 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).

2.2.3.2.3 Time Hopping Spread Spectrum(THSS)

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 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. 2Only an authorized receiver knows how the signal is spread across the range of frequencies pulse duration generates the spread spectrum profile. Time Hopping is used as a technique to generate UWB signals.

2.2.3.2.4 Orthogonal Frequency Division Multiplexing (OFDM)

2.2.3.2.4.1 Description and characteristics

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. For sub-carrier modulation simpler modulation schemes are typically used such as BPSK or QPSK, in combination with error coding. 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. The sophisticated signal structure and the ambition to improve modem performance, give rise to several challenges in OFDM modem design to cope with modem and channel impairments and imperfections. However, significant improvements in semiconductor technology and digital signal processing have boosted OFDM modem specifications and performance, particularly with respect to bit rates.

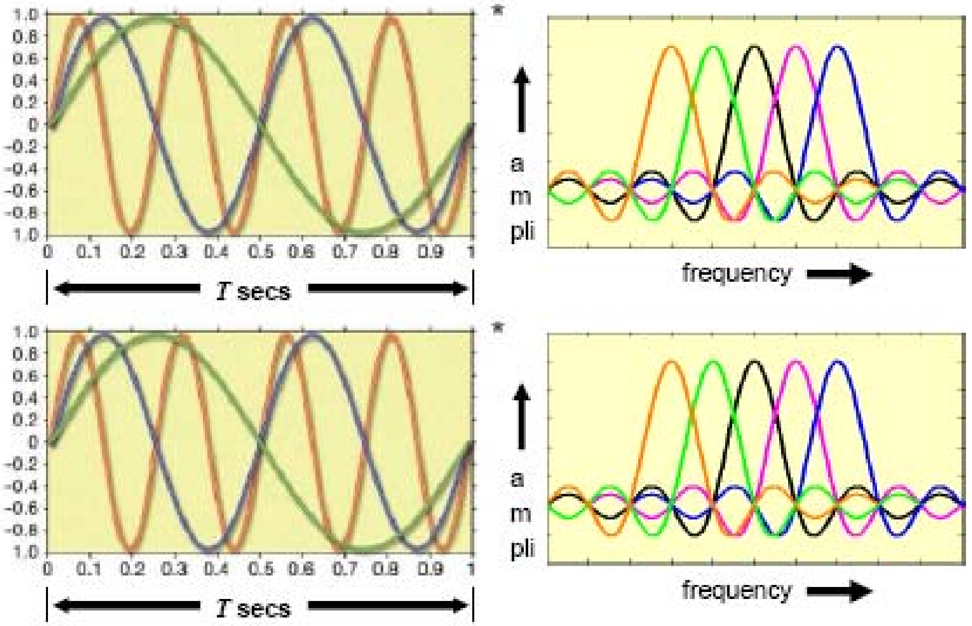


Figure.2.4: Principle of OFDM modulation: Left: data symbol and supporting carriers (wavelengths) in the time domain. Right: the resulting multi-carrier spectrum

OFDM is very often used for wireless communication systems supporting mobility and/or facing difficult propagation conditions (built-up areas), with reference to the physical layer specifications in various international standards. OFDM is used both in unlicensed bands (2.4 GHz, 5 GHz, 60 GHz) and licensed bands (e.g. VHF/UHF bands, 2.6 GHz and 3.5 GHz bands). Spectrum usage and conditions are conventional from a regulatory point of view.

With OFDM, symbol transmission is robust against single channel impairments such as deep fades. This also means that channels can be switched off deliberately, for example for spectrum management reasons. OFDM allows the designer to shape the spectral profile of the signal (spectral sculpting). This makes OFDM in principle suitable for as a spectrum overlay technique to be used in larger portions of the RF spectrum.

The MB-OFDM variant of UWB (IEEE 802.15.3) is being promoted because of this spectral sharing feature which could improve coexistence of UWB with existing services.

2.2.3.2.4.2 Current State-of-the-art

Important areas of R&D interest are OFDM combined with other transmission concepts and adaptive OFDM. Adaptive OFDM allows for throughput optimization and clever multiple-access schemes, depending upon local time varying channel conditions.

The vision for 4th generation terrestrial system is a fully IP-based integrated system offering any kind of services, at any time and able to support multiple classes of terminals. In order to accommodate future services requiring high capacity, a broadband component is envisioned with a maximum information bit rate of more than 2-20 Mbps in a vehicular environment and possibly 50-100 Mbps in indoor to pedestrian environments, using a 50-100 MHz bandwidth. One of the most promising technologies for this broadband component is MC-CDMA (OFDM-CDMA) & VSF-OFCDM, which combines the merits of OFDM with those of spread-spectrum techniques. Innovations will take advantage of the potentialities offered by MIMO techniques in order to achieve the required broadband capabilities.

2.2.3.2.4.3 Other programs and standardization activities

Relevant standardization work is currently performed under IEEE (WLAN, UWB and WiMAX).

OFDM is an important candidate technology for the 4G generation mobile broadband, applied in combination with CDMA technologies. 3GPP recognizes OFDM technology as an important enabler for 4G; OFDM is a part of 3GPP's Long Term Evolution of 3G, which can be seen as paving the way to 4G,.

Note the convergence of technologies that can be seen in both in 3G and in WiFi/WiMax standardization efforts. OFDM technologies play an important role in this convergence, as illustrated in figure 3.5.

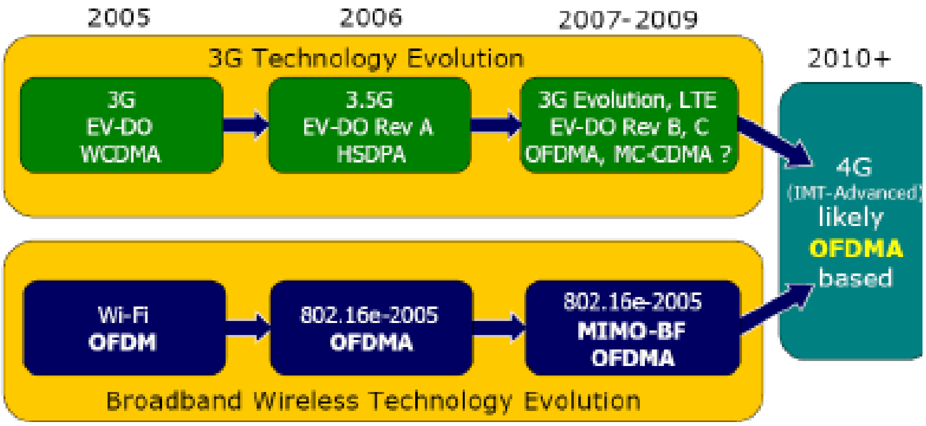


Figure2.5:Convergence of mobile technologies towards 4G/IMT-advanced.

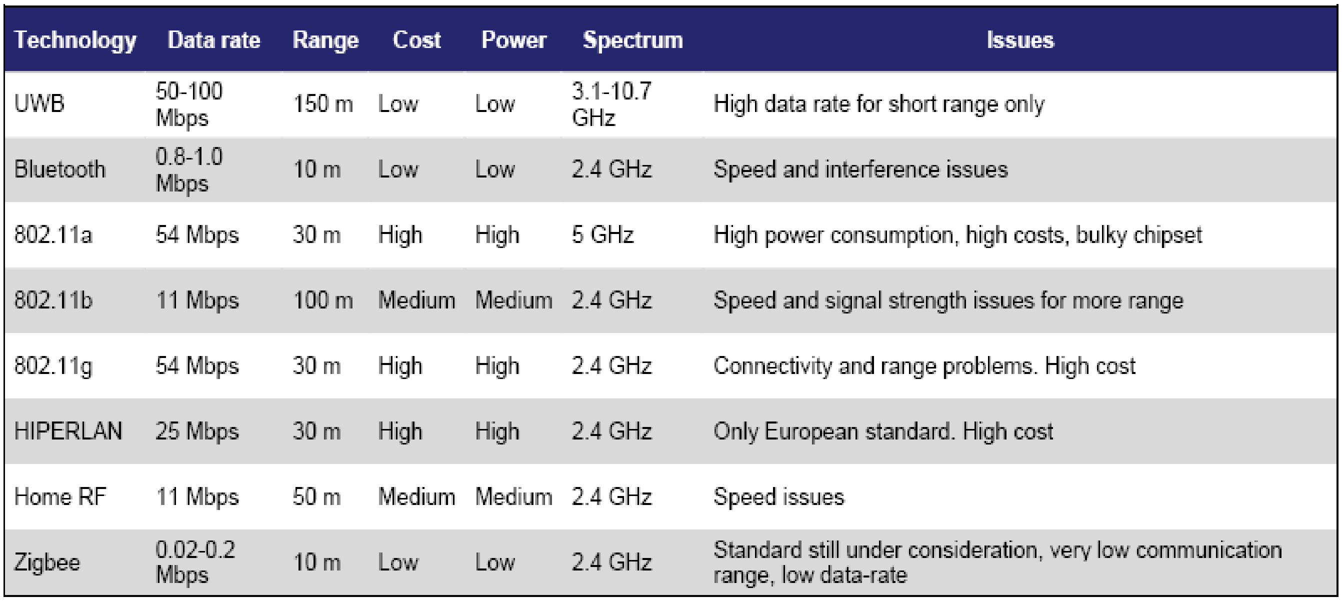
2.2.3.2.4.4 Spectrum Management issues

The principle spectral shaping capability of OFDM raises the issue what this means from a spectrum management perspective. Wideband OFDM can be considered as a interesting technology for spectrum overlay arrangements. OFDM and it’s spectrum shaping capabilities offers opportunities in spectrum management.

2.2.3.3 Ultra Wide Band Technology (UWB)

2.2.3.3.1 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 meters. 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). The main characteristics of UWB and other short range wireless standards are presented in the table below:



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

Table 2.2: Comparison between UWB and other short range wireless standards (data)

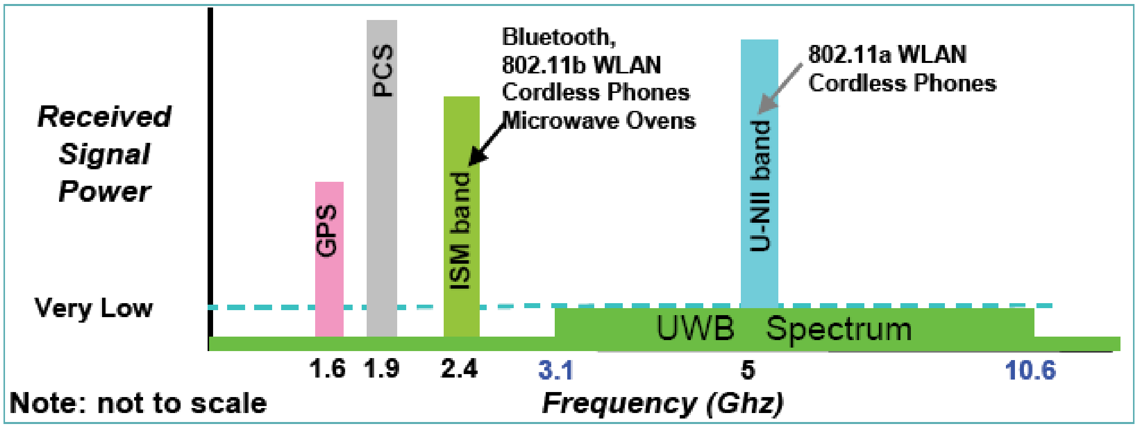
UWB has a variety of possible applications. Those that are estimated to bring most economic benefits to consumers are likely to be in the PAN environment, which includes homes and offices. Other potential applications for UWB include ground probing radar, positioning location systems, wireless sensors, asset tracking and automotive systems. It is generally assumed that the majority of UWB applications will fall into the category of consumer communications and high speed networking within PAN environments.

Until recently, almost all data connections between electronic devices in the home and office environments were made using cables (both wire and fibre), with limited deployment of infra red (IR). However, in recent years, there has been increasing interest in replacing cable and IR connections by 'wireless' links that transmit signals using radio spectrum. Prominent wireless technologies deployed to date include Bluetooth and the 802.11 series of wireless LAN (WLAN) technologies. Wireless links offer a number of benefits to the consumer, including greater flexibility in positioning devices, ease of making occasional connections and the aesthetic advantage of cable replacement.

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 Mbit/s up to 1Gbit/s) over short distances thereby using frequency spectrum in stealthy fashion (hardly noticeable).

Currently, there are no dedicated frequency bands for UWB applications identified in the ETSI, in the decisions or in the ITU Radio Regulation treaty.

The figure below shows how UWB uses already allocated radio spectrum.



Source: INTEL

Figure2.6: underlay-example of the UWB band

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.

2.2.3.3.2 Spectrum Management issues

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.

2.2.3.3.3.1 Spectrum management implications overview

*Enabling Technology

Technology	**Characterization**	**Implications for spectrum Management**
OFDM	Modern efficient transmission technologies, robust / Adaptable	**Opportunities**: Spectrum Shaping. Adaptive to local temporal environment. Characteristics (regulations).
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.

*Disruptive Technology

Technology	Characterization	Implications for spectrum Management
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
Multi Carrier - CDMA	Improvement of radio performance	• Enhanced Spectrum Efficiency • Clever multiple-access schemes • Throughput optimization

Table 2.3: Spectrum management implications

2.2.3.4 Variable Spreading Factor-Orthogonal Frequency and Code Division Multiplexing (VSF-OFCDM)

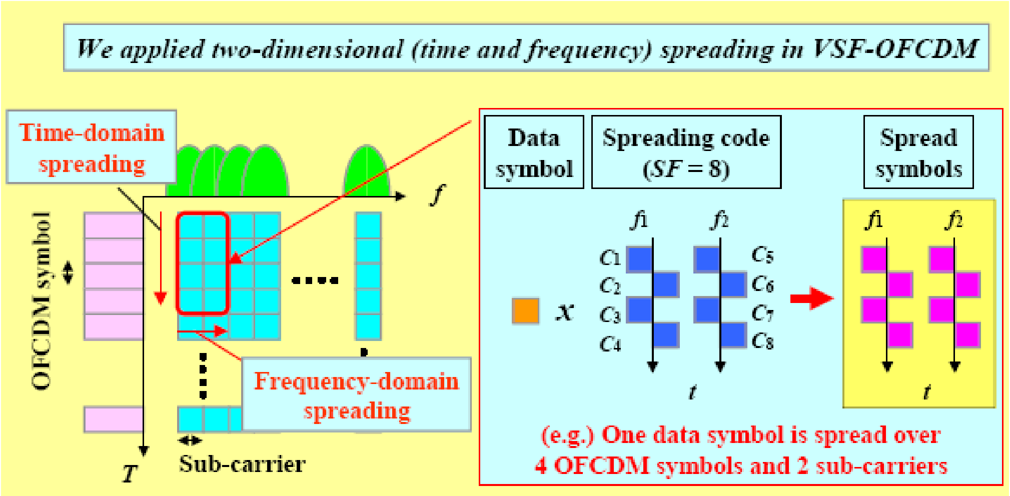


Figure 2.7 VSF-OFCDM Employing Two-Dimensional spreading with Prioritized Time-Domain Spreading, OFCDM based on MC-CDMA

One of the candidate technologies that satisfies the requirements is Variable Spreading Factor Orthogonal Frequency and Code Division Multiplexing (VSF-OFCDM), which is based on multi-career CDMA technologies with the variable spreading factor scheme for increasing the system capacity shown in Figure 3.7. The biggest advantage of the VSFOFCDM is its flexibility in the spreading factor. When it is applied to isolated hot spots, we can achieve its highest capacity by choosing a spreading factor of one to be compatible with conventional OFDM. On the other hand, it works as a kind of CDMA with a spreading factor higher than one under multi-cell environments to enable the same frequency reuse.

Then, a single air interface of VSF-OFCDM realizes capabilities of OFDM and CDMA in an adaptive manner according to environments. Success in 1Gbps real-time packet in-lab transmission experiments in combination with MIMO technology was confirmed in Aug.2004[12].

3. MATERIALS & METHODS of DSA SYSTEMS

3.1 System explanation to increase efficiency

3.1.1 Radio technologies & DSA

This chapter 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 adaptively is to be able to operate and maintain system or network performance under different and dynamic (spectrum) environment conditions.

When a frequency band has been selected for a session in a dynamic spectrum access network, the initial choices for the modulation and coding must be consistent with the bandwidth that is available and the session’s quality-of-service priorities. The resource consumption metric accounts for the bandwidth, data transmission time, and transmitted power for the session. Shannon capacity limits are employed to bound the resource consumption and permit tradeoffs between the time-bandwidth product of the signals and the amount of power that must be transmitted to achieve reliable communication.

Several protocols are required for packet radios to be able to initiate and maintain reliable communications in a wireless ad hoc dynamic spectrum access network. After a frequency band has been selected, a modulation-selection protocol must choose a modulation technique according to the capabilities of the radios, the established etiquette for transmission in the network, and the quality-of-service (QoS) priorities for the session. Because the propagation loss is typically unknown for a new frequency band, a power-adjustment protocol must adjust the transmitter power during the first few packets. A power level that is too low results in a large number of unsuccessful attempts to send packets to the destination. A power level that is too high wastes energy and causes excessive interference to other radios in the network. The metric for modulation selection accounts for the three primary spectrum etiquette parameters: time, bandwidth, and power. The metric is a measure of resource consumption that permits tradeoffs between the power and the time-bandwidth product[9].

3.1.2 Parameters

3.1.2.1 Modulation

All the code-modulation combinations are examples of bit-interleaved coded modulation, and the modulation formats include biorthogonal modulation, QPSK (Quadrature Phase shift keying), QAM (Quadrature Amplitude Modulation). Here we choose the systems that used BPSK & QAM modulations. Direct-sequence (DS), frequency-hop (FH) spread-spectrum and OFDM (orthogonal frequency division multiplexing) modulations applied to the data-modulated signal. A pseudo-random sequence, referred to as a signature sequence, can be applied to some modulation formats to provide spread-spectrum multiple-access capability, which permits multiple sessions to occupy the same frequency band simultaneously. Frequency hopping can also provide multiple-access capability, and it can easily be included in the metric for resource consumption and also OFDM.

3.1.2.2 Time-bandwidth product

A session must be established whenever one radio, the source, wishes to send a sequence of packets to another radio, the destination. Other radios within range of the source are referred to as unintended receivers; these radios may experience interference from the source’s transmissions. The source and destination are part of a dynamic spectrum access network, so they must choose an available frequency band that meets their requirements. They must select modulation and coding that are usable by both radios and satisfy all constraints imposed by the frequency band that was chosen. For example, for some modulation formats and code rates, the packet transmissions may require more bandwidth than is available at the chosen frequency in order to complete the session within the allotted time. It was propose the use of a spectrum etiquette measure in the selection of the initial modulation and coding for a new session. The spectrum etiquette measure is a function of the bandwidth, data transmission time, and power. The data transmission time is the total time that the source is actively transmitting data during the session. Headers and preambles are not included.

Let η_j be the number of signature sequence chips per modulation chip for modulation format *Mj*. If there is no signature sequence, then $\eta_j = 1$. Let *mj* denote the number of binary symbols per modulation symbol and let *Lj* denote the number of modulation chips per modulation symbol. Each packet contains the same number n_b of binary code symbols. If code *Ci* has rate r_i, there are $k_i = r_i n_b$ information bits per packet when code C_i is used. If the chip waveform is a rectangular pulse and the information rate is R_b b/s, then the null to-null bandwidth for modulation format M_j and code C_i is $B_{i,j} = 2\lambda_{i,j} R_b$ Hz, where

$$\lambda_{i,j} = \frac{\eta_j L_j n_b}{m_j k_i} \qquad \text{………………….(3.1)}$$

Represents the number of chips per information bit for a single packet that uses C_i and M_j; in particular $\lambda_{i,j} = 1$ for uncoded BPSK with no spread spectrum.

Suppose the session is required to deliver N_b bits of information regardless of which code-modulation combination is used. For code C_i and modulation M_j, the number of packets that must be decoded correctly at the destination is $N_i = \lceil N_b/k_i \rceil \approx N_b/k_i$. The expected number of packet transmissions required to complete the session, including retransmissions of any failed packets, is $N_i/Q_{i,j}$, where $Q_{i,j}$ is the packet success probability. If $B_{i,j}$ is the null-to-null bandwidth that can be accommodated in the frequency band selected for the session, then the average data transmission time per session is closely approximated by

$$T_{i,j} \approx \frac{2N_b \lambda_{i,j}}{Q_{i,j} B_{i,j}} \qquad \text{……………..(3.2)}$$

and the parameter

$$\tau_{i,j} = \frac{\lambda_{i,j}}{Q_{i,j}} = \frac{\eta_j L_j n_b}{Q_{i,j} m_j k_i} \qquad \text{………………(3.3)}$$

is approximately equal to the average number of transmitted chips per delivered information bit. Both approximations are exact if N_b/k_i is an integer. The time required for packet headers or preambles is not included in

(4.2) or (4.3), but it is easy to account for such overhead times. The average time-bandwidth product $\psi_{i,j}$ for a session that employs code C_i and modulation format M_j is $\psi_{i,j} = \mathrm{T}_{i,j}\mathrm{B}_{i,j}$. From (4.2) and (4.3) there was:

$$\psi_{i,j} \approx \frac{2N_b\lambda_{i,j}}{Q_{i,j}} = 2N_b\tau_{i,j}. \quad \ldots\ldots\ldots\ldots\ldots..(3.4)$$

Because N_b is does not depend on C_i or M_j the parameter $\tau_{i,j}$ can be interpreted as the normalized time and bandwidth product.

Thus far, it was accounted for the bandwidth and transmission time but not the power used by the source. It is desirable for the source to transmit only the minimum power needed to provide the required probability of success. The mechanism for ensuring the source uses this minimum power is the power-adjustment protocol that is described in the next section.

3.1.2.3 Power adjustment

Because of the unknown propagation loss in a new frequency band, the initial power level is likely to be above or below the minimum level that achieves the desired packet success probability. If each session has several hundred packets or more, then a session can tolerate excessive interference from the source for ten to twenty packets, but it cannot tolerate excessive interference for a significant fraction of the packets in the session. Because the source does not know the correct power level, the power-adjustment protocol must use feedback from the destination to adjust the source's transmitter power at the start of each session. For each packet that is received by the destination during the power-adjustment phase, the destination receiver derives a demodulator statistic that is used to determine the power level for the next packet that is sent from the source to the destination. For M-biorthogonal modulation, the demodulator statistic is a ratio statistic. For PSK and QAM, the demodulator statistic is based on the Euclidean distance between each received symbol and its closest point in the signal constellation. The statistic or a power-adjustment decision based on the statistic is included in the acknowledgment packet that is sent to the source. If the acknowledgment packet is received by the source, then the power level for the next packet is a function of the demodulator statistic for the previous packet. No matter where the power-adjustment decision is made, it is obtained by applying an interval test to the demodulator statistic. For each packet that is sent during the power-adjustment period but not acknowledged, the source automatically increases the power by a fixed amount (e.g., 5dB). The termination of the power-adjustment phase is determined by a stopping condition applied to the demodulator statistics for the initial sequence of packets in the session. The adjusted power level was never more than 0.7dB above the target level. For each modulation format, the adjusted power level was never less than the minimum power required to achieve a packet error probability of 10^{-2}.

3.1.2.4 Channel model

The underlying access technique is CDMA (Code Division Multiple Access). CDMA uses the spectrum more efficiently than TDMA (Time Division Multiple Access) or FDMA (Frequency Division Multiple Access). It has several advantages including: increased capacity, enhanced privacy and security, improved coverage characteristics, co-existence with other technologies with little to no interference, and reduced interference with other electronic devices. The multi-carrier and CDMA combination are the most efficient techniques available in the commercial market today. There are, however, new technologies in development that will far surpass these efficiencies.

Coded direct-Sequence Spread-Spectrum (DSSS) Code Division Multiple Access (CDMA) has well-known advantages over time/frequency division multiple access: dynamic channel sharing, robustness to channel impairments, graceful degradation, ease of cellular planning, etc. These advantages result from the assignment of “signature waveforms” with large time bandwidth products to every potential user of the system.

DSSS has the advantage of providing higher capacities than FHSS, but it is a very sensitive technology, influenced by many environment factors (mainly reflections). The best way to minimize such influences is to use the technology in either (i) point to multipoint, short distances applications or (ii) long distance applications, but point to point topologies. In both cases the systems can take advantage of the high capacity offered by DSSS technology, without paying the price of being disturbed by the effect of reflections. As so, typical DSSS applications include indoor wireless LAN in offices (i), building to building links (ii), Point of Presence (PoP) to Base Station links (in cellular deployment systems), etc.

On the other hand, FHSS is a very robust technology, with little influence from noises, reflections, other radio stations or other environment factors. In addition, the number of simultaneously active systems in the same geographic area (collocated systems) is significantly higher than the equivalent number for DSSS systems.

All these features make the FHSS technology the one to be selected for installations designed to cover big areas where a big number of collocated systems is required and where the use of directional antennas in order to minimize environment factors influence is impossible.

Typical applications for FHSS include cellular deployments for fixed Broadband Wireless Access (BWA), where the use of DSSS is virtually impossible because of its limitations.

OFDM still has a strong interest in the R&D community and industry, for example on the topic of combining state-of-the-art OFDM with other technologies to improve radio performance or even arrive at new concepts. OFDM is an important candidate technology for the 4G generation mobile broadband, applied in combination with CDMA technologies.

3.1.3 Systems comparison

3.1.3.1 Basic systems

In wireless communications, there is always a demand for more bandwidth, increased coverage or range, increased data rate, decreased interference, and lower costs. Two major standards of wireless transmission are IEEE802.11b and Bluetooth. Both are operating in the range of 2.4 GHz to 2.4835 GHz ISM (Industrial, Scientific and Medical). This frequency band is unlicensed and free to use even without the permission of FCC. Although these two standards work in the same frequency band, they use different technology of spread spectrum. Bluetooth uses (FHSS) and IEEE802.11b uses (DSSS), and also 4G wireless uses OFDM. FHSS systems are of low cost, low power consumption, low data rate, short-range application, and are more tolerant to signal interference. Hence, Bluetooth uses a narrowband carrier that hops from frequency to frequency in a pattern that is known both the sender and the receiver. The corresponding RF channels for Bluetooth are 2402+k MHz, where k=0, 1, …, 78. This technique is good at overcoming moderate signal interference because the interference signal only affect part of spread spectrum signal using same frequency band in the same time. With higher data rate and longer range of application, the DSSS IEEE802.11b has to pay the price of higher cost and higher power consumption in comparison with Bluetooth. Furthermore, it works in a fixed channel and creates a redundant bit pattern for each bit to be transmitted. This bit pattern is called chipping code. If one or more bits in the chip are ruined or damaged during transmission, they can be recovered even without retransmission. In the IEEE802.11b standard, it provides data rates with 1 Mbps, 2 Mbps, 5.5 Mbps and 11 Mbps. Therefore, it is faster than Bluetooth. However, Bluetooth changes the transmission channel 1600 times per second so that it is more secure and less interferenced than DSSS. Moreover, DSSS technique does make the system sensitive for interference as other signals using the same frequency. Accordingly, if the channel is used by other unimportant signal, the real important signal needs to wait for it or utilizes the remainder frequency to transmit data. It will really reduce the effect very much. To overcome this drawback, the DSSS products require channel planning to reach an optimal performance at higher data speeds. It is obvious for some real-time applications such as video-conference and energy management. Therefore, it is an inevitable problem that how to make a good schedule or control among many variant demands so that the systems can achieve the greatest benefit. Although Bluetooth technique is very popular so far, IEEE802.11b standards are more mature than Bluetooth. That’s because IEEE802.11b extends from IEEE802.11. Therefore, the products based on IEEE802.11b standards are in the majority.

A major challenge when deploying for example WLANs systems the channel allocation problem. This introduces interference from other electronic devices, such as microwave ovens and wireless phones. There are two types of interference in WLANs: adjacent channel interference and co-channel interference. The 802.11 standard specifies three techniques for data transmission in the physical (PHY) layer for lower data rates: Infrared (IR), frequency hopping spread spectrum (FHSS) and direct sequence spread spectrum (DSSS). There are two spread spectrum techniques used in 802.11 that use short range radio waves operating in the unlicensed ISM band at 2.4 GHz: DSSS and FHSS. DSSS generates a chipping code (redundant bit pattern) for each bit to be transmitted. Due to this redundancy in transmission if one or more bits are damaged, the receiver can still recover the original data without the need for retransmission. To the unintended receiver, DSSS appears as low-power noise and is rejected. Of course, the drawback of this technique is the need for more bandwidth which is a limited resource in IEEE 802.11. On the other hand, FHSS uses a narrowband carrier (1 MHz), with 79 channels which begins at 2.412 GHz in the U.S. , which changes frequency in a pattern known to both transmitter and receiver. This technique provides good security since a user who does not know the hopping sequence of channels, cannot eavesdrop. FHSS appears as a short duration impulse noise to the unintended receiver. The main disadvantage of DSSS and FHSS is the low data rate (1 Mbps or 2 Mbps).

Two new techniques were introduced in 1999 for higher data rates. The two techniques are: Orthogonal Frequency Division Multiplexing

(OFDM) and high range direct sequence spread spectrum (HR-DSSS). OFDM splits the data over multiple narrowband carriers (frequencies) to transmit simultaneously. The advantage of OFDM is the efficient use of the spectrum, better immunity to narrow band interference and lower multi-path distortion. OFDM is used by 802.11a in the 5 GHz band and 802.11g in the 2.4 GHz. On the other hand, HR-DSSS spread spectrum, which is used by 802.11b, is the same as DSSS spread spectrum but uses 11 x 106 chips per second to achieve 11 Mbps data rate in the 2.4 GHz ISM band. However, HR-DSSS does support and is compatible with lower data rates of 1, 2, 5.5 and 11 Mbps.

3.1.3.2 Next Generation wireless techniques

Several advances in spectral efficiency have been researched; the most promising next generation technique that may increase spectral efficiency by more than a factor of ten is called BLAST. Considerable academic research has been dedicated to this area as well as and experimentation by the Defense Advanced Research Projects Agency (DARPA).

BLAST uses the concept of a multi-element antenna array (MEA) that transmits different signals in the same bandwidth over several antenna elements simultaneously (sub-channels); taking advantage of the fact the transmitted signals from each antenna will not travel the exact same distance and path to the receiver's antenna array. The channel capacity of an MEA is the sum of capacities of these sub-channels. Multiple antenna systems provide very high capacity compared to single antenna systems in a Rayleigh fading environment. Space-time codes are used on each subchannel; these channel codes are designed to utilize this high capacity without requiring instantaneous channel state information at the transmitter.

Vertical BLAST, or V-BLAST, which has been implemented in real-time in laboratories. Using this laboratory prototype, we have demonstrated spectral efficiencies as high as 40bit/s/Hz.

The best advantage of V-BLAST, besides its increased spectral efficiency, is that the MEA technology is best suited for, and has been tested with a CDMA-OFDM scheme similar to that used by CDMA2000. The largest upgrade factor for BLAST would be the addition of the antenna array on top of existing hardware. The disadvantage of using MEAs are the size associated with the antenna system.

3.1.3.3 4G Mobile Communications System Prototype

NTT DoCoMo, Inc. said it will make a prototype of the fourth-generation mobile communications system.

The next-generation mobile communication system aims to realize a high-speed data transmission of 100Mbps or faster for downstream. NTT DoCoMo plans to develop the prototype by this summer for access testing. Discussions have been held on the fourth-generation mobile communications system, to be commercialized in 2010, at the WP8F, a working group of International Telecommunications Union-Radio communication Sector (ITU-R.)

NTT DoCoMo aims to secure a leading position in development of the next-generation mobile communications system by proposing a new data transmission method for the system earlier than its rivals. In an attempt to realize the high-speed data transmission of 100Mbps or faster, the mobile telecom giant is developing a new wireless access method called VSF (variable spreading factor)-OFCDM (orthogonal frequency and code division multiplexing), CDMA spreading factor based on OFDM (orthogonal frequency division multiplexing) for wireless local area networks (LANs) at 5GHz.

VSF-OFCDM is a type of a multi-carrier CDMA technology called MC-CDMA. As with OFDM, VSF-OFCDM employs dense sub carriers to use the frequency more effectively, and it is not affected by multipath interference. Use of spreading factor, as with CDMA, will enable VSF-OFCDM to use the same frequency as adjacent cells.

VSF-OFCDM can be employed both for services for specific areas such as hot spots and for wide-range areas utilized services as cellular phone by adopting variable spreading factor.

According to NTT DoCoMo, the new system to be proposed by the company can realize the data transmission speed of 103.68Mbps by using QPSK for the primary modulation method at 100MHz. The speed will be increased to 331.776Mbps by using 64-QAM for the primary modulation method and 1 for the coefficient of spreading factor. OFDM will have 768 sub carriers and symbol length of 9.952 micro seconds. It will use turbo encoding, NTT DoCoMo said.

3.1.4 SDR to increase spectrum efficiency

3.1.4.1 description

SDR technology has been heralded as one of the facilitators of the ABC paradigm ('Always Best Connected'), enabling the seamless interoperation between different communication platforms, not only within one family (e.g. cellular) but also between different hierarchical levels of systems (satellite, broadcast, cellular, wireless local area and personal networks). SDR is expected to enable the inter-operability of wireless heterogeneous radio access networks. This in turn raises a new range of challenges in terms of spectrum and radio resource management. One of the core features offered by SDR technology is the possibility of implementing spectrum management in a more dynamic fashion. Use of SDR Technology for dynamic allocation of spectrum was initially proposed and investigated by the OverDRiVE project [2].

Dynamic spectrum management requires a high degree of interoperability between the different access networks, but it might also require fundamental changes in the way spectrum is regulated and used by the operator. The spectrum liberalization efforts (of Ofcom) are a significant step towards regulation, which will allow such flexible management and allocation.

SDR Technology will facilitate the split of the classical combination between service/radio access technology/spectrum band. The examples in the figures below illustrate the principle.

Figure 3.1 displays the classical arrangement where a, lets say, GSM voice service is provided by a GSM system using a GSM band.

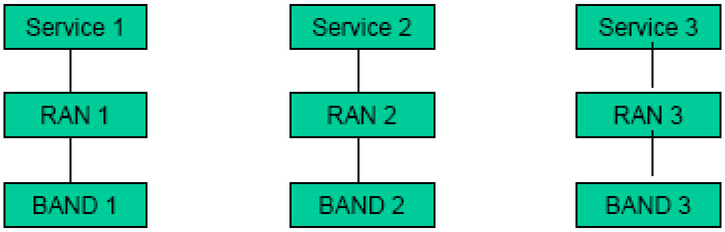


Figure 3.1: current definition of service- access technology- band

The example in figure 3.2 shows the first degree of flexibility that may be imagined, where, taking the example from before, the GSM voice service is implemented in a WLAN system, using the ISM band at 2.5GHz.

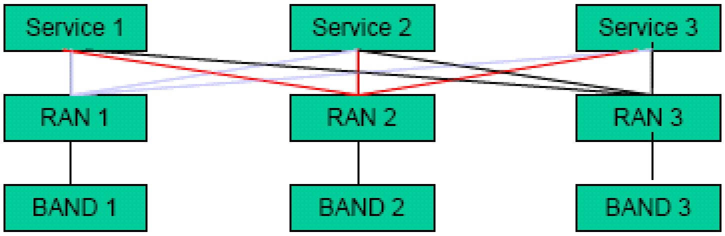


Figure3. 2: service over different access technology with fixed band

Finally, depicted in figure 3.3, the limitation of an access technology to operate in one particular band is removed; the access system can use resources that may be available in a band other than that originally assigned.

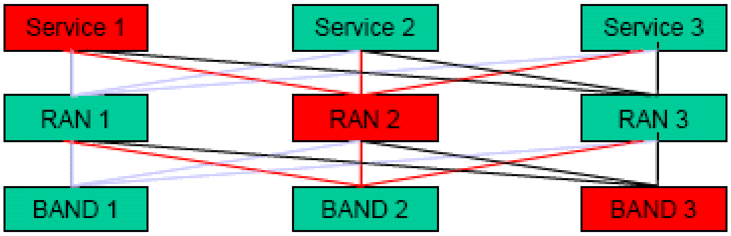


Figure 3.3: service over different access technology in any band

SDR technology provides the means to flexibly and quickly implement such scenarios; this forms the basis for any market driven spectrum regime, where the spectrum can be used for operation of any radio access technology that stays within the specifications (e.g. limitations such as power and interference levels) that have been defined for a band.

SDR Technology can enable communication services to temporally make use of bands that are not occupied or underused.

The work included definition of dynamic spectrum algorithms for flexible allocation of spectrum within different cells.

3.1.4.2 Example: cell-by-cell dynamic spectrum allocation scheme

3.1.4.2.1 definition

The cell-by-cell dynamic spectrum allocation scheme is an assignment scheme where the individual base stations of each radio access network (RAN) could be allocated any part of the spectrum. This means that each individual base station of a RAN could be operating on completely different frequencies and cells of one RAN could be using the same frequencies of other cells of another RAN in another location. A basic representation of this scheme compared to fixed allocations, and the contiguous and fragmented schemes can be seen in figure 3.4. The reason for investigating this type of DSA scheme, over the previous schemes, is that it is able to adapt to both temporal and spatial variations in load demand simultaneously. Furthermore, it has the potential to give greater improvements in spectrum efficiency, as the allocations can follow the demands more closely for each individual cell. However, this will depend on the algorithms used to implement the scheme.

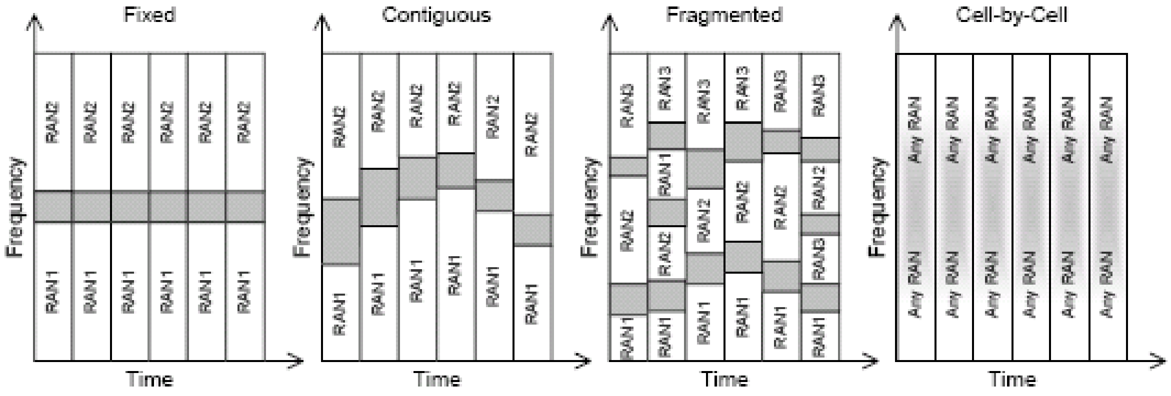


Figure 3.4: Basic operations of fixed, contiguous, fragmented and cell-by cell DSA

The fundamental idea behind a cell-by-cell DSA scheme is that it only allocates the amount of spectrum actually needed in each individual cell in the system. Traffic seen on radio access networks varies both over time and over space, and the cell-by-cell DSA scheme needs to reconfigure the allocations of spectrum to the cells in the system in order to adapt to these changes. However, the key problem that the scheme needs to overcome is that of handling the interference that could occur between different systems sharing a block of spectrum, and ensuring that all the systems have fair access to the spectral resources.

The scenarios considered here involve multi-radio systems using different radio access networks (RANs) covering the same geographical area. This includes a UMTS cellular system and a DVB-T broadcast system. The aspect that makes much of the work challenging is that the overlaid RANs sharing the spectrum are likely to have very different cell sizes, making management of interference between them more complex. However, the mitigating factor is that, since the types of system are disparate, it is likely that the time and space varying traffic patterns on the networks will be different from each other, giving scope for gain by spectrum sharing.

An example of the way a cell-by-cell DSA scheme operates can be seen in figure 4.5. This shows an example of a large-celled DVB-T system, sharing spectrum with a small-celled UMTS system. In this figure, there are four carriers available to be shared between the RANs.

This only shows the UMTS cells around the border area between the DVB-T cells, for clarity, although in reality they would cover the whole area. It can be seen that the allocation of carriers to the RANs changes from cell to cell. In this case, there may be high demand for UMTS services on the left hand side of the figure, and high demand for DVB-T services on the right side. This is shown by the allocations of frequencies, which reflect the levels of demands for the two networks.

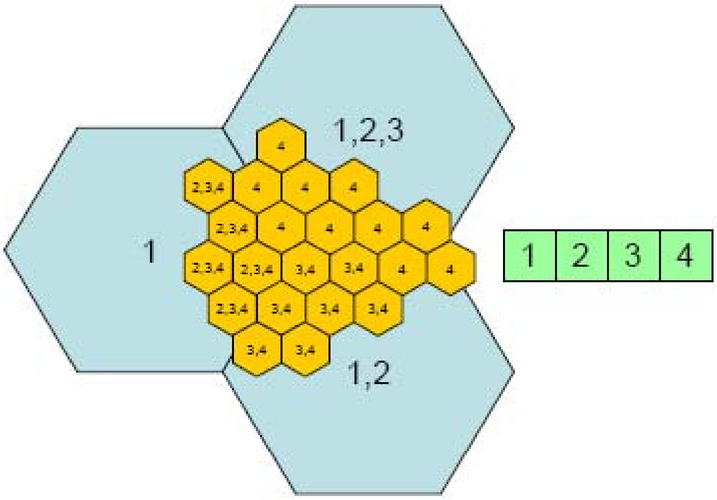


Figure 3.5: Example spectrum allocation for cell-by-cell DSA

The scheme uses an algorithm to distribute the frequencies to the cells and thereby satisfy the users as much as possible, whilst at the same time managing interference between the radio accesses networks, by ensuring networks on the same frequency are not too close together[4].

3.1.4.2.2 DSA usage scenario

It has been stated that the aim is to investigate the spectrum efficiency gain that could be achieved in a WCDMA based hierarchical cellular radio system that can access unused spectrum bands. The system under consideration consists of a UMTS cellular voice service and modern digital DVB-T broadcast network, both of which are capable of delivering multimedia traffic to the users. Furthermore, both these systems have the advantage of utilizing a similar carrier bandwidth.

For the dynamic spectrum allocation operation, the spectrum is only shared on the downlink of the radio access networks as the traffic seen on future mobile environments is expected to be largely asymmetric, with most of the traffic loads seen on the downlink.

3.1.4.2.3 Basics of the optimization model

To analyze the performance of a cell-by-cell DSA scheme with dynamically variable spectrum bandwidth, a simple model with optimization strategies is constructed. The model consists of 300 micro UMTS cells each of 1km radius with three overlaying macro DVB-T cells of 10km radius. The users are distributed uniformly and move around the area covered by the three DVB-T cells according to the mobility model discussed below. The number of users in the simulation was varied to change the overall traffic loads generated by real world measurements as described under the following traffic model. Since radio access networks are UMTS, which has a frequency re-use factor of one, and DVB-T that could be operating in a single frequency network, all base stations and transmitters in each of the radio networks are able to use the same frequencies.

3.1.4.2.4 Traffic model

The spectrum demand or arrival rate for DVB-T service is derived from the TV broadcast measurements through channels 52- 69 (698MHz to 806MHz); assuming similar demand of multicast video service over DVB-T in the future. Similarly, for voice service demand over UMTS, the adjacent 806MHz to 902MHz band is chosen. For the third spectrum block, 2390MHz-2500MHz with low average duty is selected. As the duty cycle in the third band is comparatively low, there are a lot of unoccupied frequencies that can be used for better allocation. Moreover, the exponentially distributed mean call duration of 120sec. was assumed for the UMTS voice services.

Start Freq. (MHz)	Stop Freq. (MHz)	Band width (MHz)	Allocation	Average Duty Cycle	Occupied Spectrum (MHz)
698	806	108	TV52-69	0.2958	32.59
806	902	96	Cell phone and SMR	0.4619	44.46
2390	2500	110	U-PCS,ISM (Unlicensed)	0.1347	15.93

Table 3.1: Selected frequency bands and their usage during the Republican Party Convention

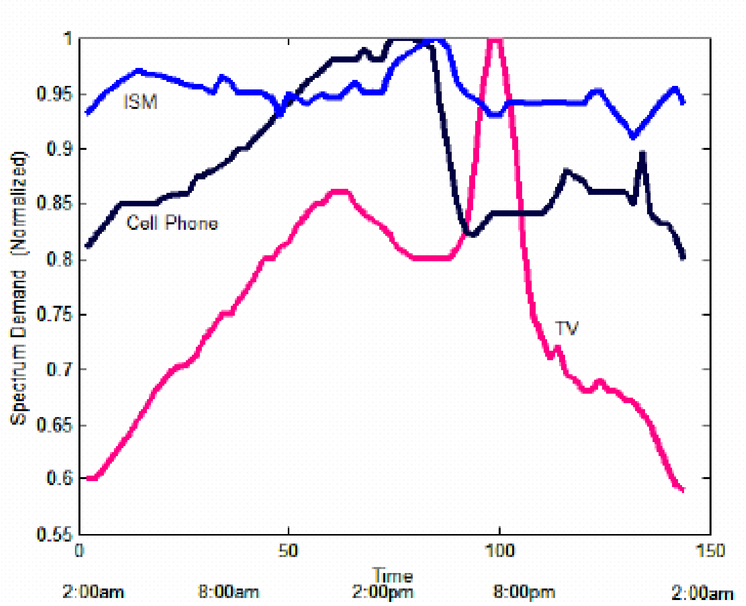


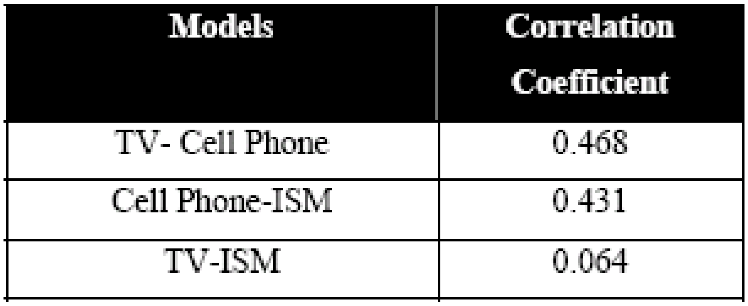
Figure 3.6: Traffic demand for the ISM, cell Phone and TV services

The three traffic services show different fluctuation patterns over the day. The maximum spectrum demand for TV viewing can be seen around 8:00pm, probably at the news time and the second highest peak usage around 2 o'clock during the day. The lowest demand is seen after midnight about 2:00am.

The usage of cell phones shows a gradual increase as the day goes (from 2:00am to 2:00pm) and the highest usage around 2:00pm in the afternoon and thereafter a rapid decrease towards the evening. However, ISM demand does not fluctuate as TV and cell phone demand does, with maximum usage again around 6:00pm.

The operation of a temporal dynamic spectrum allocation scheme relies on the time-varying traffic patterns of the radio networks sharing the spectrum being different. The traffic patterns have a major impact on the potential for DSA to improve the use of the spectrum. If the two networks have exactly the same pattern, then they are perfectly correlated, a correlation of +1 would give spectrum efficiency gain 0 %, since both networks require spectrum from DSA to support their peak loads simultaneously - giving no advantage compared to fixed spectrum allocation. The other extreme would be where the traffic patterns for the two wireless networks are perfectly uncorrelated, that is a correlation coefficient of -1, with the demands normalized to one. If the networks had equal peak demands for the spectrum, then for FSA, an equal block of spectrum would be required for each RAN to support its peak load. If the radio networks were to share this overall block of spectrum, then the networks would be able to support at least twice as much spectrum as they would with FSA, in the same total block of spectrum, leading to a spectrum efficiency gain of 100%. However, both these extremes, traffic correlations of -1 or +1 are unrealistic and therefore can not be used in evaluating different spectrum allocation methods.

The correlation coefficients between traffic patterns are shown in table 3.2. All the patterns are positively correlated. TV and Cell Phone traffic patterns show the highest correlation of +0.468 indicating similar patterns and the lowest correlation of +0.06 is seen between TV and ISM.



Models	Correlation Coefficient
TV- Cell Phone	0.468
Cell Phone-ISM	0.431
TV-ISM	0.064

Table 3.2: Correlation coefficients between models

3.1.4.2.5 Cell capacity:

As the number of channels in the network depends on the level of total interference (at least for the UPLINK, i.e. mobile to Base Station link), the WCDMA system is limited by interference in the UPLINK. The

WCDMA transmissions in neighbouring cells, which use the same carrier frequency, are accounted for by introducing a factor β. This modification reduces the number of users in a cell since the interference from users in the other cells must be added to the interference generated by the other mobiles in the user's cell. The practical range for β is 0.4~0.55. The power control accuracy is represented by a factor α and its range is 0.5~0.9. The reduction in the interference due to the voice activity factor υ has range 0.45~1.0. The type of antenna used at the base station is directional rather than omnidirectional.

The antenna used at the cell each radiate into sectors spaced at 1200, and therefore an interference improvement factor λ is included in the equation. For a three-sector cell, the practical value of the improvement factor is 2.55. With the introduction of these factors, the number of users that can be supported by a cell can be mathematically expressed as follows:

Mobile users per cell

$$M = \frac{B_w/R}{E_b/N_o} \times \frac{1}{1+\beta} \times \frac{1}{\upsilon} \times \lambda \qquad \text{………..…….} \ (3.5)$$

Where, BW is the bandwidth, R is the information rate, E_b is the energy per bit and N_0 is the noise power spectral density.

4. ASSESSMENT OF SPECTRUM UTILIZATIONIN DSA SYSTEMS

4.1 SYSTEM PERFORMANCE

In this thesis a study of new concepts will be developed to efficiently utilize the spectrum and calculate higher capacity of CDMA systems that can access dynamically to the spectrum. At the end of this research, formulation and simulation results achieved will be presented. The applicability of the systems presented in the research will be tested and compared. It is expected that the proposed dynamic spectrum access scheme will lead in utilizing the channel (capacity) access to spectrum more efficiently.

4.1.1 SPECTRUM EFFICIENCY

The fundamental figure of merit is the spectral efficiency, defined as the total number of information bits per chip that can be transmitted arbitrarily reliably. Since the bandwidth of the CDMA system is (roughly) equal to the reciprocal of the chip duration, the spectral efficiency can be viewed as the bits/s/Hz supported by the system. In our analysis we average spectral efficiency with respect to the spreading sequences.

Two main Spread Spectrum modulation techniques are defined DSSS &FHSS.

FHSS main parameters:

FHSS is defined (in IEEE 802.11) in the 2.4 GHz band as operating over 79 frequencies ranging from 2.402 GHz to 2.480 GHz (country specific bands have different frequencies, defined in IEEE 802.11 and IEEE 802.11.d). Each of the frequencies is BPSK modulated.

The rates defined are 1,2,3,11,100 Mbps and 200 Mbps for different systems.

DSSS main parameters:

DSSS is defined (in IEEE 802.11) in the 2.4 GHz band as operating on one of 14 possible carriers (country specific bands have different number of frequencies, defined in IEEE 802.11 and IEEE 802.11.d). The selected carrier (channel) is BPSK & QAM modulated. The rates defined in IEEE 802.11 are 1 Mbps and 11 Mbps.

IEEE 802.11b adds to DSSS the rates of 5.5 Mbps and 11 Mbps (in the 2.4 GHz band).

OFDM main parameters

OFDM defined (IEEE 802.11) in the 2.4 GHz band as operating on some possible carriers (country specific bands have different number of frequencies, defined in IEEE 802.11 and IEEE 802.11.d). The selected carrier (channel) is BPSK or QPSK. OFDM still has a strong interest in the R&D community and industry, for example on the topic of combining state-of-the-art OFDM with other technologies to improve radio performance or even arrive at new concepts. More important, there are some interesting spectrum management aspects related to its use.

IEEE 802.11(WiFi) & 4G up to100Mbps adds to OFDM the rate of 100 Mbps (in the 2.4 GHz band).

4.1.2 SYSTEMS BEHAVIOR

4.1.2.1 SYSTEMS COLLOCATION

The issue: How many independent systems may operate simultaneously without interference?

In DSSS systems, collocation could be based on the use of different spreading codes (sequences) for each active system (CDMA). On condition that the sequences used are highly distinguishable one from the other one (property known as orthogonality) each receiver will be able to “read” only the information dedicated to it (receiver and transmitter use same spreading code). CDMA could indeed be the solution, but orthogonal pseudo-random sequences are needed. The number of orthogonal pseudorandom sequences is limited and it is a function of the sequence length [number of chips (bits) in the sequence.

Actual (IEEE 802.11 and 802.11.a based) DSSS systems use 11 bit long spreading sequences making the use of CDMA impossible. System collocation is therefore based on the fixed allocation of bandwidth to each system (same as in narrow band systems).

For the transmission of 11 Mchips per second (Msymbols per sec), IEEE 802.11 needs a contiguous band of 22 MHz, and defines the need for a minimum distance of 30 MHz between the carrier frequencies of collocated DSSS systems. As the total available bandwidth in the ISM band is 83.5MHz (2.4GHz - 2.4835GHz) and as the distance between carriers has to be 30 MHz, only 3 DSSS systems may be collocated, without interference. If more than 3 systems are collocated, their contiguous 22 MHz channels will overlap, forcing their users to share the channels. The actual behavior and the amount of actual interference is a function of the overlapping size and signal strength.

For FHSS systems, IEEE 802.11 defines 79 different hops for the carrier frequency. Using these 79 frequencies, IEEE 802.11 defines 78 hopping sequences (each with 79 hops) grouped in three sets of 26 sequences each. Sequences from same set encounter minimum collisions and therefore may be allocated to collocated systems. Theoretically, 26 FHSS systems may be collocated, but collisions will still occur in significant amounts. To lower the amount of collisions to acceptable levels, the actual number of FHSS collocated systems should be around 14.

All the above is correct for the case in which the FHSS collocated systems operate independently, without any synchronization among their hopping sequences. If synchronization is allowed, 79 systems could be collocated (theoretically), each one of them using at any moment in time, one of the 79 available frequencies. However, this would require expensive filters in the radio circuitry. Actual products require about 6 MHz separation allowing the collocation of about 12 systems, without any collision! While such synchronization is not always allowed in the unlicensed band of 2.4 GHz, it is common practice in the licensed bands.

The possibility of having collocated systems without collisions, has a tremendous impact on the aggregate capacity / throughput of the installation as well as its efficiency in terms of bps per Hz.

4.1.2.2 THROUGHPUT

The issue: What amount of data is actually carried by the system (measured in bps).

The rate of a system is defined as the amount of data (per second) carried by a system when it is active. As most communications systems are not able to carry data 100% of the time, an additional parameter - the THROUGHPUT - is defined, as the average amount of data (per second) carried by the system. The average is calculated over long periods of time.

Obviously, the throughput of a system is lower than its rate. In addition, when looking for the amount of data carried, the overhead introduced by the communication protocol should be considered, too.

Based on the IEEE 802.11 specifications, the maximum number of DSSS systems that can be collocated is 3. These 3 collocated systems provide an aggregate rate of 3 x 11 Mbps = 33 Mbps, or a net aggregate throughput of about 3 x 7 Mbps = 21 Mbps. Let's note that because of the rigid allocation of sub-bands to systems, collisions between signals generated by collocated systems do not occur, and therefore the aggregate throughput is a linear function of the number of systems.

three systems may be installed, providing an aggregate rate of 33 Mbps. (Overall efficiency: 33Mbps/83.5MHz = 0.39 bits/Hz). Additional systems, if installed, will share the spectrum with the already installed systems, lowering the overall aggregate rate / throughput because of collision occurrences. In a 2.4 GHz FHSS synchronized environment, up to 12 systems can be collocated, providing an overall aggregate rate of 36 MHz (efficiency: 36Mbps/83.5MHz= 0.43 bits/Hz).

In a licensed FDD FHSS synchronized environment, up to 6 systems may be collocated in a 10.5MHz band, providing an aggregate rate of 18 Mbps (efficiency: 18Mbps/10.5MHz = 1.7bits/Hz).

We see at the result of the simulation, that the system have a large amount of users with low rate its work efficiently (IEEE 802.11 (FHSS)) but the range is small(10), the system that have small number of users with high rate (WiFi IEEE 802.11(OFDM)) is more efficient, other system (IEEE 802.11b (DSSS)) number of users is approximately near rate and the efficiency is good and the range of this system is large (100m), compare to that systems. The last system that work at 5GHz band with small number of users and high rate work efficiently but its range is low(30m).

Then for the long rang transmission area (IEEE 802.11b (DSSS)) is the suitable system.

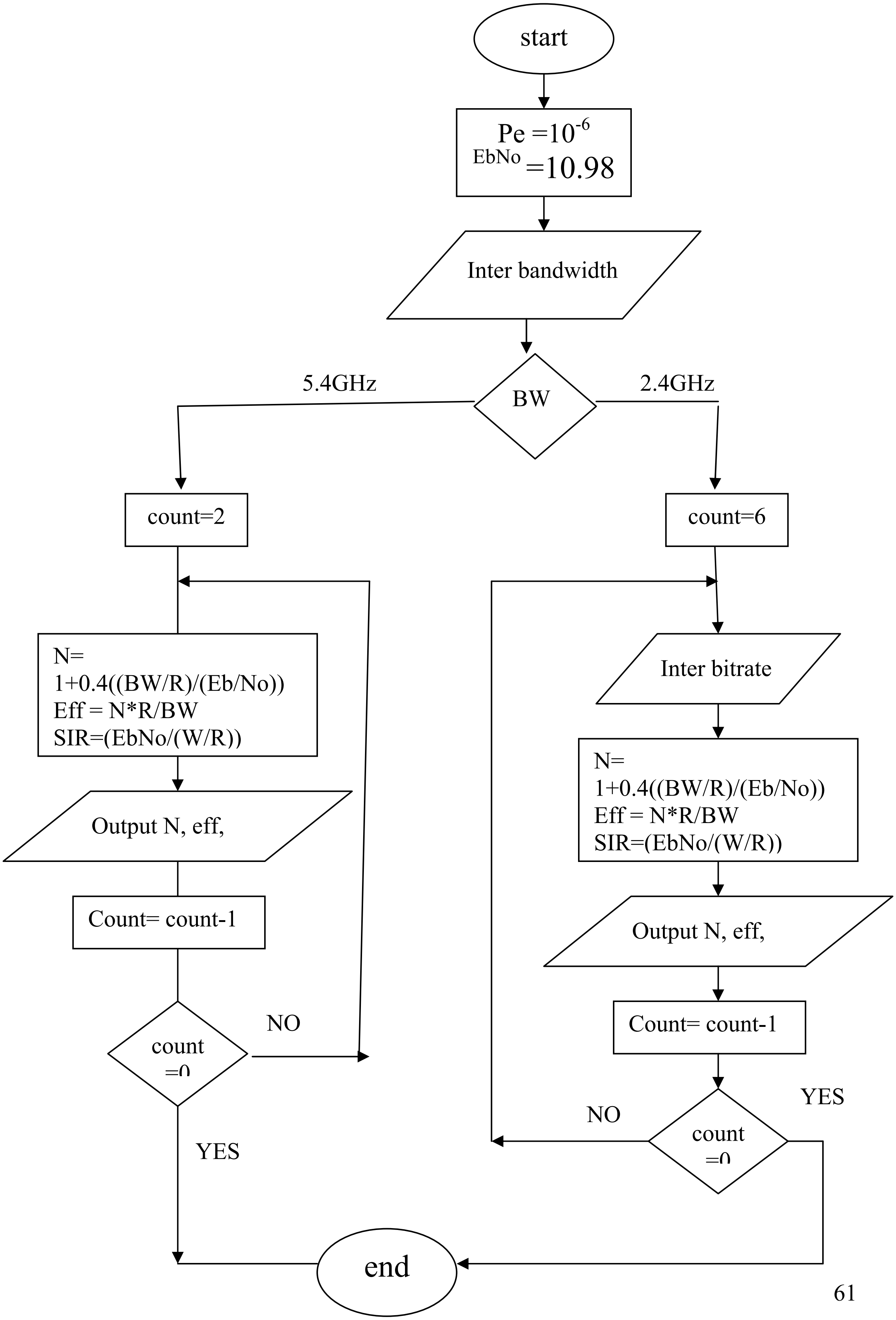
In this thesis we define the performance of this systems (mention above) by using simulation program (MATLAB), below the description of the program.

The MATLAB program is simulated to determined the efficiencies of some systems (with different rates)in unlicensed bands (2.4GHz & 5.4 GHz) and show maximum number of users that can share spectrum without interference each others. In the following the description of the program.

In this program we firstly inter the probability of error we observe in the performance of the systems, then calculate the energy per bit to noise ratio (Eb/No) by the equation of error function for two modulation types (BPSK & QAM).

Then for two unlicensed band (2.4GHz & 5.4GHz) we calculate the performance of 8 systems (6 sys. In 2.4GHz & 2 sys. In 5.4Ghz), there are number of users, efficiency and signal to interference ratio

A flow chart of this program is drown below:



The flow chart is determine these efficiencies by used the equations that mention in the first chapter. The program calculate the number of users, efficiencies and signal to noise ratio of eight system that shared unlicensed band dynamically six of them access to 2.4GHz unlicensed band and two of them shared 5.4 GHz band. And finally we plot a graphs of :

1. rates
2. number of users
3. efficincies
4. comparison between:
    a. rates and number of users
    b. rates and efficiencies
    c. efficiencies and number of users

of all these systems.

Know we can describe the steps of program:

First:

We inter a specific probability of error that we desired to the systems to be work with high QoS for specific service, then we calculate signal to noise ratio from the equation of complementary error function and the table of error function.

Second:

we choose one of the unlicensed band (2.4 or 5.4) and then the user can inter the bitrate of one of the systems that define in the program. Using this rates in the equation (5.1) (5.2) we can calculate number of users and SIR and then efficiencies of the systems in the band that we choose until we inter all the bitrate of the systems. Then we plot these outputs in a bar plot to compare all these parameters.

The program then simply determine and compare these systems to fined more efficient one which access dynamically to spectrum (unlicensed band), and we organized all parameters in a table to compare it.

5. RESULTS

5.1 Calculations

CDMA could indeed be the solution, to calculate the number of users that can be simultaneously transmitted codes (orthogonal), we can use the equation:

$$N = 1 + \frac{1}{\alpha}\left[\frac{W/R}{E_b/N_o} - \frac{n}{s}\right] \text{…………………..(5.1)}$$

Where

α is voice activity factor = 3/8 ≈ 0.4.

n/s thermal noise to signal power (assume no thermal noise).

E_b/N_o Energy per bit to noise power.

W total spread bandwidth, R information bit rate.

System capacity determined by the maximum allowable user density N that allows:

$$\overline{(S/I)} = \frac{\overline{E_b/N_o}}{W/R} \text{……………………………..(5.2)}$$

Then we can determine the efficiency of any system by its rate and number of maximum users:

$$\eta = \frac{N \times R}{W} bit/s/Hz \text{……………………….(5.3)}$$

In the next table the performance of different systems calculated theoretically:

Application	Bitrate	Bandwidth	MOD.Type	Capacity,N	Efficiency,η
WCDMA	1&2Mbps	2.4 GHZ	DSSS	11	0.27
802.11	3Mbps	2.4 GHZ	FHSS	3	0.43
802.11b	Up to 11Mbps	2.4 GHZ	DSSS	2	0.86
802.11a	54 Mbps	5 GHz	OFDM	14	0.5
WiFi	100 Mbps	2.4 GHZ	OFDM	1	1.2
Bluetooth	1 Mbps	2.4 GHZ	DSSS	27(narrow band)	0.25

Table5.1: the performance of different systems

5.2 RESULTS

*** After running the program we had the next results**

```
--------------------------------------------------------------------------------------
**This program shows the efficiency of some systems that work in
unlicensed band
and the number of users that can enter to share  the spectrum**
    •  probability of error = 10^-6
    •  Energy per bit to Noise Ratio (BPSK) = 11.9641
    •  Energy per bit to Noise Ratio (QAM) = 74.7754
    •  Bandwidth:
       for ISM (2.4GHz), ➔ 83.5MHz (inter 0)
       for ISM (5.4GHz), ➔ 125MHz (inter any)
-----------------------------------------------------
enter bandwidth for ISM band (0 for 2.4G, 1 for 5.4G) = 0
ISM band 2.4GHz, Band Width = 83.5MHz
----------------------------------------------------
The Rates of systems:
for (DSSS)==> IEEE 802.11b =11Mbps, Bluetooth = 1Mbps
for (FHSS)==> WCDMA= 2Mbps, IEEE 802.11= 3Mbps
for (OFDM)==> WiFi= 100Mbps, 4G upper than 100Mbps
----------------------------------
enter bitrate  1
It is Bluetooth (DSSS)
numberofusers =    20
efficiency1 =    0.2395
SIR1 =    0.1433
```

```
enter bitrate  2
It is WCDMA (FHSS)
numberofusers =    10
efficiency2 =    0.2395
SIR2 =    0.2866

enter bitrate  3
It is IEEE 802.11 (FHSS)
numberofusers =    14
efficiency3 =    0.5030
SIR3 =    0.4298

enter bitrate
 11
It is IEEE 802.11b (DSSS)
numberofusers =     3
efficiency4 =    0.3952
SIR4 =    1.5761

enter bitrate  100
It is WiFi (OFDM)
numberofusers =     1
efficiency5 =    1.1976
SIR5 =   14.3282

enter bitrate  200
It is 4G (OFDM)
numberofusers =     1
efficiency6 =    1.7964
SIR6 =  134.3271

enter bandwidth for ISM band=   1
ISM band 5.4GHz, Band Width=125MHz
--------------------------------------------
The Rates of systems:
for IEEE 802.11a (OFDM) with bitrate= 54MHz
for (OFDM)==> 4G upper than 100Mbps
----------------------------------------------------------
for IEEE 802.11a (OFDM) with bitrate= 54MHz
```

```
numberofusers =     2
efficiency7 =    0.8640
SIR7 =    5.1685
for 4G (OFDM) at 5.4GHz Band
numberofusers1 =     1
efficiency8 =    1.2000
SIR8 =   89.7305
******************************************
```

Results after running the program:

performance of different systems:

	Systems	**No.users**	**Rates**	**efficiencies**	**SIR**
1.	Bluetooth (DSSS)	20	1	0.2395	0.1433
2.	WCDMA(FHSS)	10	2	0.2395	0.2866
3.	IEEE 802.11(FHSS)	14	3	0.2930	0.4298
4.	IEEE 802.11b(DSSS)	3	11	0.3952	1.5761
5.	WiFi IEEE 802.11(OFDM)	1	100	1.1976	14.3282
6.	4G (OFDM)2.4MHz	1	200	1.7964	134.3271
7.	IEEE 802.11a(OFDM)(5.4)	2	54	0.8640	5.1685
8.	4G (OFDM)5.4GHz	1	200	1.2000	89.7305

6. ANALYSIS & DISCUSSION OF RESULTS

Finally, we plot figures for all these parameters to compare all systems performance with others.

If we compare these results (rates & number of users & efficiencies)in a figures we can conclude that:

6.1 RATES

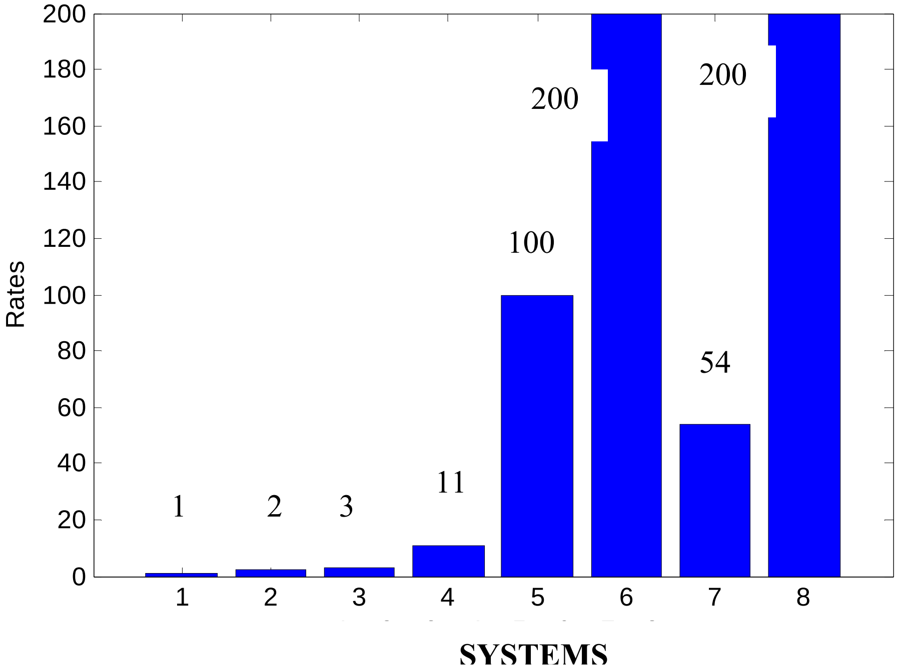


Figure 6.1 show rates of the systems

6.2 No of users

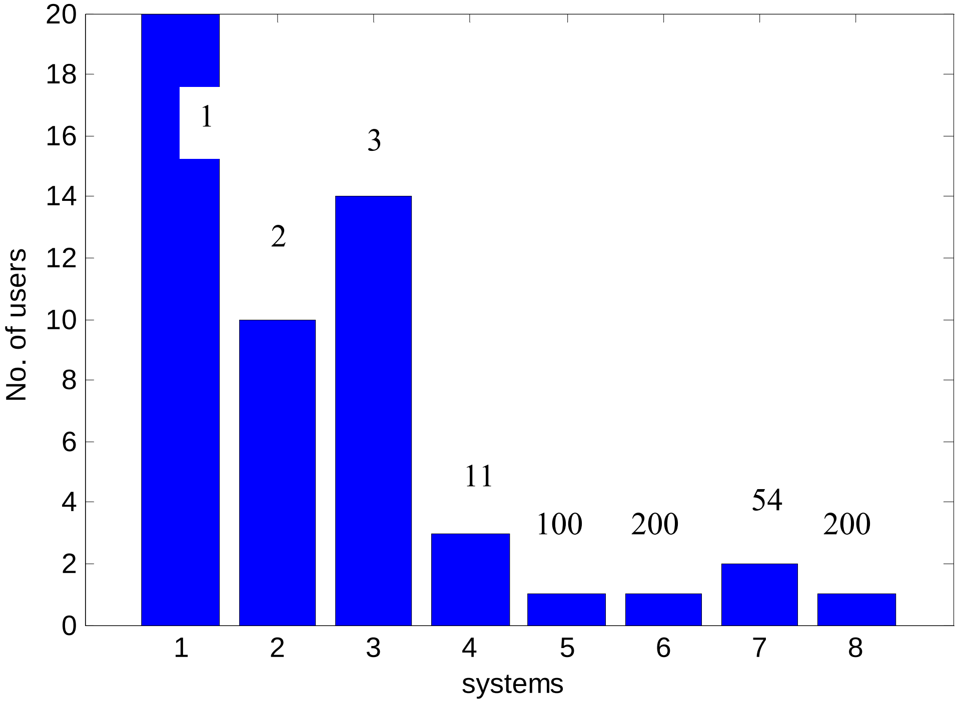


Figure 6.2 show number of users in each system

6.3 Efficiencies

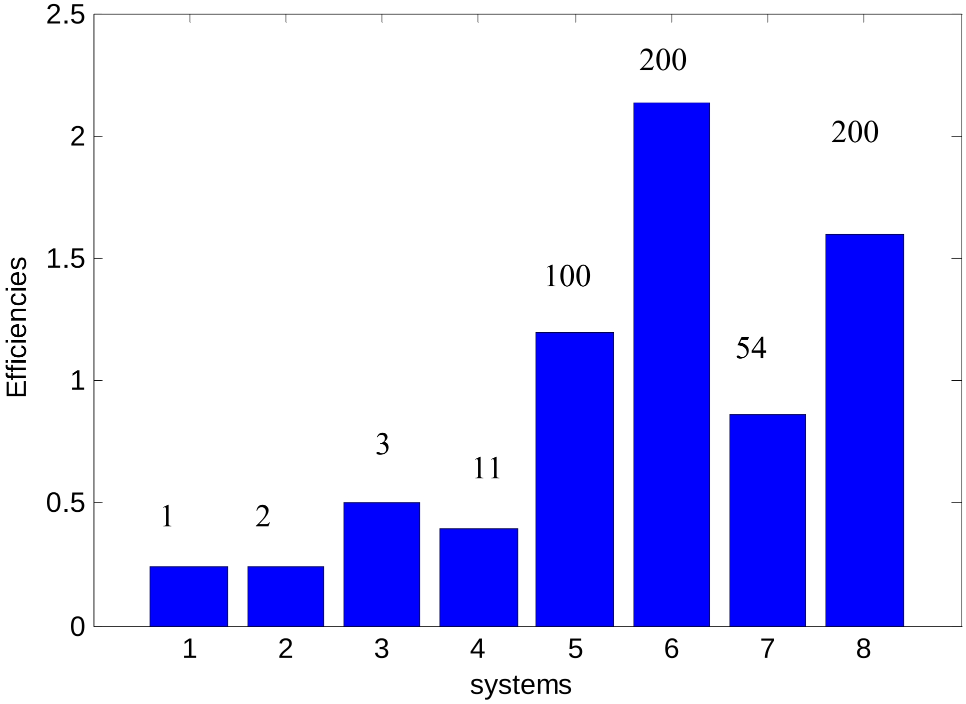


Figure 6.3 show the efficiencies

6.4 Compare Rates with number of users

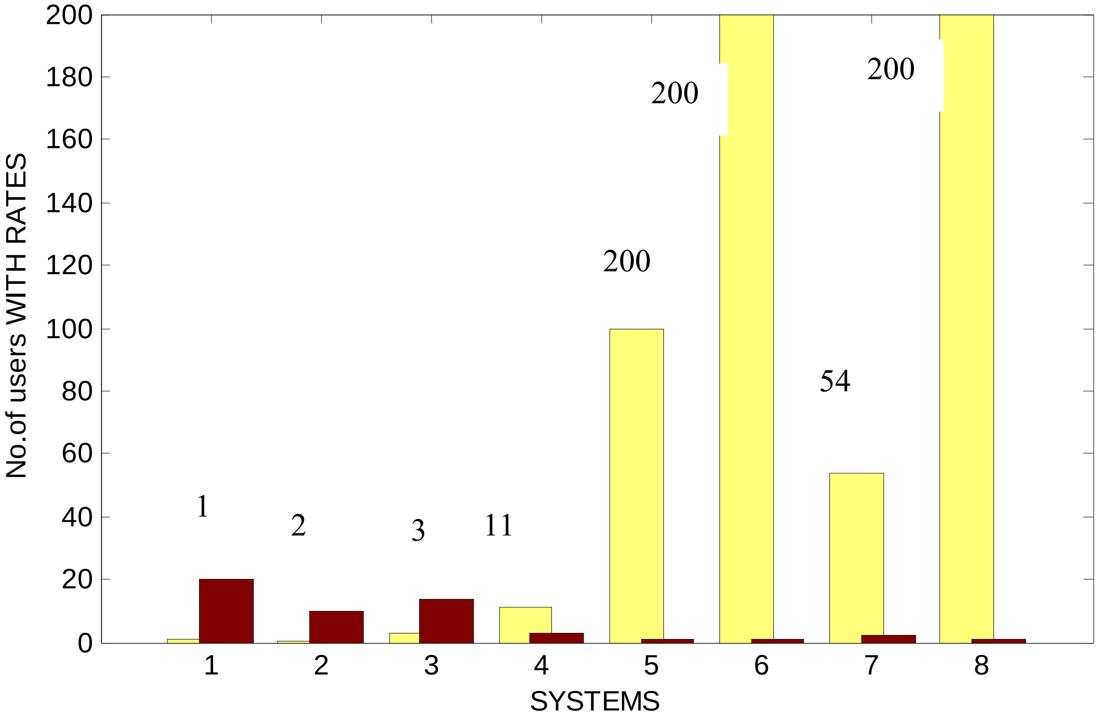


Figure 6.4 : (yellow = rates, brown = no.of users)

Here from the figure we see if the rates increase the number of users decrease (**inverse proportion**)

6.5 Compare number of users with efficiencies

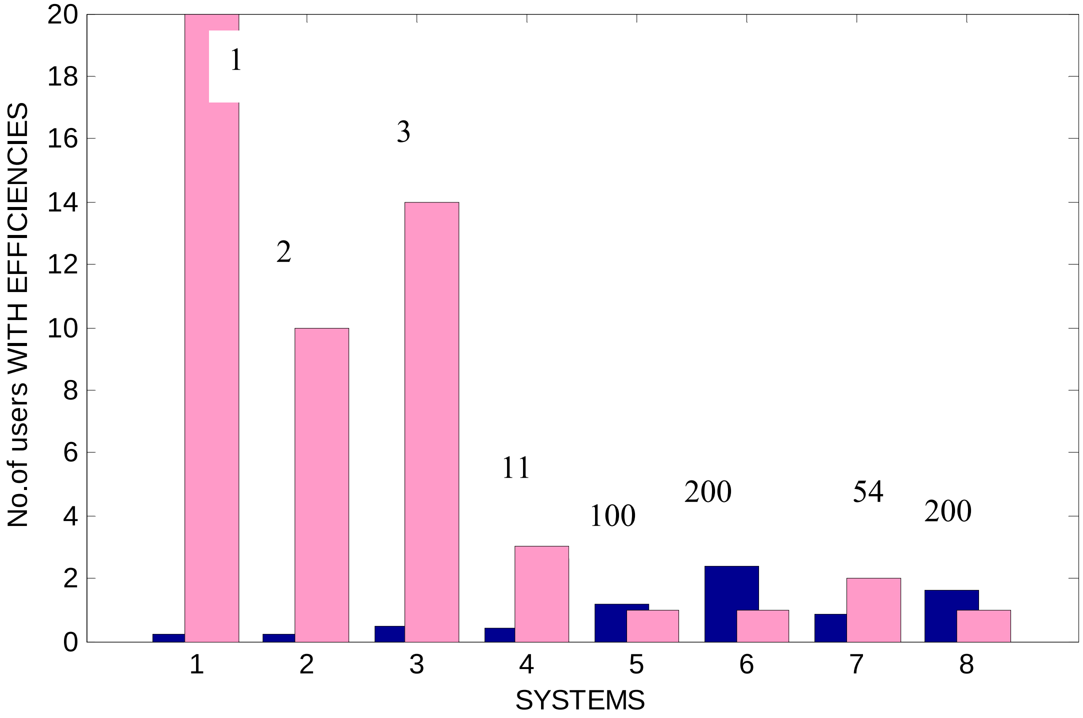


Figure 6.5 : (blue = efficiencies, pink = no.of users)

In this figure as number of users decrease the efficiencies increase (**inverse proportion**) also.

6.6 Compare Rates with efficiencies

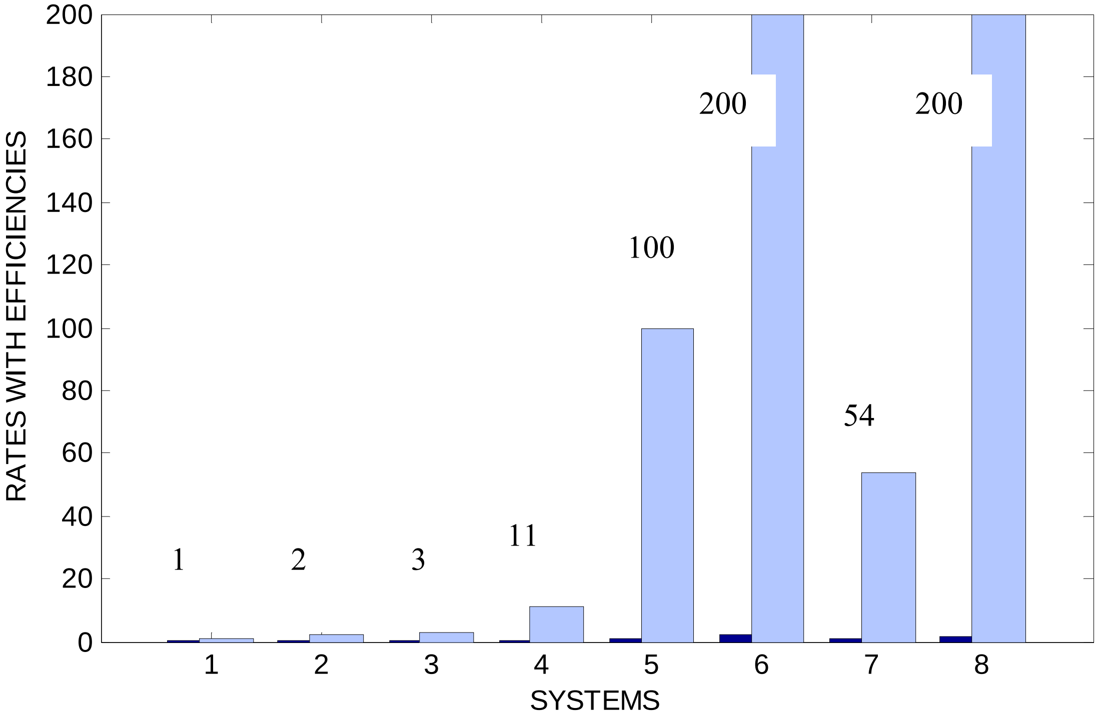


Figure 6.6 : (blue = rates, dark blue = efficiency)

In this figure as rates increase efficiencies also increase (**direct proportion**)

We can arrange these system with respect to their efficiencies in following table:

Systems	No.	rates	Efficiencies	SIR
4G (OFDM)2.4MHz	1	200	2.3952	134.3271
4G (OFDM)5.4GHz	1	200	1.6	89.7305
WiFi IEEE802.11(OFDM)	1	100	1.1976	14.3282
IEEE802.11a (OFDM)5.4GHz	2	54	0.8640	5.1685
IEEE802.11b(DSSS)	3	11	0.3952	1.5761
IEEE 802.11(FHSS)	14	3	0.2930	0.4298
WCDMA (DSSS)	10	2	0.2395	0.2866
Bluetooth (DSSS)	20	1	0.2395	0.1433

Table 6.2 performance of different systems

From the comparison table in the previous chapter, we see that the efficiencies is sorted from higher to lower, the rates, signal to interference ratio is automatically organized decreasingly (**direct proportion**) and number of users is increased as rates decreased (**inverse proportion**), then system with higher rate is had also higher efficiency, lower number of users and higher signal to interference ratio (as we see in table 6.2 and figures) at any band (2.4GHz or 5.4GHz).

The systems is recognized by their efficiencies (table 6.2) The higher efficiency in 4G mobile in 2.4 GHz band with higher rate, then 4G mobile in 5.4GHz band and WiFi these systems modulated by (OFDM). In the second level DSSS system IEEE 802.11b with low rate, in the last order FHSS systems. Thus we see systems is efficiently worked by OFDM and then DSSS last FHSS.

7. CONCLUSION

7.1 CONCLUSION

Dynamic Spectrum Allocation can achieve notable gains in terms of spectrum efficiency (i.e. serving a higher number of users with the same amount of available spectrum).

In this thesis we have seen actively and investigating how to efficiently utilize the available spectrum by implementing different techniques with different rates.

Then we noted that from the assessment of these systems we can conclude that OFDM system more efficient than other systems using DSSS or FHSS, this refer to that OFDM is the future challenges for new applications that can share unlicensed spectrum more efficiently without interfering each others.

Then we can get that:

Using spread spectrum with multiple access technique like CDMA achieve higher capacity of systems that can share the spectrum band (unlicensed) dynamically more efficient. This can be seen clearly in the simulation and comparisons.

DSSS provides high rate, but it is a sensitive technology, FHSS provides low rate, but it is a very robust technology, with excellent behavior in harsh environment characterized by large areas of coverage, OFDM provides higher rates with higher efficiency at all unlicensed bands (2.4GHz & 5.4GHz)

One can conclude that:

DSSS biggest advantage over FHSS and OFDM biggest advantage over all. When covering the whole 2.4GHz band.

The cell-by-cell DSA scheme used for channel allocation shows, in any case, higher spectrum efficiency compared to the fixed allocation method. The cell-by-cell scheme with dynamically varying spectrum bandwidth outperforms the cell-by-cell scheme with fixed bandwidth by 14% with respect to spectrum efficiency gain. The highest gain achieved was 52% higher than with fixed allocation. The case investigated is based on a rather simple example with only limited spectrum borrowing, if higher numbers of channels can be borrowed, higher gains can be achieved. Cell-by-Cell DSA in conjunction with SDR Technology can greatly increase system performance with respect to capacity and efficiency.

SDR Technology enabling dynamic spectrum allocation with temporal spectrum ‘borrowing’ in under-occupied bands can greatly increase the spectrum efficiency.

From the comparison of systems that share the band dynamically we conclude that we have better to decrease number of users if the rate is high to have high efficiency, then the better system is that have one user at a time an then we increase users we have low efficiency.

7.2 LIMITATIONS

On the whole there is flexibility enough in the regulatory framework to introduce DSA-systems nationally. However, we have not seen an introduction of DSA systems yet, mainly because of obstacles such as the fact that there are a limited number of suitable bands and that transfer of licenses have only been introduced in some markets and to a limited extent. Furthermore national border coordination is internationally regulated under the radio regulations and there is a need to harmonize the introduction DSA-systems on a wider scale.

In order to enable the introduction of DSA based systems some major and minor changes will have to be made to the regulatory framework for spectrum management.

A few of the most critical regulatory issues that are complicating the introduction of systems based on DSA principles are:

- International and national allocations are made indefinite (normally 20+ years).
- Allocations and assignments are based on worst case interference scenarios.
- Licenses are awarded with exclusive rights.
- Licenses are often limited to a system, an application or a service.
- Licenses are not generally seen as an asset that can be used for multiple services.
- Assignment of licenses have in many cases been closely linked to political goals.
- Assignment of spectrum is generally made under the paradigm of “spectrum scarcity”.

- One of the prevailing cornerstones of current spectrum management is that harmonization is always the best solution.
- In radio terms the world is divided in three planning regions, in which the use of spectrum and the allocation of different services are not the same.

7.3 FUTURE TRENDS &RECOMMENDATIONS

Here we summarize the technical areas that we believe are necessary to study in future research to enable an affordable, efficient and evolutionary path towards DSA:

* Identification and system design of flexible, realistic and scaleable technical
DSA system solutions (technology + regimes) based on the concepts. This must be done to be able to analyze the properties of DSA system level wise. It will also make it possible to demonstrate the DSA capabilities.

* What overall system performance properties should have most influence on the final decisions in the intersystem-interference analysis given a certain convenient interference metric? Several alternative performance properties could be of interest such as QoS, reliability, capacity etc.

* Flexible terminals; Standardized SDR enhances the flexibility of DSA even further. Still there is critical RF-hardware with large demands on agility and linearity. Analyze and study methods to lower the demands on the RF-parts to make them more affordable.

* Dynamic interference control. In a DSA context, the functions for intersystem-interference handling must be distributed among the users since it is impossible to perform the whole intersystem-interference analysis in advance as being done today. We need to develop methods and metrics for determining the influence of interference. Both the interference caused on incumbent systems on the DSA devices, but also the interference caused by DSA devices on non-DSA devices already using the spectrum. What kind of interference measurements (metrics) is convenient for instant decision making online?

* Measuring spectrum usage; we need to find methods to measure the use of the spectrum. The data is needed to find available spectrum that can be used for communication to avoid interfering with other devices and to allow the regulator to check that the rules for usage are obeyed.

* How to (if it is possible?) provide a certain level of QoS in distributed DSA scenarios?

- Which rules provide good spectrum?

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APPENDEX A

A.1 Program

/*MATLAB program to compare capacity & efficiency of different systems*/

```
disp('**This program shows the efficiency of some systems that work in unlicensed band ')
disp('and the number of users that can enter to share  the spectrum**')

%%% Define Probability of Error
disp('probability of error = 10^-6')
Pe=10^-6;

%%% Calculate Energy Per Bit to noise Ratio for BPSK modulation
y=erfcinv(Pe);

%%% EbNo
z=y^2;

%%% Calculate Energy Per Bit to noise Ratio for QAM modulation
z1=(6.25*z);
disp('Energy per bit to Noise Ratio= ');
disp(z);disp(z1)
%%% Choosing either 2.4GHz or 5.4GHz unlicensed Band
disp('bandwidth for ISM (2.4GHz), BW=83.5MHz/for ISM (5.4GHz),BW= 125MHz')
for j=1:2
disp('enter bandwidth for ISM band=')
 BWism=input(' ');
   if (BWism==0)
      disp('ISM band 2.4GHz, Band Width=83.5MHz')
      BW=83.5;
      disp('------------------------------------------')
      disp('The Rates of systems:')
      disp('for (DSSS)==> IEEE 802.11b=11Mbps, Blutooth = 1Mbps')
      disp('for (FHSS)==> WCDMA=2Mbps, IEEE 802.11=3Mbps')
      disp('for (OFDM)==> WiFi=100Mbps, 4G uper than 100Mbps')
```

```
    disp('----------------------------------')
    for i=1:6
      %%% Calculate the number of users & efficiency for 6 systems in
2.4GHz band
disp('enter bitrate ')
      R=input(' ');
        if(R==11)
          r4=11;
          disp('for IEEE 802.11b (DSSS)')
          N=1+(8/3)*((BW/R)/z);
          numberofusers=round(N)
          n4 = numberofusers;
          efficiency4=(R*numberofusers)/BW
        elseif(R==3)
          r3=3;
          disp('for IEEE 802.11 (FHSS)')
          N=2*(1+(8/3)*((BW/R)/z));
          numberofusers=round(N)
          n3=numberofusers;
          efficiency3=(R*numberofusers)/BW
        elseif(R==100)
          r5=100;
          disp('for WiFi (OFDM)')
          N=(1+(8/3)*((BW/R)/z));
          numberofusers=round(N)
          n5=numberofusers;
          efficiency5=(R*numberofusers)/BW
        elseif(R==1)
          r1=1;
          disp('for Bluetooth (DSSS)')
          N=1+(8/3)*((BW/R)/z);
          numberofusers=round(N)
          n1=numberofusers;
          efficiency1=(R*numberofusers)/BW
        elseif(R==200)
          r6=150;
          disp('for 4G (OFDM) at 2.4GHz Band')
          N=1+(8/3)*((BW/R)/z1);
          numberofusers=round(N)
          n6=numberofusers
```

```
           efficiency6=(R*numberofusers)/83.5

         elseif(R==2)
           r2=2;
           disp('for (FHSS)==> WCDMA')
           N=1+(8/3)*((BW/R)/z);
           numberofusers=round(N)
           n2=numberofusers;
           efficiency2=(R*numberofusers)/BW

         else
           disp('**THIS rate not valid**')
       end;
     end;
   else
 %%% Calculate the number of users & efficiency for 2 systems in 5.4GHz
band
     disp('ISM band 5.4GHz, Band Width=125MHz')
     disp('----------------------------------------')
     disp('The Rates of systems:')
     disp('for IEEE 802.11a (OFDM) with bitrate= 54MHz')
     disp('for (OFDM)==> 4G uper than 100Mbps')
     disp('---------------------------------')
      BW=125
        r7=54;
        disp('bandwidth is 125MHz-----')
        disp('for IEEE 802.11a (OFDM) with bitrate= 54MHz')
        N=1+(8/3)*((BW/54)/z);
        numberofusers=round(N)
        n7=numberofusers;
        efficiency7=((numberofusers*54)/BW)
        r8=200;
        disp('for 4G (OFDM) at 5.4GHz Band')
        N1=1+(8/3)*((BW/1000)/z1);
        numberofusers1=round(N1)
        n8=numberofusers1;
        efficiency8=(numberofusers1*200)/BW
    end;
end
```

```
%%% plot the figure for comparison
title 'IEEE 802.11b (DSSS)----- IEEE 802.11 (FHSS)-----WiFi IEEE
802.11(OFDM)----IEEE 802.11a (OFDM)'
x=[n1 efficiency1 ; n2 efficiency2 ; n3 efficiency3 ; n4 efficiency4 ; n5
efficiency5 ; n6 efficiency6 ; n7 efficiency7 ; n8 efficiency8]
subplot(2,2,1)
bar(x,2.3,'group')
  xlabel('s1-s2-s3-s4-s5-s6-s7-s8')
  ylabel('Efficiency')
  y=[r1 r2 r3 r4 r5 r6 r7 r8];
  subplot(2,2,2)
  bar(y,'b')
  xlabel('s1- s2 -s3- s4- s5- s6- s7- s8')
  ylabel(' Rates')
  n7=1;r7=1000;
  a1=[n1 r1 efficiency1];
  a2=[n2 r2 efficiency2];
  a3=[n3 r3 efficiency3];
  a4=[n4 r4 efficiency4];
  a5=[n5 r5 efficiency5];
  a6=[n6 r6 efficiency6];
  a7=[n7 r7 efficiency7];
  a8=[n8 r8 efficiency8];
  disp('                          number of users  Rates   efficiencies')
  fprintf('1)Blutooth (DSSS)           ');disp(a1)
  fprintf('2)WCDMA(FHSS)               ');disp(a2)
  fprintf('3)IEEE 802.11b(DSSS)        ');disp(a3)
  fprintf('4)IEEE 802.11(FHSS)         ');disp(a4)
  fprintf('5)WiFi IEEE 802.11(OFDM)    ');disp(a5)
  fprintf('6)4G (OFDM)2.4MHz           ');disp(a7)
  fprintf('7)IEEE 802.11a(OFDM)        ');disp(a6)
  fprintf('8)4G (OFDM)5.4GHz           ');disp(a8)
```

APPENDEX B

B.1 ISM Bands

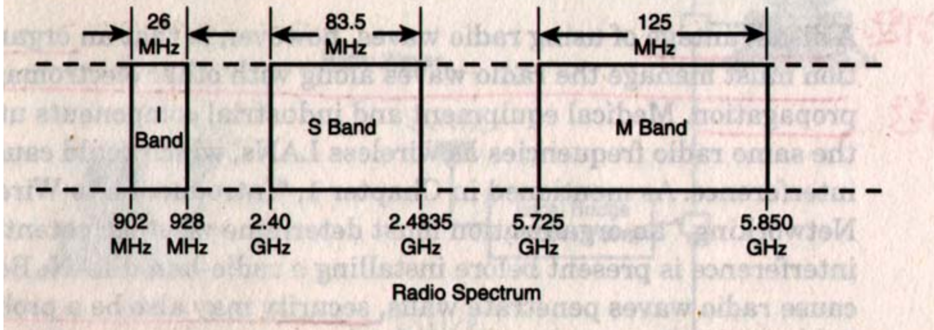

Figure 2.2
The Industrial, Scientific, and Medical (ISM) frequency bands.

ISM Spectrum Availability

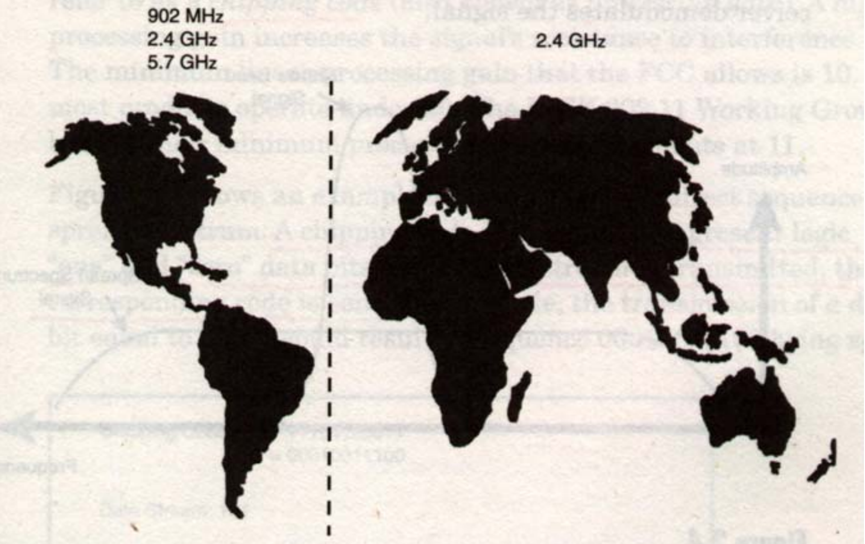

Figure 2.3
ISM spectrum availability.

B.2 Spread Spectrum Modulation

Definition: “spread” a signal’s power over a wider band of frequency.

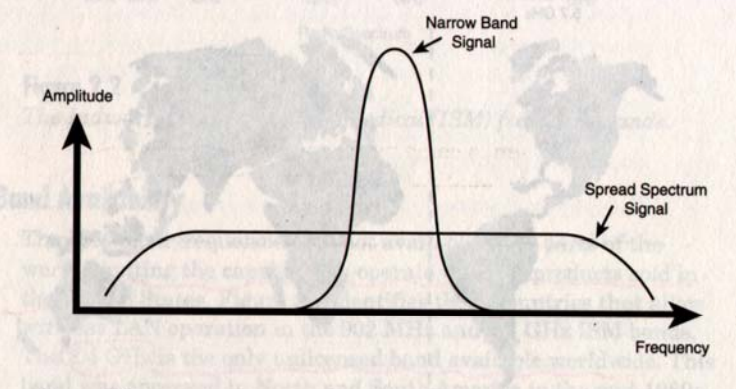

Figure 2.4
Narrow band versus spread spectrum modulation.

B1.1 Direct Sequence Spread Spectrum (DSSS)

- Use bit sequence to represent “zero” and “one”
- Also referred to as “chipping code”.
- Longer chipping codes are more resilient to noise.
- Minimum length = 10 (by FCC)
- IEEE 802.11 uses 11 chips per data bit.

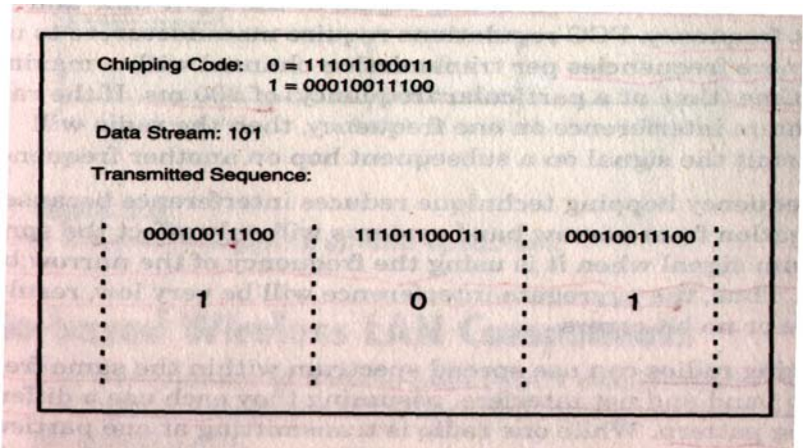

Figure 2.5
The operation of direct sequence spread spectrum.

B.1.2 Frequency Hopping Spread Spectrum (FHSS)

Data is modulated by carrier signals that hop from frequency to frequency as a function of time, over a wide band of frequencies.

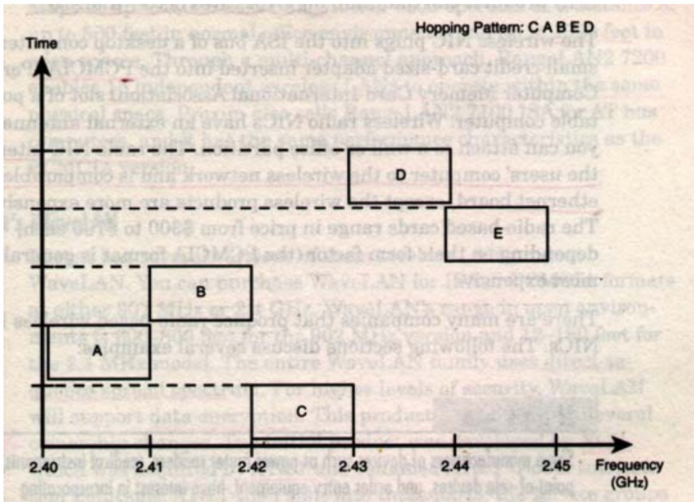

Figure 2.6
A frequency hopping spread spectrum.

- Hopping Code: to determine the order of hopping frequencies.
- The receiver must "listen" to incoming signals at the right time at the right frequency.
- FCC regulation: at least 75 frequencies, with max. dwell time 400ms.
- Adv.: very resilient to noise.
- <u>Orthogonal hopping codes</u>: a set of hopping codes that never use the same frequencies at the same time (can be on-line adjusted by software).
- Allow multiple wireless LANs to co-exist.

APPENDEX C

C.1 IEEE 802 Families:

- IEEE?
  - a non-profit professional org. founded in 1884; now has 320,000 members in 150 countries;

- Most notable standards:
  - IEEE 802 family (802.2 LLC, 802.3 Ethernet, 802.5 Token Ring, etc.)

- IEEE membership info:
  - Open to anyone. It's FREE!! Must pay meeting fees.
  - Membership Category: voting member, nearly member, aspirant member, sleeping member.

C.2 Task groups of 802.11

- 802.11a: Specification enabling up to 54 Mb/s to be achieved in the 5 GHz unlicensed radio band by utilizing OFDM
- 802.11b: Specification enabling up to 22 Mb/s to be achieved in the 2.4 GHz unlicensed radio band by utilizing DSSS
- 802.11c: Provides required information to ensure proper bridge operations, which is required when developing access points
- 802.11d: Covers additional regulatory domains, which is especially important for operation in the 5 GHz bands because the use of these frequencies differ widely from one country to another
- 802.11e: Covers issues of MAC enhancements for QoS, such as EDCF service differentiation and HCF
- 802.11f: Provides interoperability for users roaming from one access point to another of different vendor
- 802.11g: Specification enabling up to 54 Mb/s to be achieved in the 2.4 GHz unlicensed radio band
- 802.11h: Dynamic channel selection and transmission power control
- 802.11i: Specification for WLAN security to replace the weak Wired Equivalent Privacy (WEP)
- 802.11k: Radio resource measurement for 802.11 specifications so that a wireless network can be used more efficiently