In Summing Up

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1.0 About FuturePace Solutions

Spectrum Management International Pty Limited, trading as FuturePace Solutions, is a private jointly owned company operating since 1997 and headquartered in Canberra, Australia. Michael Whittaker, now a FuturePace Director, was principally responsible for designing the Australian 500MHz, 800MHz, 1.8GHz, 3.4GHz and 28/31 GHz spectrum licensing technical frameworks.

FuturePace is, consistent with the stated Government objectives for industry based management of spectrum, developing innovative on-line business practices seeking technological excellence in not only spectrum licensing but all facets radiofrequency spectrum management.

We have considered the various divergent comments that have appeared in the transcripts of the Commission's Review from various sources (all Australian related quotes in this submission are from those transcripts), concerning the operation of the existing spectrum licensing technical framework, and we believe our views on these issues may be of assistance to the Commission.

2.0 Some History

Many tens of years ago a paper in an engineering journal proposed that the objective of good spectrum management should be economic efficiency rather than technical efficiency. Since, in the main, spectrum has been managed by engineers, and their focus was naturally, technical, they mostly worked towards what they knew best, technical optimisation. This naturally led to 'picking technological winners', a game which exists to this very day, consider HDTV and IMT-2000.

In Summing Up

Despite the dominance of spectrum management by engineers, the introduction of spectrum licensing in both the USA and New Zealand saw, what could best be described as the 'steam-rollering' of engineers by economists. Until that time, engineers had simply repeated their, by then familiar mantra that spectrum licensing was impossible. However, the policy and political situation changed and economists suddenly found they were driving spectrum management policy. Unfortunately, this led to a highly market oriented solution for spectrum licensing in both the USA and New Zealand.

In the USA, Michele Farquhar, Chief of Wireless Telecommunications Bureau FCC said in November 20, 1996 "*It is commonly held that government should minimize regulations governing what services may be provided, and how they should be provided, because such regulations tend to limit competition, obstruct innovation, and impede efficient investment*". Farquhar assumed flexibility would follow from minimum regulation and that flexibility would maximise competition.

The problem is that, in the case of spectrum space, comprehensive regulation is necessary to preserve the space for use by a licensee, making very explicit; what's in and what's not in, so that flexibility could be maintained throughout the life of the licence. Vodafone has said "*We think it's important at the very time of the allocation that the risks of interference are dealt with so that those risks are minimised*". However, in the case of USA and New Zealand, it would have been a very brave engineer indeed who went out to bat for comprehensive technical regulation at that time. And the economists proceeded, mainly unadvised.

The USA, when questioned about their interference management techniques, replied to FuturePace "*we will let mutual greed sort it out*", while in New Zealand the engineers we talked to said they were not seriously consulted. Both these administrations initially came up with so-called 'simplified' frameworks.

Unfortunately, 'simplified' means that a licensee's rights are often not defined nor able to be maintained.

For example, Vodafone spoke of a problem in New Zealand (in their presentation in Melbourne on 23 April) regarding undefined rights, under the simplified NZ rules, for the settlement of interference between adjacent CDMA and GSM operators. Certainly, in this New Zealand example, minimum regulation has increased competition, however, that competition may well occur in Court. FuturePace supports rules which make management of interference a matter of routine, rather than a cause for litigation. Australian spectrum licensing uses comprehensive regulations to foster innovation and competition through technical flexibility and regulatory and managerial certainty and with that certainty achieved through a minimum of negotiation and not through settlement either in or out of Court.

Australia was fortunate in the timing of the spectrum licensing policy in that, while we essentially adopted the USA method of auction, sufficient time was allowed for the ACA, with considerable industry involvement through 1995 to 1996, to develop a comprehensive prototype for the spectrum licensing technical framework. The objectives in the Australian design have been already provided to the Commission but it sufficies to say that the objective was to clearly define the Government's and licensee's rights and responsibilities for the different types of interference mechanisms that can occur in a non-homogeneous service environment. The ACA is quite aware that the Australian framework is very explicit about what's in and what's not in: "*If they're buying a spectrum licence now without reading the fine print they could be in for some unpleasant surprises down the track*".

3.0 Additional Overseas Recognition of Australian Spectrum Licensing

In reference [1] of April 2001 the French authors say "*Spectrum licensing in Australia is an important case study of modern spectrum management where a higher degree of flexibility is available for more spectrum efficient uses.*" The French paper proposes a *new frontier* for spectrum management for 4G networks: spectrum sharing arrangements. These have been available in Australia since 1997!

We have already directed the Commission's attention to the overseas recognition of Australia's reform of traditional spectrum management methods recently published in the report of the UK Independent Spectrum Management Review, led by Professor Martin Cave.

Furthermore, the two referenced USA IEEE papers in our previous submissions have withstood academic peer review and may be accessed by the Commission for additional insight into Australia's innovative and unique spectrum licensing technical framework.

4.0 What is Unnecessary Regulation?

After the government implementation of a clearly defined technical framework we have observed that the ACA is having difficulty responding, not to the major carriers who seem on the face of comments to the Commission supportive of the spectrum licensing framework, but to the forcefully expressed opinions of a few minor players who have their own agendas in seeking to change Government policy. The dominant Australian carrier Telstra has gone on record to the Commission as saying that "*the current regime..... (is) very crucial".* Vodafone Australia have also drawn to attention problems in New Zealand which occur because of the simplified regimen applied there, which does not define interference rules and rights ab initio. In general, industry are already quite well aware of why the different elements of the

framework are in current use and of the managerial benefits to be derived from their proper application. Unfortunately, the ACA is very sensitive to criticism related to unnecessary regulation and forms of criticism that would normally not rate a mention have assumed centre stage.

Given that a comprehensive set of rules are necessary to preserve the space of a spectrum licence for a licensee, FuturePace believes that, as far as possible, government should not intervene in the economic decisions of companies, unless overriding social or community concerns prevail. Economic management in Australia is underpinned by strong adherence to a free market economic system allowing industry to respond quickly to market signals and adjust their strategies accordingly, ensuring that our economy's resources are allocated efficiently. FuturePace has argued this view strenuously in the current Australian Productivity Commission hearings into the Radiocommunications Act and the operations of the Australian Regulator the ACA.

The Productivity Commission assists with economic management at the macro level by identifying problems or opportunities, and setting broad growth directions and strategies. We understand that an important task of the Commission is to remove unnecessary regulation. FuturePace has identified a problem with the most recent 3G technical framework. We have explained to the Commission how it was both biased and partially defined assuming WCDMA as a likely use. FuturePace believes that, as far as possible, the government should not intervene in the economic decisions of companies, unless overriding social or community concerns prevail. Economic management in Australia is underpinned by strong adherence to a free market economic system allowing industry to respond quickly to market signals and adjust their strategies accordingly ensuring that our economy's resources are allocated efficiently. We therefore see no reason for the ACA intervention in the 3G design.

FuturePace views, not a comprehensive spectrum licensing framework, but the ACA 3G intervention in it as unnecessary regulation.

5.0 Trying to Create Competition.

When tasked with letting the competitive market work the ACA have often tried to create competition, not only by the use of biased frameworks, rather than creating an unbiased environment in which competition is allowed to occur. The more you try to create competition the less competition you may have.

FuturePace views a biased framework as the ultimate in unnecessary regulation.

Some government engineers would view it as seeking technical efficiency. FuturePace believes that the licensee should have the choice to treat technical efficiency as secondary in their overall search for economic efficiency.

FuturePace views a comprehensive set of rules of spectrum licensing, based on technological neutrality, as an essential regulatory minimum providing an unbiased and clearly defined radiocommunications environment in which competition can flourish. Competition can not be created by the ACA because competition and the factors which go to create it are outside the policy and technical purview of the radiocommunications Regulator.

6.0 The Regulator's Task

FuturePace is confused and somewhat disappointed that we have to again argue the case for the existing spectrum licensing framework, which is after all current ACA policy. The ACA seems content to simply admit "*that there are two very extreme ends of the debate here*" and "*we are keeping an open mind about it*". Given spectrum licensing is enunciated Government policy we see

no real need for the ACA fence sitting posture, waiting to be led by industry at yet another workshop, when these issues were discussed extensively and agreed in the mid-nineties. Seven years ago the ACA enunciated a policy and worked with industry to develop it over the following years. The assumption was that there was a reasonable level of consensus. FuturePace fails to see why the ACA is now resiling from that policy so readily in the face of two concentrated attacks by minor players, based on the apparent desire to turn the Australian spectrum licensing system into either New Zealand or apparatus licensing.

The ACA now say that they want to "*balance technical neutrality and simplicity"*. Simplicity is possible if the ACA and, more importantly, the industry it regulates, are prepared to sacrifice definition and certainty. Yet the interference management needed for technical neutrality is not simple. The ACA are happy to admit that: ***"****(a) it's difficult and (b) that it's at the cutting edge of developments in this area.*" and naturally "*But we did agree with industry last week that we would conduct a workshop*" together with "*we'd like to work with people about the best way of achieving it*".

When economists say that the spectrum licensing framework is complex and needs to be simplified, the implication is that everyone, possibly even journalists and people with marketing degrees, should be able to understand it. Specialisation is a fact of life in any field and spectrum management is no different, just as we would refer some aspects of work to colleagues and they do the same with us, and professions such as law and medicine also accept and respect specialisation, spectrum management also has its areas of specialisation.

The way to increase competition is not to dumb down the technical rigour and science to the point where marketing people and journalists can practice as radiocommunications specialists, it is to increase the amount of work available, by releasing more spectrum so as to create actual competition in the market. At the moment there is insufficient work available for the 50 or so

people accredited and consequently little incentive for the majority to add to their skills base in spectrum licensing. Faster release of spectrum against the current set of agreed rules would make it worthwhile for the majority of accredited persons to gain the skills necessary to be competitive in industry. At the moment, by constantly bowing to pressure for simplification, the ACA is indicating that such effort might not be necessary because the ACA might make it all go away. This is not the way to create excellence or a competent and competitive skills base.

It may not be possible for the ACA to be uniformly popular across industry, nor is it meant to be a mover and shaker within the industry it regulates. Perhaps a more distant posture with less emphasis on consensus, combined with a more open and accountable system of decision making, might go some way to resolving the philosophical impasse at which the ACA seems to find itself.

The ACA appears to be saying it has no ownership of its enunciated policy. However industry is saying it has significant ownership of the current policy, and this is reasonable since the ACA uncertainty relates to an area of policy over which they have little control, and for which they do not pay. While the ACA has not, as matter of stated policy, developed managerial tools for spectrum licensing, industry has, at the behest of the ACA, contributed significant resources to the task.

Managing the input of vocal and often quite aggressive industry players can be dangerous ground for a Regulator.

There is a level where it is quite reasonable for carriers and equipment vendors to argue for varying levels of flexibility. After all, they're pursuing specific business cases and may occasionally find it more convenient to address market competition issues by reducing flexibility. However, this isn't an appropriate consideration for an independent and uncaptured Regulator especially if the Regulator is keen on encouraging competition and new

industry participants. We believe it is imperative that the ACA stand above competitive issues by providing technical neutrality supported by full definition and limited negotiation together with a phased move into perpetual licences. We believe that is where competition will be created. To repeat, the ACA is not charged with creating competition. It is there to create the circumstances in which it can occur.

Commercial interests may actually want less flexibility. We could cite a number of hypothetical circumstances where commercial realities may seek to deny competitors access to different equipment. One equipment vendor may quite legitimately be seeking to establish a technical framework biased to their equipment. A carrier may have a market plan that it doesn't want to reveal, or it may want to cut off a competing commercial interest. All of these are legitimate commercial activities, and they will surface in ACA run 'workshops'. However, the ACA isn't a commercial activist and should be standing above such issues. Rather the ACA ought to be creating the widest possible, and the most technically creative playing field to allow competitive activity to happen. FuturePace believes the ACA is caught up in thinking that it has to create competition. That is not what it is being asked of it, certainly not by industry. The ACA is tasked with creating the conditions under which competition may occur. And biasing the 3G or any future frameworks is not going to achieve that objective.

7.0 ACA response to Industry Attitudes Towards the Existing Spectrum Licensing Framework

Telstra has gone on record as saying that the ACA's recent attempt of providing a 'simplified' framework for the Conversion of the GSM900 spectrum was "*withdrawn by the government ..... influenced by some fairly serious concerns and difficulties that we had .... with the technical framework*". Telstra has also stated that "*the current regime requiring interference impact certificates ..... (is) described as a technical farce. We would certainly not*

agree with that. We think that ..... the current elements of the technical framework are very crucial."

Vodafone have said that there is a need for certainty in the rules to be applied before interference management becomes a problem, and to avoid the New Zealand situation.

And yet the ACA says that it will now conduct a workshop which will focus on a number of issues designed to undo their own policy. "*On the issue of device registration similarly we're asking: are we doing things as well as we could? At the moment are we being too prescriptive? Does every device need to be registered? Is it possible to simplify device registration to require fewer details? Should we in fact be requiring an interference impact certificate with every device registration?*"

These and other quite basic questions are to be considered, yet again, and at unnecessary cost to industry, given every time the ACA "consults", industry has to turn up and provide free advice. Industry is already quite well aware of why these elements of the framework are in current use.

FuturePace is at a loss to understand the ACA approach. Companies which accepted Government policy, and many of them are significant players, are being required to prove why they accepted and acted upon that policy because of a couple of noisy critics.

It also seemed sensible to examine, from their statements made to the Commission, why a policy with a high level of general acceptance was being criticised so roundly from such specific quarters.

Peter Hilly of Spectrum Engineering Australia (SEA), the originator of the "*technical farce*" comment, has criticised the concept of spectrum licensing from its inception**.** SEA have stated very clearly to the Commission their support for central planning.

Ian Hayne of Market Dynamics whose "*background is in communications policy and in law..... at the ACA ... (was) responsible for the spectrum marketing team and was therefore responsible for the development effort behind spectrum licensing*" for approximately 5 years. During this 5 year period, one would think that Ian Hayne had come to understand the product that he was marketing to industry rather than now "*wondering at the use of it*". Ian Hayne says "*I had a lot of chuckling in my heart as I read the commission's reporting on (interference impact certificates and the section 145), particularly the colourful language of some (one) of the consultants (Peter Hilly) in the field, the "technical farce of the device boundary polygon". Unwired agrees with that. We mightn't use the words "technical farce" but we certainly agree with the sentiment. The methodology as it's currently prescribed is deeply flawed. It needs to change. Even if it were to be retained as a mechanism, it really needs to change because it's substantially flawed, but we wonder at the use of it in any event."*

Mr Hayne then argued passionately for variations to the 3.4 GHz framework which, on his reading of the technical rules, had to be changed to prevent the need for registration of potentially hundreds of thousands of subscribers.

It may reassure the Commission to know that last Friday, FuturePace registered a number of bases, receivers and subscribers in 3.4 GHz spectrum licences utilising the existing framework and the group registration capacity for subscribers designed to simplify exactly the situation with which Ian Hayne appears to be wrestling.

Quite clearly the ACA are responding, not to the carriers who seem on the face of comments to the Commission supportive of the spectrum licensing policy and technical framework, but to the forcefully expressed opinions of those who either cannot understand or will not accept Government policy.

This policy Odd Couple are also arguing from diametrically opposed philosophical perspectives, one strongly supporting central planning the other a free market approach of absolute laissez faire. And yet the ACA seem incapable of discerning the underlying rationale behind these opinions, (one doesn't want to change and the other can't get accredited), and on the basis of the Peter Hilly and Ian Hayne comments, the ACA now propose to run the policy vacuum panacea of a workshop.

FuturePace believes that the ACA should assume a position of leadership. Fence sitting in response to pressure because of a perceived polarisation on its policy is a highly inappropriate position for the regulator to assume.

8.0 Improving the Re-allocation Process

The Commission has inquired about streamlining the re-allocation process. If there is one area where the ACA might be given more innovation capacity it is in the timing of the definition of market areas. At present the legal situation is that the market areas are defined, though that is praising the precision of the process, by the ACA so that the Minister can agree to the spectrum being re-allocated for spectrum licensing. In effect this means drawing lines on maps which may have no carefully considered correlation to industry, equipment or technical realities for the spectrum. Given the Commission has asked about the role of the Minister, this is one area where the process inadvertently creates a situation where the lines on maps may actually be creating both technical and commercial inefficiencies.

9.0 References

[1] Calin D., Elicegui L., Grandblaise D., "*Spectrum Engineering Options for Software Definable Radio*" Motorola Labs – Paris, France, submitted to WWRF WG4 – Spectrum Issues, 13 April 2001.

Spectrum Engineering Options for Software Definable Radio

Submitted to: WWRF WG4 – Spectrum issues

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Introduction

The recent emergence of the control of radio functions by software algorithms embedded into future "smart" communications devices will directly affect the manner in which these devices would use the shared spectrum. Indeed, with the advent of Software Definable Radio (SDR), the change between different modes to adapt to specific operating conditions will become possible, bringing in flexibility and technology independence for both mobile users and network operators. This flexibility will improve network performances as well as Quality of Service (QoS) delivered to the user. However, it cannot be fully exploited with the traditional spectrum practices. Advanced spectrum allocation and utilization techniques have to be investigated to incorporate this flexibility and to further enhance the performance of SDR systems and so to make that 4th generation mobile technology becomes a reality.

In this paper, the motivation of SDR will be outlined in the first paragraph. A second part will focus on the current trends in the spectrum management through the existing regulation policies and standards. The last part deals with the flexibility provided by the SDR for enabling advanced spectrum sharing practices.

Software Definable Radio Technology

Challenge

Currently, numerous radio access technologies are available through different systems such as cellular (i.e. GSM, PCS, UMTS), broadcast (i.e. DVB-T), or LAN (e.g. Hyperlan) systems. Each of those systems has been initially designed for specific services and applications in identified operating areas. 4th generation system is not expected to be a brand new one but rather an effective use of existing radio technologies. The challenge consists in using harmoniously and conjointly those heterogeneous technologies. Therefore, Software Definable Radio has been identified as a means to achieve the desired interoperability. However, to achieve the full benefits, more flexibility is also needed in current spectrum management rules, and practices need to evolve and accompany the technological evolutions. Thus, an additional challenge also resides in the design of new rules for a more flexible spectrum allocation management.

Business Impacts

Thanks to this flexibility, operators will have the opportunity to diversify their services while optimally distributing traffic loading across different radio networks and maximizing capacity gains. Concerning the more specific aspect of SDR applied to spectrum sharing, interest for operators would be in setting collaboration rules in order to exploit the most optimal way the portion of spectrum they purchased. Collaboration mentioned could mean the interoperability between different technologies an operator owns as well as inter operators collaboration.

Current Spectrum Engineering Practices

Conventional Spectrum Management

Decision for spectrum sharing is highly dependent on policies and rules dictated by various regulatory bodies (ITU, CEPT, ARIB, FCC) having significant influences in shaping spectrum utilization. Traditionally, rigid rules apply in spectrum management, imposing heavy restrictions in frequency utilization. Indeed frequency channels are well defined and their allocation operation is limited only to the allocated spectrum. Nevertheless, fixed and standardized planning of spectrum give several advantages: ordered planning of frequency spectrum use encourages careful choice of technology, both for maximum spectrum efficiency and for profitability of operators. Strict standardization, both in network equipment and end user equipment, coupled with normalized practices in network design and implementation, further assist in the most efficient use of the frequency spectrum and at the same time minimize the interference. The main drawback of the conventional approaches is the lack of flexibility in resource allocation, that does not allow to consider the heterogeneous users' requirements and the wide range of traffic profiles. This lack of flexibility is illustrated in the figure 1, where UMTS FDD uplink and TDD modes operate independently on two adjacent frequency bands and in the same geographical area. The shaded area shows the different combinations of FDD uplink and TDD cell loading to achieve a 95% level of satisfaction for the existing links. Uplink performance of both FDD and TDD (both in uplink) set a finite limit on potential cell loading for both modes. Indeed, at low cell loading, TDD uplink determines the limit, while at high FDD cell loading, FDD uplink limits the overall system performance. Therefore, to increase the capacity, a solution is to have part of FDD users operating through the TDD mode at high FDD cell loading.

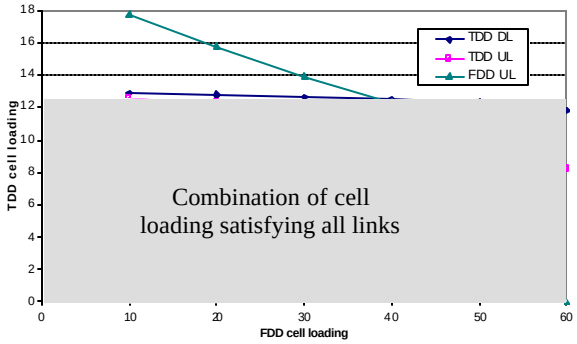


Figure 1: Cell loading yielding 95% of satisfied users

Thus, gains that could be obtained with a dynamic approach to the spectrum management, in terms of "smart" traffic load balancing mainly, is highly occulted when considering this conventional spectrum management approach.

Modern Spectrum Management

Certain degree of flexibility has been introduced in spectrum management. This is important, especially in the context of SDR, since this approach will allow its better exploitation. Two levels of flexibility have been defined:

- ***Flexible framework,*** sharing with fundamental policy and technical details provided (such as power, channels, modulations etc.)
- ***Unrestricted framework,*** where operators that own the spectrum also have the freedom to exploit their own spectrum in the most efficient way (i.e. self-defined policy). Only basic interference mitigation rules are defined by regulatory bodies. On the whole, the attempt is to remove the rigid separation of frequency bands, standardized channelization and fixed spectrum planning that exist in spectrum management methods nowadays.

Recently, FCC has opted out not to specify the channelization within an allocated spectrum space and has simply specified the minimal technical requirements necessary to mitigate

interference between licensees. The licensed spectrum owners are then permitted to define their preferred channelization and to utilize the spectrum space in the most efficient way. Some suggestions concerning the support of SDR have been proposed by FCC [1]. Spectrum licensing in Australia is an important case study of modern spectrum management [2] where higher degree of flexibility is available for a more spectrum efficiency use.

Future Spectrum Engineering Practices?

Recent Proposal from regulatory bodies for SDR Support

In ITU, some questions regarding SDR equipment conformance and spectrum management requirements are highlighted [3]. Some interesting points highlighted include:

- **No limitation of SDR operation within a single fixed spectrum space**

Due to re-configurability in SDR, a SDR entity should not be limited to operate within a single fixed frequency band or on a limited set of pre-programmed channels. It should have the capability to operate on any frequency within the limits of its design and to operate on channels of varying widths with varying modulation formats.

- **Monitoring of spectrum**

SDR network equipment with some intelligence that allows for monitoring of spectrum to detect usage by other entities and to transmit on free spectrum space should be designed. Indeed, device capabilities should allow to detect adjacent free frequency bands as well as the available Radio Access Technologies (RAT) while on communication or in idle mode. It would then be possible to take the proper decision depending on a decision criteria to switch to another frequency/carrier.

- **Spectrum loaning**

Use of SDR may also require new types of spectrum sharing methods that are currently used. Due to wide range of traffic load profiles expected in 3G and beyond mainly, spectrum loaning on a short-term basis to a third party in a need of spectrum space, should be made possible. Facilitating such sharing reduces cost, in event when spectrum space is not fully utilized by one party. Moreover it could be decided in a concerted manner between two parties about rules and policy concerning spectrum loaning between them in order for both parts to exploit the best way the available spectrum.

Different steps to achieve full Spectrum Flexibility Management

As it was outlined in the previous parts, SDR introduces a degree of flexibility in the way radio systems can be managed. Indeed, it is possible to allocate different users to the most appropriate technology. This allocation could be driven by established principles, taking into account parameters such as the user profile, mobility and so on, as well as more global load or interference conditions on one technology or another. A gain in radio resource and spectrum utilization can therefore be expected from the deployment of re-configurable terminals.

Thus, a first step towards more efficient spectrum utilization exploiting the flexibility of re-configurable radio technology is to address flexible methods of allocating spectrum and dynamic management of radio resource between several technologies.

A vision of this flexible spectrum allocation is the dynamic sharing of radio resources between different RATs, those RATs belonging either to the same operator or to different ones. These different concepts are described in the next paragraphs.

In all cases, flexible spectrum management enables the use of the most appropriate RAT and therefore enables to vary the amount of spectrum allocated to each technology depending on:

(i) User requirements (service needed, preferential RAT, cost…)
(ii) Network requirements (favors QoS, capacity or both…)
(iii) and more generally, on the traffic conditions.

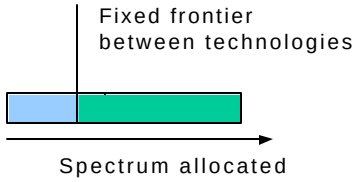
Each of these criteria or any combinations could be used to dynamically reconfigure the spectrum. Anyway, this aims at balancing the traffic load between the available radio systems while maintaining users' requirements with the objective to maximize the spectrum utilization and minimizing the interference. Another aspect that has to be introduced is the extended capability for the operator to provide users with higher QoS. Indeed, a flexible spectrum sharing context gives more opportunity of load spreading and reconfiguration since it becomes possible to juggle between technologies and/or spectrum bands.

Different systems belonging to the same operator

Different levels of flexibility can be gradually considered below. They could be considered as the most reasonable steps to reach the full re-configurability status in terms of deployment and evolution path.

(a) Fixed Spectrum Allocation

Description: Natural evolution from the current spectrum sharing rules. Each technology has its own (and fixed) allocated spectrum but each user has the capability to operate on any RAT thanks to re-configurable terminals.



Pros:

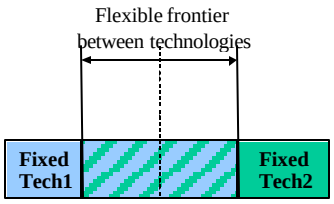
- Efficient load balancing between technologies as it becomes possible to dispatch users between different technologies depending on their profiles and RATs loading.
- RATs are not operated independently and radio resources are managed on a joint basis. Call admission control is done taking into account the status on the different technologies.
- Smooth implementation from an architectural point of view, since only a joint management module is required to move from the current practice to this solution.

Cons:

- The amount of spectrum allocated to each of the technologies is still fixed.
- More signaling is expected with respect to the static and independent resources allocation in joint technologies environment.
- It is important to ensure the robustness of inter-system handovers to warrant QoS continuity.

(b) Fixed Spectrum Band with additional sharing spectrum pool

Description: Spectrum is still kept fixed for each technology. The major difference with respect to (a) is that now a portion of spectrum is in pool and can be accessed by any RAT while providing the radio compatibility between RATs.



Pros:

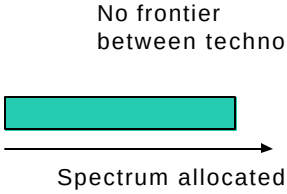
- The amount of spectrum allocated to each technology can be increased or decreased depending on the traffic needs.
- Supplementary degree of freedom is added compared to (a): the load can be balanced between the two technologies but also the spectrum resource. It becomes thus possible to adapt to various needs of different RATs by adapting to traffic fluctuations.
- There is still a fixed bandwidth for each technology, that guarantees a minimum of resources per each technology.
- Switching of technology does not mean anymore changing of carrier. Nonetheless, if interest is shown, technologies could always be linked to carriers within this spectrum sharing space.

Cons:

- One of the consequences is that reconfiguration without frequency change has to be possible.
- More signaling: information on the new spectrum allocation scheme will have to be transmitted to the different mobile stations.
- Increase in complexity in terms of radio resource management.

(c) No Fixed Spectrum Band

Description: The main difference compared to (b) is that here, there exists no predefined part of the spectrum. Therefore the spectrum allocation is totally flexible: there is no specific bandwidth allocated to any of the RATs.



Pros:

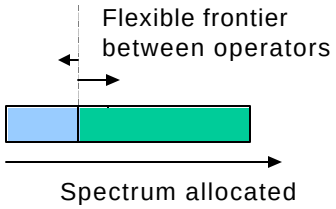
- Full flexibility: RAT and frequency are allocated to each user depending on his needs.
- Users are reconfigured if necessary.
- RATs can share the same frequency carrier at different instants of time on the same geographical area.

Cons:

- A more complex spectrum management is likely needed to be able to perform full spectrum sharing.
- Highest signaling expected when comparing to the previous solutions.

Systems belonging to different operators

Description: sharing of spectrum by several different operators (A and B in the example below), managing the same or different RATs. Difference with cases (a), (b), and (c), consists in spectrum sharing between different operators, but not necessarily between different RATs.



Pros :

- Spectrum is flexibly shared between operators.
- Spectrum resource available to an operator is dynamically adjusted depending on the needs and traffic conditions.
- Allows to face peaks of high and low traffic by respectively loaning and lending spectrum.

Cons:

- May imply increased communication and signaling between the different operators.
- Processes need to be implemented to make possible sharing agreements between independent operators.

Conclusions

Spectrum management is certainly a major issue that needs to be addressed and be solved in order to exploit the full flexibility presented by the advent of Software Definable Radio technology. Indeed, it needs to be a key topic to address in order to warrant the 4th generation systems success, by making different radio networks not only coexist but also plainly collaborate. Several fundamental changes are expected concerning spectrum sharing, implying a new vision of management of the scarce reso urce and more flexibility.

Presented ideas such as inter-operator cooperation could be perceived as very avant-gardist at a first glance, but are expected to bring a global benefit for both users and operators. Indeed, they will make possible the dynamic/hybrid spectrum allocation, definitely improving the spectrum utilization from an operator perspective. At the same time, they will give the choice to the user to select the most convenient service on the most convenient RAT and network operator.

The different steps in terms of spectrum sharing to reach this full-flexible state would help in making mind evolve and would lead to a new approach of modern wireless communications.

Acknowledgement

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