QinetiQ Bandsharing Concepts

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Abstract

This report has been prepared for the Cave Audit of Spectrum Holdings studies. The principle focus of the report is on QinetiQ bandsharing concepts, with an emphasis on the band 2.7-3.5GHz. However, most of the concepts and techniques are applicable throughout the radio spectrum. This particular band has advantageous communications properties, is internationally harmonised spectrum, and has few primary users. However, the presence of civil and military ATC radars in this band places rigorous demands on technical validation of any bandsharing proposition and on ongoing assurance measures.

QinetiQ's approach to bandsharing encompasses both freeing of spectrum and subsequent absolute assignment to new services through radar spectrum efficiency gains, and simultaneous co-channel occupancy by multiple services. In either case, a total system solution is suggested that respects the concept of exclusion zones (permanent or ad-hoc) and the need to accommodate other shared users of the spectrum. A QinetiQ experiment is described involving a high power instrumented radar and a communications network operating within a few hundred metres of one another, utilising a surveillance monitor to provide intelligence to the network configuration software. It has been demonstrated that co-existence is possible. However, further experiments are proposed for a more complex mobile scenario that exercise all the key degrees of freedom.

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1 Introduction

This report is an abridged version of a document prepared against Ofcom bandsharing contract (purchase order 830000125). The purpose of the study was threefold: to support the extant Cave audit of spectrum holdings studies; to provide an insight into relevant QinetiQ technologies; and to give a general appreciation of concepts for bandsharing and issues that need to be addressed to enable these concepts to move forward.

There is a particular bias in the report towards the problem of inserting new communications services alongside existing primary radar users. This is because the band 2.7GHz-3.5GHz has been identified as an initial band of interest, and this is populated primarily by radars. However, one might reasonably consider the whole radiofrequency (RF) spectrum for bandsharing, which then opens up the problem-space to co-existence of new and established communications systems. Nevertheless, the general analysis in this report will apply to both situations, coexistence with radars and other communications services, and arguably the bandsharing problem may be simpler in the latter case.

This report has concentrated on civil and military land-based aeronautical radars due to their potential close proximity with sharing devices. The report recognises that shipborne radars also operate in parts of the frequency range, and that civil maritime navigation radars have different characteristics to the other radars considered here, particularly that they are built to technical standards (IEC, Cenelec, IMO, ITU, EU [Maritime Equipment Directive]), are potentially numerous (millions worldwide, but fewer at any one time near to UK) though of a relatively small number of types, mobile (though interactions largely confined to the littoral region) and designed to operate at shorter ranges and often in close proximity to other, similar radars. It is expected that many of the techniques for handling military mobile radar use within shared environments, combined with appropriate communications system deployment near the coast, would continue to accommodate the safety use of these radars. There are in addition military shipborne and airborne radars used for both radionavigation and radiolocation purposes that will need to be considered

1.1 What is meant by Bandsharing

Bandsharing might be defined as "increasing the opportunity for new users to access parts of the spectrum previously denied to them". But it is also implicitly covers the ability of services to exist within the same spectrum without generating interference to each other or adjacent services.

It is virtually impossible to guarantee no level of interference even between adjacent services (i.e. services separated by frequency allocation). This is because signals require some form of modulation to carry useful information (or in the case of monostatic radar to achieve range resolution), and filtering is then required to limit the frequency excursions (i.e. to limit sidebands which do not contribute significantly to system performance and which are wasteful of both transmit power and spectrum utilised). Filters cannot be made with infinitely sharp cut-off characteristic, so there is always some leakage between adjacent channels and beyond. This is why Standards are important: they define transmit masks and maximum effective radiated power which then permits the practical specification of adjacent systems to cope with a maximum specified level of interference. This then allows multiple users to co-exist geographically.

Interference between users that simultaneously share use of the same frequencies is more problematical to cope with, and is the predominant subject of this report. Interestingly, while frequency separation allows users to co-exist geographically, it is geographic separation that is a common means of allowing users to co-exist on the same frequencies.

1.2 Means of achieving bandsharing

Bandsharing might be facilitated through three principle means:

- Improvements in spectrum efficiency (freeing spectrum)
- Improvements in spectrum utilisation (temporal exploitation)
- Use of technical means to permit co-existence of primary and secondary users

The concept of bandsharing is not new. In one sense, the spectrum, which has traditionally been structured as a series of consecutive bands designated alphabetically, has been allocated for various uses within each band on a shared basis for many years. Sharing might be on the basis of simply carving up the spectrum, with the provision of guard bands to avoid adjacent interference: for example allocation to cellular operators (GSM or 3G). However, there are many examples where multiple users literally have access to common parts of the spectrum: designated Primary and Secondary users are not uncommon, but the unlicensed bands are more dramatic examples of bandsharing.

It is interesting to note that both military and civil communications systems commonly employ frequency re-use concepts. Frequency re-use is essentially a bandsharing problem. In commercial 2G cellular operation, an operator will provide geographic coverage by notionally dividing the country into a number of adjacent cells. However, with the limited spectrum available to an individual operator, it is not feasible to allocate a unique frequency to each cell, and frequency re-use is then essential. Propagation tools and monitoring of quality of service (QOS) across the network assists frequency planning to optimise network performance. In a military context, frequency re-use is essential in order to achieve the communications capacity required (again a spectrum limited issue). Complex propagation models are used to assist frequency planning, but the situation is made more complex by the fact that the military often need to deploy fully mobile networks.

Avoidance of interference between components of one’s own communications system is one thing (it’s amenable to control measures), but avoidance between multiple un-cooperative systems is difficult. It is already the case that in wired and wireless networks, protocols exist that regulate traffic to avoid or minimise data packet ‘collisions’. These are sometimes termed ‘polite protocols’, or ‘listen before transmit’. The logic is to minimise data corruption on the network, thereby limiting the reduction in capacity that would occur through repeated requests by the intended network recipient for message repeats. However, polite protocols can suffer from ‘not being able to get a word in edgeways’! In addition, use of spatial diversity is common, both to define a zone (e.g. to optimise QOS in a cellular arrangement) and to militate against interference. The unlicensed bands represent the main challenge where multiple users may be concentrated in relatively small areas or hot spots, and manufacturers are continually refining ways of allowing such networks to interact in a limited way to accommodate each other's presence.

1.3 Windfarms and bandsharing!

At first sight the relevance of windfarms to bandsharing is slight! However, it has been recognised that windfarms can present a problem to civil and military ATC radars, and to other radars (notably air defence). The reason is that the blades rotate at a speed that can result in false detections being painted on the radar screen: i.e. the Doppler from reflected radar transmissions is commensurate with that of an aircraft. Echoes from windfarms thus present highly coherent returns to such radars (i.e. the reflected signal is highly correlated with the radar transmissions), and represent interference that could in principle mask real radar returns from aircraft, resulting in a safety of life concern. Although the origin is different, this is in essence a problem akin to what might arise from bandsharing: both concern the creation of interference that might impair radar performance, and both need to establish proof that any mitigation means does not impair radar performance to a level that would cause any concern.

The CAA, NATS, and MoD have unsurprisingly registered objections to proposed sitings of several new wind farms. However, the government, while adhering to the principle that aviation safety is paramount, has felt compelled to act in the interests of extant energy policy (not least as a contribution towards meeting the Kyoto agreements). Consequently, government, MoD and NATS have joined forces with industry to try and arrive at a solution. BAE Systems have devised a new advanced digital tracker, which has been incorporated into a Watchman radar. The system is being trialed in Wales with the co-operation of all stakeholders. Though little information is to hand, the solution is likely to be complicated by the plurality of Doppler lines from the large number of wind turbines, and the extensive area of land occupied by such farms. This means that a simple filtering solution is not possible, and neither can the interference be range-gated out. Instead, a new tracker is needed, which is understood to be a software modification. There is thus a strong parallel with some of the bandsharing solutions that would seek to exploit signal properties with advanced signal processing tools to maintain radar performance in the face of potential interference. Results from the trials are understood to be expected in October 2005. Materially, this might be seen as setting a powerful precedent pertinent to bandsharing, especially as it involves all the important stakeholders.

1.4 Report Structure

The report is divided into 6 chapters: chapter 2 provides an overview of previous international work in bandsharing; chapter 3 provides a review of QinetiQ Relevant Capabilities; chapter 4 describes QinetiQ Approaches to Bandsharing; chapter 5 provides a high level view of a Testing Regime; chapter 6 tables Concerns and Issues; chapter 7 draws together Conclusions; and chapter 8 presents Recommendations for the way ahead.

2 Overview of Previous International Work

Since the operation of the second radio transmitter in the 1890's "Bandsharing" has been at the forefront of radio development. Bandsharing was the prime reason for the early Radio conferences which laid down International regulations for the use of radio communications, and in 1934 the International Telecommunications Union (ITU) was born. Since then a number of mitigating techniques have been in general use to allow disparate services to "share" spectrum.

The radar bands have attracted a number of compatibility studies which are in the public domain and the major documents are:

(1) **CEPT Report 006 TECHNICAL IMPACT ON EXISTING PRIMARY SERVICES IN THE BAND 2700 – 2900 MHz DUE TO THE PROPOSED INTRODUCTION OF NEW SYSTEMS** Baden, June 2002.
This report was initiated by the proposed use of two new planned mobile telecommunication applications, Digital ENG/OB (Electronic News Gathering/Outside Broadcast; ground-based) and Digital Aeronautical Telemetry (down-link) transmissions, to access and use frequencies in the band 2700-2900 MHz (S-band), allocated on a primary basis to aeronautical radio navigation services (radars) and meteorological radio location.

The report addresses the technical impact of interference from digital ENG/OB and digital Aeronautical Telemetry to ARNS (Aeronautical RadioNavigation Service) radar systems, without judgement about sharing feasibility. No account has been taken of interference from radar to ENG/OB or aeronautical telemetry applications. The conclusions of the sharing conditions are expressed in terms of calculated required separation distances between stations in ARNS and interfering ENG OB terminals at a given frequency separation and for a range of radar protection criteria. Concerning radar protection, which is crucial with regard to required separation in distance and frequency, proposed amendments to ITU-R Rec. M.1464 indicates more stringent criteria than the existing (I/N= -6 dB).

http://www.ero.dk/documentation/docs/doccategory.

(2) **Radio Communications Agency Contract AY4051**: The Report of an Investigation into the Characteristics, Operation and Protection requirements of Civil aeronautical and Civil Maritime Radar Systems; October 2002

http://www.ofcom.org.uk/static/archive/ra/rahome.htm

(3) **Radio Communications Agency Contract AY4399**: Report on the UK/US Maritime Radar Trials; November 2002

The trials dealt with the protection criteria for maritime radionavigation radar systems between 2.9 and 3.1GHZ sharing with aeronautical systems.

http://www.ofcom.org.uk/static/archive/ra/rahome.htm

(4) **Ofcom Contract AY4490**: A study into techniques for improving radar spectrum utilisation;
April 2004

This study investigated methods that reduce interference between radars and other services and considered practical and theoretical possibilities of sharing radar spectrum with other services. It concluded that each technology investigated had potential to reduce the current occupied bandwidth of the radar systems in all the exemplar bands analysed.

http://www.ofcom.org.uk/research/technology/ses/ses2003-04/ay4490/

(5) **Ofcom Contract AY4620**: Assessment of the technical, regulatory and socio-economic constraints and feasibility of the implementation of more spectrally efficient radiocommunications techniques and technology within the aeronautical and maritime communities ; 15 June 2004

This contract was prompted by the initial Cave report and its title reflects the content of the report. This report provides an in depth assessment of existing services.

http://www.ofcom.org.uk/research/technology/other/sss/ay4620/?a=87101

In addition to the work already undertaken in this area the European Community have announced a "Study on Legal Economic & Technical Aspects of "Collective Use" of Spectrum in the European Community which will be taking into account a wider view of bandsharing

From the information in the public domain the following points can be made:

- Use of the band can be reorganised to free up spectrum
- Geographical areas my already be available for shared use
- The older equipment in use offers the potential for improvement in radar reception and spectrally efficiency
- Project AY 4490 whilst having a remit for the 1-16GHz band indicates that applying interference reduction techniques may offer the opportunity to release spectrum
- Many of the compatibility tests have injected the interfering signal directly into the radar receiver, and then failed to fully compensate the results with the antenna characteristics of both the radar and interferer.
- There have been few if any practical tests to calibrate the theoretical results
- A lack of Standards and common testing techniques for radar makes it difficult to compare results against a common base line
- No review has been undertaken of potential "pull through" from military avoidance technology
- Adopting a range of tools and techniques including technology transfer from the military, improvement can be achieved both in radar reception and the ability of other services to co-exist with the present regime.

It is interesting to note that the Film and TV program making community have been successfully sharing with military systems including radar since the early 1990's. This has been achieved by the licensing organisations using various traditional bandsharing tools.

3 Review of QinetiQ Relevant Capabilities

It is the author's view that any search for a solution to bandsharing should consider the whole problem space: communications systems, radars, propagation, spectrum management, network planning, users/stakeholders, regulatory framework, etc. A system analysis approach should be applied which takes all of these, together with potential bandsharing solutions, to arrive at a credible set of options for the way ahead. QinetiQ is arguably uniquely placed to lead such a wide ranging analysis, supported by relevant academic institutions, industry, and regulatory consultants.

Since there is considerable interaction between components of the system model, in this section we briefly review the key components in isolation, explaining QinetiQ's capabilities in each area. These represent a subset of QinetiQ overall capabilities, chosen for particular relevance to the concept of bandsharing (and related spectrum efficiency).

Each sub-section begins with a bandsharing comment pertinent to the technology described.

3.1 Radar

For the band 2.7-3.5GHz, bandsharing will impact on primary radar users, both civil and military. Since safety critical and safety of life is concerned (i.e. ATC radars), it is imperative that a deep theoretical understanding and practical experience of radar is brought to bear early on to validate any changes to the status quo. This should include experience in modelling interference and its mechanisms, and in practical mitigation techniques. In addition, since there is much to be gained from more efficient radar use of the spectrum, it is necessary to understand what options exist for modifying radars in the near-to-mid term (3-10 years) and for alternative design in the longer term (2020).

QinetiQ has been at the forefront of radar research dating back to its origins as a government research organisation in the Second World War. Bandsharing across the spectrum will involve a wide variety of radar types, including short and long range radar, ground-to-ground, air-to-ground, ground-to-air, synthetic aperture imaging, and phased array. They will respond to interference (and indeed potentially generate interference) in differing ways, requiring a broad and deep understanding of radar theory. QinetiQ has a world-class international reputation in the analysis and design of all these classes of radar. Among its key capabilities of additional relevance to bandsharing are: algorithms that enable weak targets to be seen against complex clutter backgrounds, advanced beamforming techniques that enable radars to discriminate against deliberate jamming and interference, and signal processing techniques that allow radars to dynamically recognise the presence of such interference and adapt the system antenna resources to effectively cancel it out.

Chapter 4 discusses approaches to radar modifications/design in the near to longer term to facilitate opening up of the spectrum.

3.2 Communications

In a bandsharing arrangement, it is important that an acceptable quality of service (QOS) is established for the secondary communications users. It is potentially the case that interference to communications from primary radar users may be experienced even though the reverse may not hold (assuming co-channel operation). Measures will then be required to adapt the communications infrastructure to optimise the level of service. Mutual interference from multiple communications networks operating in shared spectrum is a separate issue that will not be covered in this report.

QinetiQ has a strong heritage in communications research, providing critical advice to MoD on all of its major communications procurements. In addition to the design of interference tolerant, mobile networks, it has a deep understanding of propagation throughout the spectrum and of network planning to achieve a given QOS. Similar to the case of radar, techniques have been developed within QinetiQ's Advanced Signal Processing Group that enables a communications system to resolve co-channel interference and to adjust its polar response pattern to reject unwanted emissions.

Section 4.7 discusses spatial adaption concepts in more detail.

3.3 Electronic Surveillance & Spectrum Management

Although not immediately apparent, a dynamic comprehension of the electromagnetic environment is potentially a key enabler of bandsharing concepts that do not simply share on the basis of absolute frequency assignment or agreed temporal assignment. Firstly, it can provide an important assurance function, such that primary users can be confident of the absence of interfering emissions: the experience of military operations is that even with the best planning in place unexpected interference can occur. Secondly, it overcomes some of the problems associated with mobile military systems whose exact locations and prevailing propagation characteristic with respect to secondary users are unknown: this is covered further in Chapter 4.

QinetiQ's Electronic Warfare group has been established for ~30 years, covering all aspects of the research and design of surveillance and countermeasures systems applied to both communications and radar of all kinds (for example the world-leading 'SHARK' communications surveillance sensor and the companion 'PIRANHA' countermeasure system, and their equivalents in the radar bands). It has sophisticated techniques to fully characterise the electromagnetic environment dynamically, and a deep understanding of interference and interference mechanisms. QinetiQ has also been the lead research provider on spectrum management for the MoD, and has been responsible for the recent development of a pilot spectrum management system that has been deployed operationally. Whether planning the introduction of a new communications service into a specified geographic zone, validating assumptions, or policing, spectrum management tools are in advanced development that could be adapted to meet the needs (e.g. quantification of the electromagnetic environment, assessment of potential interference between existing and new services, input to QOS assessment, technical assurance).

The use of spectrum monitoring tools is discussed in section 4.5

3.4 Air traffic management

Bandsharing has the potential to impact on ATC radars. It is important that established practices are built upon to enable validation of the interference margins under variable conditions (a parallel may be drawn with MoD airborne radar exercises where flight profiles may differ for different exercises).

QinetiQ ATC group has been in existence for ~30 years. It has been a world-class research provider to NATS, the CAA, and EUROCONTROL, and has in recent years extended this to the provision of advice to MoD on ATM matters. Whenever MoD proposes to undertake exercises with equipment that may have the potential to impact on ATC radars, QinetiQ performs an interference assessment for the CAA, based on an established model. In addition, the group invented Mode S jointly with Lincoln Labs and is in a strong position to assess any impact on its performance through deliberate interference or other means.

4 QinetiQ Approaches to Bandsharing

4.1 Introduction

Although bandsharing concepts apply throughout the spectrum (from a few kHz to in excess of 100 GHz), there is an immediate interest in the band 2.7-3.5 GHz where the primary users of concern are civil and military radar rather than communications. The reasons for this are:

- Advantageous communications properties
- Internationally harmonised spectrum
- Small number of primary users in this band

We have therefore chosen to describe bandsharing in terms of new commercial communications services having to co-exist with radar. However, bandsharing need not be so restrictive, so that one might reasonably contemplate co-existence of military and civil communications; indeed, military communications might benefit from any spectrum efficiency gains involving radar (i.e. new military and new commercial comms might co-exist; see also section 6.5).

In the following sections we discuss QinetiQ approaches to bandsharing.

4.2 General considerations

As indicated previously, bandsharing might be facilitated through three principle means:

- Improvements in spectrum efficiency (section 4.3.1)
- Improvements in spectrum utilisation (section 4.3.2)
- Use of technical means (including path-loss propagation) to permit co-existence of multiple users simultaneously accessing the same piece of spectrum (section 4.3.3-4.3.6)

In this chapter we will limit spectrum efficiency discussions to those of improvements that may be made to radars.

Regarding improvements to utilisation, there is a sense that if one were to examine the probability of military radars or communications systems operating in a given geographic region of the country at any given time then it would be low. The implication of this is that parts of the spectrum allocated for such purposes might reasonably be considered for bandsharing, subject to safeguards and assurances. The simplest scenario is where parts of the spectrum are timeshared between civil and non-civil users. Here the question of interference doesn't arise.

The second scenario is where civil and non-civil operators might use same parts of the spectrum simultaneously, relying on geographic separation and other technical means to maintain isolation. Such frequency re-use is commonplace in both military and civilian communications on an agreed basis (e.g. non-interference), with procedural control and approval, and the use of techniques such as "coordination distance".

The situation is slightly more complicated where we have radars looking out to extended ranges (>100km) for small targets (i.e. where the signal to noise ratio is low), since one could conceive of a situation where a transmitter a long distance from the radar could in principle provide a source of interference. However, a combination of terrain screening, careful waveform selection, power management, etc, might render such interference inconsequential. Where such radars are safety critical then extreme caution has to be applied so that one is adequately taking account of such things as anomalous propagation effects (which might have the effect of increasing the interference levels), additive effects of a plurality of communications transmitters, and the (possible) mobile nature of the "interfering" transmitters, albeit within a controlled geographic zone. In general, for fixed radar installations the ability to survey-in and calibrate the radar susceptibility to interference is a much simpler problem than that of mobile radars. These issues are considered further below.

In considering approaches to bandsharing, there are short and long term horizons. In the short term, the issue is one of how to co-exist with legacy systems, whereas in the longer term the question may be what form radars could take to optimise freeing of spectrum while providing the appropriate level of interference rejection. In the former case, spectrum release and interference mitigation might involve modifications to radar systems, while in the latter case radically new approaches to providing the radar function may be an option. In both cases, the result is that with greater spectrum efficiency more spectrum can be freed up for bandsharing.

4.3 Technical Approaches to Facilitate bandsharing

In circumstances where spectrum is allocated uniquely to a given service provider, the technical requirements for bandsharing are in principle very straightforward, and concern the limitation of adjacent channel interference primarily by the definition of a transmission mask and maximum ERP. However, where bandsharing concerns simultaneous use of parts of the spectrum by multiple services (i.e. there is frequency re-use), then measures are needed to limit the degree of mutual interference.

Fundamentally, in situations where multiple transceiving systems have the potential to interfere with one another, there is a small number of degrees of freedom that may be available to the designer to ensure that cross-interference can be brought within acceptable margins. These are:

- Spatial filtering
- Polarisation control
- Frequency separation
- Temporal isolation
- Waveform selection (facilitating advanced signal processing measures)

It may be possible to combine any or all of these techniques, depending on the circumstances. For example, in 2G a time division multiple access (TDMA) approach is used within a cell to separate users, along with frequency channel allocation. In addition, spatial separation between base stations permits frequency re-use. In the case of 3G, users are deliberately overlaid in frequency and time within a cell, and waveform properties (in this case a set of orthogonal codes) are used to provide the intrinsic isolation between users.

In some applications, characteristic of the unlicensed bands, the potential for cross-interference is taken as read. Some manufacturers have introduced adaptive approaches that seek to optimise operating parameters in the face of such interference.

In the military communications bands, the use of frequency agility provides a means of limiting the interference impact of uncooperative users, relying either on the redundancy of spoken English or the efficacy of error correction coding (depending on model of radio). Another measure used (particularly at HF) is to employ a limited form of diversity in which the optimum channel is dynamically chosen from a set of available frequencies.

Recognising that there is unlikely to be a single, universal solution that optimises spectrum capacity, QinetiQ's approach is to treat existing primary users (radars) and proposed new communications services as an adaptive 'system' problem (where maintenance of functionality and performance of primary users are non-tradable parameters!). In effect it is an extension of what is now fashionably referred to as a 'cognitive' approach. Importantly, intelligence might be derived from any number of sources, both a-priori (e.g. known frequency allocations; known waveform properties of static emitters, known sites of fixed installations) and dynamic (such as may be derived from monitoring of the spectrum in real time). Such knowledge might be fuzzy (e.g. exact location of mobile emitters, or exact time a military network might switch to an alternate frequency), and might be subject to change or update as a result of system adaption.

In this section we begin with a discussion on the freeing of spectrum through improvements to radar spectrum efficiency (based on a previous study for Ofcom). This allows bandsharing to occur in a straightforward (relatively un-contentious) manner by simply allocating the freed spectrum to other users. We then briefly discuss a trading model concept that facilitates access to the spectrum for multiple users. The concept is based on the presumption of precise knowledge of spectrum allocations and activity.

We then go on to describe the concept of a spectrum monitoring system which is a facilitator of more radical concepts that allow simultaneous use of parts of the spectrum by primary and secondary users. It is here where the greatest gain in spectrum accessible to commercial users might be made. This technology can provide both an important input to the cognitive system adaptive concept (i.e. decision making for communications steerage) and can provide technical assurance for systems whose operation must not be compromised.

We then describe QinetiQ's adaptive approach to permitting simultaneous sharing of the band, and the experiments conducted to-date. This recognises the complications with scenarios employing non-fixed site transceivers (e.g. military radar) due mainly to uncertainty of path propagation.

4.3.1 Radar Spectrum Efficiency

As indicated in section 4.2, an approach to bandsharing might in its simplest form be adoption of measures to reduce radar bandwidth with the savings given over to alternative communications services.

A study of radar efficiency was undertaken by QinetiQ and its partners (UCL, University of Bath, and RAL) for an Ofcom spectrum efficiency scheme [1]. The study was augmented with workshops involving the major radar companies in the UK. Three approaches were identified, which were:

- Use of filtering to better control radar transmitter spurious outputs

- Modifying the nature of the transmitted radar waveform from simple pulsed to coded
- A new concept for a narrowband radar

A brief overview is provided below.

Many radars use high power, short pulse magnetron transmitters which emit with an impure spectrum. In addition magnetrons are subject to frequency drift and mode changes, both of which result in the need to allocate a wider bandwidth than technically necessary to achieve the radar required performance. Filtering could reduce the level and extent of spurious emissions and provide an immediate release of spectrum. Further improvements could be made with a combination of filtering, improved modulator design (to control moding), and injection locking to improve frequency stability. A headline figure quoted[1] for spectrum that in principle could be made available in the 2.7-3.1 GHz band was 105MHz.

Retrofitting[2] existing pulsed radars with the ability to transmit different, stable waveforms offers two advantages. Firstly, with the adoption of a coded waveform it is possible to trade high peak power for longer pulse duration while preserving the same level of radar performance. The lower power enables more linear transmitters to be built. Combining coded waveforms with filtering offers a greater margin against interference for communications users while improving spectrum efficiency. A second and important benefit that further increases spectrum release is the potential ability for such radars to re-use the same piece of spectrum: essentially by choosing an orthogonal set of waveforms, the output from a given radar does not 'match' in any other radar and therefore intrinsically generates much less interference than simple (incoherent) magnetron radars would. Similar arguments apply to reducing interference to the radars from communications by selecting comms waveforms sympathetically with those of the radars. The headline figure for spectrum release is 200MHz in the same 2.7-3.1MHz band.

The final option is for the more distant future and concerns a new radar concept. Essentially the premise is to replace existing monostatic radars with a multistatic arrangement of narrowband radars. Thus, instead of a radar requiring 10MHz bandwidth, it might be feasible to achieve similar performance with a few Hz: being narrowband the radar could have a high sensitivity and should be relatively low cost. Although more work needs to be done to validate the concept, it appears that spectrum efficiency gains should result in a freeing of spectrum of >200MHz.

4.3.2 Trading models based on perfect knowledge of spectrum allocation

In addition to yielding spectrum from radar efficiency gains, in principle (as identified in section 4.2) it may be feasible to exploit under utilisation of the spectrum. Analysis might show that certain frequencies would only be available for use within prescribed geographic regions at certain times of the day. Nevertheless it is a resource that together with absolute freed spectrum might then be made available for trading.

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[1] A study into techniques for improving radar spectrum utilisation, contract ref AY4490; QINETIQ/S&E/SPS/CR040434/1.1

[2] Depending on the details of the radar, retrofitting may necessitate replacement of the waveform generator and decoder, and potentially some elements of the transmit/receive chain.

If perfect knowledge were available on spectrum allocations, both in the civil domain (which in principle should be accessible) and the military, then it would be possible to conceive of a bandsharing arrangement that exploited temporal, geographic, and frequency channel opportunities. A simple arrangement might be for a communications provider to apply via a secure means (e.g. secure internet) to a spectrum broker for a token to operate his/her service for a specified period in a specified area of the country. Technically, the token could be an electronic “key” that was essential for the communications system to operate, and expiry of which would cause the system to shut down. NB This would also support spectrum pricing and revenue collection.

A common objection to these ad-hoc arrangements is that mobile comms users might stray into geographic areas for which there was a restriction on frequencies that could be used, thereby potentially causing interference. However, with the ubiquitous spread of GPS (and similar means), in principle it would be possible for any device on the proposed communications network to have a complete understanding of time and place, and of course its own frequency of operation (synthesised internally and commonly commanded externally). Since each device would have its own unique address, if any user strayed the device could be de-activated or switched to an alternate means: this is a feature that could be designed into the firmware without the operator having to effect any separate form of device position estimation (e.g. using base-station position fixing schemes).

Nevertheless, freeing spectrum has an associated cost, and there is interest in exploring differing business models. As an example of one approach which offers a contribution to the thinking, QinetiQ has devised a commercial model for exploiting the opportunities provided above in the form of a trading concept. This is essentially a revenue model aimed at attracting the highest value from utilisation of the spectrum.

4.3.3 Spectrum surveillance/monitoring

Where bandsharing involves the simultaneous use of defined parts of the spectrum, technical assurance is an important consideration. At issue is the certainty on behalf of the primary user that what is thought to be happening in the spectrum is actually happening. Examples of where technical assurance will be necessary are as follows:

- Secondary users’ equipment malfunctions creating interference
- Anomalous propagation conditions persist, causing increased interference
- New communications services are added, potentially with a density of users that combine to reduce the interference margin

An approach to technical assurance and an enabler to a number of bandsharing concepts is a compact, wideband surveillance monitor that is capable of rapidly characterising the electromagnetic environment. Such a capability might need to work in a totally blind fashion, i.e. with no prior understanding of the environment, or at best it might have a database loaded with available information on what is known about the environment (including frequency allocations). The concept is that an array of sensors could either be located to cover a wide area, or an individual sensor could be integrated with each primary radar to provide both an alert and a characterisation of the interference activity. NB It is thought feasible that one could derive the exact source of the interference based on mandatory identification coding associated with each communications network, which the sensor could then decode. This would provide a rapid means of switching off the offending components of the interfering network (in the time taken to send an automated electronic switch-off command).

QinetiQ has developed surveillance sensors which operate throughout the communications and microwave spectrum of direct relevance to this role. An example is shown below (*Figure 1*) of a multi-octave, microwave band sensor which has an approximate diameter of 16 inches. The sensor provides 360 degrees azimuth coverage and contains no moving parts. It is fully self contained, and can provide bearing as well as parametric information for each emitter. In principle it would also be feasible to connect it into the RF chain of a radar to obtain a (high gain) feed synchronised with the radar scan that could provide bearing (based on radar beam pointing direction) information, as well as allowing the sensor to experience the exact 'interference' environment seen by the radar. In practice there would be advantages in operating in both modes (independent and coupled) simultaneously.

Figure 1: QinetiQ Surveillance monitor

In addition to providing technical assurance, a surveillance monitor could provide the eyes and ears with which to optimally steer one or many communications network to avoid mutual interference as well as to avoid interfering with primary users. This is particularly important for the complicating scenario where in a mobile context detailed knowledge of positions of military systems may not be to hand. Conceptually, such monitors could be positioned as part of the communications systems infrastructure. This is explored further in the next sub-section.

It is important to understand that these sensors have been designed for military applications where the environment is likely to be a mix of known/controlled emission sources and uncooperative transmitters. Key to their success are the algorithms that can characterise difficult environments in real time, which for military applications are generally classified. However, for bandsharing concepts where all emissions (in principle) are either controlled or may be classed as 'interference' (with one of a standard set of modulations), then an unclassified derivative of the technology becomes possible. This is one of the distinguishing technology components of the QinetiQ approach to bandsharing.

On grounds of security, one might conceive of situations where the parameters needed to fully characterise a military radar transmission are not releasable. However, while it requires further investigation, it is thought that under these circumstances the rather limited types and numbers of active radars within a shared band of interest would be so low that a small sub-set of the parameters would suffice.

From a compliance with RIPA (Regulation of Investigatory Powers Act, which includes radio intercept in the context of human rights) perspective, it should be noted that the units do not have to undertake demodulation or storage of any message content, or to generate the personal identity of any caller.

4.3.4 Adaption to prevailing environment

As mentioned above, QinetiQ's approach to bandsharing is through intelligently adapting to the prevailing electromagnetic environment, using all information available. The objective is to effect successful communications while not interfering with other users of the spectrum. Many communications schemes exist that attempt to do this to varying degrees. Among these are the so-called "polite protocols".

With polite protocols the concept is that one listens for the presence of other traffic before transmitting. This could be with respect to an individual frequency channel or a selection of channels. In the case of bandsharing, in principle the concept might be to listen for radar or communications activity within a given geographic zone (irrespective of the actual location of source emitters) and if judged to be of sufficiently low level, or absent, to then enable civil use. However, there are several regimes that must be considered: fixed versus mobile primary users, live versus switched-off users, and any passive receiving users. In the case of fixed installations, we have already indicated the relative simplicity of calculating and validating interference margins. Mobile users are more complicated for two reasons: it is generally not feasible to survey every location they might use, and there may be reluctance to release such information on security grounds. Regarding live versus switched off users, this is complicated by the use of EMCON (emission control procedures) that might mean radio silence is being observed for a period which cannot reasonably be conveyed to a broker of spectrum use; under these circumstances it would be important that EMCON is not mistaken as an opportunity for secondary users to start using the spectrum.

An interesting example in the USA relates to the proposal to allow high power unlicensed operation on unused TV channels (FCC proposal, ET Docket No. 04-186). The Society of Broadcast engineers in preparing their response have conceded that protecting licensed full service TV etc would be practicable (for known fixed sites), but raised the problems with protecting mobile equipment (e.g. wireless microphone) that is not always on. In addition, they had some concerns about an embedded scanning receiver's ability to necessarily detect the presence of a licensed user (this was exacerbated by the unlicensed device being able to transmit on high power, desensitising the scanning receiver). They also raised concerns with users bringing devices into non-approved areas, which they conceded could be mitigated with GPS lockout (although they also put forward concerns about cost of GPS and viability in shielded high rise buildings). There is an obvious parallel with UK bandsharing, where for licensed user (in the US) we might think of MoD or CAA/NATS, and the unlicensed user (in the US) being the bandsharing services (which may or may not need to be licensed). We would discount the cost of GPS argument for the UK concepts.

QinetiQ has undertaken a series of experiments based on polite protocols. The experiments involved a communications network operating in the close proximity of a powerful radar, with a surveillance/spectrum monitoring equipment providing the 'eyes and ears' and effecting system adaption. Unlike the perceived problems with the FCC proposal mentioned above, the QinetiQ concept was to position surveillance monitoring equipment at locations with advantageous spatial coverage (e.g. selected base station locations). In addition, the sensors were conceived to retain a history of traffic activity so that patterns of spectrum use could be established. In the case where perhaps for various reasons only imprecise information on the location and of the transmission parameters (such as frequency for a given time of day) of mobile primary emitters was known, the sensor could provide a powerful augmentation to any a-priori information that had been made available to enable smart network steerage.

The QinetiQ experimental trials report showed the impact of the communications system on the radar before and after the introduction of the intelligent surveillance monitor to provide steerage. The radar was fully instrumented and raw data was recorded for subsequent analysis. Down-range calibrated targets provided a routine means for checking radar sensitivity. The experiment comprised a modified wireless LAN network (for convenience), one node being designated a master to which commands from the surveillance sensor could be sent. The network was configured to transmit bi-directional traffic, and a means was incorporated to measure data throughput. Figure 2 (below) shows the radar PPI with the radar operating in isolation. With radar and communications systems operating co-channel, and without surveillance monitoring active, the communications system throughput dropped markedly and the radar experienced strobes of interference as shown in *Figure 3* below. Activating the monitor resulted in disappearance of the radar interference (see *Figure 4* below) and recovery of the communications throughput. In many ways this was an extreme experiment: the radar had a very high radiated power (ERP) and the communications system was located within a few hundred metres. This placed severe constraints on the design of the WLAN which would not normally be required. Nevertheless, the experiment provided validation of the overall concept. Importantly the surveillance monitor could be used to provide steerage to a large number of independent communications networks, rather than having to necessarily incorporate such a means into the infrastructure of each network or indeed each device on the network: thus the problem of networks (or devices on the network) potentially not being advantageously positioned to see a primary user is eased.

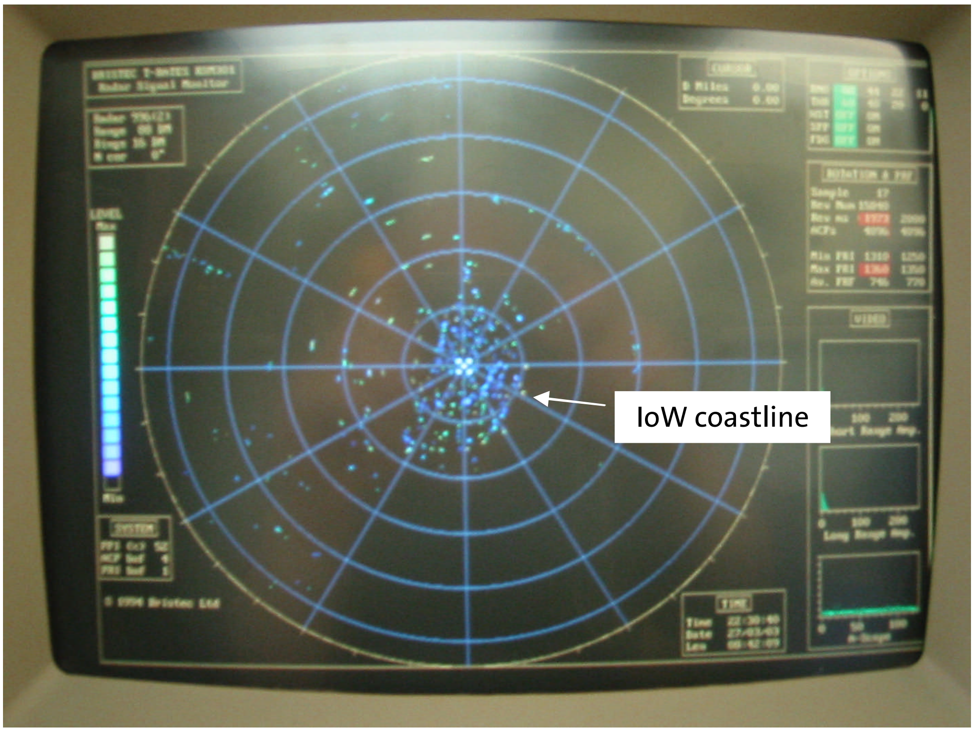

Figure 2: Radar operating in isolation

Figure 3: Radar PPI showing interference from wireless LAN

Figure 4: Radar PPI post interference mitigation

4.3.5 Spatial segregation

The experiments described above are but one component of QinetiQ's bandsharing concept. However, it is a key component in that it shows how one can integrate advanced technology derived from the military domain with civil communications wireless networks, working through the protocol stack to mitigate mutual interference. It is also the key to dealing with military mobile emitters and for providing technical assurance.

Another component of QinetiQ's concept is real time adaptive spatial control. Again, QinetiQ has developed world-leading signal processing algorithms that can separate out individual co-channel emissions and then process each to recover signal information. This has already been demonstrated for both static and mobile emitters. The significance of this is twofold. Firstly, if a concept were adopted whereby communications services had to incorporate positional and ID information on transmissions, then this could be recovered (importantly, even though as one of many co-channel mutually interfering signals) and used as intelligent input to an algorithm to determine the strategy for adaption (along with other sensor information and sources of knowledge). Absence of an ID might indicate a non civil network or emitter, creating a different strategy. Secondly, for example even if ID were not used, a base station experiencing co-channel interference (due to bandsharing with other services) could automatically separate out the directions of the competing emitters and by sharing knowledge with other base stations determine the location of these emitters. An 'electronic dialogue' between competing networks could then be initiated to recover the status quo. In the simple case this might involve changing the spatial gain profile (i.e. transmit polar diagram).

A pictorial representation of a scenario where spatial adaption to the environment is advantageous is shown simplistically in *Figure 5* below. The diagram shows the site of an ATC radar and its (simplified) rotating beam pattern (shaded brown). The green shaded area is an exclusion zone where devices over a certain power limit are excluded. Also shown are base stations (yellow dots) and mobiles (green dots). The issue is how to achieve communications coverage (with an acceptable QOS) without causing interference to the radar. With only path loss due to propagation, the exclusion zone might be unreasonably large, and unattractive to service providers.

Figure 5: Scenario showing large exclusion zone (no interference mitigation)

However, an approach to this might be to utilise a larger number of lower power, spatially controlled basestations in regions surrounding the radar. *Figure 6* is a simple pictorial representation, where each basestation close to the exclusion zone has sectored coverage and independent sectored power management. The exclusion zone has now been shrunk dramatically. Mobiles still operating within the new exclusion zones might simply bridge via another means to provide call connectivity (e.g. WLAN in a terminal area). The precise nature of the communications infrastructure is not important in this discussion; rather it's the potential with modern technology to be able to cope with co-channel interference, control transmitter power intelligently, and to produce handsets economically incorporating multi-standards to permit connectivity between users via several means (allowing zoned frequency deconfliction with primary users). Indeed, it is postulated that software defined radios will facilitate seamless connectivity between a host of service providers in the future.

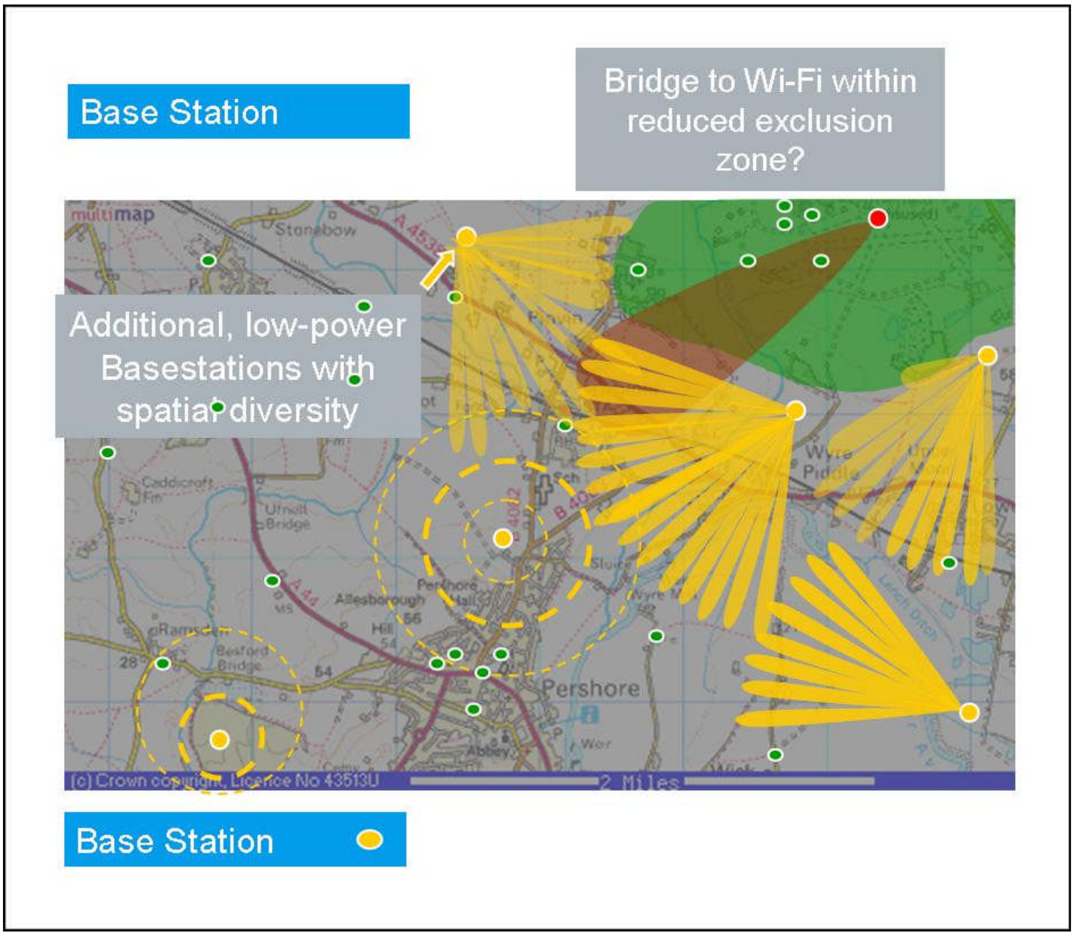

Figure 6: Scenario with much reduced exclusion zone (mitigation in place)

If one now introduces mobile military emitters into the scenario, then we have the concept of an ad-hoc exclusion zone being formed. This is problematical because one cannot survey-in sites to assess and measure propagation. However, the surveillance monitor described in section 4.3.3 could provide the necessary steerage for intelligent spatial control of the communications networks (more particularly the basestations which would be the dominant high power transmitting sources). Alternatively, it could be monitors associated with the military systems (feeding into the military spectrum management tools) that indirectly provide simple commands to the interfering civil communications to change behaviour. This would enable the military to close the loop and maintain control.

4.3.6 Summary

In the discussions above we have separated out a number of concepts and techniques that could contribute towards optimising bandsharing; for example, using a-priori knowledge such as absolute frequency assignments by geographical zone, improvements to radar spectrum efficiency, technical assurance, adapting to the environment by sensing emission activity, and adaption through spatial control (which in effect is a form of intelligent power management). However, the QinetiQ concept folds these and other measures together into an adaptive system problem, which we have likened to an extension of the more restrictive cognitive radio concepts.

We have undertaken trials which have gone some way towards developing the overall concept, showing that high power radar and communications can co-exist, and we have supported these trials with theoretical analysis of radar performance in the presence of interference. However, more work needs to be done to develop, demonstrate, and validate the concepts.

5 Test Regime

A validation study is proposed. Proposed techniques should be subjected to the rigorous examination of the Public Spectrum Safety Test Group (PSSTG). The Technology Demonstrators (TDs) assembled and tested would be aimed at verifying bandsharing as one viable concept for increasing public access to new areas of the spectrum.

Ideally tests will comprehensively address the more restrictive areas covered from previous TDs by including:

- Interference to the main beam pattern of a series of radars generated by both single and multiple sharing services at various ranges.

- Air transmission of the interfering signals, detection by the radar antenna and the effectiveness of the radar built in signal processing.

- The impact assessment on the performance of magnetron and solid state based radars. These could include the NATS's own sets performing real ATC tracking, the military radar 996 test set on Portsdown Hill and test sets previously made available through the MCA by maritime manufacturers.

- The aim of the trial will be to assess parameters such as determining the Interference to Noise (I/N) ratio, signal processing effects such as the interference level at which targets are lost from the system and operational parameters such as the ability of the radar to detect targets at the limit of their range.

- Assess the degradation in performance (Probability of Detection, effective range, etc)

The conduct of the tests should take into account that:

1. ATC is a safety of life service and the conduct of any study will need to take into account the additional responsibilities this implies. Results will be scrutinised with regard to the implications for safety as well as the normal aspects such as commercial interest, spectrum management, etc.

2. Ofcom is starting from a solid technical base with existing reports on trials sponsored by the RA/NTIA and the radar protection studies which are highly relevant to this subject. However, it is noted that all previous work contains elements of simulation which make them less than ideal in the safety of life scenario.

3. Industry support from radar manufacturers has been readily forthcoming in the past and should continue if studies and trials are seen as of benefit to all parties. The cost of assembling equipment for TDs is seen as a problem when trials are required. Development systems may not perform to standard and therefore adversely influence opinions.

4. It is intended to involve as wide a set of interested parties as possible in order to generate a consensus view of the results. To this end a live contacts list will be maintained and published and suggestions for those

to be included are welcome. Initial thoughts are that contributors should include the aviation community, the Met Office, the Coastguard, manufacturers and the military.

5. Wherever possible the data sets produced should be in a format that can be made publicly available and practically distributable. The aim should be to produce the definitive bank of real world data that can be used as a reference.

6. It would be valuable to enable software simulations to be validated, and extended liaisons with academic/industrial organisations that use such software will be strongly supported. Input characteristics will also be used for the CEPT SEAMCAT tools and translation into the international arena.

7. To facilitate the above the study will be directly administered by Ofcom, implemented through a suitable contract within the existing research structure. Gearing will be achieved by interested parties contributing specific expertise and equipment.

8. Stringent quality control and documentation standards will be set up and maintained to make output from this study suitable for follow on activities. These should include input to safety cases, standards generation, military effectiveness studies and work within CEPT.

6 Concerns & Issues

6.1 Safety

Aviation and maritime safety are of paramount concern and therefore any proposition that changes the status quo must be backed by an absolutely rigorous process of analysis and test validation (see chapter 5 and section 6.9).

6.2 Assurance

Closely allied to safety is ‘assurance’. In any approach to bandsharing that involves frequency re-use, it is important to know that the electromagnetic spectrum at any time is what may have been expected. For primary systems that require absolute assurance and swift remedy for any deviation, a co-located means (e.g. associated with each ATC radar) should be provided as a monitor/policing function. This will mitigate the potential problem of equipment going out of specification and causing interference. Note: In practice it would be advisable to have a double layered approach in which the communications systems also continually monitor their own network transmissions.

As mentioned in chapter 3, an aspect of the current assurance process between MoD and the CAA is the use of interference prediction models whenever MoD proposes to undertake exercises with equipment that may have the potential to impact on ATC radars. The model should be reviewed for its potential to support wider interference assessments, involving proposed new communications waveforms and possibly the introduction of new services within an area, and revised radar models (reflecting any radar modifications that may be implemented).

6.3 Maintenance of performance

A statement was made at the Cave Spectrum Holdings Audit seminar that no-one seemed able to specify the maximum level of interference to a radar that would be deemed acceptable. This had long been regarded as a barrier to making progress in bandsharing. While a valid concern, the author of this report believes that the underlying question needs to be turned round into a question the users can address and questions best addressed by experts in the radar and signal processing field. Materially, customers/users of radars can and do express the performance they require from a radar in very tangible terms: for example, the types of targets of interest, at what ranges and altitudes, with what speeds they travel, positional accuracy required, and under what weather conditions. It would be unreasonable to expect users to know what interference level can be tolerated as such. Similarly, engineers routinely take user requirements and turn these into system specifications, taking account of technical constraints, clutter spectrum, sources of noise etc. Given the known nature of the interference, it should be possible to determine what effect it would have on a radar, particularly false alarm rate, probability of missed detections, and range reduction. Since radars integrate the returns from many pulses, what one might imagine the user would wish to know is how any interference translates into what is presented on the display (noting that it is already processed information as opposed to raw data). The author believes that this is the common ground where the customers/users and the technical community can present their respective analyses to unlock the problem. Materially, this could be an iterative process which would lead to a determination of any boundaries on types of waveforms used for communications (and future radar, either as modifications to existing radar or entirely new radars). In considering this, it is interesting to reflect on the wind farm radar interference situation and proposed mitigation means referred to in section 1.3. The parallels are striking, and the trials set a precedent for MoD, NATS, industry and government cooperating to resolve a potential interference problem through radar technical modifications. Exactly the same questions arise concerning levels of interference that can be tolerated, and the process whereby the solution can be validated.

6.4 Military use of the spectrum

A number of assumptions have been made in this report and more widely about the military utilisation of spectrum and spectrum efficiency. In terms of utilisation, it is important to obtain greater clarity on the frequency with which equipment throughout the bandsharing spectrum is used (including how the usage is distributed throughout a period) and how this varies on a geographic basis.

In addition, the impact of land mobile, airborne, and littoral exercises need to be understood, particularly with respect to the potential need to create ad-hoc exclusion zones.

Security issues also need to be examined to understand any limitations that might apply to proposed bandsharing solutions (for example the provision of information on emitter deployments and of their external parameters). These all need to be examined in more detail with the cooperation of MoD.

The importance of unconstrained (calibrated against current practice) military training exercises is appreciated. Spectrum efficient approaches to fixed installation (ATC) radars may not all apply to military mobile, with the effect that these mobile emitters may utilise wider bandwidths. This needs to be understood and factored into any commercial service provision that exploits spectrum freed through efficiency schemes applied to fixed radar installations. Again, this is an area where an understanding of military utilisation (spatial and temporal) is important.

It should also be noted that interest in radar imaging techniques has increased (particularly applied to airborne radar). For example, there is considerable interest in the use of foliage penetration radars to detect and track moving targets under dense foliage. These are bandwidth hungry radars (100s MHz) that have been demonstrated to operate variously from UHF through low microwave frequencies. This and other demands for radar imaging will maintain pressure on the military requirement for spectrum. Future military radar developments, and the frequency with which one might need to train with these radars, requires examination with MoD.

6.5 Network Enabled Capability

In military circles, the expression ‘network enabled capability’ (NEC) refers to the linking together (networking) of disparate assets to achieve a greater effect than could be obtained had the various systems not been networked. For example, surveillance sensors that might ordinarily act independently could be linked together (potentially on an opportunistic basis) to provide enhanced situation awareness. And tying this together with decision making and ‘effector’ means (e.g. countermeasures) could produce the appropriate timely response to an evolving situation. NEC is still a relatively immature concept, but it is a major pillar of MoD thinking. The operational details are unimportant to this report, but the key to successful NEC is data communications, particularly wireless. With large amounts of data projected to be passed around the future combat zones, the pressure for extra communications capacity will increase. Bandsharing might provide the MoD with an opportunity to achieve extra capacity. Materially, freeing up spectrum through radar efficiency gains could provide an incentive to MoD if it could be seen to improve its communications capacity to support NEC initiatives. The expectation is that the MoD use would be relatively modest in peacetime, and increase somewhat during times of conflict. Importantly, communications technology derived for the freed spectrum might obviate the need for MoD to develop its own equipment (or at least it could provide the key cores).

6.6 Dependable QOS

With bandsharing, it is important for communications providers/users to have a dependable and satisfactory quality of service.

6.7 Cost of change

To implement the various spectrum efficiency measures will cost many £Ms. There are many possible ways of financing the changes, including revenues from new commercial services. Such models are outside the scope of this report.

6.8 Unintended use of equipment abroad

As with any equipment not licensed to operate abroad, there is the potential for new communications devices operating in freed spectrum to be taken abroad and used in an unapproved manner (i.e. where services are not fully harmonised across the world). Equally, there may be potential for cross border interference. The upshot is that international consultation among the various regulatory bodies will be necessary.

6.9 Regulatory considerations

Bandsharing between safety of life services and other equipment will require a careful review of the existing regulatory position. Any progress must be taken forward in a manner so as to ensure the confidence of all parties.

Identification and examination of existing licences, technical restrictions and international agreements for present users will be urgently required.

All testing and compatibility studies should be prepared with stringent quality controls to ensure wide acceptance within the national and international community.

A study of the "Single European Sky" initiative should be undertaken with a view to ensuring compatibility with the technical proposals being put forward. (There is presently an ETSI Special Task Force mandated to carry out some of the preparation for this initiative).

At present Radar equipment is not required to conform to a European Standard and does not come under the Radio and Telecommunications Terminal Equipment Directive (R&TTE), this is slowly changing.

Common standards for both the various forms of Radar and other equipment using the band would provide a technical road map for the progress of bandsharing in the 2.7 to 3.5GHz band. This process will need to take into account compatibility with existing equipment in the aeronautical community and be reflected into the International standards bodies.

A second area of consideration for the "other equipment" is that of receiver parameters. Under the R&TTE Directive, receiver parameters, unless part of a transmitter control function, are at present excluded from harmonised standards. In the case of bandsharing with radar, consideration of the link budget for other equipment may necessitate the designation of receiver parameters within a standard to ensure minimum RF output power from “other” transmitters.

Technology neutrality is increasingly required within European Standards, but if a software or hardware implementation is required for successful sharing, complete technology neutrality may not be achievable but this approach may be allowable under recital 18 of the framework directive.
(We would see the mitigation implementation as “the roadway” allowing existing protocols to be carried).

Consideration must be give to the mechanism by which the other equipment may be placed upon the market. The R&TTE Directive allows manufactures to self certify. In the initial stages of bandsharing with safety of life services it may be more appropriate to return to the previous “Type Approval “regime where a third party, (here an organisation with the technical expertise and knowledge of both civil and military issues is required) must independently test and asses the equipment against the standards appropriate to that part of the band. In addition a batch sampling system may also be appropriate to ensure continued conformity to the standard.

In order to achieve the above objectives in a realistic time scale a parallel approach to both the technical and regulatory issues should be taken. Initially coordinated with Government and Industry and after the preliminary testing and assessment phase, work items should be raised with CEPT and ETSI and discussions initiated with NATO, ICAO and IMO through MoD, CAA, and MCA respectively.

7 Conclusions

Most commentators believe that the demand for additional communications capacity will continue to rise. Further bandsharing, by which we include the introduction of extra services through both simultaneous sharing of parts of the spectrum and freeing of spectrum by efficiency schemes, appears to be the only realistic option (noting that improvements from new technologies such as MIMO will provide some addition to the existing capacity).

To properly assess the potential for bandsharing, a dialogue is required with primarily NATS/CAA/MCA and MoD. In the latter case there is a particular need to ascertain their pattern of utilisation in the UK for different parts of the spectrum. This is particularly pertinent to mobile scenarios, whether land based or airborne.

In this report we have presented some of QinetiQ's thinking on bandsharing concepts. Two regimes have been addressed: freeing spectrum for absolute assignment to other services, and simultaneous (co-channel) use of spectrum by a number of services. We have concentrated on the band 2.7-3.5GHz, although the technical approaches are relevant to any band. The significance of this band is that it is currently occupied by a small number of users, the most important being the civil and military ATC radar and MCA primary allocations. In many respects this represents the most challenging band for bandsharing simply because of the safety of life considerations. However, it is highly attractive for commercial communications.

Freeing of spectrum through bandsharing technologies could bring important benefits to the MoD, either through being able to satisfy more of its demands for additional communications capacity, or as a means of making best use of its own spectrum holdings.

There are parallels with the kind of interference assessment required for bandsharing and the assessments being made in connection with windfarms; the latter providing a powerful precedent for the type of analysis and level of assurance required for co-channel situations.

QinetiQ's approach to bandsharing is an extension of what is now called cognitive communications. However, it allows for any source of information to guide selection of the optimum strategy, for example known spectrum allocations, surveillance monitoring reports, or individual network quality of serviced measurements.

We have described an approach that allows for fixed and ad-hoc exclusion zones, and a closed loop mechanism for asserting assurance. In the latter case, we have described an Assurance means, based on a QinetiQ spectrum surveillance monitor, which would enable a 'protected' system to immediately determine the source of interference and automatically cause a cessation or curtailment of services in the offending direction.

QinetiQ has conducted a key enabling experimental trial involving a powerful radar in close proximity to an wireless communications network, steered by a surveillance monitor. This has demonstrated potential for such systems to co-exist, though further work is required to incorporate a range of additional mitigation modes.

8 Recommendations

A dialogue is required with MoD to ascertain their pattern of (primarily radar) equipment utilisation in the UK for different parts of the spectrum and by geographic region. This is particularly important for mobile equipment trials involving land-based or airborne assets, and applies equally to the littoral domain. At this stage, absolute information is not required, more what is required to scope the potential QOS that might be offered by service providers. It is suggested that QinetiQ would be well placed to undertake this assessment based on its strong defence heritage.

Concepts for bandsharing must be developed sympathetic with the operational demands of existing users, and taking due account of safety of life issues.

The experimental trials undertaken by QinetiQ have gone some way towards developing an overall concept for bandsharing, showing that radar and communications can co-exist. However, more work needs to be done to develop, demonstrate and validate the concepts. Trials should be extended to include the spatial domain and intelligent waveform selection, with particular emphasis placed on exploitation of co-channel separation algorithms as a means of adapting to ad-hoc exclusion zones.

The QinetiQ proposed assurance concepts should be studied, particularly in the context of ATC radar and military deployed mobile systems. This should include concept development, technical performance achievable, level of assurance provided, and an estimate of cost.

The concept of an electronic token system for communications service providers wishing to utilise 'shared' spectrum, facilitated through a spectrum broker, should be investigated. This would need to consider secure transaction methods, the ability of such a system to provide a rapid means of curtailing or modifying a provider's network behaviour in the event of reported interference, and the viability of such a scheme based on findings of the MoD study recommendations above and the attractiveness of the offering to service providers.

Regarding resource trading concepts, it is recommended that the current work is built on and developed through the phased development of a field trial leading to a scalable implementation of the solution. Work should be done to populate the trading tables with a view to introducing a spectrum trading system into service.

The recent Cave (spectrum holdings audit) seminar at Ofcom was a clear success in bringing together all the major stakeholders relevant to bandsharing, and in airing wide ranging issues of economic, regulatory, and technical concern. Such proactive engagement with this complex area is to be encouraged.

Bandsharing in various guises has been on the agenda of international regulatory authorities for many years. Renewed engagement is required to ensure that Dialogue with the on bandsharing concepts should be actively pursued.

9 Acknowledgements

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