Abstract

The amount of spectrum sharing continues to grow with time largely because of the continuing growth in the number and types of equipments which utilize the electromagnetic spectrum. Spectrum sharing includes all three coordinates of spectrum: time, frequency and geographical space. This paper discusses those factors which may affect spectrum sharing towards the turn of the century. These factors include technological developments, spectrum usage and the national and international regulatory situation.

1. Introduction

The principle which, for the most part, guided the initial international frequency allocation decisions was to reserve individual blocks of spectrum exclusively for use by one service. Later, to accommodate the greater demand for frequencies "sharing" of the spectrum was introduced. As we move to the twenty-first century the trend in spectrum allocation is to implement more sharing.

Technological development, new trends in spectrum usage and national and international regulatory changes are the factors which will determine the nature and amount of future spectrum sharing. This paper discusses these factors. Section 2 discusses the fundamental technical elements of spectrum sharing. Section 2 also gives some examples of representative sharing situations. Section 3 discusses the impact of new technologies on future sharing and Section 4 identifies possible new methods of spectrum sharing. Section 5 examines future domestic and international regulatory aspects of sharing. Section 6 identifies procedures and techniques which on a case by case equipment basis can help promote sharing. Section 7 is a summary.

2. Technical Elements of Sharing

Spectrum space has three coordinates: geographical space (area, volume), radio frequency bandwidth, and time. Spectrum sharing among services is accomplished by separating equipments an appropriate distance measured in units of spectrum space (M, Δs, Δt; f = frequency, s = space, t = time). This separation provides a propagation loss and/or frequency dependent rejection (FDR) sufficient to protect a receiver from interfering signals.

Figure 1 adopted from CCIR Report 654-1 [1] shows the trade-offs in distance and frequency separations which achieve a sharing criteria of reducing the interfering signal by ξ dB. Mathematically, the sharing criteria is

\[ \text{FDR}(Δf) + L_b(Δs) > ξ \]

where

- \( \text{FDR}(Δf) \) = frequency dependent rejection
- \( L_b(Δs) \) = propagation loss.

This sharing is based on satisfying a particular protection ratio \( S/I \), (or \( C/I \)), where \( S \) is the signal power (C, carrier power) and \( I \) is the interference power. Spectrum sharing is successful when the equipments of the two different sharing services can be shown in their operations to achieve this protection ratio. In an environment of moving sources (e.g., mobile) a probabilistic interference sharing criteria, \( \text{Prob}(S/I>Δ) = Y\% \), is used. The sharing criteria for sharing of space and terrestrial services is to limit the power flux density of the space service at the ground.

Often, the difficulty in developing a sharing method among services is gaining agreement on the sharing criteria. The development of appropriate sharing criteria is one of the most important spectrum engineering problems. The CCIR has established many IWPs and JWPs to develop sharing criteria among services. Much of the CCIR preparatory work for approaching WARC's involves gaining agreement on the sharing criteria among services.
Some examples of the various types of sharing for each of the spectrum coordinates space, frequency, time are:

Geographical Space
Constraints on the Geographical Location of Equipment
- UHF TV Broadcasting and Land Mobile in Ten Major Cities
- Radio Astronomy quiet sites
- Space service tracking stations
- Fixed Satellite and Fixed Radio Relay
- Passive Services (antenna discrimination)
- Geostationary Orbit (antenna discrimination)

Frequency (Bandwidth)
Constraints on Frequency Selection
- Assignment of adjacent channels in the same geographical area to different services
- Frequency Division Multiple Access

Time Sharing
Different Times of Operations of Equipment
- Land Mobile (e.g., taxi-cab) channels
- "CB" radio channels
- Daytime and Clear channel AM Broadcasting
- HF services in an individual channel
- Time Division Multiple Access

The International Frequency Allocation Table (Article 8) [2] lists on a by-block basis the services which jointly operate in each block of spectrum. The services are listed as Primary, Permitted and Secondary. Permitted and Primary are given equal rights to the spectrum except that if a frequency plan is developed the primary services have initial rights to frequencies. The stations in the secondary services 1) shall not cause harmful interference to stations of primary or permitted services to which frequencies are already assigned or to frequencies which may be assigned later, 2) cannot claim protection from harmful interference from a primary or permitted service to which frequencies are assigned or may be assigned at a later time, and 3) cannot claim protection from harmful interference from future stations of the same or other secondary services. The allocation chart is also divided into three geographical regions: The Americas (North, South, and Central) is Region 2. The international allocation table also defines, by footnote, an additional number of allocations for individual countries.

The United States has a domestic allocation table which follows the same guidelines as the international allocation chart but for a number of blocks of spectrum. The United States table includes different services from the international allocation table. Additionally, the U.S. allocation table identifies different spectrum blocks as either Government or Non-Government. Also, most blocks in the U.S. allocation table are "shared" between government and non-government users.

3. Effects of New Technologies on Sharing

One of the most important technological trends in telecommunications is the accelerated move to use digital modulations. Future cellular and personal communication networks will use digital modulations along with smaller geographical cell sizes and smaller channel bandwidths than previous analog mobile systems. Lee [3] suggests that for cellular mobile systems the required cochannel C/1 is for digital cellular can be lower than in analog systems for the same bandwidth and voice quality. The technical reason is that digital systems are more robust and can work better in a mobile fading environment, thus improving spectrum efficiency. The digital personal communication networks, if implemented, might be amenable to a geographic sharing plan that can avoid close in cochannel sharing with equipment operating in another service. Sharing may be possible with certain fixed point to point and point to multipoint systems along with links between terrestrial and space [4]. Additional study is needed to determine the sharing potential of these new digital mobile cellular systems.

The fixed radio relay service is also moving to the use of digital modulation accompanied by higher levels (e.g., 64 QAM and possibly higher). These higher level modulations are being adopted to improve spectrum efficiencies (i.e., more bits/second/Hertz) and to respond to the need to pass much higher bit rates. This increase in efficiency for high level digital modulations in the frequency coordinate however is accompanied by an increased sensitivity to interference in the spatial coordinate which may affect inter-service sharing [5],[6].

Digital Spread spectrum modulation systems, which are a class of code division multiple access (CDMA) have both advantages and disadvantages. The principal advantage of spread spectrum modulation is that a number of digital communications systems can share a portion of the spectrum. Spread spectrum systems spread the power of their signal over a large bandwidth resulting in a lower average power spectral density. The advantage of spread spectrum modulation for sharing is that an individual spread spectrum system(s) might be overlaid on a block of spectrum and not cause interference, to other systems operating in the same geographical area. The disadvantage is that if a multiple number of spread spectrum systems equipment is overlaid this may cause a significant increase in the environmental noise power spectral density over ambient noise and possibly degrade the performance of other system using the same spectrum.

Another new digital technology is packet radio. Packet technology divides the message up into individual "packets" of information and each packet is sent individually between sender and receiver. The advantage of packet technology is that the transmission channel is not dedicated to a particular user but is time shared among many users. Packet technology is being used extensively by wire communication (copper, fiber) for computer/data communication. The protocols used are the X.25, CSMA and Token Ring. Packet technology is being used for radio communication by the amateur services, meteor burst communication systems and data communication systems. It is expected that there will be other radio communication packet users including the Fixed and Mobile [8] services. Packet radio, like spread spectrum systems, may show advantage for overlay systems but, as with spread spectrum, there must be concern over noise floor buildup.

There continues to be growth in the numbers and types of certain "nonlicensed" devices which, individually, emit low levels of radio frequency energy. These include such things as garage door openers and the low level signals emitted by computers. These devices are not regulated as authorized radio services and are covered by Part 15 of the FCC Rules and Regulations. Another similar group of equipments is Part 18 Industrial, Scientific and Medical equipments such as microwave ovens and industrial heaters. These non-licensed devices must not cause harmful interference to authorized radio services and must not suffer interference from such services. The principal interference problem resulting from these devices is the cumulative incoherent power addition of signals from many of these devices which like spread spectrum and packet technology may build up the ambient noise floor.

This aggregate buildup of signal powers from many emitting sources is illustrated by an example. Suppose an airplane is flying over a geographical area with an emitter density of 1 emitter per acre. Figure 2 [8] plots as a function of aircraft altitude the field strength received at the aircraft from the aggregate incoherent sum of the fields from the many emitters visible to the aircraft (Curve A). For comparison the field strength from a single emitter directly below the aircraft is shown. (Curve B). It can be seen that the aggregate field from a number of sources is 50 to 60 dB greater than from a single emitter.
Flexibility

One suggested approach towards sharing which would tend to increase flexibility for new technologies would be to allow the introduction of new equipments into a part or block of spectrum based strictly on whether the equipments can share technically. This is in contrast to the original philosophy towards allocation that blocks of spectrum are allocated for particular service use.

Priority

Another sharing allocation proposal is to utilize spectrum based on a priority preemptive basis. Such a scheme is being tried in one European country to allow public services to utilize a portion of the spectrum with the proviso that in an emergency these users of the spectrum would vacate temporarily the spectrum for the priority government/non-government communications.

Geography and Time

Greater use of geographic and time sharing may also make more effective use of the spectrum resource. In the United States most frequency blocks are allocated throughout the country to the same service. Thus, there is limited domestic use of time and geographical sharing. One example of geographical sharing which is utilized is land mobile utilizing unoccupied UHF TV channels in ten large cities in the frequency band 470-512 MHz. There are regional differences in use of the spectrum and some blocks may be lightly used at certain times of day and more heavily used at other times.

Emission Characteristics

The allocation table (or blocks of it) might be modified to allocate certain blocks according to emission characteristics rather than radio service. The efficient use of the spectrum might be improved by allocating blocks of spectrum to communication systems with similar operating parameters, e.g., power levels or similar modulation types. These technical parameters, rather than the type of radio service are often more directly involved in promoting sharing.

Options/Conversions

In this approach two services which may not be able to share on a technical basis are allocated to the same block of spectrum. Each administration is given the option to choose among the two different allocated services. Also, this dual allocation method allows an administration to undertake at a later time a transition from one allocated service to another.

5. Regulatory changes

The last general allocation World Administrative Radio Conference (WARC) held in 1979 significantly increased spectrum sharing by adding new services to the tables and by adding a multitude of added footnote allocations for individual administrations. The ITU recently scheduled a WARC to consider allocations at HF, 500-3000 MHz, HDTV and space services above 20 GHz.

Sharing will play a dominant role in the 1992 WARC. The HF sharing issues at WARC 92 include considering whether HF allocations should be regional or worldwide and if geographic or time sharing is possible at HF. In the 500-3000 MHz band some of the services under consideration for new or additional spectrum are the mobile, mobile satellite, and satellite sound broadcasting. Also to be considered is frequency support for high definition television in the frequency range 12.7 - 23 GHz. Added space services may be allocated above 20 GHz. Concerning these
possible added allocations technical studies are required to
determine if and how these new services can share the spectrum
and if worldwide allocations are necessary. The CCIR in its
preparations for the 1992 WARC will have to study the technical
criteria for inter-service sharing among these services.

Additionally, looking to the longer term beyond WARC 92, the
ITU Plenipotentiary established a committee of voluntary experts
to examine, for the purpose of improving spectrum efficiency, new
approaches to allocate the spectrum. The CCIR, in response to
this request recently established IWP 1/7 to examine the technical
elements of new allocation methods.

6. Case by Case Methods

There are some technical techniques and procedures which
on a system by system basis can help to promote sharing. These
are summarized in CCIR Report 827 [12] and include:

Frequency Management
- Computerized frequency compatibility models
- Computer techniques for data management
- Computerized frequency assignment

Interference Reduction Techniques
- Antenna and emission spectrum sidelobe reduction
- Polarization discrimination
- Image suppression

Avoidance Techniques
- Frequency agility
- Polarization changes
- Diversity

Others
- Judicious siting of equipments
- Adaptive devices
- Interference cancelers
- Signal processing techniques

7. Summary

It is expected that in the coming decade there will be
increased sharing of the spectrum. It is suggested to make
effective and efficient use of the spectrum all three types of
spectrum sharing: space, frequency and time be utilized when
practical. Also, consideration should be given to implementing
the various sharing methods presented in section 5 and the case by
case sharing procedures identified in section 6.

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