Frequency Assignment Strategies in Australia

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SUMMARY There are two basic options available when selecting a frequency (channel) for a radiocommunication service. The first option is to release all channels within the allocated band for selection immediately. The second option is to release a channel for selection only when those already released are not suitable on compatibility grounds. When several channels are available for selection, further options are: to choose the channel which either maximises or minimises isolation between the proposed and existing services. The application of these options in frequency assignment strategies will produce different results in the overall use of the spectrum. The choice of strategy may be influenced by political, legal, social, economic or technical considerations.

1 INTRODUCTION

The Australian Radiocommunications Act 1983 under Sections 18 and 19, gives the Minister for Transport and Communications the power to prepare a Spectrum Plan and Frequency Band Plans. Before plans are prepared, draft plans must be published for comment for at least one month. An Australian Spectrum Plan was prepared in December 1990 [1] after being published for comment in February 1990. The Spectrum Plan contains a Table of Frequency Allocations. An allocation is the process where a frequency band from the spectrum (e.g., 410 MHz - 420 MHz) is entered into the Table, restricting it for use by a given type of radiocommunication service (e.g., FIXED) and sometimes limiting its use under specified conditions. The term allocation is also applied to the frequency band concerned. Frequency Band Plans also contain allocations which must be consistent with the Spectrum Plan. For example, the Spectrum Plan may allocate a frequency band to the fixed service while a Frequency Band Plan may divide the same frequency band into segments for use by several different types of fixed services. After plans are prepared, they are required to be tabled in Federal Parliament, which has the option to accept or reject them.

In deciding whether to issue a licence to operate a transmitter, the Minister is required to take into account whether the proposed operation of the transmitter is in accordance with the appropriate plan. The process of issuing a licence is called assignment. Assignment of a frequency is the authorisation given by an administration for a radio station to use a radio frequency (or radio frequency channel) under specified conditions (e.g., maximum transmitted power limit). The terms allocation and assignment are often misused. The major difference between the two terms is that while spectrum is allocated for use by a specific service type, spectrum is assigned to a specific user.

A frequency assignment strategy is that part of the process of frequency assignment where a frequency (or channel) is chosen from all those which are within the allocated band and are compatible with existing services near the proposed location. Frequencies may be assigned in a sequential manner to individual locations or a completely

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preplanned approach may be used with assignments being made to a group of locations, e.g., cellular assignment schemes or broadcast station planning. The frequency assignment strategy determines the manner in which spectrum is released for use. Since the compatibility criteria are based on a minimum system performance requirement, the strategy also has implications for the rate at which service quality approaches that minimum performance requirement.

In Australia, the Department of Transport and Communications (DOTC) administers the assignment of frequencies to radiocommunication services. Recently, frequency assignment strategies have been promoted which seek to minimise the spectrum required for a service. In the case of UHF mobile services, owing to the use of a manual assignment procedure, a strategy which seeks to maximise the availability of frequencies free of third and fifth order transmitter intermodulation interference at a site is used [2]. In the U.S.A. a policy of assigning the frequency which causes the smallest increase in the total committed spectrum space is promoted [3]. This U.S.A. policy is a result of the adoption of a recommendation contained in a paper by Zoellner [4]. How successfully this policy is implemented or achieves spectrum efficiency has not been assessed.

2 A FREQUENCY ASSIGNMENT OBJECTIVE

It is difficult to find general agreement to an objective in the broader task of spectrum management, and hence an objective in frequency assignment is equally elusive. In broad terms an objective may be keeping all users satisfied both now and in the future. It contains political, social, legal, economic and technical considerations. The assignment objective usually turns out to be a compromise between conflicting requirements. Many requirements are considered when choosing a frequency assignment strategy. The main technical requirement, in high-demand areas, is to maximise the density of services while maintaining acceptable system performance. Other requirements may be to:

(a) achieve an acceptable system performance within the limits of inexact compatibility criteria;

(b) only clear existing services for a new type of service when necessary;

(c) balance user expectation, demand for services, availability of channels, economics of use and minimum performance;

(d) take into account the conflicting spectrum demands of various user groups;

(e) conform to international agreements and legal obligation.

These requirements can influence the choice of basic selection options. The degree to which they do influence the choice depends upon the priorities perceived by the spectrum planner.

Previous theoretical papers [4,7] presented frequency assignment strategies which seek to maximise the service density and consider that this objective satisfies the need for efficient use of the spectrum. This paper examines the benefits of using different assignment strategy options for the real world and seeks to broaden the concept of spectrum efficiency. For example, in remote areas where demand is not great, it is not the primary objective to maximise the service density. In city areas, the goal of maximum service density may be tempered either by the inability to accurately define the minimum performance requirement of the communication service or by the high reliability required for a service where safety of life is involved. The efficiency of spectrum use not only involves the technical measurement of spectrum use [8], it is more concerned with the overall process of using the spectrum.

3 THE ASSIGNMENT MODEL AND SERVICE RELIABILITY

An assignment model is a mathematical representation of the communication system and consists of the average technical parameters for the system. It is chosen to be a viable solution to the real world problem of assigning frequencies. The technical parameters include transceiver and antenna characteristics, message statistics and radio wave propagation characteristics.

The model usually includes a minimum performance requirement. This includes a target grade of service (TGS) which is a lower limit for the grade of service of the system. The TGS is usually defined in terms of a minimum wanted-to-unwanted signal ratio at the receiver input such that a specified reception quality of the wanted signal is achieved at the receiver output. The ratio is often called the protection ratio and is expressed in decibels. The reliability of a service is defined in terms of the probability of obtaining the TGS in a given service area. Harmful interference occurs when the actual grade of service is less than the TGS for a given percentage of locations and time.

The model includes a representation of the degree of variation displayed by the technical parameters found in real systems. In radiocommunication systems, the major cause of variation affecting the grade of service is usually the location variability associated with propagation. For a small change in location, the received signal level can be greatly affected by topography and multipath propagation. A service reliability which achieves the TGS for 90% of locations in a given service area is considered to be acceptable. This requirement translates into a safety margin, in decibels, which is added to the protection ratio. If the wanted and unwanted signals are assumed to be a log-normally distributed this additional margin may be estimated for mobile or fixed systems [9].

4 FREQUENCY SELECTION OPTIONS

The two basic options available when selecting a frequency deal with the manner in which frequencies are released for use, i.e.:

(a) release all channels immediately, "horizontal loading", or

(b) release channels as required (when those channels released already are not suitable due to compatibility requirements), "vertical loading".

When several channels are released for use in an area and some are suitable for use by the proposed service on compatibility grounds, the isolation between services may be considered, i.e., choose the compatible frequency which:

(a) has maximum isolation between the proposed and existing services, or

(b) has minimum isolation.

Horizontal loading is used in reference 10 to maximise the grade of service for a network of systems. The selection strategy maximises isolation between services and selects from all allocated channels. Vertical loading is used in reference 11 to maximise service density by minimising isolation and releasing a channel for use only when those already released are not compatible with existing services.

The two most useful combinations of options are horizontal loading / maximum isolation and vertical loading / minimum isolation. In the past, horizontal loading was commonly used. Frequencies were selected with a view to minimising interference, i.e., release all channels initially and then maximise the isolation when choosing a new channel. This maximises system reliability but no one really knew if the resulting level of reliability was necessary. Demand for spectrum is now at a stage where a more accurate definition of the effect of interference on system reliability is needed. Radiocommunication systems have always been subject to interference, however no system should experience harmful interference. Vertical loading may be implemented when harmful interference is accurately defined and only those frequencies which are immediately required need be released for use.

5 MEASURING ISOLATION BETWEEN SERVICES

Isolation between a proposed frequency and any existing services is a measure of the difficulty of assigning that frequency. Assignment strategies differ in the manner in which "difficulty" is defined.

The assignment model may be used to gauge isolation between the proposed and existing services. Compatibility criteria are based on the assignment model and determine which frequencies are available for a proposed service. Criteria are necessary to evaluate electromagnetic or sharing compatibility.

Electromagnetic compatibility criteria are usually expressed as frequency/distance rules. They are rules which require services to have a minimum spatial separation for a given frequency separation. For example, cochannel UHF land mobile services in Australia which use two-frequency operation, must have their base stations separated by at least 100 km. This minimum cochannel separation is often called the reuse distance. These rules are derived from the assignment model and seek to avoid harmful interference.

Base interference in two-frequency land mobile services (i.e., the base transmits on one frequency and receives on another) is likely to be caused by unrelated cochannel mobile transmitters or by cosited transmitter intermodulation products. For these services harmful interference caused by cochannel services is the major concern. In single frequency services (i.e., base transmits and receives on the same frequency), base interference is likely to be caused by cochannel base transmitters, receiver or transmitter intermodulation or transmitter sideband products [2]. For these services harmful interference may be caused by nearby transmitters with frequency separations up to 1 MHz. With the narrowing of channels (down to 12.5 kHz for FM services) adjacent channel interference caused by transmitter modulation products has the potential to degrade service reliability, especially where digital modulation is employed. In this case either additional frequency/distance rules (i.e., rules applying to the use of adjacent channels) or special transmitter emission limits may be necessary to maintain a given service reliability. In addition, frequency/distance rules may be applied in order to avoid harmful interference from receiver intermodulation [2,11].

An example of a measurement of isolation is the additional distance above the reuse distance which may exist between cochannel services. The frequency which possesses either the maximum or minimum additional distance may be chosen. In another example, the actual level of unwanted signal is calculated according to the assignment model [12]. The additional isolation, measured in decibels, above that required for the protection ratio is calculated for compatible frequencies and used in the assignment process.

When measuring isolation, sharing compatibility should also be considered. Sharing compatibility is discussed in reference 2. The main consideration is occupancy of a channel. Occupancy of a channel is the percentage of time that a channel is in use. It is usually measured for each hour of the day. Occupancy influences the probability of interference and thus contributes to the estimation of system reliability, e.g., a minimum isolation assignment strategy requires maximum occupancy and a maximum isolation assignment strategy requires the distribution of users throughout all available channels.

6 BENEFITS AND DISADVANTAGES OF VARIOUS SELECTION STRATEGIES

The assignment strategy limits the degree to which services may be concentrated in an urban area. Vertical loading may be used to minimise the increase in spectrum space as each new service is assigned a frequency. Vertical loading enables the service density to be increased above that which would be achieved with horizontal loading. However, problems occur with vertical loading. For example, care must be exercised when employing a vertical loading / minimum isolation strategy so that assignments to services near high-demand areas do not inhibit the use of channels in those high-demand areas.

The assignment strategy also has implications for the rate of spectrum release. With vertical loading (release of channels as required) the spectrum is used in a controlled manner. This is useful if the demand for the service is not accurately known. If frequencies are chosen from one end of the band, the other end will be effectively reserved for another type of service if the demand is not as great as originally predicted. Vertical loading represents a degree of intervention in the market place in that there is a cost to existing users to ensure that spectrum space is reserved for future users.

Horizontal loading is used whenever a preplanned approach is required. In preplanning, channels are grouped for use in certain areas or sites. Preplanning has been used in one case [13] to simplify the assignment process by generating interference-free simplex channel assignment grids for land mobile base stations in large urban areas. In another case [14], preplanning is used to minimise interference from transmitter intermodulation products while maximising the frequency separation of cosited channels. Maximum frequency separation for cosited channels is required to minimise power losses when coupling several transmitters onto one antenna. When vertical loading is used, preplanning is not possible and frequencies are assigned as requested. This strategy leads to a more dynamic assignment process which automatically takes account of changing demands for services.

Choosing the frequency which either maximises isolation or minimises isolation between the proposed service and the existing services, has implications for the service reliability. The average speed at which all systems approach the TGS is determined by the assignment strategy. If the assignment model is accurately defined then minimum isolation may be used to achieve a faster rate of reaching the TGS. This is useful, as it provides a check that all licensees are operating within the technical conditions for the service. The user also becomes familiar with the TGS initially instead of seeing the service reliability gradually deteriorate. If the assignment model is not accurately defined then the use of maximum isolation may be necessary to reach the TGS at the slowest possible rate. If necessary, a correction may be applied to the assignment model before any real damage is done.

Some of the benefits and disadvantages associated with the two most useful selection strategies are listed in Table 1.

Table 1

Effects of two useful strategies

HORIZONTAL LOADING, MAXIMUM ISOLATION	VERTICAL LOADING, MINIMUM ISOLATION
Decreased service density.	Increased service density.
Faster spectrum release.	Slower spectrum release.
Slower to create any cases of harmful interference.	If assignment model is not well defined, cases of harmful interference may occur more quickly.
Users have to accept gradually decreasing service reliability.	Constant service reliability for total service life.
Systems using below-grade equipment are detected as service reliability decreases.	Below-grade equipment detected when service established.
Service reliability is dependent upon the demand for services.	Service reliability is the same in high and low-demand areas.
Enhanced potential for localised sharing of a channel.	Makes localised sharing difficult.
Channel occupancy dependant upon the demand for services.	High channel occupancy for all services.
Decreased restriction on choice of channels in high-demand areas caused by assignments in low-demand areas.	Services in low-demand areas may limit the choice of channels in high-demand areas.
Preplanned assignment procedure possible if spectrum space is initially clear.	Accounts for changing demands on spectrum space.

7 EXAMPLES OF PRACTICAL FREQUENCY ASSIGNMENT STRATEGIES

Since January 1987 an automated frequency assignment procedure called LYNX has been used by DOTC for the assignment of two-frequency single-channel fixed services. This program has been previously described [12]. It assigns frequencies to the two-frequency point-to-point service at 400 MHz and 900 MHz. The service reliability was chosen as a protection ratio of 20 dB for 90% of locations. This meant a protection ratio of 20 dB for the assignment model plus an additional margin of 10 dB to account for variability of the assignment model. The frequency assignment strategy for the original LYNX procedure (Version 1.1) was such that the frequency with the greatest isolation (but greater than 30 dB) and which was already used within 135 km (the worst case reuse distance) of either of the two ends of the proposed point-to-point service was chosen. If a frequency could not be found using these criteria then a new frequency was opened for use in the area. The frequencies were released in a sequentially increasing manner. The isolation was estimated using models for the antenna gain, propagation loss etc. Maximum isolation was used to enhance the potential for localised sharing of a channel. This sharing was necessary to allow for the growth of point-to-multipoint services which at that time used this point-to-point allocation.

With experience, this strategy (vertical loading / maximum isolation) was shown not to be the optimum choice. When applied in city areas at the release of LYNX (Version 1.1), the strategy was in effect horizontal loading, because in these high-demand areas all frequencies were already used within 135 km. However in low-demand areas only a few frequencies were already in use in which case the grade of service in low-demand areas quickly approached the TGS.

A change to the strategy was applied in a later version of LYNX (Version 1.4, released in November 1989) where horizontal loading / maximum isolation is applied for 400 MHz services, i.e., new frequencies are released for use in an area until all those available for the service are in use. This new strategy brings all users to the TGS at a rate dependent upon the demand for services in their area. This prevents country users having to operate at the TGS before spectrum congestion renders it necessary. The difficult task of defining low-demand areas is also avoided. Service density is dynamically defined by the number of frequencies found nearby.

The new strategy for 400 MHz services takes account of:

(a) the existing use of the spectrum (all channels already in use in high-demand areas);

(b) the expectation of users (country users do not operate at the TGS until necessary);

(c) the economics of use (country users do not initially require selective call facilities);

(d) the demand for services (when the service is established and demand is known, horizontal loading is practical).

The strategy for 900 MHz in high-demand areas is vertical loading / minimum isolation and takes account of:

(a) the existing use of the spectrum (initially clear of services therefore vertical loading is possible);

(b) the expectation of users and economics of use (the ability to control the release of spectrum is more important than a slowly decreasing system reliability);

(c) the demand for services (demand not fully known owing to both a new allocation for service and the effect of other planning, e.g., development of a point-to-multipoint service);

(d) the degree of confidence in compatibility criteria (minimum isolation is consistent with vertical loading and with the successful use of the model over several years).

The strategy for 900 MHz in low-demand areas is the same as that for 400 MHz. The frequency assigner determines if an area is a high or low-demand area.

8 CONCLUSION

The optimum strategy for maximising service density may not be the optimum strategy for maximising overall spectrum utilisation. The optimum strategy from a technical viewpoint is not necessarily the optimum strategy in practice. The real world requires other factors to be taken into account which are difficult to quantify but affect the useability of the spectrum. A good spectrum planner will correctly weigh all requirements and choose a strategy which reflects the perceived priorities.

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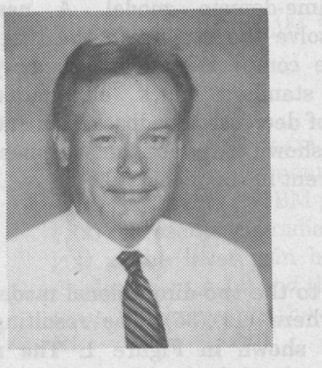

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