RECOMMENDATION ITU-R SM.1132-1*

GENERAL PRINCIPLES AND METHODS FOR SHARING BETWEEN RADIOCOMMUNICATION SERVICES OR BETWEEN RADIO STATIONS

(Questions ITU-R 45/1 and ITU-R 203/1)

(1995-2000)

The ITU Radiocommunication Assembly,

considering

a)   that efficient and effective use of the radio spectrum often requires the sharing of frequencies or frequency bands by different radiocommunication services or by radio stations;

b)   that general principles are needed for considering spectrum sharing;

c)   that methods to facilitate sharing need to be delineated;

d)   that methods to apply in specific sharing cases are recommended in a variety of ITU-R Recommendations appropriate to the specific sharing situation,

recommends

1   that administrations consider the general principles and methods described in Annex 1 for facilitating efficient and effective sharing of spectrum by multiple radiocommunication services or by radio stations.

ANNEX 1

General principles and methods related to spectrum sharing

1   Dimensions of allocation sharing

Spectrum sharing holds the potential for increasing the efficiency and effectiveness of spectrum use. Interservice sharing exists when two or more radiocommunication services effectively use the same frequency band. RR Nos. S1.166 to S1.176 define the parameters to be taken into account in frequency sharing. Interservice and intraservice sharing of spectrum are facilitated by application of sharing principles and methods that are considered on a general basis but also used in the assignment of frequencies on a station-by-station basis. Utilization of the radio spectrum is dependent on frequency, spatial location, time and signal separation. Any sharing of the spectrum will have to take into account one or more of these four dimensions. Sharing can be accomplished in a straightforward fashion when any two of these dimensions are in common and the third and/or fourth dimension differs by a degree sufficient to ensure that all the involved services or stations (two or more) can operate satisfactorily. Sharing can also be accomplished when services or stations have all four dimensions in common. In such cases, service sharing rules cannot ensure non-interference and individual assignments must be made on the basis of the totality of assignments already made in all of the overlapping services, so that combinations of factors can be found for individual assignments that will not interfere with each other.

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*   This Recommendation should be brought to the attention of Telecommunication Development Study Groups 1 and 2.

2   Sharing methods

Table 1 shows some of the methods which can be used to facilitate sharing, grouped in columns based on the four dimensions: frequency, spatial location, time and signal separation.

TABLE 1

Methods to facilitate sharing

Frequency separation	Spatial separation	Time separation	Signal separation
Channelling plans Band segmentation Frequency agile systems Dynamic sharing: – dynamic real-time frequency assignement[1] FDMA Control of emission spectrum characteristics Dynamic variable partitioning Frequency tolerance limitation	Geographical shared allocations Site separation Antenna system characteristics: – adaptive antenna and polarization discrimination – antenna pattern discrimination Spatial division multiple access (SDMA) Physical barriers and site shielding	Duty cycle control Dynamic real-time[1] frequency assignment TDMA	Signal coding[2] and processing FEC Interference rejection CDMA Spread spectrum: – direct sequence – frequency hopping – pulsed FM Interference power/bandwidth adjustments: – co-channel – dynamic transmitter level control – pfd limitation and power spectral density (psd) limitation (energy dispersal) Modulation complexity Antenna polarization

[1]   Dynamic real-time frequency assignment facilitates sharing by simultaneously using frequency and time domains. Therefore, this method is shown in both columns.

[2]   Coding techniques may also be applied to frequency, spatial and time separation technology.

Within Table 1 some of the methods are new or innovative and may make more efficient use of the spectrum or provide flexibility. Many of these methods result from the introduction of new equipment technologies, computerization of analysis and new ideas. Some of the methods are complex, involving real-time computer controlled frequency management.

Often, the specification of particular technical parameters for equipment is necessary to implement sharing methods shown in Table 1.

2.1   Frequency separation

2.1.1   Channelling plans

It is possible to arrange channels of operation on a homogeneous or inhomogeneous basis so as to interstitially configure one or more communications systems. This means of avoiding interference must be coordinated ahead of time so that the channels are appropriately separated to take advantage of the type of modulation used, the frequency domain envelope shapes, the transmitted necessary bandwidth, and receiver bandpass characteristics. This technique is appropriate for use by adjacent satellites that do not use homogeneous transponders in the GSO

The economics of channel plan coordination are often a necessary expense of coordination required between co-primary users of the same spectrum. The burden is shared between system operators and almost always gives satisfactory results.

2.1.2   Band segmentation (see Note 1)

The grouping of a number of channels, or the creation of a sub-band for non-channelized systems, for different users or uses of the spectrum is similar to the use of channel plans. In some situations this will be desirable because it has the advantage of minimizing or avoiding the need for coordination, while enabling multiple uses of a band. It encourages efficient use of the spectrum if additional spectrum is not available. It enables the full development of the respective services, rather than having the early or unexpected growth of one service or type of system curtail the growth of another desired service or system.

NOTE 1 – Band segmentation between radiocommunication services can be viewed as actually eliminating sharing by creating sub-allocations. In light of the fact that administrations take internationally shared allocations and segment those bands for national uses, the material is appropriate for discussion as a sharing method.

2.1.3   Frequency agile systems

Frequency agile systems select frequencies of operation anywhere within a specified band on a real-time basis, using the techniques of listening before transmitting. These are systems that do not rely on a mutual coordination process or on another systems operator's decision. Frequency agile systems seek out unused spectrum for a communication. These types of systems may not be suitable for public telecommunications or for transfer of critical data because of a higher possibility for interference.

Technology has made some types of frequency agile radio systems quite feasible and relatively inexpensive today. If a system can tolerate the time necessary to often change frequencies and synchronize terminals, the technique can prove cost effective.

2.1.4   Dynamic sharing

Using advanced computer techniques, spectrum managers have greater opportunities to share frequencies, and thus greater opportunities to reduce inefficiencies created by rigid service boundaries. Dynamic sharing of frequencies between different systems in the same similar services allows more than one system to use the same frequencies but at different times, in the same geographic region. Traditionally, sharing the same frequencies at similar, high power in the same geographic area required adoption of discrete time periods for use by each service. Dynamic sharing techniques permit such sharing on an as-needed basis. Dynamic sharing requires reliance on sophisticated technologies and methodologies.

Trunking is an example of dynamic sharing. In a trunked system, channels that might otherwise be assigned to individual users are joined in a single system, and frequencies are automatically assigned to individual users on an as-needed basis. Trunked systems allow disparate users to share spectrum, and generally provide a significant increase in efficiency over conventional assignment methods.

Another type of dynamic sharing occurs between cellular providers and other users in the 900 MHz band. Access to these frequencies has greatly expanded the pool of available channels for cellular use. In this arrangement, the priority users have pre-emptive access to these frequencies, and as they need them, computer software programs automatically reclaim the frequencies for the priority use, excluding them from cellular access. In such instances, cellular users would experience graceful degradation, rather than a complete loss of service.

Dynamic sharing is a possible means to improve efficiency in radio spectrum use in cases where it is feasible to merge services, and thus broaden radio service definitions. The effect of such sharing would be similar to reducing distinctions among subclasses of users. For example, in the 2 GHz band, MSSs were divided into three radio services: aeronautical, maritime and land-mobile satellite. At WRC-97 they were combined into a generic MSS. While the services are different, they have common aspects that could allow a sharing of the services under a broader classification, MSSs.

2.1.4.1   Dynamic real-time frequency assignment

The system now proposed for sharing among the MSSs is quite complex. It would involve a process of dynamic allocation, where each of the MSSs would be allocated spectrum on an as-needed basis, requiring a mechanism to implement priority and pre-emptive access, as necessary. Such systems serve a variety of users with diverse needs, including different and continuously changing requirements for channel bandwidth, signal power, priorities and network interfaces. The replacement of analogue with digital transmission technology may increase the potential for dynamic sharing.

2.1.5   FDMA

The FDMA technique consists of assigning to each user a fraction of the bandwidth and confining its access to the allocated sub-band. Orthogonality is achieved in the frequency domain.

2.1.6   Control of emission spectrum characteristics

The control of emission spectrum characteristics increases the amount of spectrum available to radiocommunications by limiting the amount of spectrum wasted to unwanted emissions (both spurious and out-of-band emissions). Sharing of spectrum is facilitated by increasing the efficient use of the spectrum. Control of unwanted emissions generally comes at a cost since methods such as filtering must be employed in system design to control these characteristics. The addition or switching-in of RF filters to the transmitter or receiver transmission line is one way to improve spectrum efficiency by minimizing either transmitted energy or received voltage that are not necessary to recover desired information. Vestigial sideband filters on television transmission lines is one example.

2.1.7   Dynamic variable partitioning

Another sharing method which results in a flexible use of the spectrum is dynamic variable partitioning, which is real-time sharing of a block of spectrum among two services for which one service has priority over the other. In dynamic variable partitioning there is a partition that divides the channels contained in a block of spectrum into two portions, one for service A and the other for service B. The partition moves in real time in response to actual or perceived demand from service A. A network operation centre is required to respond immediately to provide the channels necessary for service A. The method is based upon the establishment of a buffer of channels to respond immediately to requests. This method of sharing has been simulated using a Monte Carlo simulation but has not, as yet, been validated operationally.

2.1.8   Frequency tolerance limitation

Frequency tolerance is defined as the maximum permissible departure by the centre frequency of the frequency band occupied by an emission from the assigned frequency or by the characteristic frequency of an emission from the reference frequency. The limitation of frequency tolerance cuts down the wasting of spectrum by controlling the wandering in frequency of the transmission signal increasing the number of systems that can operate within a portion of the spectrum.

2.2   Spatial separation

2.2.1   Geographical shared allocations

Users in different geographical areas can reuse the same frequency if separated by sufficiently large distances. Geographical or area sharing of frequencies is a technique that speaks for itself and has long been considered of practical application. This type of sharing has been used for many years on a global basis in the HF broadcast band, for example. It is useful in any band depending on the requirement for service links and geographical coverage. It can take into account the characteristics of propagation to facilitate its use. This is also a technique that can use, to advantage, specific antenna system characteristics. In space service bands, where antennas point to the GSO, and depending on the latitude of operation which in turn determines the elevation angle and boresight direction in three dimensions, it may be possible to share spectrum around a terrestrial terminal. Antenna diversity can be an aid to geographic sharing either through automatic or manual switching between sites.

Another possible sharing method is to allocate a block of spectrum to two or more services and then implement the sharing within administrations by geographically separating users in the different allocated services. This utilizes sharing by separation in the spatial coordinate of spectrum. An example is the sharing between television broadcasting and terrestrial mobile services where geographical separation has facilitated sharing. The allocation tables contain a number of country footnotes, which define a different service for use within a particular administration. These footnotes provide

flexibility for countries to utilize an allocated service differently from the world or regional allocation. These footnotes define a *de facto* sharing arrangement among users who utilize the Table of Frequency Allocations and the administrations utilizing a service defined by the footnote. This type of sharing is most useful for terrestrial services on the surface of the Earth. It is more difficult to effect the sharing when one or both of the services involve an airborne or a space or satellite communication service.

2.2.2   Site separation

Site selection primarily involves the determination of an operating location that provides adequate distance separation from other operating stations at the same frequency.

2.2.3   Antenna system characteristics

Different possibilities exist for employing antenna system characteristics to facilitate frequency sharing or to minimize interference. The most obvious way is to use directional antennas to the extent that technology allows.

2.2.3.1   Adaptive antenna and polarization discrimination

Active antenna arrays (adaptive antennas) can quickly focus in real-time pattern nulls in the direction of a detected interference signal. Improved side-lobe control over current antenna designs can be a technique for further facilitating sharing.

Active antenna arrays and side-lobe cancellers are feasible, depending on the frequency of operation, but can be quite complex, and they require a significant amount of hardware. Active side-lobe cancellation does not decrease the amount of interference received through main beam coupling. Improved side-lobe control on fixed antennas may also be possible, with its feasibility inversely proportional to the amount of additional side-lobe suppression. Factors such as scattering from antenna mounts and other surrounding objects or structures may limit the amount of side-lobe suppression that can be easily achieved. Mechanical and construction tolerances on antenna elements directly impact the achievable side-lobe suppression of fixed phased array antennas.

The economic impact of side-lobe cancellers and active antenna arrays is proportional to the complexity and additional amount of hardware required. Lobe suppression through use of absorbing material and/or shielding will result in more costly equipment and installation costs, but back-lobe suppression should be more cost effective to implement from a design point of view than lobe suppression in other directions.

2.2.3.2   Antenna pattern discrimination

The antenna associated with each radio transmitter takes the output power of the system and translates that into radiated power. The resulting radiated power has a pattern based on the design of the antenna. The signals radiated by omnidirectional or nearly omnidirectional antennas spread equally along all azimuths with little or no gain. Therefore, their signals may deny spectrum to others in all directions but over a distance only limited by the transmitter power. Highly directional antennas focus and amplify the radiated power in a specific direction. These signals deny spectrum along a specific line but possibly for longer distances due to the gain of the antenna. However, some directional antennas rotate combining the characteristics of high gain and omnidirectional pattern. These patterns determine how systems can be fit together geographically. Receive antenna patterns also impact sharing by increasing or decreasing the receiver's ability to pick up the desired signal over others in the same geographic areas. Highly directional antennas are not receptive to signals away from the intended direction of reception.

Antenna patterns can be measured and gain determined along each azimuth. For spectrum planning purposes, patterns are usually considered in terms of a separate gain value for the main beam, back lobe and side lobes.

2.2.4   SDMA

Techniques have been developed to allow transmission discrimination based on spatial orientation according to a controlled variation of antenna patterns. This technique has particular importance to new applications of satellite, wireless local loop and cellular mobile radio.

2.2.5   Physical barriers and site shielding

Shielding can limit the direction that a transmitter can radiate and therefore interfere with other systems and a receiver can receive interference. Such limitations allow greater sharing by fitting systems together geographically that might otherwise interfere with each other. Site shielding can be accomplished naturally through vegetation, terrain or buildings. Site shielding can also be constructed by building berms, or metal shielding.

2.3   Time separation

Users can share spectrum in time, as when taxicabs alternately use the same frequencies or citizen band (CB) radio operators share frequencies.

2.3.1   Duty cycle control

Duty cycle is the product of the pulse duration and the pulse repetition rate. It is also the ratio of the average power output to the peak power output.

2.3.2   Dynamic real-time frequency assignment

Another sharing method which results in a flexible use of the spectrum is dynamic variable partitioning which is real-time sharing of a block of spectrum among two services for which one service has priority over the other. In dynamic variable partitioning there is a partition that divides the channels contained in a block of spectrum into two portions, one for service A and the other for service B. The partition moves in real time in response to actual or perceived demand from service A. A network operation centre is required to respond immediately to provide the channels necessary for service A. The method is based upon the establishment of a buffer of channels to respond immediately to requests. This method of sharing has been simulated using a Monte Carlo simulation but has not, as yet, been validated operationally.

2.3.3   TDMA

The TDMA technique consists of assigning fixed predetermined channel time slots to each user; the user has access to the entire bandwidth, but only during its allocated slots. Here, signalling waveforms are orthogonal in time. The TDMA approach is more complex to implement than FDMA, but an important advantage is the connectivity that results from the fact that all receivers listen to the same channel while senders transmit on the same common channel at different times. Accordingly with TDMA, many network realizations, both in ground and satellite environments, are easier to accomplish. With digital modulation, coordinated time sharing such as with appropriately synchronized time-division multiplexed signals could allow simultaneous use of the same frequency band by two or more systems. With analogue FM, certain types of bursty interference may be more tolerable than others due to the well-known FM capture phenomena providing improvement, and discrimination against unwanted signals with low duty cycles. Dynamic, real-time frequency assignment can be managed by a control station in some cases where one frequency band is used for more than one purpose and sub-bands are shifted in width to meet demands. Usually, shifts will occur in blocks of spectrum for substantial blocks of time.

Analogue FM can provide an improvement on the order of up to 10 dB of interference rejection when there is a frequency separation between the desired and interference carriers, with greater improvements for large carrier separation within the total signal bandwidth. Digital time sharing between transmitters in the same system (TDMA) must overcome the difficulty of synchronizing transmissions from different locations.

There is no additional economic impact for analogue FM improvements for systems using this type of modulation. The economic impact of digital time-sharing is proportional to the difficulty in solving the synchronization issue.

2.4   Signal separation

Transmission of communication signals using digital radio also promises improvements in spectrum efficiency. Since many signals (such as audio and video) originate as analogue signals, they must be converted to digital format prior to transmission to exploit this technology. Ironically, the bandwidth of the digital signal is greater than the analogue version. The spectrum efficiency benefit of digital technology is derived from different factors, including compression techniques. Digital communication systems often employ error detection and FEC algorithms to improve system performance in the presence of interference sources, thus enhancing sharing possibilities.

2.4.1 Signal coding and processing

Several techniques generally classed under signal coding (or coded modulation) and processing are available. The coding may occur as part of the modulation process (channel coding, as with CDMA) and it may also occur in the original signal prior to transmission (source coding, as when data strings are compressed).

2.4.2 FEC

One method is the use of FEC on digital links to reduce the required $C/(N + I)$ ratio. The FEC design allows for decreased power margins at the expense of either throughput or bandwidth. In this case, source coding techniques are used to detect errors and control the transmitter to require retransmission of erroneous data blocks.

2.4.3 Interference rejection

An advanced interference mitigation technique is non-linear interference rejection using powerful signal processing algorithms that exploit the spectral correlation properties of both the desired signal and the interference signal.

2.4.4 CDMA

Spread spectrum modulation or CDMA offers significant advantages for uniformly sharing in either the same system or in several systems.

The CDMA technique allows overlap in transmission both in frequency and time. It achieves signal separation by the use of different signalling codes in conjunction with matched filters (or equivalently, correlation detection) at the intended receivers. Each user is assigned a particular code sequence, which is modulated on the carrier with the digital data modulated on top of that. Two common forms exist: the frequency-hopped and the phase-coded. In the former, the frequency is periodically changing according to some known pattern; in the latter, the carrier is phase modulated by the digital data sequence and the code sequence. Multiple orthogonal codes are obtained at the expense of increased bandwidth requirements (in order to spread the waveforms). With CDMA, there is also a lack of flexibility in interconnecting all users (unless, of course, matched filters corresponding to all codes are provided at all receivers). However, CDMA has the advantage of allowing the coexistence of several systems in the same band, as long as different codes are used for different systems.

2.4.5 Spread spectrum

Transmitters using spread spectrum techniques spread the signal over a bandwidth many times larger than the original signal bandwidth, using a predetermined repeating code. The receiver uses the same code to despread the signal back into its original form.

A benefit of spread spectrum is interference suppression. Commercial applications include personal communications, cellular telephones, wireless alarm systems, local area networks and paging systems.

While overlaying spread spectrum systems on frequency bands could improve spectrum efficiency (as with unlicensed low-power devices), the possibility of interference increases with an increasing number of spread spectrum systems. The proliferation of direct sequence systems may substantially raise the noise floor, degrading the operation of all narrow-band systems. If the number of frequency hopping systems increases dramatically, the occurrences of interference, though brief, may become so frequent as to degrade operation.

Spread spectrum systems can be defined as ones in which the average energy of the transmitted signal is spread over a bandwidth that is much wider than the information bandwidth. These systems usually trade the wider transmission bandwidth for a lower average psd and increased rejection to interfering signals operating in the same frequency band. They therefore have the potential of sharing the spectrum with conventional narrow-band systems because of the potentially low power that is transmitted in the narrow-band receiver passband. In addition the spread spectrum systems are capable of rejecting the narrow-band interference.

Another factor which affects sharing of spread spectrum systems is the near-far problem which results when an interfering spread spectrum system is geographically nearby and the wanted signal is from a source spatially some distance away. When, because of the near-far problem, interference occurs between equipment in different services, sharing is difficult to accomplish.

A number of new technologies such as mobile data systems and low-Earth orbit (LEO satellites) may transmit their information as low duty cycle packet communications. These types of communications are candidates for overlay sharing. However, studies must be undertaken to determine the probability of interference and to define applicable performance protection criteria.

Both spread spectrum and packet radio systems are multiple access communication systems and sharing can best take place when the number of active equipment in the overlay is small. The limitation to any sharing of these schemes is dependent upon the number of active users in any particular frequency band. Each overlay increases the noise level slightly and therefore increases the probability of interference. The important issue is how to control the use of a block of spectrum that contains spread spectrum or intermittent packet users. When an overlay sharing is effected among services, it may be necessary to regulate the number of users that are present in the overlay to be sure that the interference level is below a predefined level. This is similar to present procedures where, by assignment methods, there is a limit to the number of users and their bandwidth. New systems such as intelligent frequency agile radios also operate as an overlay and could facilitate frequency sharing. These devices are intelligent enough to determine in real time if the spectrum is occupied. Intelligent radios could find and utilize unused spectrum in the allocated shared spectrum block.

2.4.5.1   Direct sequence

One technique, known as direct sequence spread spectrum, expands the signal's frequency spectrum over a wider bandwidth. A direct sequence modulated system is one where the carrier is modulated by a digital code sequence whose bit rate is much higher than the information signal bandwidth. Interference from a direct sequence system to a narrow-band receiver will appear similar to random electrical noise.

2.4.5.2   Frequency hopping

Frequency hopping, the other primary spread spectrum technique, alternates frequencies over the spread bandwidth in a seemingly random manner. Frequency hoppers use carrier frequency shifting in discrete increments in a pattern dictated by a code sequence. The transmitter jumps from frequency to frequency within some predetermined set; the order of the frequency usage is determined by a code sequence. Interference from a hopped system, although of the same power as a conventional system, is so brief that it does not adversely affect many types of systems.

Frequency hopping is the repeated switching of frequencies during radio transmission according to a specified algorithm, to minimize unauthorized interception or jamming of telecommunications. The overall bandwidth required for frequency hopping is much wider than that required to transmit the same information using only one carrier frequency.

The time of transmission for time hoppers and time-frequency hoppers (usually of low duty cycle and short duration) is governed by a code sequence. The code sequence determines both the transmitted frequency and the time of transmission.

2.4.5.3   Pulsed FM

Pulsed FM or chirp modulation is where a carrier is swept over a wide band during a given pulse interval.

2.4.6   Interference power/bandwidth adjustments

If it can be assumed that noise and interference affect receiver performance equally, as is the case in some systems, the technique of power or bandwidth adjustment may be used to exploit the non-linear nature of acceptable carrier-to-interference (C/I) ratio, as a function of carrier-to-noise (C/N) for a constant $C/(N + I)$. The technique is employed by increasing the transmitter power in the system being interfered with. By increasing the transmitter power of a noise limited system by a small amount, e.g. < 3 dB, the amount of interference that can be tolerated at the receiver is increased by a much larger amount, e.g. 10 dB.

Satellite uplinks are often noise limited due to the amount of transmitter power required to overcome path loss over the large distance involved. Under this limiting condition, very little margin is left for interference. Increasing the transmitter power of satellite uplinks is difficult when the required uplink power is close either to the state-of-the-art limit or to the maximum authorized limit. An alternative to increasing maximum transmitter power is to reduce the amount of power control allocated to overcome rain fades. This leads to a decrease in system availability that may not be acceptable depending upon system service objectives. An increase in satellite uplink power may create interference into terrestrial receivers, but terrestrial systems that share frequencies with satellite uplinks could be self-interference limited and not noise limited. Hence, an increase in uplink transmitter power does not lead to a comparable increase in the amount of interference power that can be tolerated in some terrestrial systems. The feasibility of increased power and the impact on satellite uplinks must be agreeable before this technique can be used.

The economic impact of increased transmitter power depends on how close the designed transmitter power is to the state-of-the-art maximum. If the designed power is well below the currently achievable maximum, then an increase in transmitter power may not be too expensive. If the designed transmitter power is already relatively high, this increase could be costly, if applied to a large number of terminals. Reduced system availability, and the resultant deterioration of service, lead to a reduced ability to charge users for service. The magnitude of the reduction in system availability is related to the available excess margin and the rain rate statistics in the region where the earth station is located.

2.4.6.1   Co-channel

Co-channel frequency sharing is possible, as with low-power unlicensed devices, which have such low power that they can operate at the same time and on the same frequencies as licensed services.

2.4.6.2   Dynamic transmitter level control

Also known as automatic power control, this capability allows the power of a transmitter to be varied based on the environmental situation. For example, as rain increases, the power may be increased to compensate for the increased signal attenuation. This allows for greater sharing by eliminating or decreasing the amount of spectrum denied by systems that radiate more power than they need in order to accommodate situations where more power may be needed. This particularly works well where all systems in a geographic area can be expected to be experiencing the same variations in signal attenuation.

2.4.6.3   pfd limitation and psd limitation (energy dispersal)

The limitation of pfd or psd is an approach to setting limits on emissions at a potential receiver as opposed to the transmitter. This allows the operator to make a determination with respect to transmitter power, antenna gain and system location in order to comply with the limitation. This approach is often used in facilitating sharing between satellite systems and terrestrial systems.

2.4.7   Modulation complexity

The use of quadrature amplitude modulation with higher numbers of states (n-QAM) provides the possibility of increasing the bit rate within a fixed channel bandwidth or decreasing the channel bandwidth for a fixed bit rate. Increasing the modulation complexity requires increased reliance on the use of error correcting codes and may require more complex dynamic channel equalization to meet transmission performance objectives.

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