Digital Radio Networks and Spectrum Management

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Abstract

Spectrum Management is a vital part of amateur radio. Questions of where to place services in the available spectrum continue to plague frequency coordinators. This paper contends that multiaccess radio systems should be allocated in the spectrum below one GigaHertz, and that monoaccess or link oriented systems be placed above that frequency.

Introduction

Electromagnetic Spectrum is a scarce, sometimes renewable resource. Much of the research in radioscience today is devoted to spectrum - efficient methods of communication, including such mechanisms as amplitude - companded sideband telephony, and minimal shift keying data transmission. Only recently, however, has research touched on the area of spectrum reuse, and the impact of position within the radio spectrum considered.

Propagation characteristics of certain bands make those spectra valuable to classes of users. Ionospheric propagation below 30 MHz makes the High Frequency bands valuable to the world community. Small component size and portability are important to mobile users, and so the Very High and Ultra High bands play an important part in mobile communications.

Beyond these characteristics, however, little can be generalized about the appropriate spectra for certain classes of applicants. It is not readily apparent that one band should be preferred for multiaccess applications, and another for link - oriented systems.

Packet Radio is considered to be a spectrally efficient mechanism for digital communications. Using time - division techniques, several users may share spectrum without interference, if certain traffic characteristics hold, and if the network load is limited. Techniques for time - sharing spectrum abound, but all require some degree of omnidirectionality in the transmission or reception system, which is characteristic of all all multiaccess networks.

Using packet switching techniques, it is possible to construct a link - oriented, or monoaccess network, which is functionally equivalent to a multiaccess network. This duality can be exploited for networks with fixed or portable stations.

In a hierarchal networking architecture, the Terminal Network is usually defined as that hierarchy or subnet which connects to end users. The telephone local loop plant, and radio repeaters are two examples of terminal networks. This paper is primarily concerned with terminal networks, although many of the principles may apply elsewhere.

Synthesis

The forward gain of a parabolic reflector antenna is given as:

$$G=\eta\pi^2 d^2\frac{f^2}{C^2} \qquad \{\text{Gain}\}$$

It is of no small consequence that the gain of a reasonably sized antenna increases dramatically with frequency; many digital satellite services exist explicitly because of this fact.

For the purposes of discussion, a "reasonably sized" antenna is considered to be unity, or one meter in diameter, for terrestrial applications. "Reasonable size" is often a matter of community tastes and economics; however, the one meter size covers a large portion of of the contingencies. Thus, the gain of reasonably sized antenna is:

$$G_0 = \eta \pi^2 \frac{f^2}{C^2} \qquad \{\text{Normal}\}$$

The half power beamwidth of a typical parabolic reflector is:

$$A = \frac{139}{\sqrt{G}} \qquad \{\text{Degrees}\}$$

Digital modulation schemes may be divided into two classes: orthogonal modulation techniques, such as phase shift keying, and antipodal modulation, such as amplitude or frequency shift keying. In order to add another bit per symbol in a constant - bandwidth channel, an increase in the signal - to - noise ratio of 3 db is required for orthogonal modulation, and 6 db for antipodal systems.

Frequency Division Tradeoff

The Frequency Division Tradeoff between multiaccess and monoaccess networks arises out of the increase in signal - to - noise ratio that occurs with the use of directional radiators. With the increase comes the ability to either multiply the bit rate, or divide the bandwidth to obtain equivalent service. Because antenna gain is tied integrally with frequency, the ability to fraction the bandwidth increases frequency, until a point is reached where each node occupies its own channel. The transition from a multiaccess network to its monoacccss dual occurs at a certain Critical Frequency, which is determined in turn by channel access technique, and network size.

As an example, consider a terminal network of eight. nodes, using a Carrier Sense - Multiple Access, and frequency shift keying, running at a rate of ***19.2*** Kbps. Assuming the best case for CSMA (no hidden nodes), the best aggregate throughput we can expect from such a network is about 10.6 Kbps.

The dual of this network is a set of eight links connected to a packet switch. Again assuming the best case for CSMA, each user has access to a 19.2 Kbps data rate. We wish to accomplish this transition using equivalent power and bandwidth; therefore, we require an eightfold increase in the aggregate bit rate. Assuming the use of n-ary frequency shift keying, this in turn requires an increase of 42 db in the signal - to - noise ratio. Such an increase can be obtained by a pair of one meter aperture antennas, operating at 1.5 GHz, using a 55% efficient feed. The aggregate throughput for this network is 153.6 Kbps, in the same bandwidth.

In general, for a large class of terminal networks, the Critical Frequency lies around one GigaHertz. The extent of the tradeoff is limited in practice by packet switching speeds, and the extensibility of multilevel modulation schemes.

Space Division Tradeoff

The propagation characteristics of radio limit the spatial dimensions of any network. However, it is often the case that the network itself covers far less territory than the radio spectra used to service it. This is particularly true with multiaccess networks which require omnidirectional radiators.

Radio propagation models are somewhat involved; the more exacting models have been implemented as computer simulations by researchers. However, even a cursory analysis reveals that spectrum reuse is much more practical at higher frequencies. In particular, path loss increases as the square of the frequency, as does antenna gain (which results from a narrower beamwidth). Wave polarity separation also increases accordingly. In general; it should be possible to model the multiaccess - monoaccess tradeoff, using the available computer tools.

As an example, consider the CSMA network mentioned earlier. The farthest node is at a distance R from the hub. In order to preclude the "hidden station" problem, stations on the circle described by R must have enough power for range 2R. In the limit, as the number of stations grows, the area covered by the radio network becomes four times as large as the area of the physical network. The monoaccess dual is no larger than physical network area at some Critical Frequency, and can indeed be: considerably smaller.

Towards a Spectrum Efficiency Quotient

Clearly, a combination of three separation techniques (spatial, spectral, and polar) can yield a spectrally efficient monoaccess network at higher frequencies. At lower frequencies, however, the multiaccess model predominates.

The term "spectrally efficient" has been used to describe multiaccess networks, without specificity. What is needed is a "figure of merit" to describe a radio network, and compare it with other alternatives. Propagation characteristics of the spectrum below one GigaHertz lend themselves to applications requiring a high degree of mobility and portability. For fixed or semiportable operation, however, a monoaccess network provides a spectrally efficient alternative, when operated above the Critical Frequency.

Summary

The spectral efficiency of monoaccess and multiaccess networks varies with the frequency used. The exact calculation of the Critical Frequency of the tradeoff is currently the subject of research. However, in general, multiaccess networks tend to be more spectrally efficient below one GigaHertz, and monoaccess networks predominate above.

Implications for the Amateur Service

Coordination between different types of services in the Amateur Service at frequencies above 30 MHz has been accomplished fairly haphazardly and ad hoc. With the advent of packet radio, it has been difficult in major metropolitan areas to coordinate use of spectrum. Repeater links have been traditionally placed in bands close to repeaters, because of the availability of equipment, and economy.

Ultimately, some changes need to be made in bandplans for the Amateur Service. In particular, it is recommended that stations in Auxiliary Service (as defined in Part 97.86) should be relocated to frequencies above one GigaHertz. Terrestrial digital links, used to interconnect multiaccess networks, should also be placed in the microwave region. In turn, multiaccess digital networks should be placed in the Amateur VHF and UHF allocations.

References

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