On the Subject of Spectrum Sharing

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Introduction

In this white paper it is argued that spectrum sharing by unrelated parties, using methods other than traditional frequency division multiplexing, presents difficult engineering challenges and difficult business/regulatory challenges that are far greater than those associated with traditional frequency division multiplexing… even though, theoretically, new methods of spectrum sharing, such as spread spectrum methods, are mathematically equivalent to frequency division multiplexing.

Traditional Frequency Division Multiplexing

Traditional sharing of the spectrum by using frequency division multiplexing… i.e., different users utilize different, non-overlapping bands of frequencies, is relatively easy to implement (from an engineering perspective) and manage (from a business and regulatory perspective) because it is technically and economically feasible to implement band-limiting filters that have very high levels of blocking of unwanted frequencies (e.g., easily greater that 70 dB of attenuation of adjacent frequencies), and that have very high dynamic range (i.e., they will not have problems separating very strong signals that are well outside of the "passband" from very weak signals inside of the passband*). It is the very nature of frequency division multiplexing (the use of sinusoidal "basis vectors") to be compatible with frequency separation methods based upon passive components (inductors, capacitors, mechanical filters, crystal filters….) that have these desirable properties. One can implement filters using modern digital signal processing methods… and this is often done in modern radio transmitters and receivers. However, the imperfections of analog-to-digital (A/D), and digital-to-analog (D/A) converters, limit the dynamic range of "digital filters". Thus, to ensure that systems using non-overlapping frequencies bands do not cause harmful interference, transmitters and receivers often supplement digital filters with traditional analog filters (in the front end and 1st i.f. stages of the receiver, and in the final stages of the i.f. chains, and the r.f. stages of transmitters).

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*Since radio frequency signals experience a very wide range of attenuation values as they propagate through a real environment… and since radio frequency receivers can function properly with received signal levels that are very tiny (e.g., -110 dBm received signal level, compared to the greater than 0 dBm level of the transmitted signal) it is very important that the receiver be able to separate a very strong interfering signal from a weak desired signal.

It is relatively easy to determine, with simple, inexpensive, and easy-to-understand measurement equipment, whether or not a given transmitter is emitting signals outside of the band of frequencies that it is authorized to be using; and whether or not those spurious emissions are within prescribed limits set by the FCC. It is relatively easy to determine, with simple, inexpensive, and easy-to-understand measurement equipment, whether or not a given receiver is overly susceptible to harm caused by signals that are outside of the band of frequencies it is intended to be sensitive to.

Combining Traditional Frequency Division Multiplexing with Spread Spectrum Techniques

Case 1. Spread Spectrum Techniques Employed by Unique Administrative Entities within Non-Overlapping Frequency Bands

It is well known that 2nd generation cellular systems employ modern spread spectrum techniques. Even the consumer name, "CDMA", captures one of these methods. [One can also consider TDMA as a spread spectrum method… but some experts might not think of it as such].

What is less well known, even among some academics teaching courses on modern telecommunications technologies, is that 2nd generation cellular systems, operated by different administrative entities (e.g., Verizon, Cingular, AT&T), do not operate in overlapping frequency bands. In CDMA systems, the overall (aggregate) band of spectrum available for use by cellular operators (e.g., 20 MHz) is divided into non-overlapping bands of frequencies that are 1.25 MHz wide. Within a given 1.25 MHz band, the associated system operator (e.g., Verizon) may employ spread spectrum techniques to increase the effective utilization of that band (i.e., number of customers that can be simultaneously served in a given geographical area)… but no other cellular systems, within the same geographical area, operate in that band.

Naturally, when a single administrative entity operates a system or network that employs spread spectrum techniques… that administrative entity is highly motivated to resolve any harmful interference problems that arise as the result of the signals being produced and the equipment being employed within his own system. It makes no business sense for the chief engineer of that administrative entity to be pointing his finger at himself. Therefore, the administrative entity will quickly take whatever steps are needed, at its expense, to resolve its own harmful interference problems. It may seek technical support and subsequent compensation from the suppliers of its equipment… but litigation, if any, is an after-the-fact (i.e., subsequent to resolution of the harmful interference) matter.

Since different administrative entities use non-overlapping frequency bands (traditional frequency division multiplexing) it is relatively easy to determine whether or not a system operator is generating spurious signals (outside of his assigned frequency band) that are in excess of what is permitted under FCC rules. It is relatively easy to design cost-effective transmitting equipment in such a way as to ensure that such spurious emissions do not occur; and it is relatively easy to design cost-effective receiving equipment to be sufficiently insensitive to strong signals on frequencies outside of the band of frequencies that it is intended to be receiving.

Case 2. Multiple Administrative Entities Employing Spread Spectrum Techniques to Share Overlapping Bands of Frequencies

It is well known that the FCC has designated certain bands of frequencies as “unlicensed bands”. In those bands, various spread spectrum techniques are employed to enable uncoordinated (e.g., administratively unrelated) users to share the available spectrum in a shared geographic area. Examples of applications of technologies that use these unlicensed bands are: 802.11x local area networks, cordless telephones, wireless point-to-point links, etc.

To the extent that users of the unlicensed band manage to avoid, or are willing to tolerate operational problems caused by excessive interference (reduced throughput, erratic operation, the need to “find a good spot” to operate their equipment), and to the extent that users manage to cooperate to alleviate interference problems that do occur… sharing of a band of frequencies using spread spectrum methods is a very cost effective and administratively easy approach.

However uncoordinated sharing of a band of frequencies by administratively unrelated users is likely to result in significant, difficult to resolve conflicts among users who do not share a spirit of cooperation because:

As in any other radio frequency wireless methodology, the systems must be designed to accommodate a very large amount of attenuation between a transmitter (output ~ 0 dBm) and a receiver (minimum required signal typically -80 dBm or less, depending upon the data rate), and thus one has to design the system to accommodate a very large interfering signal (from a nearby transmitter) while receiving a very weak desired signal.

However, because of the technical limitations of receivers and transmitters which employ spread spectrum techniques (e.g., limited transmitter output stage linearity, limited dynamic range/linearity of the receiver front end, limited accuracy of A/D converters that are employed at i.f. or baseband), a combination of engineering design errors, component variations (a bad A/D converter, a bad r.f. or i.f. amplifier stage), and uncooperative operational approaches (I don’t have to outrun the bear, I just have to outrun you) will lead to difficult-to-diagnose, technically complex (extremely hard for a technical expert, not to mention a regulator or a juror, to understand) cases of harmful interference.

Conclusion

While spread spectrum techniques offer the possibility of more efficient use of available spectrum, and also the operational benefit of uncoordinated spectrum sharing… the FCC should be concerned about the serious practical difficulties of employing pure spread spectrum techniques (as opposed to combinations of spread spectrum and frequency division multiplexing) among administratively unrelated users.