CHAPTER 1

In Pursuit of Bandwidth Efficiencies for Wireless Terrestrial and Satellite Communications

1.1 Introduction

To the world in general, the term wireless communications implies personal telephony as manifested by handset communications, or simply radiotelephony. To others, wireless connotes different services such as paging, which displays text and numeric messages (one-way or two-way, e.g., Motorola's Pagewriter 2000). To some it means short-range cordless telephone (CT-2, DECT), and to others data transmissions, which are in the nascent stage but will increase with the use of handheld computers. Whatever wireless communications means to different people, it is anticipated that the demand for mobility will make wireless technology the primary source of voice communications in the future.

To date, the route taken to the above services has been mostly via terrestrial means, but emerging satellite-based personal communications providing voice and data are coming to fruition and will provide ubiquitous and seamless wireless connectivity globally. Witness the non-geostationary satellites (LEOs and MEOs), e.g., IRIDIUM, Globalstar, IOC, which are operational or near operational. These will provide voice, paging, fax, and messaging to fixed and mobile locations. The world's appetite for high-speed data services continues to grow and satellites appear to be the next best delivery system for high-speed access to the Internet, e.g., Teledesic (Gates, McCaw, Motorola), Skybridge (Alcatel). However, because of the limited power provided by satellites and mobile ground transceivers and a substantial building RF-altenuator, the link margins are not adequate to provide voice service directly into buildings.

From its humble beginnings in the early 1980s, using analog modulation (AMPS, IS-553, NMT, TACS) untethered personal cellular communications (voice) has experienced unprecedented growth, and has become a leviathan encompassing the entire globe. The trend now is to more efficient digital communications with added attributes above analog systems. These include voice mail, caller ID, call waiting, call forwarding, paging, and lately Email.

Wireless voice networks span a broad range which stretches from local cordless telephones to global satellite delivery systems. In the U.S. alone, there are more than 70 million subscribers and this number is growing. Worldwide, the number is close to 250 million.

Concomitant with this growth has sprouted a host of technical and regulatory problems which require solution. Clearly some are extensions of wireless technology, while others are peculiar to wireless service. For example, multi-path fading demonstrates statistical variations in signal levels, which are more hostile than AWGN (Additive White Gaussian Noise) and affect the BER. Fading also introduces bursty errors (continuous error bits), which can be handled using Reed-Solomon codes and frequently complemented by interleaving, or by employing the latter method singularly. Delay spread (frequency-selective fading), in which a bit arrives at the receiver at different times because of the different paths taken, causing bits to run into each other and thus cause inter-symbol interference (ISI), limits the usable digital signalling rate for a given error rate. This problem has been combated by equalization in the receiver. The use of spread spectrum can temper this delay effect since delay is frequency-sensitive and the wide spectrum allows most frequencies to pass unscathed.

Co-channel interference in cellular systems, where spectrum is shared by frequency reuse, is also a problem because of the proximity of the cells to each other. Here, digital systems also ameliorate this problem. In analog cellular systems, e.g., AMPS, the FM threshold criterion for C/I is about 17 dB. In digital systems, the acceptable threshold C/Is are in the range of 7-14 dB. The other source of interference is intra-system interference, resulting from inter-symbol interference. Both limit the number of users supported by a system.

On the other hand, handsets provide a host of problems, including packaging high-density circuits in a limited volume, i.e., removal of heat and poorer consumption. MMIC (Monolithic Microwave Integrated Circuit) and VLSI (Very Large Scale Integration) technologies alleviate these problems by providing adequate battery power to ensure long talk and standby times, nevertheless, this continues to be a problem. Of course, transceivers that are small and moderately priced are also important. Economies of scale in manufacturing and distribution exert a downward trend in cost. However, price in some instances is not a factor, since organizations will sell transceivers at a nominal price to have users sign up for the service.

From the early days of analog systems, the trend has been to move toward digital communications. Benefits accrue from the use of digital communications, including efficient modulation schemes, use of error correction coding, use of interleaving, increased voice activation (picks up almost a factor of two in capacity improvement), both voice and data compression, use of networks to combat multi-path fading (intra-receiver time diversity RAKE, adaptive equalization), and security.

All digital communications use low bit rate speech coding to increase system capacity, but are not necessarily accompanied by an improvement in voice fidelity (contrary to what one reads in the open literature); in fact, they may even degrade it. Toll-quality voice (Mean Operating Score) (MOS : 4.0-4.5) is hard to come by at these low bit rates. Wireless digital voice now falls in the “communication quality” range with a MOS in the range of 3.0-4.0 (MOS: mean operating score – figure of merit of voice quality).

We must also realize that the use of some of the signal processing schemes alluded to above introduces delays which may not be insignificant. Clearly, they are not as severe as those found in Geostationary Satellite Orbit (GSO) satellite transmissions (>250 ms), but nevertheless they could be a problem, especially when there is a concatenation of networks. Some of these delay problems associated with satellite transmissions have been avoided by going to wireline fiber and other *quasi*-terrestrial means (low-orbit communications satellites (IRIDIUM, Globalstar, Intermediate Orbit Communications (IOC)).

The advent of digital has forced researchers to use different types of signal formatting, which are incompatible with each other. In the U.S., there are three interim standards[1] that appear to predominate: IS-54 (136) or D-AMPS, IS-95 (CDMA), and GSM (in PCS-1900). A popular modulation scheme includes the GSM constant envelope GMSK (Gaussian Minimum Shift Keying), which has a spectral efficiency of 1.3 b/s-Hz. This is an elegant signal format which is insensitive to received signal amplitude fluctuations. It also allows the use of efficient Class-C amplifiers without fear of spectral regrowth. On the other hand, where there is a paucity of spectrum, spectral efficiency prevails with IS-54, which uses $\pi/4$-DQPSK (with a 35% filter roll-off factor, Nyquist), and which has a theoretical efficiency of 2 b/s-Hz (practically 1.6 b/s-Hz). This modulation normally requires the use of less efficient Class-A amplifiers (to prevent spectrum regeneration), adding more weight to the handset. Constant envelope

1. The U.S. (FCC) has not established a digital cellular standard.

modulation systems are generally less efficient than linear modulation systems like $\pi/4$-DQPSK. The CDMA (Code Division Multiple Access) standard IS-95 uses direct sequence spread spectrum with QPSK/BPSK modulation. It has a spectral efficiency of 0.98.

All proponents of the above standards claim to provide greater capacity than the U.S. entrenched FM-AMPS system. Claims of up to 20 times greater improvement have been bandied about. And, claims of near toll quality voice fidelity are suspicious. It is realistic to expect that both of these claims are inflated.

It is unfortunate that these systems are not mutually compatible, which in turn suggests that handsets must be multi-mode types to operate and enable roaming different parts of the country and the world. Europe has basically agreed on the digital GSK standard. Therefore, roaming is possible in most of Europe.

Significant capacity improvement results have been realized with cellular systems. A capacity increase has also been realized by cell sectorization (3-6), which is facilitated by the use of directional antenna beams.

A more recent emerging technology that is showing considerable promise is the smart antenna system. As stated by Dr. A. Viterbi, "Spatial processing remains the most promising if not the last frontier in the evolution of multiple access systems." Essentially what he is saying is that dynamic space diversity, or space division multiple access (SDMA), is necessary to further increase capacity, above using classical means, by increasing C/I and reducing ICI. This results in smaller cell clustering ($N<7$). This area includes switched multiple beams and adaptive arrays of the Widrow genre. In smart antenna systems, the basic building blocks are array structures consisting of multiple antenna elements. Their application is now limited to fixed base stations where "real estate" is available, but not at the user transceiver level. These concepts, and others indicated above, will be discussed in subsequent sections of this book.