Considering Next-Generation Amateur Voice Systems

Jon Bloom, KE3Z

ARRL Laboratory

ABSTRACT

Next-generation voice systems are a logical outgrowth of high-speed networking. Replacement of existing systems (repeaters), which is needed to address the current spectrum-use problems, must be preceded by design of appropriate multiple-access systems. Some of the key issues to consider are analog vs. digital modulation schemes and the types of multiple access arrangements.

1. The role of computer networking in voice communications

It may at first seem odd to give a paper about next-generation voice sys terns at a conference devoted to computer networking. But this reflects a trend: computer networking is becoming less about computers and more about applications. That is, the availability of high-speed digital networks evokes new classes of applications, ones that have little or nothing to do with classical "computer networking." For this conference to consider the subject of voice communications systems is simply a recognition of that reality.

Most of the communication carried across existing amateur digital systems is text. But most of the communication amateurs ***do*** is by means of speech. This is hardly surprising; most human communication is by way of speech. So the predominant amateur communication systems in use today are those that are designed for voice communications. On the VHF and higher frequencies, analog voice repeaters are the principal means of communication. The underlying premise of this paper is that speech will continue to be the means of choice for most amateur communication. The issue to be addressed, then, is in what way the advent of high-speed digital capabilities can and will change the way in which voice communication is accomplished.

2. Limitations of existing systems

Present VHF voice systems' use analog FM single-channel-per-carrier (SCPC) transmissions. This is a technology developed in the period following World War II. Except for implementation details (the use of solid-state circuitry, for example), this technology has remained essentially unchanged since the 1960's. While the fact that a technology is more than twenty years old doesn't count against it, a twenty-year-old technology that hasn't changed perceptibly in that period can be assumed to be mature: little further improvement can be obtained by refining that technology. If technological improvements are needed in amateur voice communications, it seems unlikely that analog FM SCPC systems will provide them. Certainly the experience of other services, such as Land Mobile, which have strong economic incentives for the improvement of the technology, indicate that a technological plateau has been reached.

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[1] This paper neglects HF voice circuits. While HF has a role in providing long distance point-to-point circuits, it has little foreseeable role in a general-purpose voice system.

Are improvements in voice systems needed? Consider these attributes of existing repeater systems:

- ***Poor frequency reuse of voice channels.*** Although amateur frequency reuse has yet to make full use of existing techniques (CTCSS, for example), applying such methods would cause only an incremental improvement. If a large number of (codeless?) licensees are to be accommodated in existing spectrum, more spectrum efficiency must be obtained.[2] Frequency reuse is a key to efficient use of the spectrum, but existing wide-area repeaters that can tolerate no interfering signals at levels above the receiver noise floor are near-worst-case systems with regard to frequency reuse.
- ***Idle channels.*** In major urban areas of the US, at least one of the available amateur VHF bands, and often two or three bands, are full of repeaters. That is, in the segments of the band reserved for repeaters, every channel is occupied. But many of these repeaters sit idle most of the day, coming to life only during "drive time." While peak loading performance is an important measure of any communications system, there are better ways to deal with it than having idle channels for most of the day.
- ***Encroachment of packet.*** To date, packet radio has made use of narrow-bandwidth systems. In areas where voice repeaters "own" all of the existing repeater allocations, packet is relegated to use of simplex techniques. At present no efficient simplex channel-access mechanisms are in widespread use. Because of this, packet users are making use of more channels to achieve lower per-channel loading, or are using repeater pairs for duplex packet systems. This, plus the push to higher speeds and concomitant higher bandwidths, is beginning to cause friction between packet and voice users. Packet systems are evolving, however, which provides an opportunity to address part of the problem in the design of new packet systems.

But at present, voice systems are ***not*** evolving. To address the issues noted above, amateurs need to design and implement new voice systems.

3. Amateur vs. cellular

Amateurs are not the only ones looking to the development of new voice communication systems. Cellular phone services (and others) are evolving designs to meet their voice communication needs. Since huge amounts of research and engineering are being devoted to these efforts, it might seem that amateur system designers should wait and benefit from these efforts by applying the techniques developed for cellular systems. But there are some striking differences between the amateur environment and the commercial mobile communications environment. These differences may mean that designs optimal for commercial service are anything but optimal for amateur service. Some of the key differences:

- The commercial systems will handle primarily station-to-station communications. Little if any broadcast or party-line facilities will be provided; there isn't much need for it. But the amateurs do need such services. The ability of amateurs to call CQ is important. Any type of communication that is point-to-multipoint in nature, or in which the initiating user may not know the identity of the station he is calling, requires a class of service that commercial systems are not being designed to optimize, if indeed they offer it at all.

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[2] The oft-mentioned "moving to higher bands" solution is illusory. Microwave bands hold great promise for point-to-point circuits, but mobile operation becomes difficult at higher frequencies, and mobile operation comprises a significant part of amateur voice use.

- One of the factors driving the design of commercial systems is the need for security. Encryption of voice signals is highly desirable in a commercial radio environment. Amateurs have an exactly opposite requirement: amateur systems must be capable of being monitored. More, they should ***encourage*** monitoring in order that self-policing be effective.
- The economic base for the construction of amateur systems is significantly different from that for commercial systems. While commercial operators (presumably) can afford to use a large number of stations to achieve near-total coverage of a given area, this often is not the case for amateurs. In areas of hilly terrain or urban, it is difficult to avoid regions of poor coverage, and amateurs are unlikely to be able to resort to large numbers of cell sites to get around the problem.
- While commercial systems are highly reliable, the need for amateur communications is greatest in precisely those circumstances where commercial systems fail. In such circumstances, a tightly-coupled, centrally controlled system is likely to be unworkable.

The economic factors and the reliability factors argue for wide-area coverage systems. Monitoring of amateur communications will be easier in such an environment, as will point-to-multipoint applications. This is philosophically at odds with the commercial cellular approach. How much of commercial practice will be transferable to amateur systems is an open question, but it seems likely that the amateur architectures will differ from the commercial in more than name.

4. Future Amateur Voice System Capabilities

Let us assume that the locations of stations won't change significantly: repeaters will still be located at heights that provide wide-area coverage, fixed amateur stations obviously won't move, and mobiles will be... mobile. Only the characteristics of the stations will change. How must the characteristics of these stations change in order to solve the kinds of problems described above, and what useful additional services can be included in next-generation systems?

To accommodate increased traffic, more channels need to be available[3] From an economic standpoint, it makes sense to occupy more channels not by putting up more repeaters, but by making existing repeaters service more channels (i.e., repeaters will become multiple-access systems). At the same time, a capability for full-duplex voice communication is highly desirable. Finally, repeaters should be able to operate together in a network (using the high-speed networks under development now) to increase communications range.

Fixed and mobile stations should include both half- and full-duplex capability. They should be able to communicate via repeaters or directly, just as they can now. New applications such as store-and-forward (voice-mail), "call waiting" etc. can be designed into the system. For mobiles, especially, integration of data and voice capability into one unit would be useful.

[3] In this context, "channel" does not (necessarily) refer to a contiguous block of spectrum that carries a circuit signal. Rather, we use a broader definition of channel: a spectrum resource-a bandwidth for some period of time-that carries a single circuit.

5. Digital vs. analog systems

One of the key questions in designing future voice systems is whether to use analog FM techniques or digital techniques between the repeaters and the user stations. For a variety of reasons, it appears that digital is the way to go. Some of the advantages of digital techniques are:

- ***Error detection and correction capability.*** Digital systems can potentially detect errors in received data. Error correction can in turn be implemented using FEC or ARQ techniques. This capability could be most usefully exploited in adaptable systems, wherein degradation of the RF channel would cause the use of error handling. (Error control would increase the needed bandwidth, so it probably would not normally be used. Potentially, several steps of increasingly capable error correction could be available, trading bandwidth for channel performance as the need arises.)
- ***Data transparency.*** In analog voice systems, any digital data must be converted to voice-bandwidth analog signals. The resulting system, optimized for voice, does a poor job of carrying non-voice data. An all-digital system doesn't care whether the data being transmitted is voice, image or text. Only the endpoints are concerned with the real-world representation of the data. This is a much more flexible system. (An example: present repeater control systems use crude tone-signalling [DTMF] techniques to provide control capability. An all-digital system could send many times more control information in a much shorter time.)
- ***Spectrum efficiency.*** There are two trends of technology that hold great promise in the continued narrowing of digital voice bandwidth requirements. The first of these is the work being done in speech encoding (an example of one place where amateur systems can benefit from commercial technology). Speech encoding at speeds of around 16 kbit/s is a part of current commercial development efforts, and advanced vocoder designs are expected to produce acceptable speech quality at speeds as low as 4 kbit/s.[1][2] The second technological trend is that of digital signal processing (DSP). At present, the transmission speeds of mobile systems are limited to a few hundred kbit/s or so, a speed limitation that is carrier-frequency dependent.[3] The practical number of bits per baud is also limited to two or three.[4] DSP promises improvements in adaptive equalization that will improve those numbers, allowing us to squeeze more bits-per-second into a given bandwidth. (Note, though, that even present-day systems are perfectly workable, and can give bandwidths at least as narrow as present analog systems.)
- ***Interference tolerance.*** Although the FM capture effect provides a measure of tolerance to co-channel interference in analog systems, it is likely that properly designed digital systems will be even more tolerant, allowing greater frequency reuse. (Note that even the tolerance of FM analog is often not used in amateur systems. Systems without CTCSS access cannot tolerate any signal that will open the squelch.)
- ***Time-division multiple access (TDMA).*** As we will see shortly, TDMA has significant architectural advantages, and, while an analog TDMA system is possible, a digital TDMA system is far easier to implement.
- ***Security.*** A digital system can easily be designed to require an integral transmitter identification (call sign) in the data stream. This would provide traceability and debugging advantages.
- ***Newness of technology.*** One of the under-used facets of the amateur service is that experimental techniques can be tried out there without the need to produce a commercially viable system. Amateurs can build operational experience with new systems and, in so doing, add to the technology.
- ***Flexibility.*** Inherent in several of these points, but worth a mention of its own, is the ability of digital systems to change with the technology. For example, a system designed now would probably use speech coding rates on the order of 16 kbit/s. In a few years, when 8- or 4-kbit/s coding techniques are

accessible, existing digital systems could incorporate them without complete system redesign. In fact, such systems could be phased into service along with 16-kbit/s systems transparently to the user.

6. System Architectures

The architectural challenge is to devise systems that ensure that each station transmits in a manner that ensures reception by the intended recipient without unduly restricting the use of the system by other stations. Inasmuch as multiple access is required (see section 4), a key design decision will be to determine the best type of multiple access. Of the three classical techniques: frequency-division multiple access (FDMA), time-division multiple access (TDMA), and code-division multiple access (CDMA, or spread spectrum), we can select one or more or a combination of techniques.

FDMA is the system used in current cellular phone systems. In these systems, channels are segments of the band that are wide enough to contain the FM voice signal. They are no different from amateur repeaters in this respect. But in cellular systems, channels are assigned *on demand.* Such a controlled mechanism is a requirement in any useful multiple access system.[4] Cellular systems simply assign a particular frequency to the calling station for the duration of the call. This seems simple enough, and in an analog world it's by far the easiest approach. But it requires that the cell-site (or repeater) have multiple receivers and transmitters, an expensive proposition for amateurs. If full-duplex communications are required in an FDMA system, the fixed and mobile units must be capable of receiving and transmitting at the same time; a duplexer is normally required for this. However, in a digital FDMA system the transmitted bit rates are lower than in an equivalent TDMA system. This has advantages, not least of which is that bit periods can be relatively long compared to the delay-spread times.[5]

In a TDMA system, each station takes turns sending a burst of data on a particular frequency. This has the advantage of requiring only a single receiver and transmitter at the repeater, and allowing full-duplex communications *sans* duplexer. Also, by not fixing the channel bandwidth TDMA provides for more flexible selection of data rates: if a higher data rate is needed, the bursts of data are simply made longer. This latter characteristic may override other considerations.

CDMA, or spread spectrum has utterly different characteristics from either FDMA or TDMA. Spread spectrum operates by spreading the signal out over a large band of frequencies. One method of spread spectrum, *frequency **hopping,*** simply rapidly changes the frequency of the transmitter. The associated receiver "knows" the sequence of frequencies and follows along. Several such systems operating in the same band of frequencies can operate with little interference. In ***direct sequence*** spread spectrum, a high-speed (quite a bit higher than the data rate) pseudo-random bit stream is mixed with the signal to "spread" the transmitted spectrum. The receiver mixes what it receives with the same bit stream, resulting in a copy of the transmitted signal.' Adding stations to the band in such a system simply makes the apparent noise level increase, so interference degrades communication rather than interrupting it. CDMA has the advantage that the signal can be spread beyond the *coherence **bandwidth.*** This reduces the susceptibility of the system to multipath effects, which is particularly attractive for mobile applications. CDMA has great potential, if little operational history.[6] Amateur efforts have proved promising,[6] but it seems unlikely that CDMA will be the

[4] For a demonstration of why control is a requirement, listen to any CSMA simplex packet channel. 145.01 MHz will do in most areas.

[5] One of the technical challenges of spread spectrum is to keep the transmitter and receiver bit streams synchronized.

[6] The military has been using spread spectrum for years, but they aren't too forthcoming about the technical details.

technique of choice for next-generation amateur systems.[7]

7. Conclusion

Next-generation voice systems are a logical outgrowth of the push toward high-speed networks, so designing systems now to accommodate voice data is prudent. Such systems can address some of the spectrum-management issues facing amateurs today and can provide enhanced voice capabilities as well as integrated voice and data. The technical challenges of designing and implementing such systems will open up a world of interesting experimentation and building such as has not been seen in amateur radio in recent times. Some aspects of the possible approaches have been discussed here, hopefully in a way that encourages amateurs to begin serious consideration of next-generation voice systems.

References

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[5] Calhoun, p 366

[6] Kesteloot, André, N4ICK, "A Practical Direct-Sequence Spread-Spectrum UHF Link," *QST*, May 1989, p 14

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[7] The author is willing to be convinced otherwise.