QRM, Packet Satellites and Spread Spectrum

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Digital messaging satellites designed for general use may attract considerable user interest. High interest will mean heavy interference on the satellite uplink channels, which could make the satellite useless. This paper discusses the characteristics of this interference, and proposes a solution using spread-spectrum technology.

INTRODUCTION

The amateur radio community has a long and successful history of building and launching its own small satellites. Most recent amateur satellites have contained communications payloads designed for general use. Every "ham" whose equipment was up to the task was encouraged to communicate through these satellites.

Almost all of these communications payloads have been analog transponders ("linear translators"), which simply shift the frequency of an incoming signal, amplify it, and rebroadcast it. No other processing is done. The simplicity of this scheme has allowed the amateur satellite community to escape certain potential problems. With the advent of digital messaging ("packet radio") transponders on amateur satellites, these problems must be addressed.

For such a high-technology activity, amateur radio is remarkably unstructured. The government specifications for amateur radio gear primarily ensure that it won't interfere with non-amateur radio. No two hams have the same set of equipment, much less the same procedures for operating their equipment. Coordination of frequencies, modes, operating schedules, and so forth is done by small groups who wish to communicate among themselves, but very little coordination is imposed on the hobby as a whole. This lack of structure has many advantages; it allows the sort of freewheeling experimentation which has produced so many breakthroughs in radio to date. Unfortunately, the lack of structure also has a dark side, known to every ham as QRM.

QRM

QRM is a term used by amateur radio operators to describe interference from man-made sources. It generally refers to the phenomenon of two or more transmitters trying to use the same frequency at the same time. Sadly, QRM is often deliberate, and often destroys any possibility of communication. The best example of this is the extreme form of QRM known as a "DX pile-up."

Many hams like to talk to stations from unusual or far-off places. Such stations are called DX, from "long distance." DX signals tend to be weak, due to distance and power limitations. Unusual DX stations attract quite a bit of interest. Clipperton Island, for example, is only heard for a week or so every few years. When Clipperton goes on the air, everyone wants to talk to them. Human nature being what it is, everyone tries to talk at once. This creates the pile-up.

When the DX station finishes a conversation with one ham, hundreds call to request the next. Each ham turns his station up to maximum power, attempting to be heard over the din. The cacophony of hundreds of high-powered stations obliterates the weak DX signal. Since no one can hear the DX station reply, everyone keeps calling. The DX station eventually gives up and switches to another frequency—or switches off and goes home. The pile-up eventually disintegrates from sheer exhaustion. No one ends up happy except the power company.
Hams have developed a partial solution to the problem of DX pile-ups. This solution is a crude form of frequency-division multiplexing, known as split-frequency operation. The DX station transmits on a particular frequency, but listens on a different frequency, say 20 kHz higher. The pile-up occurs on the DX listening frequency, but everybody can still hear the DX station. In this way, the DX station can work any station whose callsign he can hear in the pile-up. This is only a partial solution; the pile-up continues, but communication can take place despite it.

Hams were able to discover the pile-up problem, and work around it, because everyone on the frequency could hear exactly what was going on. The QRM was loud and clear in everyone's headphones. Unfortunately, this is a quirk of the communications system used for DX contacts, not a general property of QRM. In general, your signal can easily be jammed by a signal you cannot hear.

**QRM IN SPACE**

Satellite communications are especially prone to this "invisible" QRM. The best examples of this to date come from the "Ham-in-Space" missions, in which an astronaut ham operated an FM transceiver from the Space Shuttle. An astronaut in space is obviously rare and exciting DX. As you might expect, there was a pile-up. But it didn't sound like any pile-up hams had ever heard before.

As the Shuttle crossed over the United States, hundreds of hams on the ground poured thousands of watts into space. The receiver on board the Shuttle heard every ham within the Shuttle's "footprint," a circle 1500 miles across. Unlike shortwave, an FM receiver cannot handle multiple signals. A pile-up on FM sounds like dead silence. The astronaut ham saw his S-meter pegged, indicating a very strong incoming signal, but no sound came from the radio speaker. This was very confusing. The pile-up was not only eliminating any possibility of communication, it was also hiding the fact that a pile-up existed.

Meanwhile, the hams on the ground were baffled. The curve of the Earth hid all but a few hams from each other, so most thought the uplink frequency was clear. Their equipment seemed to be working properly, and they heard the astronaut's periodic calls asking for contacts, but no one seemed to be getting through. It was all very confusing, and it took most of the first Ham-in-Space flight to figure out what was going on. The hundreds of hams trying to talk to the Shuttle were simply jamming each other in an invisible pile-up.

**QRM IN PACKET RADIO**

Hams have observed similar phenomena in terrestrial packet radio networks. Packet radio is a way of transmitting digital data reliably over the radio. The computer transmitting a stream of data breaks it up into chunks, or packets, and calculates an error-detection number for each packet. A computer which receives a packet recalculates this number on the data which it received. If the received packet contains an error, the two numbers won't match. When this happens, the receiver discards the erroneous packet, and the transmitter tries again.

Packets are transmitted using an algorithm known as Carrier Sense Multiple Access, or CSMA. This complex acronym translates to "don't interrupt." When a transmitter is ready to send a packet, it listens first to make sure no one else is using the frequency. This works reasonably well when every station can hear every other.

The typical amateur packet radio system uses low-power FM transmitters, with a range of 5 to 50 miles. Hams who wanted to extend this distance invented the "digipeater." A digipeater is an autonomous packet radio station which simply rebroadcasts packets addressed to it. Digipeaters are typically placed at sites which give maximum range: towers, mountaintops, and such.
Digipeaters often have such good range that they can hear two packet stations which cannot hear each other. This is where the packet system starts to break down, because the CSMA algorithm depends on all stations being able to hear one another. Suppose station A is sending a packet to the digipeater while station B has one ready. Under the CSMA algorithm, B will listen to see if the channel is busy. B doesn't hear A, on the other side of the mountain, so B goes ahead and transmits its packet. But the digipeater hears both A and B. The two packets clobber each other, and neither gets into the digi. Packet radio gurus call this the "hidden transmitter" problem.

Note that neither A nor B knows that they jammed each other. They only know that their packets did not go through. Packets can be clobbered by many things, from equipment failure to lightning. For that matter, even the digi doesn't know exactly what happened. All it knows is that it received a string of errors while signal strength was high. Again, many things could cause this. A human at the digi site, listening to the changing signals on a FM radio, might be able to tell that QRM was the cause, but that's a skill we can't yet teach to a computer.

**PACKET RADIO SATELLITES**

Packet radio is currently a short-range medium. In the interest of expanding their range of communication, packet enthusiasts have proposed packet radio "transponders" for amateur spacecraft. A packet radio satellite is seen as a digipeater or computer "bulletin board" in the sky. Several amateur radio groups have built satellites carrying packet radio equipment, and several more packet satellites are currently awaiting launch.

Most amateur satellites to date have carried analog transponders, which behave much like shortwave radios: when a pile-up begins, everyone can hear it. As we have seen, this is not the case with packet radio. A pile-up on a packet radio satellite would mean that none of the competing packets would get through. Hearing no valid packets, the satellite would never respond. The amateurs on the ground would be left to wonder what was wrong, just as they did during the Ham-in-Space missions.

To date, three satellites with packet radio payloads have flown. The experience with these satellites has been much better than this discussion would suggest. The reason is that these satellites are not terribly popular. Very few hams are both equipped and motivated to access them.

The Microsats, the new generation of packet satellites currently awaiting launch, are more "user-friendly." More hams will upgrade their packet stations to talk to the Microsats. Will the Microsats trigger the first packet pile-up in space? If not, it is not long in coming. The packet community agrees that the next step is to build packet satellites which can be used by any packet station, with minimal modifications. In the United States alone, there are some 100,000 packet users. The potential for a problem should be clear.

The professional satellite community solves interference problems administratively. Each satellite is controlled by an organization which can grant or deny permission for any user to transmit to the satellite. This operations concept works extremely well in practice. Unfortunately, it requires a highly structured user community. This degree of structure is not feasible and not desirable in amateur radio.

The amateur community cannot be forced to cooperate, even to reduce interference. But they can be encouraged to cooperate, and satellites can be designed to tolerate interference. One viable design for an amateur packet radio satellite involves the use of direct-sequence spread-spectrum technology.
An ideal amateur packet radio satellite would have a number of uplink channels. Each user who wanted to connect to the satellite would be assigned a channel, up to the total number of channels the satellite has available. Additional users attempting to connect when the satellite is "full" would have to wait their turn, until one of the connected users signed off (or was kicked off for overusing a valuable resource). Ideally, the additional users clamoring for connections would be completely ignored by the satellite, and would have no effect on ongoing connections. Furthermore, ground stations conversing among themselves on the uplink frequencies would also have no effect. Finally, there should be little or no additional cost to the user ground stations.

That's the ideal. Fortunately, a system which closely approaches that ideal can be designed using a technique known as direct-sequence spread spectrum. In this technique, a transmitted signal is phase-modulated by a high speed pseudo-random (PRN) bit stream generated in a known manner. This has the effect of "spreading" the transmitted signal energy over a wide bandwidth. This spreading operation is its own inverse; the receiver "de-spreads" the incoming signal by phase-modulating it with an identical PRN bit stream generated in the receiver. The same operation that de-spreads the desired signal also spreads any interfering signals which are not already spread in the proper way. A spread-spectrum receiver thus has a significant advantage over a normal receiver in the presence of QRM.

The main problem to be solved in the design of a spread-spectrum communications system is the synchronization of the receiver's PRN stream with the transmitter. This can be done by synchronizing both transmitter and receiver to an outside signal, or by clever design of the receiver. The proposed satellite system uses the latter approach.

PROPOSED SATELLITE SYSTEM

The proposed amateur satellite system consists of one satellite and a large number of ground stations. The satellite downlink, and the receivers at the user ground stations, will be conventional. However, all uplink transmissions from user stations will be "spread" with the same parameters (PRN code and "chip rate," or speed). The PRN sequences will not be synchronized to any outside source. The chip rate clocks will not be held to a precise speed, but will be allowed to wander over a range of a percent or so. These measures are deliberate, to ensure high odds against any two ground stations falling into synchronization for a long period. That is the only way in which ground stations can QRM one another in this system.

The satellite will contain one (normal) transmitter and several spread-spectrum receivers. The number of receiver channels is a matter for discussion. One satellite downlink channel can support a number of user uplink channels, but the exact number depends strongly on the style of user interactions. If the users are uplinking mail, and the satellite is merely acknowledging packets as they arrive, then the satellite can support perhaps sixteen users. However, if one user attempts to downlink a long file, than even two users may overload the downlink channel. Clever software design can multiplex a large number of users on one downlink, but there is an upper limit related to the average length of a satellite pass.

Each user ground station will transmit continuously from the time it first requests a connection until it ends the connection. Since the ground stations are unsynchronized, they will be transmitting different portions of the long PRN sequence at any given time. Thus, despite continuous transmission, and despite using the same PRN code and chip rate, ground stations will not interfere with each other (in general).

The continuous transmissions enable the satellite receivers to synchronize with a particular signal and remain locked on for the duration of the contact. The ground station's continuous transmissions must include the station ID every few seconds, to ease the satellite's task of finding new signals. The best way to accomplish this is for the ground station to repetitively send all unacknowledged uplink packets. If all uplink packets have been acknowledged, the ground station can repetitively send its last acknowledgement of a downlink packet.
The satellite receiver channel acquires signals in a two-step process. First, it scans through the PRN "code space," looking for any uplink signals. When it finds a signal, it locks its onboard PRN code generator to the transmitted signal, de-spreading it. That completes the first step. The second step is to listen to the uplink packets and make some decisions. If the uplink packet is addressed to another satellite, the signal is abandoned; the receiver de-synchronizes and continues its search. The signal is also abandoned if the packet is coming from a station which is already in contact with the satellite through another receiver channel or a station which the satellite has been told to ignore, or if the incoming packets simply do not make sense. If the new signal passes all the tests, the satellite sends a connection acknowledgement on its downlink, and contact is made. The receiver continues to track this signal until either side ends the connection. The receiver then falls back to search mode and repeats the process.

Because the PRN code generators at the ground stations are not synchronized to any external source, and because their clocks intentionally drift, there is a small probability that two ground stations may drift into sync with each other. This is the only way in which one ground station can interfere with packets transmitted by another. The ground stations, of course, will have no way of knowing when this happens. The satellite will see a long burst of errors; the receivers may even lose lock on the PRN codes. When the satellite receiver regains a clear signal, it will check that it is still hearing the same station it was hearing before the errors. If it has lost lock, it will search the incoming signals for the previous station. However, errors can be caused by things other than QRM. If the desired station is not found after a certain amount of time, the satellite will give up the search and contact the next acceptable station.

The optimum uncertainty for the ground station PRN clocks will be a function of the number of simultaneous contact attempts, the length of the average contact, the length of the PRN code itself, and the tolerable length of a contact interruption due to interference. Some of these numbers can be calculated, but others (e.g. length of a typical contact) must be derived from experiment.

Existing packet satellite ground stations will require minimal changes to work with this new scheme. Each ground station will need to insert a simple box between its transmitter and its power amplifier. The box will contain a spread-spectrum code generator (a couple of digital ICs) and a high-level mixer. These boxes can be mass-produced and distributed in the same manner as most of the packet radio gear has been to date. The ground station will also need new software for satellite contacts, a matter of changing a ROM or a floppy disk. These changes are easier than the upgrades required by the current generation of packet satellites.

This spread-spectrum mode of operation is fundamentally different from the CSMA technique used in terrestrial systems. The ground stations can almost never interfere with each other. The spread-spectrum receivers on board the satellite can select which stations to hear from the babble of connect attempts, much like a human eavesdropper at a cocktail party. Transmissions not synchronized with the receiver have no effect other than to raise the noise floor slightly; channelization is enforced at the RF level. A user station which connects with the satellite has good assurance that its packets will get through on the first try for the duration of the contact. This allows the station to transact its business and end the contact quickly, freeing up the channel for another user station.

This is not quite a perfect solution to the problem of multi-user amateur packet satellites. A perfect solution would involve no possibility of interference. In this solution, although the probability is low for any given contact, interference will undoubtedly occur. Nevertheless, this spread-spectrum uplink concept should be a vast improvement over the confusion which will probably haunt the Microsats.
CONCLUSION

This paper has described a potential interference problem facing the next generation of amateur digital satellites, and proposed a relatively simple solution to the problem. If all user uplink transmissions are encoded by direct-sequence spread spectrum techniques, the problem of user uplinks interfering with each other is greatly reduced. This solution gives an additional benefit of increased immunity against amateur signals not specifically directed at the satellite. As the packet satellite user community expands, some form of interference reduction will be necessary. Spread-spectrum schemes seem to hold promise for this application.

The views expressed in this article are those of the author and do not reflect the official policy or position of the Department of Defense or the US Government.

REFERENCES
