Global Frequency Management Using Cognitive Radio

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ABSTRACT

Global Frequency Management (GFM) is a daunting problem because agility is required to select transmission frequencies, at the moment they are needed while regulatory agencies may take years to approve frequency plans from the initial planning steps to becoming a regulated user. This problem is further complicated when the transmitting platform is mobile and may be anywhere on the earth. Typical scenarios may involve aircraft, missiles and satellites. Each platform has a need to communicate with a receiver that may be in the receptive field of interfering RF emitters. This resulting interference could introduce unstable to catastrophic outcomes for the platform mission. This paper describes some issues concerning dynamic frequency allocation and the use of cognitive radio concepts that suggest some functions for an operational protocol that may resolve some of the frequency allocation problems. The functions are compared to standard communications techniques to demonstrate that part of the solution may be a combination of adapted these techniques to the problem of GFM.

1. INTRODUCTION

Traditional frequency allocation is decided by a highly formalized process whereby applications and testing is done to grant provisional and then final spectrum rights for a particular mission to operate in specific regional areas. There are several regulatory and planning agencies that map out frequency allocation on a world-wide basis. History has show that even these best laid plans may become interrupted by unintentional users or malicious jammers trying to defeat the sanctioned users' communication. It is also apparent that the static allocation plans are not fit for the growing RF community that has limited spectrum, as airwaves that remain quiet for abundantly long time periods are not practical. Since few institutional things change rapidly, it is likely that automating a revised process will undergo a cautious and long transition. However, we believe that principles of cognitive radio may be applied to automate frequency management so that time, frequency, geo-location and signal direction may be exploited to increase the likelihood of successful transmissions between sender/receiver pairs. The prime automation concept requires that each platform be equipped with GPS sensing, attitude determination, and frequency power level monitoring equipment at the receiver. Once the receiver's ambient RF spectrum is known these data are passed to the transmitter to determine the best signaling waveform. The basic concept can be broken into a GFM functions that requires multiple steps;

1. Determine Location and Attitude
2. Allowable Frequency Bands for Geo-location
3. Measure receiver frequencies power
4. Pass transmitter ambient RF parameters
5. Transmit the usable time and frequency for receiver direction.
6. Update of Successive Transmissions.

2. FUNCTIONS OF A GFM PROTOCOL

The simplified GFM protocol was broken into a half dozen functions – all of which play a significant role in achieving higher reliability communications. This section will describe each function with enough depth with the hope to stimulate the community to engage in a broader definition process. An obvious cornerstone of cognitive radio is the capability to understand the transmitter/receiver environment. If the location, antenna pointing, and ambient conditions are all known about a potential link then the best combination of frequency and timing can be exploited to close that link.

2.1 DETERMINE LOCATION AND ATTITUDE

GPS location can provide accurate antenna pointing vectors for any system using antennas with directive gain. When transmitter and receiver positions and attitudes are know an accurate estimate can be made for pointing directional or phased array antennas. An ephemeris prediction model can be used to estimate the initial to final pointing vectors to any directive gain antenna.[1] This feature becomes very useful when there is a cluttered spectrum and a max power steering control algorithm could divert the receiving antenna away from the desired transmitter source.[2]

2.2 ALLOWABLE FREQUENCY BANDS FOR GEO-LOCATION

Positional data can provide any user with allowable frequency bands for their specific region. This is a feature that could be a hosted as server database by an international regulating agency such as the Joint Spectrum Office.[3] While these data may be slow to change, a pre-mission operation could download these frequency/geospatial allocations for the planned mission flight. Anomalies or changes to these data during the mission could be updated. One could envision either a database uplink or web-based downloading of these data based on incremental changes similar to Microsoft's automated patches to remedy bad code or enhancements to their software.

Another key concept in Frequency/Geo-location is to have an automated function that leases frequency-time bursts owned by the regulatory approved user to a requesting user. If the release is not granted, then that frequency/geo-location/time slot stays allocated to the traditional user/owner of that spectrum. This may be quite controversial as some bands are used for military and civil authorities, but others can and are leased at costly pricing to the highest bidder.[4] For cellular phones this is the equivalent of roaming charges by a non-member user. This model can and should be extended into other domains beyond cellular telephony.

2.3 MEASURE RECEIVER FREQUENCY POWER

Measuring the ambient RF power and duty cycle is a very useful way to determine the best operating environment. If the transmission system has keying and frequency agility it can exploit apriori knowledge of both time and frequency parameters that provide the lowest noise floor for their transmission. The CDMA 2000 standard exploits a similar technique by transmitting to multiple antennas, and rejecting input from all but the highest SNR signal.[5] Transmissions to the lower SNRs are terminated during that frame, so the noise levels injected into the non-receiving antennas are minimized; hence a quieter RF background. The process is repeated for each frame to accommodate user motion and channel changes.

A point-to-point link is the reciprocal scenario to CDMA 2000. There are multiple transmitters (one transmitter, several interferers) and one receiver present. It is possible to measure the interferer RF signals, and exploit any inter-pulse time periods or low RF levels for that time-space-frequency segment directed at the intended receiver. (Note that the space parameter is a vector direction of the transmitter to the receiver.) If an omni antenna is used, the space parameter is not required.

Another consideration of this measurement is to understand your geo-location and allocated mission frequencies so that the ambient frequency measurements are suited to allowable transmission frequencies.

2.4 PASS TRANSMITTER AMBIENT RF PARAMETERS.

The ambient RF parameter measurements provide a basis for the waveform definition of the transmitter. The transmitter in turn requires agile adaptation to circumvent the measured time-space-frequency that is already in use. This has several implications on the waveform implementation of the transmitter. For example, the measurement could identify a broad uncluttered slot with no time restrictions. The waveform controller has the liberty to assign a continuous single available frequency transmission. Alternately, pulse interferers could be periodically bursting as shown in Figure **1**. The three frequencies may produce pulsed characterized by amplitude, pulse width and arbitrary pulse repetition rates. The transmitter assignment algorithm would need to allocate frequencies in the time periods available, and remain quiet when the interference levels would degrade the intended transmission.

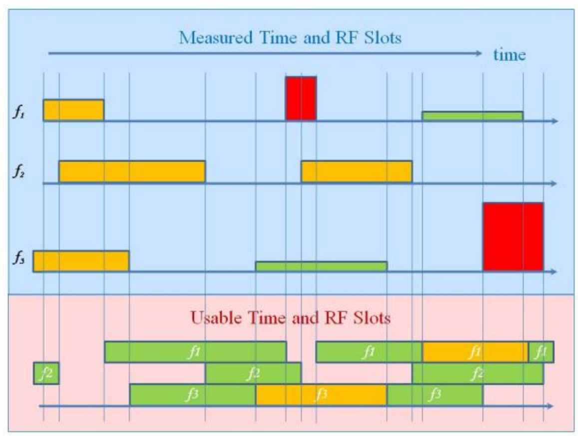

Figure 1. Measured and Usable RF Spectrum Slots

2.5 TRANSMIT THE USABLE TIME AND FREQUENCY FOR RECEIVER DIRECTION

The measurement algorithm requires constant RF measurement updates during routine signaling to insure the best SNR in a changing environment. This process can be a tradeoff between ambient RF measurement during the unkeyed portions of the transmission cycles, or adjusting the receiver SNR measurements to compensate for the known RF activity of the transmitter.

2.6 UPDATE OF SUCCESSIVE TRANSMISSIONS.

The simplified measurement and allocation of time-space-frequency slots is not a static process nor is it complete. The pointing vector between the transmitter and receiver may change during the mission contact due to platform motion. With each new pointing angle, a radiating source could either leave or enter the field of view of the receiver. Alternately, an interferer may be on a mobile platform and its negative effects may enter or leave the receptive field of the receiver. In either case a constant update of the ambient RF background is required in order to make choose the best waveform for the transmission.

3. OTHER CHANNEL LOSS EFFECTS

Effects from moving platforms introduce channel attenuation due to changing range and/or atmospheric density changes. Channel compensation effects may require data rate adjustments, and/or transmit power increases. In some instances a loss of signal will occur as the channel losses are insurmountable. This scenario is typical for a LEO satellite or missile platform that may follow a ground based link from horizon-to-horizon, and the dropped call with cellular phones. Figure 2. details air density change with altitude. The line integral of the density can be multiplied by calibrated data for attenuation vs. frequency at sea level (See Figure 3.) For K-band and higher frequencies the product of the integrated density times the attenuation coefficients becomes increasingly important. At K-band, water vapor and Oxygen can introduce a -54dB loss when compared to a sea level link versus a 20Km earth limb for the same range. Attenuation effects due to absorption are described in detail in the referenced work.[6] The saving grace for highly dynamic channel attenuations is also reliant on a cognitive radio design that measures geo-position and can estimate the channel attenuation by computing the line integral as described above.[7]

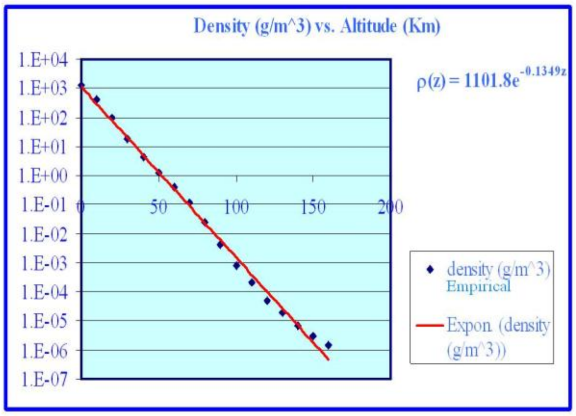

Figure 2. Attenuation due to Altitude Differences

4. PRACTICAL IMPLEMENTATION

This section describes the type of technology required to implement the various function described in section. Given today's technology with ASIC and FPGA manufactures, the functions mentioned in section 2. can be programmed into a unified system as routine tasks that would hardly challenge the performance limits of this technology.

4.1 GEO-LOCATION AND ATTITUDE

The GPS receiver is available in many formats and is matured technology. Part of each transmission is to share position between transmitter and receiver so pointing vectors can be determined for directional or phased array antennas. This can be combined with received power steering, but such algorithms run the risk of following jammers, or unintentional users. Attitude sensors will vary with mission, but this can be gyroscopic to celestial star maps with sensor registration equipment to attitude fix the platform relative to celestial coordinates. This type of equipment is typically on most satellites, to insure they can acquire their intended communications link.

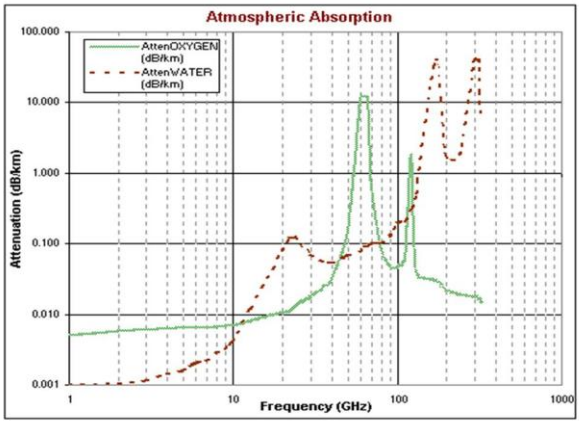

Figure 3. Atmospheric Absorption of RF Energy

4.2 ALLOWABLE FREQUENCY BANDS FOR GEO-LOCATION

A database is maintained by the Joint Spectrum Office and equivalent government agencies that details global spectral use. This is subject to international differences and oftentimes local allocations are not coordinated. Given coordination issues there are two potential alternatives that may assist in mapping out the current utilization of frequency spectra; the SIGINT community for identifying current RF emitter on a global basis, and developing a sharing plan so typically dormant spectrum/geo-location can be identified and possibly leased to increase their utilization. These alternatives assist with determining the "in use" spectra or leasing allocated spectra that is not in use.

The traditional frequency allocation database is relatively static. Customers petition the government to receive a frequency allocation that can vary from a test to a permanent global assignment. These allocations are generally geo-location and frequency band dependent, and the process may take years from the initial application to the final granting of the request.[8] Automation to this scheme requires a server or a pre-canned database that contains the latest agreements for frequency use, and geo-location.

This is an inefficient method, as a user community does not have continuous signaling over the entire earth hence frequency spectra can remain dormant by the static allocation. The rule also suffers from communities not adhering to this rule-set, and the potential for unintentional users to be emitting contrary to the established rule-set.

Possibly the best configuration for using frequency is to lease frequency-time slots on a demand basis from the current user community who has the rule set right to use this frequency. Roaming services for the cellular community are a perfect example of this concept. If such a scheme could be applied to other areas – then spectral bands that remain dormant for a majority of the time could be put into use. Spectral bands could be leased when dormant or used exclusively by the customer when they need them. For government owned frequency allocation, this could even assist to reverse the lack of funds associated with most communication programs. Cognitive radio techniques can implement an algorithm insuring that each lease is agile enough that the prime customer would not be impacted when they need the channel space. This technology is very similar to Demand-Assigned Multiple Access (DAMA) already in operation today on USN UHF satellite systems.[9]

4.3 Measure receiver power for the for frequencies

A global database could be formed with the cooperation of the SIGINT community which may be capable of detecting RF signal levels based on global geo-location. Since their equipment is likely to be broadband they could generate known frequency emitters on a global basis. This information can then populate a data base so prior frequency bands could be exploited for operation for specific geo-locations. This method does not rely on apriori ownership rule set rather it's a reflection of the current activity.

A more accurate measurement of the ambient RF background can be performed by using channelizer on board the receiver. This would provide realtime use of the spectra regardless of any rule set. Channelizers can digitize most IF bands and some of the lower frequency RF bands via discreet Fourier transform (DFT) algorithm. This technology can eliminate the need for down converters and other analog components that may be subject to drift and oftentimes have performance that is less that its digital counterpart. Channelizers can rapidly produce updates to power measurements. If the operational frequencies are above the Nyquist rate of DFT technology, then either tuned comb filters or sweep correlators can determine the relative power of each potential sub-band that the transmitter has capability to generate. These types of measurements will provide the best operating bands because they are realtime and specific to the receiver's antenna current background environment.

4.4 Pass transmitter ambient RF parameters

Any communication system that can provide the transmitter feedback concerning the received signal quality will work better than an open loop system. The key to passing such feedback parameters is the capability to support an orderwire-like service that constantly updates this quality-of-service (QOS) information. For example, if the transmitter knows the frequency bands with the lowest noise floor it will require the least amount of power to successfully transmit their information. If the signal is competing with unintentional users or jammers, bit errors and high power is required. Both effects tend to use more than necessary spectra and may cause adjacent channel interference.

4.5-4.6 Transmit the desired signal whose waveform is shaped in time, frequency and direction

Based on the receiver's measured spectra, the transmitter can adjust many facets the transmission waveform to best adapt to the potential frequency bands. This could vary the waveform considerably, because the measured bands could be packed together, or they could be spread across the spectra in non-uniform bandwidths. For example a traditional broadband modulation may be used if the sequential bandwidth is available. If the bans are interspersed with interspersed noisy bands then a hopping modulation scheme is better suited for the transmission. There are techniques that adapt to pulsed or continuous interference so the modulation technique can be tailored to fit the ambient conditions.

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4.6 Update of Successive Transmissions

Updated the transmission criteria for successive transmissions require the onboard measurement at the receiver be updating and passed the transmitter control producing the waveform. Constant update insures that the QOS can remain optimized as the transmitter will seek the best waveform possible

5 CONCLUSIONS

The possibility to use cognitive radio techniques to perform global frequency management is at an early stage of development. It is encouraging to note that tried and proven techniques from proven communications technology could be adapted to resolve some of the problems. The key component in fostering the growth of such schemes is to engage a global community similar to the Request for Comment (RFC) development of the Internet Protocol or international coordination that was responsible for the GSM cellular standard. It is time for the community to draw on the success of these communication triumphs that will provide the final answers to this problem.

REFERENCES

[1] Harris Corp., Personal communications, Jon England, Melbourne, Florida, 2003.
[2] TDRSS Trouble Report, "Loss of COBE signal due to HST signal level", NASA Code 450, 1985
[3] Joint Spectrum Office, Personal communications, Art Radis, Washington, D.C.
[4] An estimated bidding price for exclusive operating rights of GSM 1900 in Panama is $32M., Embassy of Panama.
[5] "Commonalities between CDMA2000 and WCDMA Technologies" White Paper, QUALCOMM Inc., http://www.qualcomm.com/common/documents/white_papers/Commonalities_CDMA2000_WCDMA_wp.pdf
[6] "Efficient Use of Ka-Band Channels for Leo-to-Exoatmospheric Communications", Michael J. Furman, Harris Corp., 1201 E. Abingdon Dr., Alexandria, VA 22314 USA, 23rd AIAA International Communications Satellite Systems, Rome, Italy, Sept, 2005
[7] Op Cit (ref 6)
[8] Op Cit (ref 3)
[9] "Demand-Assignment Multiple Access" Final Report, M/A-COM Linkabit, Inc., Vienna, VA., 1985