DOPPLER EXTRACTION FOR A DEMAND ASSIGNMENT MULTIPLE ACCESS SERVICE FOR NASA'S SPACE NETWORK

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ABSTRACT

NASA's Space Network (SN) provides both single access (SA) and multiple access (MA) services through a pre-scheduling system. Currently, a user's spacecraft is incapable of receiving service unless prior scheduling occurred with the control center. NASA is interested in efficiently utilizing the time between scheduled services. Thus, a demand assignment multiple access (DAMA) service study was conducted to provide a solution. The DAMA service would allow the user's spacecraft to initiate a service request. The control center could then schedule the next available time slot upon owner approval. In this paper, the basic DAMA service request design and integration is presented.

KEY WORDS

NASA's Space Network (SN), Demand Assignment, Multiple Access, Doppler Shift, Spread Spectrum

INTRODUCTION

NASA's Space Network (SN) provides both single access (SA) and multiple access (MA) services on the Tracking and Data Relay Satellites (TDRS) through a pre-scheduling system. As technology advances, the spacecraft being deployed today have the ability to perform self diagnostic tests. In the event of an emergency on board the spacecraft, the ability to relay the emergency to the spacecraft's ground station via a demand assignment multiple access (DAMA) service would prove to be advantageous. The control center could then contact the spacecraft owner with the service request information and next available time slot. The spacecraft owner could then take the neccessary actions to remedy the emergency.

The DAMA service would be an order wire type of service in that only identification of spacecraft and type of service required would be transmitted [1]. The transmitted signal would than have a low data rate. The DAMA service would have a unique Pseudo Random Noise (PN) code assigned to distinguish between a scheduled MA user and DAMA user. The proposed DAMA service requires that the current TDRSS receiver be modified in such a way that the spacecraft has the capability of initiating an MA service request without pre-scheduling.

Since the DAMA service is a demand assignment service, the SN does not know the position of the spacecraft prior to reception of the incoming signal. Therefore, the DAMA service requires a new method of using the phased array antenna configuration to provide global coverage. With the global coverage, the problem of frequency shifting due to the Doppler effect arises. The expected worst case frequency shift exceeds the current SN constraint. Thus, a modification to the current SN receiver in the form of a DAMA service processor is required. Figure 1 displays the integration of the DAMA service processor with the current system.

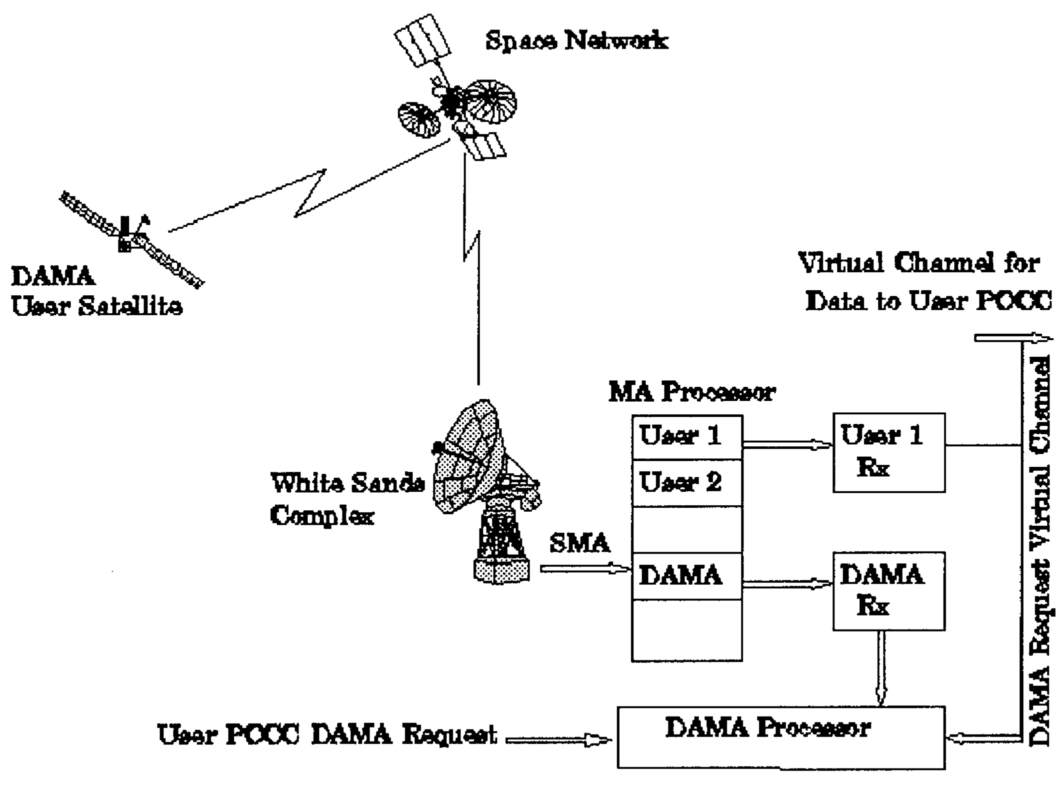

Figure 1 - DAMA Service Integration and Modification

The main obstacle in the design of the DAMA service processor is to recover the carrier frequency of the incoming signal under severe Doppler shifts. This paper discusses how the implementation of a bank of sub-band Fast Fourier Transforms (FFTs) which span the Doppler shift frequency range are used to recover the carrier frequency in each sub-band.

Real-time signal processing is then performed to determine which carrier frequency corresponds to a potential DAMA service user. The DAMA service processor can then process the signal at a known carrier frequency.

ANTENNA CONFIGURATION

The MA system uses a 30 element phased array antenna. As a result, a spot beacon in the direction of the desired spacecraft is achieved by appropriately weighting the array. For the DAMA service, the location of the spacecraft and time of transmission is not known. Therefore, a global beacon is required to assure that at any time or location TDRS is capable of receiving the signal from an unknown spacecraft. Previous work was done in determining whether or not the phased array antenna could be configured in such a way to provide global coverage [2]. It was found that the use of only a single element in the array could achieve a global beacon.

With the new single element configuration of the antenna, the antenna gain is 16 dB. Since the DAMA service is of order wire type, the DAMA service request will be at a low data rate of 1 Kbps. Due to the lower data rate and antenna gain, the link power must be examined to insure enough power is seen at the TDRS MA antenna. A link budget was performed to calculate the required and expected received power. The link budget evaluations appear in Table 1. From the link budget, a large link margin can be achieved with the low data rate of the DAMA service and the gain of the single element of the phased array.

Service Type		DAMA	MA
RETURN SERVICE CARRIER	UNITS	VALUE	VALUE
Transmitter Power	dBW	10	10
Transmitter Frequency	MHZ	2287.5	2287.5
Antenna Gain	dBi	16	16
Antenna Circuit Loss	dB	2.2	2.2
Antenna Pointing Loss	dB	3	1.5
Information Bit Rate	kb/s	1	1
RF Modulation Index	rad-pk	0.09	0.09
Topocentric Range	km	40000	40000
Signal Suppression at TDRS	dB		
RF Bandwidth	dBHz	71.94	71.94
Polarization Loss	dB	0	0
Expected C/N at TDRS	dB	-11	-11
Transmitting EIRP	dBW	20.8	22.3

Service Type		DAMA	MA
RETURN SERVICE CARRIER	UNITS	VALUE	VALUE
Free Space Loss	dB	192.2	192.2
TDRS Figure of Merit	dB/K	8.57	8.57
Received C/No at TDRS	dBHz	65.77	67.27
RF Bandwidth	dBHz	71.94	71.94
Received C/N at TDRS	dB	-6.17	-4.67
C/N Margin at TDRS	dB	4.83	6.33
Overall TDRSS Performance			
Net Eb/No at WSGT	dB	30.9	32.4
Reqd Eb/No at WSGT	dB	4.4	4.4
Tolerance	dB	0	0
Overall Link Margin	dB	26.5	28

Table 1 - Link Budget for DAMA and MA Return Services

Both MA and DAMA users will be present in the single element of the phased array antenna. This brings about the question as to whether the MA signal has higher gain than the DAMA user. TDRS forms the incoming signal by multiplexing the 30 elements of the phased array antenna. Therefore, each signal in each element in the array has the same gain. The DAMA user and any MA users that happen to be in single element chosen for the DAMA service will have the same gain acting on each respective signal. The defining factor as to whether or not the MA users signal strength will out power the DAMA user signal strength is the power flux density of each signal. The power flux density, S, is determined by

$$\Omega = \left(\frac{\mathrm{EIRP}}{4\pi \mathrm{d}^2}\right) \tag{1}$$

where EIRP is the effective isotropic radiated power and d is the slant range [3]. Using equation (1), the power flux density for the DAMA and MA user in the single element were calculated to be -142.48 dBW/m^2 and -140.98 dBW/m^2 respectively. It can be seen that the power flux densities are very similar. Therefore, the MA user and DAMA user have the same relative power in a single element. By using a single element of the phased array antenna, a global beacon can be achieved to provide both link closure and an appropriate power flux density.

DOPPLER SHIFT

When the White Sands ground station configures the phased array antenna, the ground station knows the incoming nominal frequency of the spacecraft to within ± 3KHz. So, the ground station receivers have a constraint of ± 3KHz uncompensated Doppler shift that can be accomodated. Therefore, the amount of Doppler shift to be expected due to the global beacon must be examined. It must be determined whether or not the expect worst case Doppler shift is within the constraint of the ground station receivers. The shifted frequency due to Doppler, f_d, can be found by using

$$f_d = f_t\left(\frac{c}{c \mp V_s}\right) \tag{2}$$

where f_t is the transmitting frequency, c is the speed of light, and V_s is the velocity of the spacecraft [4]. The sign of the velocity depends on whether the spacecraft is moving toward or away from the detector respectively, Using equation (2), the worst case Doppler shift to be expected with a global beacon was calculated to be ± 64KHz. The ground station receivers would be incapable of receivng a signal coming from a spacecraft with the expected worst case Doppler shift. Thus, a method must be implemented to accommodate the expected worst case Doppler shift.

CHARACTERISTICS OF A SPREAD SPECTRUM SYSTEM

The SN MA service is a spread spectrum communications system. The main idea of a spread spectrum system is to spread the digital data signal for various signal processing advantages. The digital data signal is spread using a spreading function called a PN code. By spreading the digital signal with a PN code, the spectrum of the signal changes. The spectrum changes in that the bandwidth is broadened and the amplitude of the power spectral density is decreased. The chip rate of the PN code determines the overall data rate of the transmitting signal. This characteristic can assist in determining the carrier frequency due to a Doppler shift in a spectrum of other users operating at different frequencies. The PN code chip rate would be used to manipulate the spectrum to assist in the carrier recovery. Figure 2 displays the change in the spectrum of a digital signal before and after spreading by a PN code. Normally, the spreading ratio is much larger than the 1:2 ratio illustrated here.

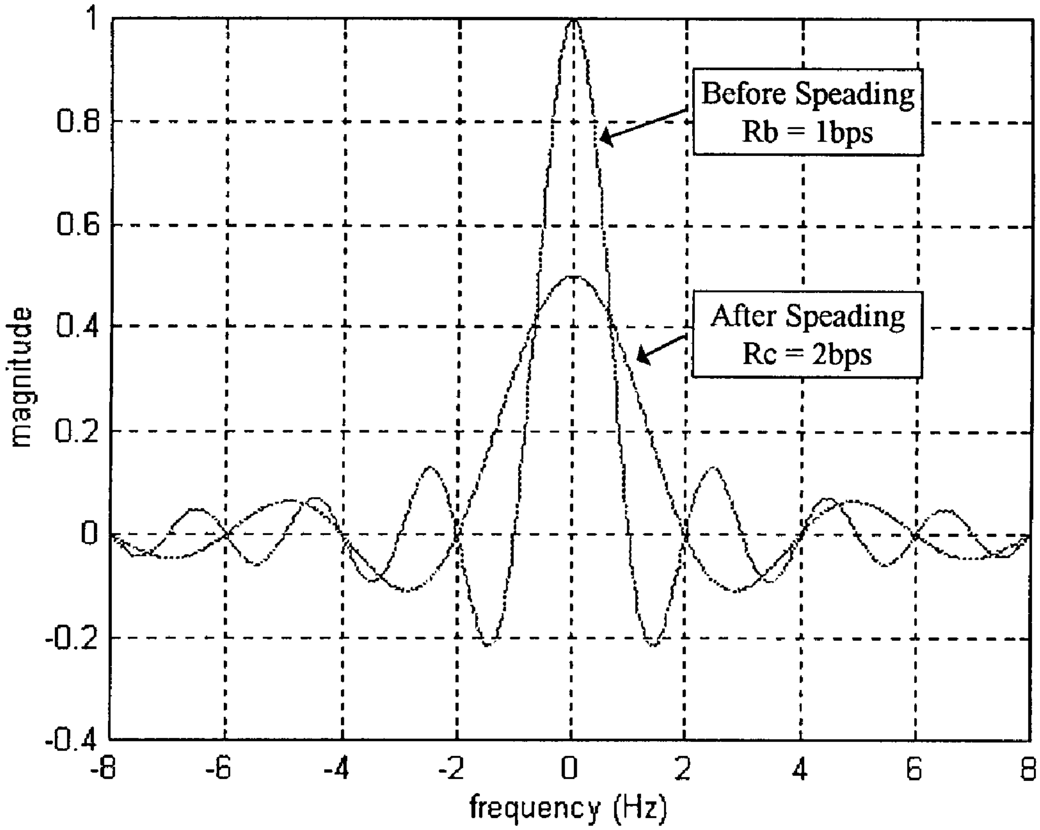

Figure 2 - Spectrum of a Digital Signal Before and After Spreading

IMPLEMENTATION OF THE FFT FOR CARRIER RECOVERY

The FFT is a signal processing tool widely used to determine the carrier frequency of a signal. The carrier frequency of a DAMA user within a spectrum of scheduled MA users can be found by combining the power of the FFT and the characteristics of a spread spectrum system. By making the chip rate of the DAMA user much less than the scheduled MA user chip rate, the DAMA user's spectrum should be the prominent one with the MA user looking like noise. The ratio between the DAMA user chip rate and the MA user chip rate would be determined by the current constraints of the SN. The DAMA service should not interfer with the current operation of the SN. The goal of the addition of a DAMA service to the current SN is to broaden the capabilities of the SN which efficiently utilizes the time of the SN.

The MA system has a specific chip rate for spreading which does not present a problem. The problem arises with the data rate restrictions which correspond to a specific power flux density. Currently, spacecraft must adhere to power flux density limits to avoid interference with other users operating at the same frequency. Thus, new constraints on the data rates that an MA user is able to transmit would defeat the purpose of the addition of a DAMA service. Therefore, further research into the lowest chip rate that a DAMA user is able to operate at must be done. Figure 3 shows the results of a simulation where an MA user and a DAMA user are present in the spectrum.

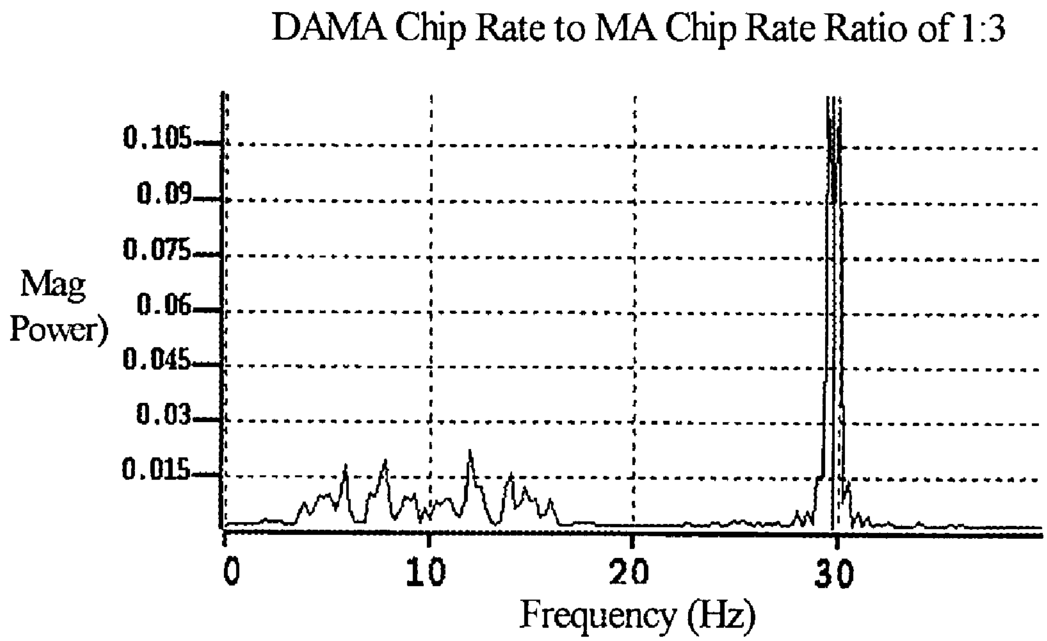

Figure 3 - FFT of MA and DAMA Users Signals

The parameters of the simulation run to achieve the results in Figure 3 were an MA user operating at 10Hz and a DAMA user at 30HZ which corresponds to a Doppler shift of 20HZ. The data rate of the DAMA user and MA user were 1Kbps and 10Kbps. The results of Figure 3 assume that only one MA user was present at 10Hz. If more than one MA user were present at 10Hz, the power of each signal would be combine. Thus, the MA users spectrum would now be the dominant one. The DAMA user would now look like noise at the number of MA users increased. The FFT would be incapable of detecting the carrier frequency of a potential DAMA user.

Since all scheduled MA users are receivce by the SN at the same nominal frequency to within ± 3KHz, simply taking an FFT of the incoming signal would not be sufficient in determining the carrier frequency of a DAMA user. By filtering the incoming signal into sub-bands spanning the Doppler shift range, the carrier frequency within each respective sub-band could be determined by an FFT. The region over which the scheduled MA users should appear would be assigned a separate MA sub-band. As a result, the spectrum of a DAMA user at a lower or higher frequency would not be affected by the scheduled MA users and the carrier frequency cold then be determined. Since the position of the spacecraft in unknown, the DAMA user could have a Doppler shift which results in a frequency equal to that of an MA user. Therefore, the signal power in the MA sub-band would need to be compared against a threshold value equal to the signal power due to the number of expected MA users. If the signal power is greater than the threshold, then a potential DAMA user may be contained with that sub-band. Figure 4 is the block diagram of the carrier recovery of the DAMA processor. Once the carrier frequency of the DAMA user is determined, the signal is then demodulated and despread [5]. The control center would then verify the spacecrafts SN authorization and contact the owner for further action.

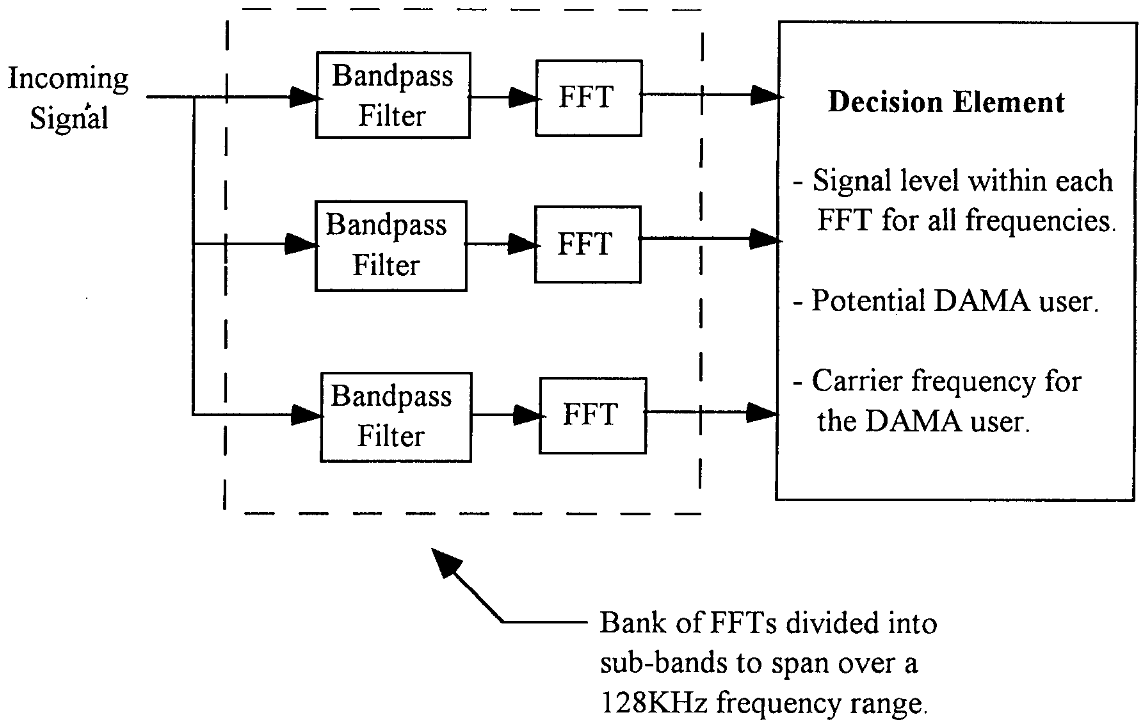

Figure 4 - Carrier Recovery Block Diagram for the DAMA Processor

CONCLUSION

The expansion of NASA's SN to offer a demand assignment multiple access (DAMA) service provides a viable solution for efficiently using the time between scheduled MA services. The appealing aspect of the DAMA service design is the fact that a minimal and cost effective modification to the current SN is required. The modification to be made is the addition of a DAMA processor. Along with hardware advantages, a users spacecraft would be capable of initiating a request for service in the event of an emergency on board the spacecraft. The function of the DAMA processor is to analyze the signal from a single element of the phased array antenna. The main idea behind the DAMA processor is the ability to recover the carrier frequency of a DAMA user with a Doppler shift by implementing a bank of sub-band FFTs.

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