Use of the 30/20 GHz Band by Multipurpose Satellite Systems

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ABSTRACT

The World Administrative Radio Conference (WARC) held in 1992 allocated the bands 19.7-20.2 GHz and 29.5-30.0 GHz to both the Mobile Satellite Service (MSS) and the Fixed Satellite Service (FSS) on a co-primary basis. An economic and flexible solution for the provision of both services is to place both payloads on one spacecraft. This paper describes some of the proposed applications of such a hybrid satellite network. It also examines the facility for spectrum sharing between the various applications and discusses the impact on coordination. The paper concludes that the coordination process would not be more onerous than traditional FSS inter-satellite coordination.

INTRODUCTION

WARC-92 addressed the spectral requirements of a new generation of multi-purpose satellites (MPS) operating in the bands 29.5-30 GHz and 19.7-20.2 GHz (Ka band). These satellites would provide both fixed-satellite and mobile-satellite services from the same spacecraft. WARC-92 decided that the mobile-satellite applications of these systems should have equal status from the radio regulatory perspective with the fixed-satellite applications in the aforementioned bands in Region 2 (the Americas).

The Canadian Department of Communications (DOC), in conjunction with the Communications Research Centre, has studied the technical and economical feasibility of a Ka band satellite offering fixed and personal communication capabilities. A pre-commercial payload is planned to be launched in 1997, followed by a fully operational commercial system in the 2005 - 2010 time frame.

This paper assesses the spectrum sharing capabilities between two such MPS satellites and its impact on the geostationary orbit resource. MPS satellites provide both fixed and mobile applications, and thus should provide a fair representation of the expected spectrum/orbit sharing environment.

THE CANADIAN MULTI-PURPOSE SATELLITE PROGRAM

The Canadian system will accommodate a wide variety of communications offerings, ranging from personal communications using relay terminals operating at a 2.4 kbps rate, vehicular mobile and portable terminals operating at a 144 kbps (2B+D) rate, aeronautical terminals carrying voice, data, or video information at 144 kbps or higher rates, and fixed terminals operating up to 1.544 Mbps (T1 rate). The smaller lower-capacity terminals of this menu will operate through one of 52 beams 0.6° in diameter in a beam hopping mode of operation controlled by the on-board network controller. The higher-capacity terminals with larger antennas and usable bandwidths will operate through a four-beam satellite antenna covering Canada. At the core of the satellite is a demodulator and modulator for each beam and a base-band digital switch to re-route traffic based on information in the message or carrier type. This regenerative on-board processing (OBP) essentially de-couples the uplink noise from the downlink and permits different types of modulation and access schemes between the uplinks and downlinks.

The option of a wide band, single beam, point to multipoint application may also be available. It would use a conventional repeater amplifier.

Services and Applications

Market viability studies have identified a large number of potential applications which could take advantage of the characteristics of Ka band satellite communications. These studies identified four major application groups to be supported by the Ka band payload applications and fall into one of the following broad categories:

- Single user relay services
- Narrowband multimedia applications
- Multiuser multimedia applications
- Point to multipoint application

Single User Relay Service

This service is designed to provide full connectivity with a terrestrial Personal Communications Network (PCN) and therefore it will offer the user single channel voice and messaging capabilities. As currently planned, the system will consist of a fixed or portable Ka band repeater terminal which provides satellite access to a mobile hand-held terminal.

Narrowband Multimedia Applications

The Narrowband Multimedia network services are based on the provision of a basic-rate Integrated Services Digital Network (ISDN) service anywhere within the satellite service area. Satellite access is provided via a portable terminal to either the public or a private network. The range of services to be provided via the family of multimedia terminals is equivalent to those in the basic ISDN environment. This includes one or two voice connections, low speed packet data, higher speed file transfer and video transmission at rates up to 144 kbps. A variety of terminals to support these fixed, mobile and aeronautical mobile applications will be made available.

Multi-user Multimedia Services

The Multi-user Multimedia (MUMM) service will support multimedia applications and a multi-user population within the same locale. The MUMM terminal will provide the link between the satellite and a number of users operating within a microcell which may be an office building or an industrial campus. Data rates up to primary rate ISDN are envisaged. A full range of voice, data, image and video applications will be supported.

Point to Multipoint Application

A point to multipoint capability may be available through a single wide band channel capable of transmitting a high bit rate. This application would be used in conjunction with a single wide coverage beam. On-board processing would not be used with this application due to the high bit rates.

APPLICATION LINK BUDGETS

Five link budgets are given in Table 1. Four of the budgets are currently proposed for the MPS. A fifth budget (Conventional - 1.544 Mbps) was derived based on the characteristics of the MPS but the satellite was assumed to be a simple repeater or bent pipe satellite.

All the link budgets assume 1/2 rate forward error correction (FEC), Viterbi soft decision decoding and a constraint length of 7. Other salient features of each of the example link budgets are described below.

Single User Relay (SUR)

This is used for personal voice and messaging communications. The antenna is a 5x5 cm microstrip patch antenna. The data rate is 2.4 kbps and high gain, 0.6° satellite spot beams are employed. Coherent MSK and differential BPSK are used on the uplink and downlink respectively.

Fixed Multimedia (FMM)

This application uses 20-30 cm parabolic antennas and can transmit up to 256 kbps (144 kbps for ISDN applications). It will also be served by high gain spot beams. Coherent QPSK is used for both up and downlinks.

Multi-User Multimedia (MUMM)

A 90-120 cm parabolic antenna in conjunction with medium sized satellite beams (G/T = 2.2 dB/K) are utilized. The link is capable of providing primary rate 1.544 Mbps (T1 rate) service. Coherent QPSK is used on both links.

Conventional

This link budget is not proposed for the MPS commercial satellite but is provided for comparative purposes. It has the all the same system characteristics as the MUMM application except the satellite is assumed to be a bent pipe. It was derived such that the faded C/N would result in the same bit error rate

(BER) as the faded C/N of the MUMM; approximately 10^{-7} BER.

High Definition Television (HDTV)

A digital wide band HDTV application could be implemented in the future. Its inclusion in this study is to see the effect of sharing with the narrowband applications. Coherent QPSK is also used for both links.

ORBITAL SEPARATION CALCULATIONS

The basic C/I equations used are given below.

$$(C/I)_D = (EIRP_w - D_w + G_w(0)) - (EIRP_i - D_i + G_w(\Theta)) + Q$$

$$(C/I)_U = (EIRP_w - D_w) - (EIRP_i - G_i(0) + G_i(\Theta) - D_w) + Q$$

where:

$(C/I)_D$ - downlink carrier to interference ratio (dB)
$EIRP_w$ - effective isotropic radiated power of the wanted transmitter (dBW)
D_w - wanted satellite discrimination (dB)
$G_w(0)$ - maximum gain of the wanted receiving earth station (dBi)
$EIRP_i$ - effective isotropic radiated power of the interfering transmitter (dBW)
D_i - interfering satellite discrimination (dB)
$G_w(\Theta)$ - gain of the wanted receiving earth station in the direction Θ (dBi)
$(C/I)_U$ - uplink carrier to interference ratio (dB)
$G_i(0)$ - maximum gain of the interfering earth station (dBi)
$G_i(\Theta)$ - gain of the interfering earth station in the direction of Θ (dBi)
Q - bandwidth factor = $10 \log (B_i/B_w)$ (dB)
B_i - bandwidth of the interfering signal (Hz)
B_w - bandwidth of the wanted signal (Hz)

Given the link budgets contained in Table 1 along with their C/I criteria, orbital separation requirements (Θ) between various applications can be calculated.

Assumptions

Co-coverage and co-frequency are assumed in all cases.

The C/I criterion used in all cases is found by allowing a 6% increase in the total noise power of the system. This corresponds to a C/I criterion of 12.2 dB above the C/N. All calculations were performed assuming clear air conditions.

Depending on the antenna size, the earth station antenna rolloff characteristics were assumed to be either:

$$29 - 25 \log \Theta \text{ for } D/\lambda \geq 100$$
$$\text{or } 49 - 10 \log(D/\lambda) - 25 \log \Theta \text{ for } D/\lambda < 100$$

where:

Θ - antenna off-axis angle
D - antenna diameter or length
λ - wavelength

Studies recently performed within Canada have shown that a small rectangular microstrip patch antenna can be designed to meet the $49 - 10 \log (D/\lambda) - 25 \log \Theta$ sidelobe rolloff requirement.

Finally, the victim earth station was assumed to be 2 dB down from its own boresight and at the boresight of the interfering satellite beam.

RESULTS

The results of the orbital separation angle calculations are given in Tables 2 and 3. Separate angles are given for the uplink and downlink due to the regenerative on-board processing assumed. Links using regenerative OBP cannot be combined into a single separation angle using the same method used for bent pipe links. In practice, the angles could be 'combined' to reduce the overall separation, but as there is no accepted criterion or method for this, they are presented separately here.

For the uplink angles, the maximum number of narrowband carriers allowed to interfere into a wider band application was limited to the number of narrowband carriers actually planned for operational use. For example, consider the case of the SUR (2.4 kbps) interfering into HDTV. Over 5,000 of these narrowband channels could fit inside the HDTV's noise bandwidth. However since only 16 channels x 52 beams = 832 channels could be in use at any one time, only 832 carriers were allowed to interfere. Taking this same approach for the downlink only allows one interferer per wideband channel due to the proposed MPS frequency plan which only contains one downlink carrier per hopped beam. However this does not allow for generalization to other satellite systems where there could be several simultaneous interferers. To improve this, Table 4 is provided which allows a maximum of 10 interferers. Only the SUR interfering case is given as this is the only case with significant increases in separation angles with the increased number of interferers.

Generally the angles are in the same range as conventional FSS/FSS separation angles except for the lower rate applications (SUR, FMM). These applications cause larger separation angles due primarily to the following:

- smaller earth station antennas compared to, for example, Ku band antennas, even after frequency scaling;
- high powered narrow bandwidth downlink transmissions;
- low powered uplink transmissions.

Some of the carrier combinations result in 0° separations (eg. SUR into MUMM). This is because even when the interferer is directly in the victim's mainbeam, the victim's C/I criterion is met. Note that this does not mean that 0° is required overall since the opposite interference mode (eg. MUMM into SUR) is always non-zero.

It should also be noted that some of the small non-zero angles are outside the applicable limits of the antenna rolloff equations and those angles would change somewhat (usually slightly larger).

Finally, the SUR/SUR interference on the downlink resulted in 96.9° separation. This is well beyond the valid range of the assumed antenna template and indicates that there is no off-axis angle which would yield the required discrimination from the SUR antenna.

Uplink

Generally the uplink separation angles are smaller than the downlink angles. One might expect that due to the very low uplink power of some of the applications, the EIRP differential between these and higher powered carriers would cause extremely large separation requirements. However, in most cases, this power deficit is offset by the superior discrimination of the larger antennas associated with the higher powered applications.

Downlink

The large angles found are due to the high powered narrow bandwidth applications; especially the SUR. The SUR (2.4 kbps) has the highest downlink EIRP of all the applications and yet also has the narrowest bandwidth. The high EIRP is required to overcome the low receive G/T of the relay terminal.

The angles become larger when there are multiple SUR interferers as shown in Table 4. The assumed number of 10 SUR interferers is arbitrary but the actual number will be limited to TWTA capability. Nonetheless, Table 4 is useful as it shows that different satellite frequency plans result in larger orbital separation requirements.

DISCUSSION

The majority of carrier combinations result in fairly small orbital separations and are comparable or slightly larger than the current situation in other bands. The lower rate, small antenna applications will require extra attention, but solutions for sharing are available. We will focus on the SUR for discussion purposes.

It can be seen that SUR shares better with the wider band applications. With the two satellite examples used here, the SUR can use the same frequencies as any of the wider band applications. For other satellite configurations, the SUR may be forced to share with an application such as digital television. It is interesting to note that the narrowband SUR shares well with the HDTV service which is the opposite of what might be expected.

It is important to keep in mind that the results are from one typical example of Ka band satellite systems. A wide range of different parameters are possible which could result in larger separation requirements. In the extreme case, where a large number of narrowband SUR carriers were in the same radio frequency channel as the wideband application, large orbital separations would be required. However, for most carrier combinations, traditional coordination arrangements would still exist at Ka band.

Overall, it would seem that the coordination process for Ka band satellites will not be much more involved than coordination in conventional bands. The addition of new applications using narrowband signals does add an extra element, but reasonable solutions exist to share the spectrum while conserving the orbit.

Despite the abundant spectrum at Ka band, as more systems migrate to the higher band more emphasis will have to be placed on designing systems which are more amenable to spectrum sharing with other satellites. Traditional methods such as frequency re-use and cross-polarization will eventually have to be employed.

CONCLUSION

This paper has described the applications proposed for a Canadian Ka band multi-purpose satellite and examined the spectrum sharing potential between such systems. For the types of traffic expected, co-frequency sharing with modest orbital separations is possible with care taken in the selection of carrier frequencies.

Table 1. Application Link Budgets

APPLICATION		SUR	FMM	MUMM	Conventional	HDTV
DESCRIPTION		2.4 kbps	256 kbps	1.544 Mbps	1.544 Mbps	30 Mbps
MODULATION		MSK/BPSK	QPSK	QPSK	QPSK	QPSK
UPLINK						
Frequency	(GHz)	30.0	30.0	30.0	30.0	30.0
Antenna Diameter	(m)	0.05	0.30	1.20	1.20	3.00
Antenna Gain	(dBi)	20.8	37.3	49.7	49.7	57.3
Antenna Rolloff Coefficient	(dB)	49	49	29	29	29
EIRP	(dBW)	15.0	39.2	61.2	63.0	79.8
Propagation Loss	(dB)	213.9	213.9	213.9	213.9	213.9
Availibility	(%)	95.50	99.50	99.50	99.50	99.30
Rain Fade	(dB)	2.0	6.0	6.0	6.0	5.1
Atmospheric Loss	(dB)	2.1	0.8	0.8	0.8	0.8
Satellite G/T	(dB/K)	16.7	16.7	2.2	2.2	-0.1
Additional Losses	(dB)	3.0	3.0	1.5	1.5	1.5
Data Rate	(Mbps)	0.0024	0.2560	1.5360	1.5360	30.0000
Noise Bandwidth	(MHz)	0.0062	0.4400	2.2440	2.2440	36.0000
Allocated Bandwidth	(MHz)	0.0070	0.5000	2.6000	2.6000	54.0000
Clear Sky C/N	(dB)	3.3	10.4	12.3	14.1	16.5
Clear Sky C/I Criterion	(dB)	15.5	22.5	24.5	26.3	28.7
DOWNLINK						
Frequency	(GHz)	20.0	20.0	20.0	20.0	20.0
EIRP	(dBW)	56.2	55.3	45.6	49.4	44.9
Propagation Loss	(dB)	210.4	210.4	210.4	210.4	210.4
Availability	(dB)	99.50	99.50	99.50	99.50	99.40
Rain Fade	(%)	6.6	4.6	4.4	4.4	4.0
Atmospheric Loss	(dB)	2.5	1.0	1.0	1.0	1.0
Antenna Diameter	(m)	0.05	0.30	1.20	1.20	3.00
Antenna Gain	(dBi)	18.9	33.7	46.2	46.2	53.7
Antenna Rolloff Coefficient	(dB)	49	49	49	49	29
Earth Station G/T	(dB/K)	-7.0	7.9	22.1	22.1	28.0
Additional Losses	(dB)	3.0	3.0	1.5	1.5	1.5
Data Rate	(Mbps)	0.0480	4.0960	12.2880	12.2880	30.0000
Noise Bandwidth	(MHz)	0.1350	6.8400	16.6800	16.6800	36.0000
Allocated Bandwidth	(MHz)	0.1550	7.9000	19.0000	19.0000	54.0000
Clear Sky C/N	(dB)	10.6	9.0	11.2	15.0	13.0
Clear Sky C/I Criterion	(dB)	22.8	21.2	23.4	27.2	25.2
COMPOSITE						
Availability	(%)	95.02	99.00	99.00	99.00	98.70

Notes:

1 - Forward error correction, rate 1/2, Viterbi soft decision decoding, constraint length of 7.

2 - SUR link is from/to Halifax; all others are from/to Ottawa.

3 - Antenna sidelobe rolloff is $\underline{29} - 25 \log \theta$ or $\underline{49} - 10 \log(D/\lambda) - 25 \log \theta$

Table 2. Uplink Separation Angles

Interferer ---> / Victim	SUR 2.4 kbps	FMM 256 kbps	MUMM 1.544 Mbps	Conventional 1.544 Mbps	HDTV 30 Mbps
SUR 2.4 kbps	35.3°	6.4°	5.0°	5.9°	4.5°
FMM 256 kbps	22.0°	7.2°	5.6°	6.6°	5.1°
MUMM 1.544 Mbps	0.0°	2.1°	1.7°	2.0°	1.5°
Conventional 1.544 Mbps	0.0°	2.1°	1.7°	2.0°	1.5°
HDTV 30 Mbps	0.0°	1.7°	1.3°	1.5°	1.2°

Table 3. Downlink Separation Angles

Interferer ---> / Victim	SUR 2.4 kbps	FMM 256 kbps	MUMM 1.544 Mbps	Conventional 1.544 Mbps	HDTV 30 Mbps
SUR 2.4 kbps	96.9°	18.6°	0.0°	0.0°	0.0°
FMM 256 kbps	11.4°	10.4°	3.0°	4.2°	2.1°
MUMM 1.544 Mbps	6.2°	5.7°	2.3°	3.3°	1.6°
Conventional 1.544 Mbps	6.2°	5.7°	2.3°	3.3°	1.6°
HDTV 30 Mbps	3.6°	3.3°	1.3°	1.9°	1.3°

Table 4. Downlink Separation Angles with Multiple Interferers

Interferer ---> / Victim	SUR 2.4 kbps
SUR 2.4 kbps	96.9° (1)
FMM 256 kbps	28.5° (10)
MUMM 1.544 Mbps	15.5° (10)
Conventional 1.544 Mbps	15.5° (10)
HDTV 30 Mbps	9.0° (10)

Note:

Numbers in brackets refer to the number of assumed interferers.

Session 4
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