Analysis of Capacity vs Orbital Spacing for military purpose Ka-band satellites

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Regulatory bodies such as FCC and ITU have established interference limits for FSS networks in the Ku band, and also have partially covered the Ka band. However the 30 – 31 Ghz and 20.2 – 21.2 Ghz that cover the military Ka-bands are not yet covered.

A sensitivity analysis has been made for capacity vs aperture using as a reference the limitations recommended by FCC for commercial FSS satellites, showing the amount of T1 equivalent links that can be accommodated at different modulation and coding rate schemes.

Here an analysis is presented for capacity vs satellite spacing at different antenna apertures. We know that different application require different type of terminals and different data rates as mentioned in MIL-STD-188-164A. Mobile earth terminals are expected to handle data rates as low as 64kbps and as high as E-1 rates (2.048 Mbps).

The analysis is made by optimizing the capacity while varying the spacing between satellites. The design goal is to find an orbital spacing such that the placement of more military payloads is limited but there is enough space to avoid interference among systems that can take advantage of DVB-S2/RCS features such as ACM.

The methodology used is as follows. The first step is to find the interference threshold that this military purpose satellites (MPSAT) can handle. The characteristics of the MPSAT are in the link budget attached. In order to do this, we have translated the ground terminal EIRP spectral density to power flux density at the satellite (before the antenna). And also the interference generated on ground by users of an adjacent network was referenced as flux density at the satellite. Then the interference was raised to the point where the link margin starts degrading with a tolerance of 1/10 dB. At this point the level represents the interference that can be tolerated at an adjacent MPSAT.

The limiting factor is the radiation pattern of the different apertures that can be used for mobile applications. The orbital spacing is decided upon the sidelobes being beneath the interference level that was already identified.

This way there is no need for signal spreading which impacts the capacity on the service.

It is assumed that if the goal is towards finding a spacing greater than the commercial 2 degrees, then the main lobe level is not a concern, since the first null of a 0.3 m antenna is at 2.2 degrees.

As we see in table 1 the larger the spacing between satellites the larger the capacity the system can handle, the trade off would be then the amount of payloads that can be placed in the arc.

Table 1 Orbital spacing vs capacity

Aperture	Data rate	ModCod	Link Margin	EIRP	**Spacing reqd. >**	T1's
0.3	1.544	16-4/5	0.09	41	10	589
0.3	1.544	16-2/3	0.10	36	8	491
0.3	1.544	8-3/4.	0.14	35	6.00	414
0.3	1.544	Q-9/10	0.16	34	4.00	331
0.3	1.544	Q-1/2	0.09	30	4.00	184
0.45	1.544	16-4/5	0.08	41	6.50	589
0.45	1.544	16-2/3	0.09	36	5.20	491
0.45	1.544	8-3/4.	0.14	35	4.00	414
0.45	1.544	Q-9/10	0.17	34	4.00	331
0.45	1.544	Q-1/2	0.24	30	2.50	184
1	1.544	16-4/5	0.089	41	3	589
1	1.544	16-2/3	0.058	36	2.5	491
1	1.544	8-3/4.	0.687	36	2.5	414
1	1.544	Q-9/10	0.921	35	2	331
1	1.544	Q-1/2	0.357	30	2	184

In figures 1 and 2 we can see the spacing needed for the system to operate at 8psk modulation and ¾ FEC, and 16apsk and 2/3 FEC. All calculations in table 1 are assuming a design goal for optimizing capacity, therefore signal spreading is avoided but larger spacing between satellites is required.

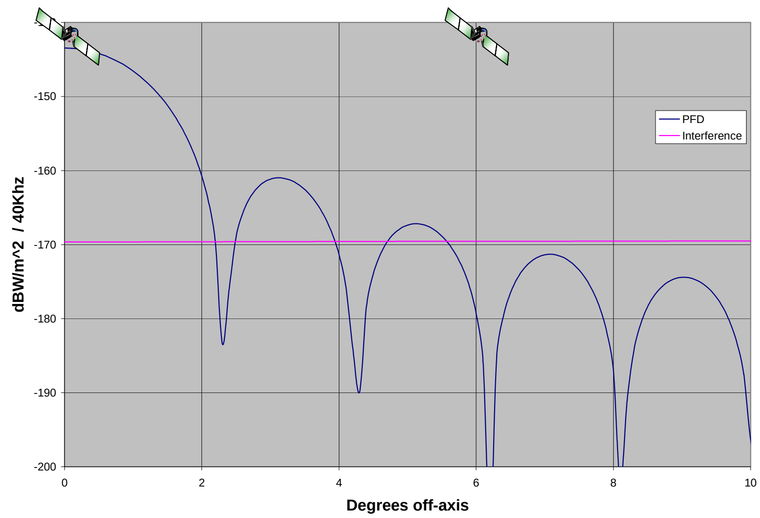

Figure 1 Spacing required for 8psk modulation and 3/4 FEC with 0.3 m. aperture

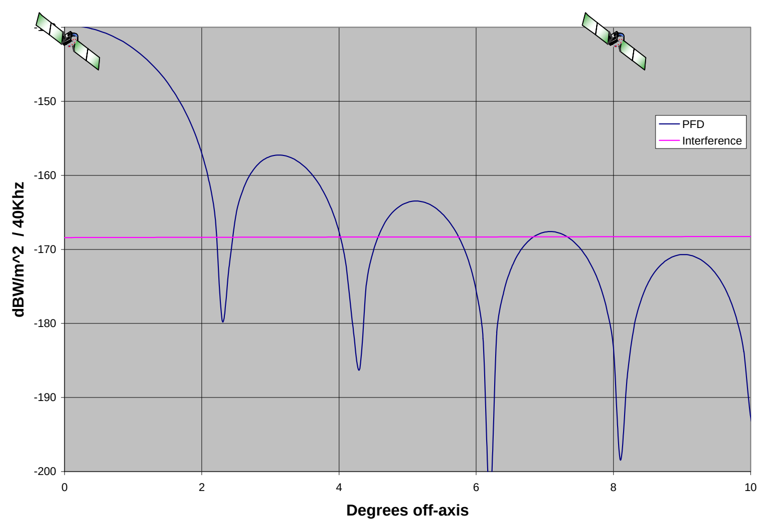

Figure 2 Spacing required for 0.3 m. aperture at 16apsk modulation, 2/3 FEC

The government is seeking to procure commercial resources as a means to reduce expense and time in the delivery of satellite resources, but also wants to tap into the commercial best practices. Some commercial DSS satellites are currently spaced 9 degrees in order to avoid interference with each other. This same approach can be recommended to the government in order for them to use the full capacity of DVB-S2/RCS features, such as ACM. The less spacing between satellites, as seen in table 1, the less order modulation scheme and stronger coding required, leaving much less room for flexibility in modulation and coding and still maintain the capacity.

Using a 6 degree spacing, the system can handle T1 rates at 8psk, ¾ FEC which has a spectral efficiency of 2.2 bps/Hz and still have room to adapt coding and modulation for events where the terminal is under rain, foliage or other temporal impairments. This spacing yields to over 400 T1 equivalent links under clear sky conditions.

WGS Spacing

The WGS satellites are spaced at more than 20 degrees as we see in the following table and figure

Table 2 WGS Spacing

Satellite	Longitude
WGS-1	175 E
WGS-2	60 E
WGS-3	12 W
WGS-4	150 E
WGS-5	135 W
WGS-6	104 E

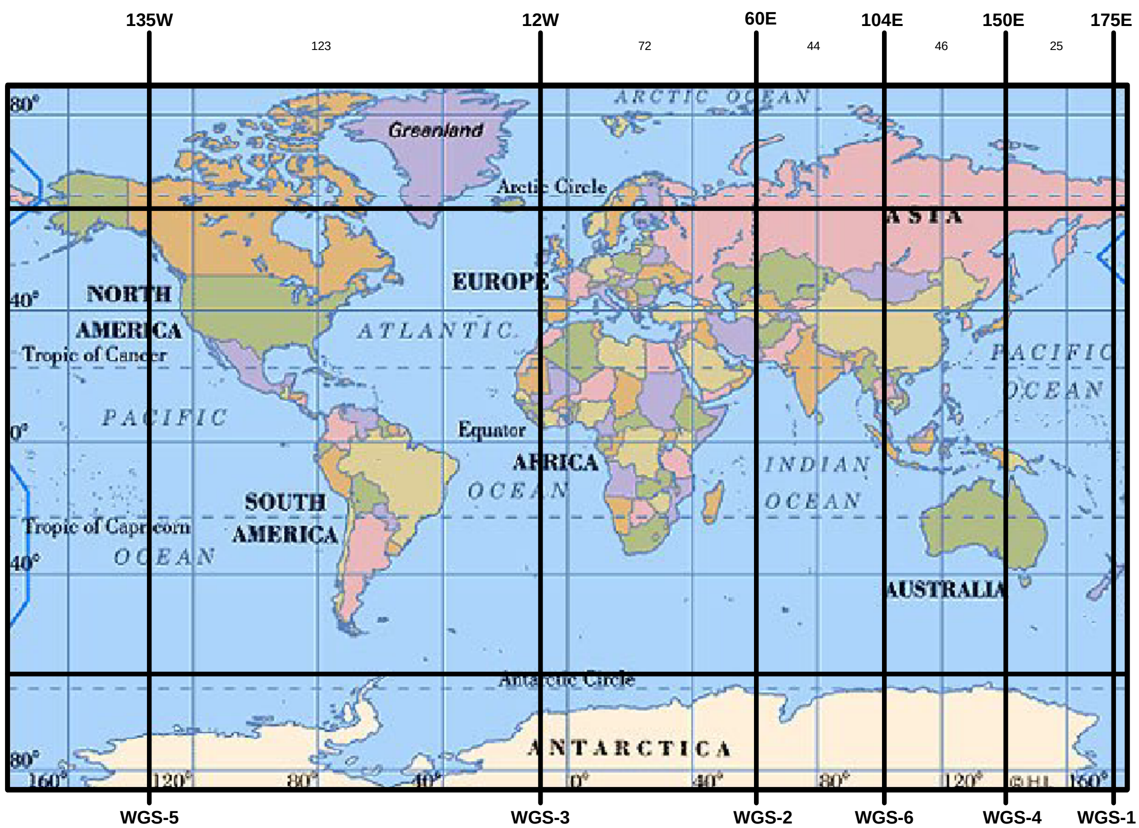

Figure 3 WGS distribution

This indicates that if four MPSATs were located at 162E, 127E, 80E and 30 E respectively, each of these satellites could be more than 10 degrees apart from any WGS and therefore be able to support up to 589 T1 equivalents per 450 Mhz beam, using a 0.3 m ground antenna operating at 16apsk, 4/5 coding, as shown in table 1. This allows for the terminals to make good use of DVB-S2 features, such as ACM, since there is a larger dynamic range for adaptation.

The foreseen problem resides in the popularity of mil Ka-band, which today is not significant but is expected to grow as more companies see a niche in this band and go after the Government business. Since the Government is the only user of the 20.2 – 21.2/30 - 31 GHz band, it would be recommended that the Government decides what priorities does it have, so different trades can be analyzed.
For example is it preferred to have as many satellites as possible so redundancy and diversity are the priority ?; or is it preferred to have faster applications needing a higher throughput at the cost of more complex mechanisms for handover between narrow beams ?; or the use of small aperture antennas in the range of 0.3 m. for mobile applications while maintaining high throughput at the cost of spacing the satellites porting mil-Ka band so the interference effects are reduced ?

Government priorities	Trades
Multiple satellites or payloads for redundancy and diversity	Can provide more coverage or redundancy. More satellites porting mil-Ka band would require to be closer to each other increasing the possibility of interference, or requiring larger antennas on ground.
Small terminals (0.3 m) to be used in mobile applications	Requires signal spreading in order to reduce spectral density and reduce interference impacting the capacity that can be offered. Or require to space the satellites porting mil-Ka in order to maintain throughput and reduce interference.
High throughput for faster applications	Narrow beams (0.4^{o}) with higher EIRP reflecting in higher throughput requiring more complex handover mechanisms while mobile applications transverse beams.

Different approaches can be taken, leading to different architectures depending on the priorities set by the Government. The outcome of setting the priorities for the military missions may lead to a careful planning of the mil-Ka band and the spacecraft's position.