

An Upward Compatible Spectrum Sharing Architecture for Existing, Actively Planned and Emerging Mobile Satellite Systems

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ABSTRACT

Existing and actively planned mobile satellite systems are competing for a viable share of the spectrum allocated by the ITU to the satellite based mobile services in the 1.5/1.6 GHz range. The very limited amount of spectrum available worldwide and the sheer number of existing and planned mobile satellite systems as known to date dictate adoption of an architecture which will maximize sharing possibilities. A viable sharing architecture must recognize the operational needs and limitations of the existing systems while accommodating the reasonable demands for spectrum of the planned systems. Furthermore, recognizing the right of access of the future systems as they will emerge in time, the adopted architecture must allow for additional growth and be amenable to orderly introduction of future systems. This paper describes an attempt toward devising such a sharing architecture. A specific example of the application of the basic concept to the existing and planned mobile satellite systems as known to date is also discussed.

INTRODUCTION

The 1987 World Administrative Radio Conference on Mobile Services (WARC-MOB-87) redefined the spectrum allocation to mobile satellite systems by explicitly recognizing the need for introduction of land mobile service. Noting the limited extent of raw available spectrum in the 1.5/1.6 GHz range, the conference further requested the ITU to convene a limited Allocation Conference in 1992 to seek additional spectrum.

While it is comforting for mobile service interest groups to know that the ITU will do its utmost to find ways of providing additional growth capacity for future

years, it is also well recognized that irrespective of the degree of success of WARC-92 in securing a sizable growth capacity, the most suitable spectrum for truly mobile applications is likely to stay below 3 GHz. This, in conjunction with what we know to date on the nature and extent of worldwide utilization indicate that the spectrum in this range will continue to remain relatively in short supply and by necessity *must therefore be utilized prudently and shared extensively.*

CHARACTERIZING FEATURES OF MOBILE SATELLITE SYSTEMS

Unlike their Fixed Satellite Service counterparts, the emerging mobile satellite systems are characterized by user terminals which by the very nature of the envisaged mobile services cannot afford the ability to discriminate between satellites at small to medium spacings in the geostationary orbit. Consequently, spectrum reuse through orbit separation is not likely to become a widespread and practical sharing tool in the entry period of these systems. As a result, the most effective means of reusing the limited raw spectrum over the next decade or so will most likely remain to be through isolation by geographical separation of the service areas.

There are two practical considerations, however, which tend to inhibit the full potential of a satellite cellular structure in reusing the spectrum. Analogous to its terrestrial counterpart, generation of small cells (satellite beams) requires a larger overall infrastructure which in satellite terms translates into a larger antenna assembly and repeater complex. This in turn requires a minimum user density per beam area to justify the associated cost of a given size beam. Furthermore, assuming that the potential market is sufficient enough in the long

term to support a given beam size, the economic realities of the first generation systems in terms of the speed with which they can build up a subscriber base are likely to further limit the ability of the operators to economically justify such a beam size. In view of this, the elemental cell size which defines the relative ability of the spacecraft antenna in concentrating its transmit capability and receive susceptibility is not likely to be appreciably smaller than 2.5 degrees in satellite coordinates for mobile satellite systems to be implemented over the next decade. This practical consideration is demonstrated¹ to approximately define the upper bound achievable reuse factor over the land mass to be:

| REGION | REUSE FACTOR |
|----------------|--------------|
| North America | 1.7 |
| South America | 2.0 |
| Africa/Europe | 4.0 |
| Asia/Australia | 4.0 |
| TOTAL | 11.7 |

The total reuse factor stated above merely suggests that, if 30 MHz of raw spectrum were made available, 350 MHz would be close to the upper bound worldwide aggregate capacity that can be expected to be realized for sharing amongst the emerging systems which are still at their infancy stage.

To better appreciate this potential capacity, it is worthwhile to note that for mobile satellite systems, the main applications are thin route voice and data messaging which by nature are not spectrum thirsty when spectrally efficient analogue and digital modulations are employed. In fact with any stretch of imagination, it is hard to conceive a realistic scenario in which power constraints of the largest available spacecraft bus today for deployment of commercial payload (3-4 kW DC range) will mandate a single satellite to demand more than 10 MHz of usable spectrum. This 10 MHz is considered to be enough to support a subscriber base per satellite in excess of 200,000 voice users, an order of magnitude larger data and messaging users or a proportion of both. To summarize, , given a 30 MHz of raw

spectrum, the first consideration imposed by economic realities of early entry systems defines the upper bound to the capacity to be 350 MHz which is considered to be sufficient to respond to the realistic needs of up to 40 large sized start-up satellites, or alternately, 70 medium sized satellites of Delta class to serve the worldwide market. While this potential capacity by no means is trivial for start-up systems over the next decade or so, it could conceivably be further increased if coverage over the oceans were also added to the assumed aggregate service area.

The second practical consideration relates to the non uniformity of the elemental beam size from system to system in a real life situation. To better appreciate the nature of the problem, Figure 1 is intended to depict the beam sizes of the planned mobile satellite systems as have been filed officially with the ITU by various administration and international organizations. The smallest beam dimension which defines how fast the beam rolls off from the intended service area varies from 2.5 degrees for the Canadian MSAT on one extreme to approximately 18 degrees at the other extreme characterizing a global beam.

This gross disparity, does significantly reduce the potential capacities from the figures derived earlier for the first generation systems. The larger the degree of non uniformity, the smaller becomes the potential capacity. This reduction, however, is partially compensated by the fact that, in general, the larger the beam size, the smaller is the resulting aggregate EIRP for a given power level which in turn implies that less spectrum is needed to fully utilize the satellite's on board power.

While non uniform distribution of beam size reduces the ability of a satellite cellular structure to form an efficient reuse pattern, it is the existence of the global beams which drastically affect the worldwide sharing situation. Global beam satellites by their very nature offer no reuse capability through beam isolation. This means that unless the use of large

mobile antennas in conjunction with large orbit spacings become the prevalent

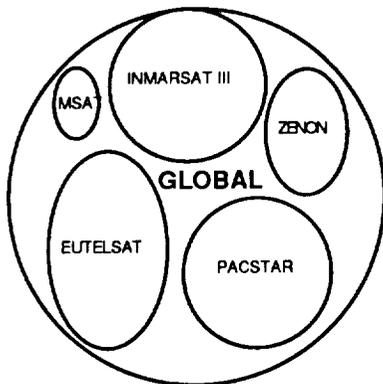


Fig 1. RELATIVE BEAM SIZES FOR PLANNED MOBILE SATELLITE SYSTEMS.

operating mode; a scenario which violates the very foundation of the business cases put forward for emerging mobile systems, very little reuse will be feasible in overlapping beam areas of global versus global or global versus spot beam systems. The coordination problem is further aggravated by the large gain difference between spot and global beams which tends to lead to non homogeneity and incompatibility of traffic on these two classes of mobile satellite systems. While it is conceivable that global beams will eventually reduce in number due to competitive market forces and, as a logical consequence, in demand for spectrum, global systems will remain a fact of life for the next 10-15 for certain applications and as such will have to be accommodated. Indeed, the only existing mobile satellite systems today, although very modest in power capability and spectrum requirements, are solely characterized by global beams.

MEANS OF COEXISTENCE

Frequency coordination problems of spot beam based systems are generally localized and the task is expected to be manageable as long as the beam sizes are not exceptionally large and grossly non uniform. The variation observed in the beam sizes of the planned systems to date may become more subtle in time as they move from conceptual design stage. It is believed that when time for implementation of the actual hardware arrives, economics will most likely favor

the national and regional systems to adopt small to moderate size beams; a position primarily driven by the desire to conserve the satellite's expensive power over the intended service area while maximizing reuse capability and minimizing the foreseen international coordination difficulties. Consequently, the most complex issue in coordination of mobile satellite systems will become finding means of coexistence between global and spot beam based systems.

Based on extensive experience accumulated by Canada over the past three years in relation with frequency/orbit coordination of the Canadian MSAT, four technical tools have been identified as the major facilitators of the process. Depending on the characteristics of the systems under coordination and their associated traffic, any or a combination of these options could be resorted to in order to maximize sharing of the limited spectrum. While all of these technical options are graphically described in Figures 2 to 5, by far the most effective tool for spectrum sharing is Option 1 or simply stated; geographical separation of service areas by means of *Global Radio Horizons* and sharing in an East/West complementary fashion with spot beams.

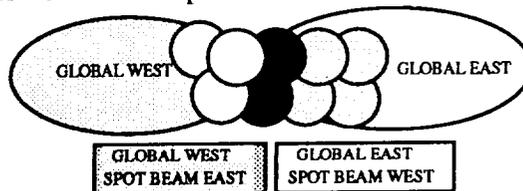


Fig 2. OPTION 1; USE OF RADIO HORIZON.

This option draws upon an organized pattern of spectrum usage to allow sharing and reuse of the same spectrum by both global beam and spot beam systems. The spectrum for spot beams happening to fall in the overlap areas of the global beams indicated by a darker shade in Figure 1 need to be sought by other technical means.

Option 2 as depicted in Figure 3 is intended to usefully employ the intercarrier spectrum which has been left unused by a given operating entity due to such operational considerations as intra-system interference consideration

and/or limitations imposed by the existing ground segment infrastructure.

- Global Traffic
- || Spot Beam Traffic

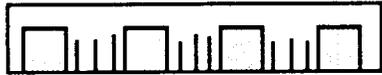


Fig 3. OPTION 2; FREQUENCY INTERLEAVING.

Exploitation of this option, however, mandates careful scrutiny of the uplink inter-system transponder loading and/or power robbing that could result and become excessively large if not attended to. To control this loading, the location of transmitting mobiles, if available to the Network Control Center of the interfering system, could be advantageously used to assign non overlapping uplink carriers for the mobiles operating in the areas close to the spot beams of the victim system.

Option 3 utilizes inter-transponder guard bands built into the hardware design of a given satellite constellation as shown in Figure 4. These guard bands, while normally small in the amount of spectrum, since are not used by a given global network, could be reused several fold by spot beam systems over a relatively large service area.

- Global Traffic
- ||| Spot Beam Traffic



Fig 4. OPTION 3; USAGE OF GUARD BANDS.

Option 4 as depicted in Figure 5, is merely brute force spectrum segmentation approach in the frequency

- Global Traffic
- ||| Spot Beam Traffic

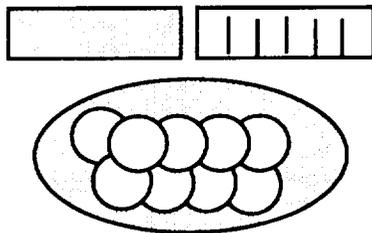


Fig 5. OPTION 4; SPECTRUM SEGMENTATION FOR MUTUALLY INCLUSIVE COVERAGES

coordination process when other options are not viable due to a multitude of technical and operational reasons.

DESIRED SHARING FEATURES

In order to make geographical sharing possible (Option 1), an organized pattern of spectrum usage need to be adopted to maximize sharing and reuse of the same spectrum by both global beam and spot beam based systems. Furthermore, for situations where the only viable solution proves to be brute force spectrum segmentation (Option 4), such an organized pattern of usage is needed even more in order to ensure that coexistence between such grossly incompatible systems will not lead to inefficient sharing scenarios. Moreover, the method should be robust enough not to mandate extensive inter-system traffic coordination on a case by case basis during the early phase that the new mobile satellite systems are moving through their infancy stage and have yet to acquire the operational experience and master the art of coexistence in a shared environment. The assumed sharing architecture should also be amenable to orderly introduction of new entries as they emerge in time; irrespective of whether they have global or spot beam configuration, without disruption of the existing and replacement systems or requiring major reorientation of the actively planned systems. In other words, the adopted strategy should be sound enough not to fall apart like a house of cards when new systems emerge in time.

A PLAUSIBLE USAGE ARCHITECTURE

With the above objectives, we proceed now to define a possible spectrum sharing architecture. Without loss of generality, we concentrate on defining the approach using the 10 MHz spectrum allocated to Aeronautical Mobile Satellite Service (AMSS). The application to the other components of the service such as Land Mobile Satellite Service (LMSS) or Maritime Mobile Satellite Service (MMSS) is similar with differences primarily stemming from the nature and extent of the existing systems or the specifics of the planned systems in each part of the band.

With the exception of ETS V experimental project with limited life expectancy, the operational or existing satellite hardware are those of USSR and INMARSAT Organization. These two entities also happen to have the most extensive plans for satellite based mobile networks around the globe and, with the exception of the planned INMARSAT III, are all characterized solely by global beams. With this preamble, it is logical to start first by devising an architecture which organizes the spectrum usage around these systems. Since INMARSAT and USSR have global networks with extensive concentration in the Atlantic and Pacific regions with a geostationary orbit distribution independent from each other, their usage can be organized over five distinct blocks of spectrum, namely:

- o POR block to be shared by global beams over Pacific Ocean Region with horizon lines crossing the North America service area. The same spectrum can be used and reused by spot beam based systems in a cellular structure over eastern North America, entire South America, Europe, and Africa. It could further be reused by spot beam systems over western North America and Pacific region in conjunction with a limited quantity of mobile terminal antennas which could provide sufficient isolation towards POR global networks with orbit spacings greater than 30 degrees and for certain traffic combinations which would allow such sharing. To improve sharing possibilities by spot beam systems, POR block can be subdivided into POR1 and POR2W, with INMARSAT using POR1 and USSR using POR2W for global coverage in the Pacific region.

- o AOR block to be used by global beams over Atlantic Ocean Region with horizon lines limited to mid North America. The same spectrum can be reused by spot beam based systems in a cellular structure over western North America. Like POR case, it could further be used by spot beam systems elsewhere in conjunction with mobile terminal antennas which could provide sufficient isolation towards global networks with orbit spacings greater than 30 degrees for certain traffic

combinations. To improve sharing possibilities by spot beam systems, AOR block can be subdivided into AOR1E and AOR2, with INMARSAT using AOR1E and USSR using AOR2 for global coverage in the Atlantic region.

- o AOR W block is to be used by global beam satellites over the Atlantic having full North/South American visibility. It can also be used by systems having beams over eastern Africa, Asia, Pacific region and Australia. The same spectrum could also be used elsewhere by spot beam systems in conjunction with mobile terminal antennas offering sufficient intersystem isolation.

- o POR E block is to be used by global beam satellites over the Pacific having full North/South American visibility. It can further be used by systems having beams over eastern Africa, Asia, western Pacific and Australia. The same spectrum could also be used elsewhere by spot beam systems in conjunction with mobile terminal antennas offering sufficient intersystem isolation.

- o IOR block to be used by global beams over Indian Ocean Region. In order to maximize sharing possibilities for spot beam based systems, this block should further be subdivided into IOR1 and IOR2. Global satellites in the range of 60-85 degrees east longitude should preferably use IOR1 and global satellites within 85-100 degrees east longitude should use IOR2. The same spectrum can be shared by spot beam based systems with service areas primarily in western Europe, western Africa, Atlantic region, North and South Americas and east Pacific. As before, application of mobile terminals with directive antennas is permitted wherever sharing is feasible

- o SP block is to be solely used by spot beam based systems around the world to effectively deal with their localized coordination problems. These interface problems arise from the non uniformity of spot beam sizes of various systems or are prompted by spectrum requirement for spot beams used as entry port by international systems connecting the continents. Furthermore, this spectrum in

needed to feed the spot beams which fall in the beam cross-over area of two complementary global beams configured in an east/west fashion.

In line with these guidelines, Figure 6 depicts how this basic architecture could be applied towards accommodation of mobile satellite systems as known to date. The systems above the top horizontal line are the global satellites that need to share the spectrum within the block by whatever means seen feasible. The systems immediately below this line are spot beam systems which, transparent to the global systems cited in each block, can use and reuse the same spectrum with minimal coordination requirement amongst themselves in interface areas. The regions identified below the bottom horizontal line represent additional growth capability of the proposed

architecture. In the case of INMARSAT II, AOR1W is also labeled as IOR as a transitional step necessitated by the degree of accessibility of AMSS band built into the hardware design of INM II satellites.

The compatible usage in North America is illustrated by means of beam patterns arranged under the relevant blocks of frequencies. These beams approximately demonstrate the North American coverage pattern of interest to date over Canada and USA including Alaska, Hawaii and Puerto Rico. The relative utility of blocks SP1-SP4 in North America is largely dependent upon the degree that these blocks of frequencies will be required to accommodate the needs of spot beams of international systems used as entry port in the coastal areas of North America.

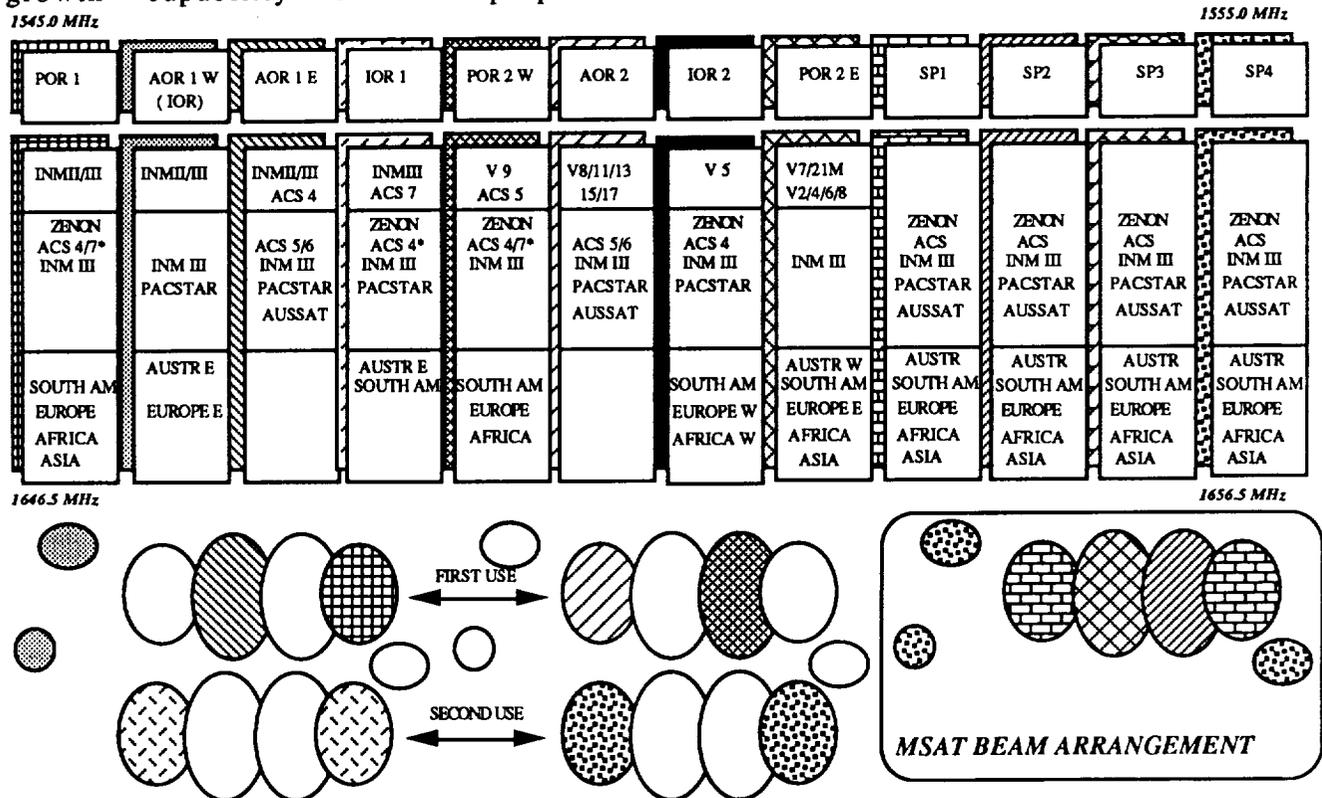


Fig 6. PROPOSED SPECTRUM SHARING ARCHITECTURE TO ACCOMMODATE EXISTING, ACTIVELY PLANNED AND FUTURE MOBILE SATELLITE SYSTEMS AROUND THE WORLD.

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