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Applicability of Different Onboard Routing and Processing Techniques to Mobile Satellite Systems

A D Craig, P C Marston,
British Aerospace Space Systems Ltd
Gunnels Wood Road
Stevenage, Hertfordshire SG1 2AS
England
Tel: (+44) - 438-73-6228
Fax: (+44) - 439-73-6637

P M Bakken
Frobe Radio A/S
Prof Brochs gt
7030 Trondheim
Norway
Tel: (+47)-754-0347
Fax: (+47)-754-0447

A Vernucci
Space Engineering
Via dei Berio 91
00155 Roma, Italy
Tel: (+39) -6-22595-203
Fax: (+39) -6-2280739

J Benedicto
European Space Technology Centre
Postbus 299
2200 AG Noordwijk
The Netherlands
Tel: (31)-1719-86555
Fax: (31)-1719-17400

ABSTRACT

The paper summarises a study contract recently undertaken for ESA [1]. The study compared the effectiveness of several processing architectures applied to multiple beam, geostationary global and European regional missions. The paper discusses architectures based on transparent SS-FDMA analogue, transparent DSP and regenerative processing. Quantitative comparisons are presented and general conclusions are given with respect to suitability of the architectures to different mission requirements.

INTRODUCTION

As mobile systems develop towards a mass market with smaller mobile Earth stations (MES) a key requirement is for high gain spot beams to limit onboard and MES power and to provide scope for frequency reuse (FR). Associated with this is a need for channel to beam routing to accommodate a non-uniform and variable traffic distribution. The objective was to compare onboard processing and routing architectures, based on different approaches for future multibeam GEO missions and to identify regimes where the different approaches are most applicable.

In a generic sense all architectures comprise the Feeder Link (FL) antenna and Rx/Tx system, the Mobile Link (ML) antenna and Rx/Tx system (L-band) and the forward link (FWL) and return link (RTL) processors. The following options were studied:

A. Transparent SS-FDMA with processing of transponder channels comprising groups of user accesses. Implementation is analogue and divides between filter plus switch and Chirp Fourier Transform (CFT) options.

B. Transparent digital signal processing (DSP) characterised by channelisation to individual or small groups of FDMA user accesses with routing by either beam switching or beam steering.

C. Regenerative with channel demodulation and independent optimisation of FL and ML access and transmission characteristics.

Comparisons were made for integral Land-Aero-Maritime Global (LAMG) and Land Mobile Regional (LMR) missions.

Candidate architectures were defined for each option. An internal tradeoff for each option was based on a range of performance and implementation parameters leading to a number of preferred architectures. The preferred architectures were then compared using spread sheet models based on key system budgets and parametric implementation models.

The tradeoff is complex involving many criteria which will have different importance for different missions. These include payload mass and power, spectral efficiency, erlang efficiency and flexibility to changing traffic, flexibility to vary channel characteristics (data rate, modulation), and to change frequency plan, flexibility to exchange channel power and bandwidth, system security against unauthorised access, associated ground segment and control requirements and development risks and timescales. The options display strengths and weakness with respect to these criteria; a key objective was to define regimes where the different options are preferred.

ASSUMPTIONS AND COMMON FEATURES

Various coverage concepts may be considered for the ML. A global beam has a simple antenna and good traffic flexibility but gain is low and there is no FR. Fixed contiguous spot beams provide high gain and FR but require a large antenna and routing capability. Alternatively larger numbers of overlapped spot beams (fixed or agile) may be used each supporting a single or limited group of users close to the beam peak; such an approach also provides higher spatial FR because of the localisation of users to the beam peak allows closer co-frequency beams. Antenna models were defined based on a focus fed multimatrix approach for contiguous beams and phased array (direct or imaging) for highly overlapped beams.

The LAMG mission assumes a global public service with a limited number of gateway stations within a single FL beam and 9 contiguous beams (or equivalent sized overlapped beams) on the ML (MES G/T = -12dBK). FDMA/FDM access is assumed with 9.6kbit/s channels taken as representative but with emphasis on service flexibility. Traffic distribution is assumed to be highly non-uniform.

The LMR mission combines public and private (VSAT) European services with a single beam FL and an ML with up to 12 contiguous beams (or equivalent size overlapped beams) (MES G/T = -12dB/K). Access is FDMA or CDMA.

Propagation characteristics on the ML are important particularly for land mobile services with shadowing and multipath losses which are dependent on environment, elevation and MES antenna pattern. Shadowing effectively excludes an urban service at European latitudes. For LMR shadowing and multipath margins of 5dB and 2dB were assumed. An average environmental link margin of 2.5dB was assumed for the LAMG mission (due to mixture of services).

Channel Level Control (LC) emerged as a key issue with respect to system optimisation in view of the large variations in link performance (in particular for land mobile). Without LC, margins must cover worst case conditions leading to excessive power requirements. Ideally individual channels would be dynamically controlled according to instantaneous link conditions. Various schemes involving ground or onboard LC were studied including those using the correlation between mobile uplink and downlink in order to save power on the critical mobile downlink.

Spectral efficiency is a key issue for the ML. Factors affecting it are channel and erlang efficiency and FR. FR is limited by antenna isolation, traffic distribution and control issues. The overlapped beam approach offers an advantage in this respect. Onboard Active Interference Suppression (AIS) aimed at nulling specific interferers is possible within some architectures.

Erlang efficiency drops if fixed channels are used in fixed spot beams. Methods of recovering erlang efficiency and traffic flexibility involve the use of beam overlaps, frequency addressing with multiple FL bands mapping to a common ML band in different beams, channel to beam switching, Variable Bandwidth and Centre Frequency (VBVCF) filters and agile beam steering.

OPTION A. ANALOGUE SS-FDMA

A transparent transponder is assumed with channels wide compared to individual accesses but narrow compared to the total bandwidth. Routing to beams is by analogue means (as Inmarsat 3).

Filter and Switch Matrix Architectures

Key requirements are for sufficient granularity in channelisation and beam switching and to maintain spectral efficiency on the ML.

Orthogonal FL polarisations may be used to give contiguous usage of the ML by feeding SAW filters adjacent in frequency from opposite FL polarisations. All signals have the same frequency translation. A disadvantage is the 100 percent overhead needed in FL bandwidth. Architectures were considered with typically 8 switchable filters (for each service in the case of LAMG) covering a band of typically 7MHz. If all filters have the same bandwidth a high level of granularity is implied which will limit traffic flexibility. A finer granularity and more flexibility is obtained if the filters are made different (for example with a binary relationship between bandwidths); this however implies that the traffic to a beam may be split between disjoint bands.

Alternatively FL bands, separated by guard bands, may be translated by different frequencies to provide contiguous bands on the ML maintaining ML spectral efficiency without the overhead in FL bandwidth. The disadvantage is in the number of synthesisers required to provide the translations.

VBVCF Architectures

A VBVCF filter makes it possible to reallocate the spectrum by filter tuning instead of switching. The bandwidth and centre frequencies are set by synthesisers. The maximum flexibility occurs when the VBVCF filters are considered to have 3 free variables, namely FL frequency, ML frequency and bandwidth. It is possible to have guardbands only for the FL with contiguous band usage for the ML to minimise spectrum. ESA sponsors SAW filter, VBVCF SAW filter bank and miniaturised switch development.

Fourier Transform Architectures

The architecture uses CFT technology and its inverse (ICFT). The 2 transform devices combine to provide an identity transform. The transform domain signal may be manipulated in the time domain by gating (multiplication by a periodic function) to shape the effective filter function between the input and output. The multiplier waveform may be read from a digital memory and changed by telecommand providing a high degree of traffic flexibility. Developments on CFT technology have been supported by ESA [2]. Expected performance is a guardband width of 100kHz over a processed band of 30MHz.

All the above options can be implemented with technology that exists or is in an advanced stage of development. The CFT architecture was selected for comparison with Options B and C following an internal tradeoff for Option A was based on performance, mass and power and technology risk. The approach offers a fine level of granularity and avoids mobile bandwidth fragmentation. Developments are required with respect to high precision SAW devices, chirp generators and mounting technology but no technical barrier to their implementation is known. The CFT approach showed comparable mass and power to filter based alternatives LMR but showed an advantage LAMG where one CFT processor provides flexibility and bandwidth for all 3 services. Figure 1 shows the FWL processor configuration applied to LAMG; the time domain processor (TDP) provides the gating waveforms.

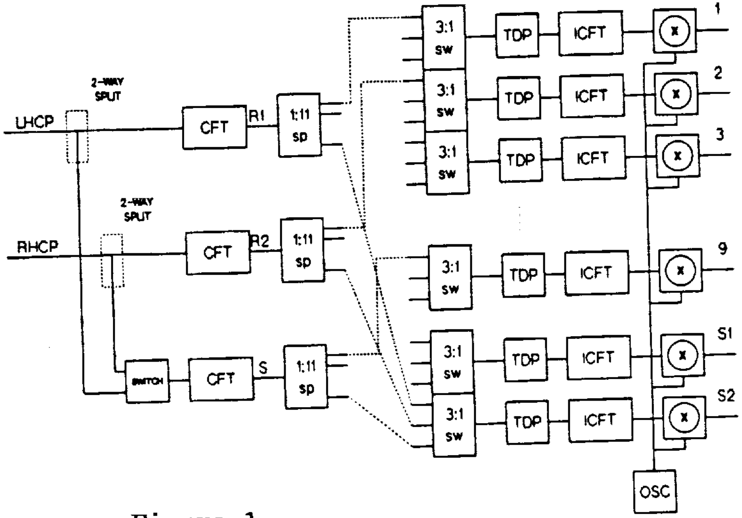

Figure 1.

Option A CFT forward link configuration.

OPTION B. TRANSPARENT DSP

The architecture features digital processing of FDMA channels based on either contiguous or highly overlapped beams.

The contiguous beam case assumes a small number of beams formed by a multimatrix antenna (traffic independent power handling). The processor interfaces at a beam port level giving relatively low processor mass and power due to the small number of ports. Total channelisation gives full routing flexibility. Individual channels have LC applied. This may be used to maintain FWL and RTL HPA drive, compensate for static downlink variations and for dynamic variation on the mobile downlink on the basis of observation of the return uplink power. Dynamic LC can in principle compensate for MES shadowing and gain variations but is limited by delay and multipath errors. Small numbers of channels are multiplexed into beam switching groups.

The overlapped beam case assumes a large number of beams (up to one per channel). Each beam is steerable (generated by a Phased Array (PA) using digital beamforming) providing near to peak gain to individual MESs thereby reducing power requirements both on-board and at the MES. The processor interfaces on a PA element basis. Individual channels may have LC and AIS applied. Routing of individual or small groups of channels is by beam steering; a tradeoff exists between the number of independently steered beams and edge of coverage gain loss between beams. Overlapped beams allow higher FR because the use of beam peaks allows co-frequency beams to be closer whilst meeting isolation requirements. Figure 2 shows an example of a FWL architecture for the overlapped beam case.

The processor utilises a mixture of analogue and digital technology. A coarse level of channel demultiplexing and multiplexing involves a bank of fixed filters or a SAW CFT (or ICFT) device. The CFT approach is particularly advantageous when the total ML bandwidth is large and/or the spectrum is fragmented. Where small bandwidths are envisaged demultiplexing and multiplexing may be performed entirely digitally. The key digital processing functions are fine channel demultiplexing and multiplexing, beamforming, LC and AIS.

AIS is based on complex weighting and addition of co-frequency beam outputs; weighting control may come from an onboard directional based adaptive algorithm. An additional DSP function which lends itself to inclusion in such architectures is source location using super-resolution processing of the array covariance matrix. Mobile terminal location is required prior to beam steering.

The processors have been assessed assuming projected parameters for rad hard 0.8μm CMOS technology (typically 80000 useable gates with 3μW/gate/MHz dissipation). The mass and power has been estimated based on optimised partitioning between ASICs, realistic constraints on individual ASICs and PCBs and on realistic packaging assumptions.

The major potential advantages of Option B are reduced onboard power due to onboard channel LC, the use of near peak gain (overlapped case), increased G/T, increased FR using overlapped beams and AIS and high traffic flexibility from agile beams. These must be traded against complexity, mass and power of the processing.

The RF power savings can be balanced against the power and mass of the processor. Where the RF power is large, as in LAMG, RF power savings are

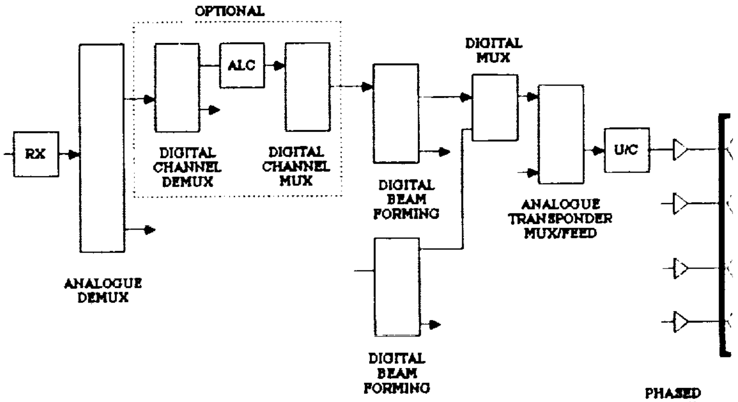

Figure 2. Option B overlapped beam forward link architecture.

large justifying the increased processor mass and power. Where RF power is modest, as in LMR, the RF power savings are accordingly smaller for the overlapped beam approach; in this case the contiguous beam architecture is preferred because of a reduced processor overhead.

OPTION C. REGENERATIVE

Architectures are characterised by baseband processing and feature onboard regeneration, baseband channel to beam routing/switching, signal reformatting, onboard network control functions, etc.

The architectures considered for the LMR mission were a fixed beam CDMA and a hybrid FDMA approach based on agile overlapped beams (as Option B) with a regenerative front end. An FDMA approach was considered for the LAMG mission.

LMR CDMA Architecture

This architecture is described in a companion paper at this conference [3] and will only be outlined here. The FWL is characterised by TDMA access and regeneration of synchronous CDMA by onboard multi-carrier modulators (MCM) for the mobile downlink. Synchronous CDMA has nominal zero self noise, advantages in terms of spectral efficiency on both FL and ML, onboard power and FES complexity. The less critical RTL is assumed to adopt a transparent approach as in Option A or B.

LMR FDMA Architecture

The FWL is characterised by TDMA, onboard regeneration, buffering and reformatting, FDM MCMs and digital beamforming to provide multiple agile beams to routing flexibility. The architecture is therefore as a hybrid between a regenerative and overlapped beam Option B architecture. The RTL assumes a non-regenerative Option B approach. Performance is comparable despite the cross noise generated by non-synchronous codes operating in adjacent beams. The approach has to the overlapped beam Option B architecture with the benefit of peak gain and high ML spectral efficiency. The essential difference is that the FL demux/mux section of Option B is replaced by the regenerative section in Option C.

LAMG FDMA Architecture

The LAMG mission is characterised by the requirement to flexibly accommodate a range of services characterised by different transmission parameters. A regenerative architecture which provides such flexibility was studied characterised by a dual C-band and Ku-band TDMA FL with onboard regeneration, baseband processing and FDMA ML. Both FWL and RTL are regenerative in this case.

OVERALL TRADEOFF

Preferred architectures have been defined for each mission within each of the options. Quantitative comparisons

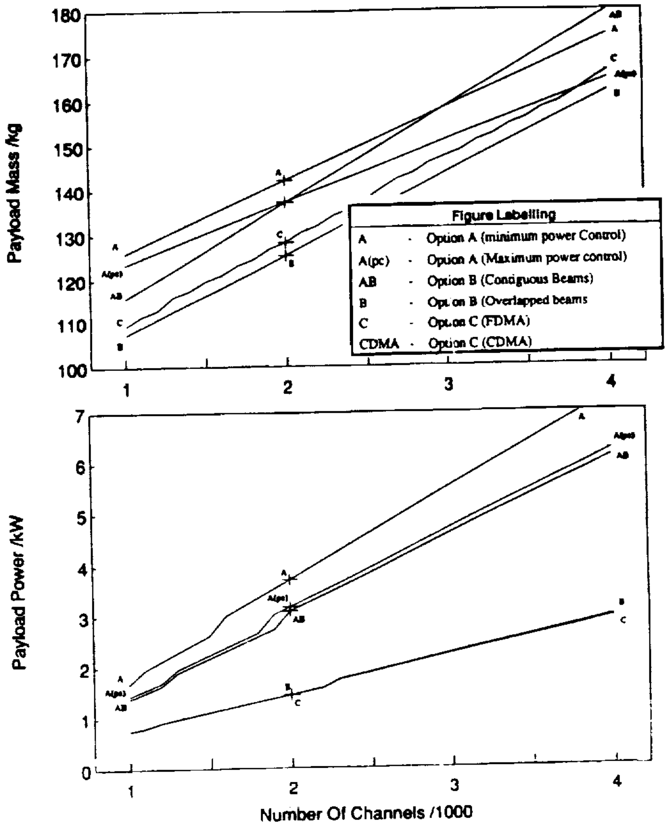

Figure 3. Payload tradeoff for LAMG mission.

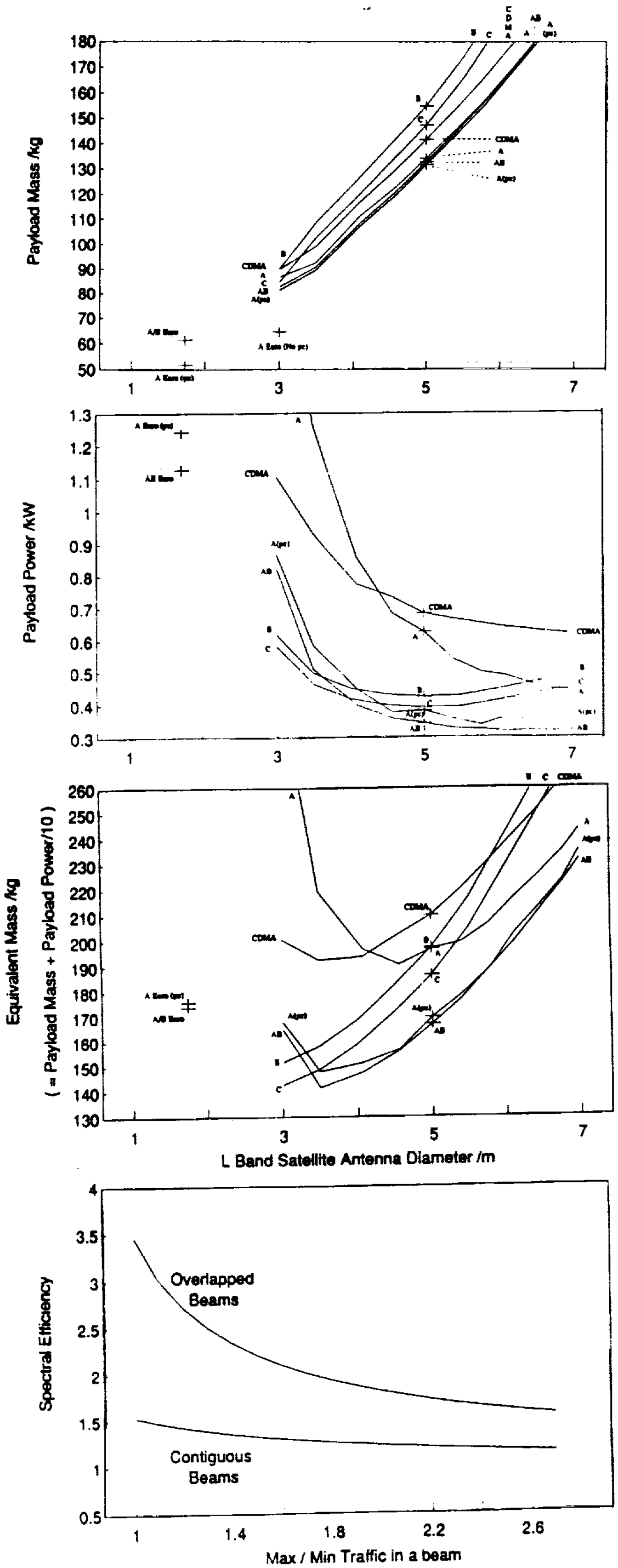

Figure 4. Payload tradeoff for LMR mission

were then made using spread sheet models. The minimisation of payload mass and power represents a complex tradeoff between antenna, power and processor subsystems depending strongly on RF power requirement.

Quantitative results showing payload mass and power versus channel capacity are shown in Figure 3 for LAMG (constrained to 9 beams). Option B (overlapped) provides the minimum mass and power; this is due to the large RF power savings resulting from the high ML gain. Option C has similar mass and power because it also assumes overlapped beams. The contiguous beam options are less efficient. Option A depends strongly on LC strategy.

The LMR mission has 2 major variables, namely capacity and antenna diameter (determining size and number of beams for the contiguous options). Figure 4 shows mass and power versus diameter (in the range up to 12 contiguous beams) for 2000 channels. The contiguous beam options are preferred because they involve lower processor mass and power and the RF power advantage of overlapped beams is low because total RF power is low. Figure 4 also shows total payload equivalent mass (10W/kg equivalence); the minimum for the contiguous beam cases as at approximately 3.5m representing a tradeoff between the effects of decreasing RF power and increasing processor and antenna equivalent mass. Also shown in Figure 4 is a comparison between spectral efficiency where overlapped beam approaches are preferred.

REFERENCES

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[3] A Vernucci and A D Craig 'A European Mobile Satellite System Concept Exploiting CDMA and OBP' (presented at this conference).