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AN ADVANCED OBP-BASED PAYLOAD OPERATING IN AN ASYNCHRONOUS NETWORK FOR FUTURE DATA RELAY SATELLITES UTILISING CCSDS-STANDARD DATA STRUCTURES

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SUMMARY

While preparatory activities for a first-generation European Data Relay Satellite System (DRSS), due for deployment in 1998, are currently being performed, investigations are also taking place to define the technologies and the architectures for advanced DRSSs, featuring the absence of zone-of-exclusion, improved European regional coverage and a high level of interconnectivity and flexibility. The main challenges for such a system are to accomodate a large variety of users, with different requirements in terms of data volumes, bit-rates, service characteristics, etc., and to provide a high degree of flexibility in routing data through the various network links.

Major advances in terms of on-board mass and power savings are expected for digital devices in the next decade, while the same may not occur for RF devices. It is considered appropriate then to exploit the possibilities offered by technology and to propose the use of an On-Board Processor (OBP) aboard each satellite of the DRSS. OBP allows the system designer to individually optimise the various link parameters, to achieve full interconnectivity and flexibility, to accept and process data structures having different multiplexing formats, to terminate useless information (namely "idle frames") on-board and to simplify optical links operation and design.

After introducing a possible DRSS topology and network architecture, the paper discusses an asynchronous network concept, whereby each link (Inter-orbit, Inter-satellite, Feeder) is allowed to operate on its own clock, without causing loss of information, in conjunction with packet data structures, such as those specified by the CCSDS for advanced orbiting systems. The paper then describes a matching OBP payload architecture, highlighting the advantages provided by the OBP-based concept and then giving some indications on the OBP mass / power requirements. This paper is derived from the results of a study performed under a European Space Agency contract.

INTRODUCTION

The European Space Agency (ESA) has in place a number of development programs aimed at establishing an autonomous European manned presence in-orbit. These programs include the development of the Hermes Manned Reusable Space Plane, the Columbus Pressurised Module (an integral part of the International Space Station Freedom), and a Man Tended Free Flying Laboratory. To support the communication requirements of these and other programs, ESA is also developing a Data Relay Satellite System (DRSS) similar to the American TDRS system. The European DRSS is planned to be operational by 1998.

In parallel with this activity, ESA has initiated studies which seek to plot out the strategic future of the In-orbit Communications Infrastructure required to support the space programs of the next century. In this paper, we discuss some of the results of such a study into a future Space Communications Network (SCN), focussing in particular on one key result, namely the importance of On-Board Processing (OBP) to the success of such a system. The time frame under consideration is 2000 - 2035.

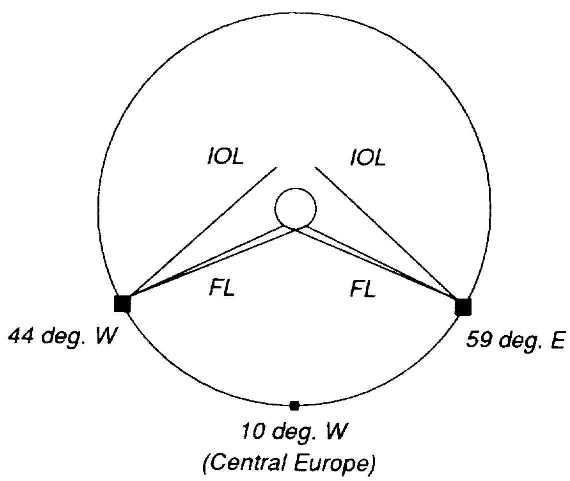


Fig. 1 Present DRSS topology

Before discussing the "near-earth" part of the SCN, we first outline the current DRSS concept. The present DRSS topology is shown in fig. 1. The system consists of two Data Relay Satellites (DRSs) placed at 44 deg. West, and 59 deg. East. Each DRS carries a Feeder Link (FL) at Ka-band (20/30GHz), and Inter-Orbit Link (IOL) accesses at S-band, Ka-band (23/27GHz), and at optical frequencies (0.8μm), the latter being provided on a pre-operational basis. Discussions are ongoing at this time to ensure interoperability with current S-band services on TDRS, and future Ka-band and possible optical services on advanced TDRS. As with the TDRS system, a zone of exclusion exists around the far side of the earth, where communications is not possible with either DRS. This zone extends up to several thousand kilometers altitude for the current DRSS configuration.

AN ADVANCED TOPOLOGY FOR FUTURE DRSSs

In the SCN definition activity, forecasts were produced for the number and type of space programs likely to be undertaken in the timescale under consideration. These forecasts considered every type of space activity from expendable and reusable launchers, through to large space stations and industrial activities. We can summarise the main findings of the study as follows: *i*- the nominal growth scenario projected 19 user satellites of the SCN by 2015, and 33 by 2035; *ii*- each user would require continuous communications with minimal interruption resulting only from link handover; *iii*- standard space link access rates would be defined compatible with bearer services available to users on the ground and the delivery of data should be transparent to the network interworking process; *iv*- the system should seek to deliver data to the ground users in the most cost-effective manner possible.

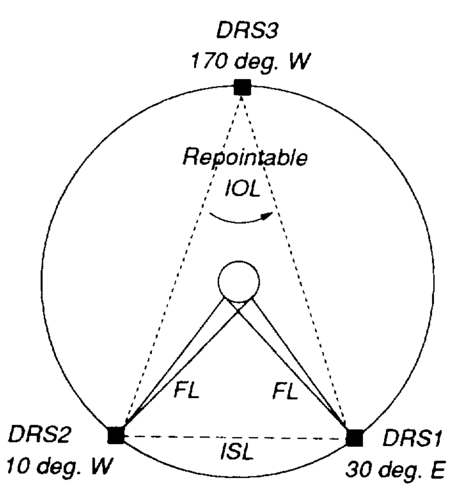


Fig. 2 The reference near-earth SCN topology

The reference near-earth SCN configuration, selected among a number of topologies traded-off against each other, is shown in fig. 2.

It consists of three DRSs (30 deg. E, 10 deg. W, and 170 deg. W), the first two carrying IOL, Inter-Satellite Link (ISL), and FL payloads and the last one carrying only IOL and ISL terminals. This configuration provides total global coverage for the space users with no zone-of-exclusion.

From DRS3, connection is made via ISL to one of the two DRSs over Europe for data to be downlinked to the ground. Alternative routing paths are feasible with the Pacific DRS having a choice of European DRSs to crosslink to, and each of the European DRSs having the ability to crosslink data onto either FL.

SPACE LINKS TRADE-OFFS

Technologies for the implementation of each of the link types (IOL, ISL, FL) were studied. The following conclusions were arrived at: *i*- the FL should continue to be implemented at Ka-band; *ii*- ISL's would be most efficiently implemented at optical frequencies; *iii*- IOL's would be a mix of optical and S-band technology. The reasons behind this last decision were that S-band is the most appropriate technology to service those space users requiring low data rate and having omni-directional antennas. All higher data rate services would be best served by a single technology, leading to a homogeneity of IOL terminals, or *accesses*, on the relay spacecraft. Given the rapid advances that are now taking place in optical technology and terminal design and the inherent limitations of RF technologies, it was recommended that the technology used here should be optical. The decision to go optical was re-enforced by the findings that the network would of necessity be regenerative. This requirement arose from the findings on phase noise present in millimetre wave and coherent optical systems. This precludes the transparent carriage of low data rate services; baseband multiplexing of these services is therefore required at the DRS. Given this, there is a very little penalty and great benefits to be gained from making the whole system regenerative.

Probability	99.9%	99.5%	95%	90%
Accesses 2015	*17*	*16*	*14*	*13*
Accesses 2035	*26*	*25*	*22*	*21*

Tab. 1 Availability vs. number of accesses

The size of the payload on each DRS is critically dependent on the number of IOL terminals provided. This in turn is a function of the grade of service offered to the users in terms of access availability when a link is requested. Tab. 1 shows the relationship between link availability and number of accesses provided on the 170 deg. W spacecraft. It shows that, for a link availability of 99.9%, 26 IOL terminals are required, on each DRS, for year 2035.

Of course, this availability is realised only if any user can access any terminal and obtain the service he requires. It is not sufficient simply to provide terminals of the same technology. Homogeneity of data rates is also required. To address this issue, three levels of data rates were defined (see tab. 2). The first is the *space link data rate*, defined as the data rate of the service between user and relay spacecraft, including CCSDS packet protocol overheads. The *user data rate* is that rate which is generated from the instrument or unit on board the user spacecraft.

Electrical Rate	Data rate without insert		
	User data rate		Space link data rate
	GI or GII	GIII	
16 Kbps	*11.06 Kbps*	*12.67 Kbps*	*12.96 Kbps*
64 Kbps	*44.24 Kbps*	*50.67 Kbps*	*51.84 Kbps*
1.92 Mbps	*1.327 Mbps*	*1.520 Mbps*	*1.5552 Mbps*
35 Mbps	*24.19 Mbps*	*27.7 Mbps*	*28.35 Mbps*
156 Mbps	*107.83 Mbps*	*123.5 Mbps*	*126.36 Mbps*

Tab. 2 Data rates on the various SCN segments

The *electrical rate* is the rate which results in the ground network, in this case ISDN, after encapsulation of the CCSDS packet. Additionally, it was recognised that many users require more than a single service or channel. Thus services from the user spacecraft are multiplexed onto higher rate bearers. There are many such schemes for defining these bearers. One such scheme provides for three ***IOL*** bearer rates carrying combinations of the services offered, i.e.: ***1.672 Mbps*** (1.5552 Mbps + 2*51.84 Kbps + 12.96 Kbps), ***30.113 Mbps*** (28.35 Mbps + 1.5552 Mbps + 3*51.84 Kbps + 4*12.96 Kbps) and ***126.865 Mbps*** (126.36 Mbps + 9*51.84 Kbps + 3*12.96 Kbps).

The implications of introducing a scheme such as this is that each terminal is then designed to operate at three standard bearer rates. At the same time no user has to dramatically oversize his terminal package, as the size and mass of an optical IOL terminal is a weak function of data rate. The OBP package can then operate on the received data stream and demultiplex and route services as and when required.

The ***ISL*** between relay spacecrafts carries a single high data rate multiplex on an optical carrier. Thus, the OBP has complete flexibility on how it orders packets and services. With the user community discussed above, it is conceivable that data rates of up to ***1.1Gbps*** could be required on ISLs.

The ***FLs*** are assumed to be multi-channel links, with each channel carrying up to ***140Mbps***. This is considered to be the maximum feasible for Ka-band High Power Amplifiers, given the projected development of this technology over the timescale under consideration.

THE ASYNCHRONOUS NETWORK CONCEPT

In the system architecture previously illustrated, the function of the OBP is that of ensuring the proper routing (to an IOL or an ISL or a FL) of the individual communications channels multiplexed over digital streams, operating at different bit-rates. Typically, the need for synchronisation of all such streams would exist, as frame start epochs have all to appear properly aligned at the on-board switch inputs. In previous study activities, it was demonstrated that the synchronisation schemes required for systems based upon multiple satellites interconnected by ISLs are very complex and may also suffer reliability problems.

An alternative approach is that of adopting an *asynchronous* network concept, which is particularly suitable when operating with *packet* communications structures. According to this concept, the on-board switch and the various links independently operate on their own clocks, which are necessarily not identical to one another. Information loss is prevented by the presence of useless or "idle" frames in the data stream. These are transmitted whenever there is no useful information to be delivered, for the sole purpose of maintaining the receiver synchronisation.

In many cases, the presence of idle frames is guaranteed by the natural traffic statistics. Their number can also be increased, should it be required, by overdimensioning the multiplexed stream rate. An overdimensioning will anyway result from the fact that only "standard" bit rates are allowed in the IOLs, as discussed before.

With this scheme, it also becomes possible to dimension the various links taking advantage of the fact that idle frames can be terminated at the OBP, thus increasing the links fill factor, especially in presence of services having a bursty nature.

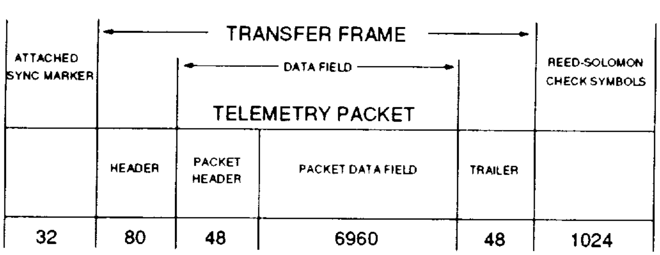
CONSISTENCY WITH CCSDS-STANDARD STRUCTURES

For an SCN to be implemented in the first decades of the next century, it seems appropriate to propose the adoption of the communications structures specified by the Consultative Committee for Space Data Systems (CCSDS).

Consistent with CCSDS specifications, the communications structures which have been considered are *transfer frames*, each of which comprises one or more *telemetry packets*, which are in close relation with the *source packets* generated by user's instruments. The transfer frames, which are optionally Reed-Solomon encoded, constitute a time-continuous stream, so that *idle frames* are generated when there is no outstanding telemetry packet to be transmitted. Dedicated sequences of transfer frames, not necessarily adjacent to each other, are assigned to carry selected groups of source packets. These are called *virtual channels*.

CCSDS links are typically point-to-point links. In the proposed SCN, which adopts multiplexing techniques on all links, interleaving of information generated by different entities (spacecrafts, ground stations) will necessarily occur. It may be difficult to keep the interleaving pattern under control, it being also dependent on the information statistics. However this is not expected to be a basic problem, because transfer frames are protocol data units independent of each other, in the sense that interleaving of transfer frames of different virtual channels, even if generated by different spacecrafts and/or ground stations, is possible without conflicting with the CCSDS protocol.

Several issues had to be addressed for ensuring the possibility of implementing the desired OBP features and for verifying their consistency with CCSDS specifications. Problems relevant to the availability of *routing information*, to the *segmentation* of the overall link protocol and to the *termination* of idle packets on-board were considered in the study, coming to the conclusion that acceptable solutions can be found to each of them. It was determined that no higher-layer functions (e.g. error correction) shall be provided by the OBP. These will be implemented in the end-to-end protocols. Independent and consecutive frame counts shall be used on each link section. To allow the on-board termination of idle frames, the OBP shall not only operate at transfer frame level, but it shall also examine the content of the transfer frame data field, to interpret the header of the embedded telemetry packets.



Note: field lengths are expressed in symbols

Fig. 3 Proposed transfer frame structure

As to the transfer frame length, this shall be equal for all frames, to simplify the on-board switch design. This does not pose any constraint, as CCSDS specifications indicate the transfer frame length as a mission set-up parameter. It was considered very appropriate that the telemetry packets length be selected such that an integer number of telemetry packets can be fitted within the transfer frame data field (the CCSDS-specified "synchronous" insertion). In particular, it is proposed that *only one* telemetry packet, comprising a 48-bit header and a 6,960-bit (or 870 octects) data field, be fitted within the transfer frame data field. The resulting transfer frame arrangement is shown in fig. 3.

THE OBP PAYLOAD

The SCN system supports two logical capacity flows of very different size, i.e. the Forward-Link (FWL) and the Return-Link (RTL) traffic. The inbound and the outbound sections of an ISL will *both* have to support FWL and RTL traffic; therefore a single OBP unit, common to the FWL and the RTL, has been considered. Overall, the OBP can be visualized as an on-board subsystem having the capability of interconnecting several asynchronous input and output streams (IOLs, ISLs, FLs), operating at different bit-rates and comprising CCSDS-standard frames.

OBP ports	IOL	ISL	FL
Input	*n @ 13 Kbps* *9 @ 1.7 Mbps* *4 @ 31 Mbps* *13 @ 127 Mbps*	*2 @ <1.1 Gbps*	*1 @ 31 Mbps*
Output	*3 @ 13 Kbps* *17 @ 52 Kbps* *6 @ 1.7 Mbps*	*2 @ <1.1 Gbps*	*5 @ 127 Mbps*

Tab. 3 OBP capacity requirements

The OBP shall be capable of terminating idle frames and of routing all other incoming frames to the appropriate output ports. The number of streams to be handled by the OBP is shown in tab. 3 (rounded bit-rate figures are indicated). The number of 13 Kbps IOL streams remains TBD; nevertheless this has a minor impact on the OBP design. The general OBP block diagram, presented in fig. 4, was developed considering that the same design shall be consistent with both the DRS1/2 and DRS3 operational modes. The high-level functions visualised in the block diagram are:

- *Demodulators*, which handle the incoming IF signals (signals travelling over optical links, namely ISLs and the high-rate IOLs, are not to be demodulated, the interface with the OBP being at baseband level).

- *Demultiplexers*, operating on ISLs only. Eight 127 Mbps streams are derived out of each aggregate high-rate (up to 1.1 Gbps) ISL stream (a bit-by-bit multiplexing strategy is adopted to minimise memory requirements). Unique Words are inserted, at multiplexed stream level, to allow the required alignment function.

- *Decoders* (Reed-Solomon), operating on the transfer frames (the attached synchronisation marker is not encoded), utilising the appended check symbols. The Decoders, although placed *in front of* the Synchronisers (next item), have to perform an alignment function, to detect the Start Of Transfer Frame (SOTF flag) within the received stream. Only the transfer frames are to be delivered to the Synchronisers, filling the inter-transfer frame gap (due to the missing synchronisation marker and check bit fields) with "don't care" bits.

- *Synchronisers*, used to align the incoming transfer frames to the unique on-board frame clock (127 Mbps units) and to also perform rate conversion (13 Kbps, 1.7 Mbps and 31 Mbps units). All streams exiting the Synchronisers operate at 127 Mbps. A FIFO-based buffer/alignment device, written with the incoming stream clock and read with the onboard clock, is used to align frames. To counteract the effect of situations where the incoming frame clock rate is higher than the on-board one, it is necessary to terminate some idle frames before they are stored in the FIFO. The Synchronisers shall therefore incorporate logic able to read the header of the telemetry packet embedded in the transfer frame and to accordingly control the FIFO writing operations. They also have to interpret the transfer frame header, thus generating a Transfer Frame Designator (TFD) for each transfer frame. The TFD contains information on both the frame destination-entity (derived from the transfer frame header) and on whether a frame is idle or not (derived from the telemetry packet header).

- *Input Frame Processors*, having the main tasks of generating a Routing Code (RC), subsequently used by the Switching Module to route individual frames to the appropriate output port, and of attaching it in front of each transfer frame, in place of the previously terminated CCSDS synchronisation marker. The RC is a short sequence which unambiguously designates one specific Switching Module output port. The RC is determined on the basis of the TFD pattern and the network route (i.e. direct to a FL or via an ISL) to be followed by each transfer frame to reach the destination entity. This association, decided by the Operations Control Centre (OCC), is stored in a look-up table contained in the On-board Control Unit (OCU), written and periodically updated by the OCC, via a control channel.

- *Switching Module*, which routes the incoming 127 Mbps frames to the appropriate output port. Like switches used for terrestrial ATM applications, it shall be able to provide internal buffering functions, intended to solve conflicts of frames appearing at different inputs but having the same destination port. Each transfer frame has to be handled by the Switching Module preserving the sequencing of frames belonging to the same virtual channel and reducing, as far as possible, the switching delays and their spread.

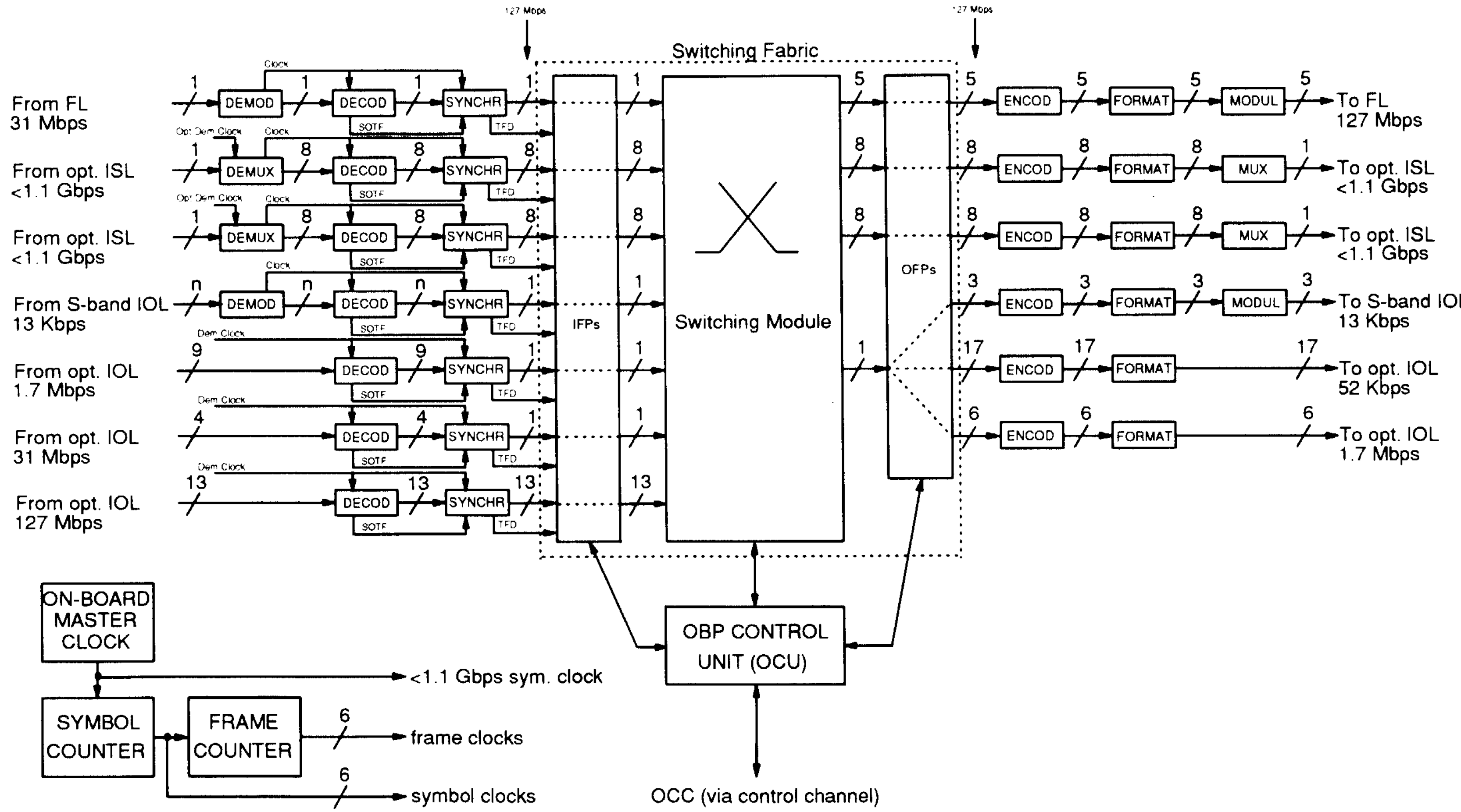


Fig. 4 OBP subsystem functional diagram

- *Output Frame Processors*, intended to change the transfer frame header, to vary the stream bit-rate, to provide buffering where appropriate, and to retime frames at the output of the Switching Module.

- Transmissive equipment, i.e. *Encoders*, performing Reed-Solomon encoding of transfer frames and appending the check bit field, *Output Frame Formatters*, having the simple task to attach the synchronisation marker to the encoded frame, *Multiplexers* (bit-by-bit), only for ISLs, and *Modulators*, for the low-rate IOLs and the FL.

- *OBP Control Unit*, having the main task of keeping look-up tables containing frame routing information. In particular, it controls the associations between the destination entity and the OBP output port. The OCU operates under instructions of the OCC, via a control channel. Look-up tables updating may be expected at all times when a new connection is set-up or when it has to be rerouted for inter-satellite visibility problems.

OBP IMPACT ON PAYLOAD IMPLEMENTATION

From the analyses performed, it was possible to preliminarily evaluate the main OBP parameters, as shown in tab. 4.

Year	Technology	Power (W)	Weight (Kg)	Structure
1990	*commercial*	*185*	*74*	*assembly*
2015	*qualified*	*4*	*1.5*	*board*
2035	*qualified*	*0.12*	*n.a.*	*chip*

Tab. 4 OBP capacity requirements

The most interesting result is the effect of components integration. With today technology, the OBP assumes the aspect of an assembly; however it is expected that, via a massive utilisation of ASIC devices, the OBP can become a simple board in 2015 or even a single chip in 2035. The OBP impact on the overall payload becomes then virtually negligible.

CONCLUSIONS

This paper considers the applicability of OBP techniques to an advanced DRSS, constituting the near-earth part of the SCN. OBP has been found to be beneficial with regard to the:

- *Overall network performance*. The payloads utilised in an SCN typically have to support a wide variety of links characterized by different optimal link parameters (bit-rate, multiplexing, information bundling, modulation, coding, etc.) and heavy interconnectivity and flexibility requirements. OBP can accomodate all such requirements, allowing, in addition, to terminate useless information on-board.

- *Network synchronisation*. A formidable problem is represented by the requirement for synchronising the various streams. This problem can be overcome by adopting packet structures (e.g. the CCSDS standard) in conjunction with OBP, allowing the implementation of an SCN where all links have no mutual synchronization requirement.

- *Optical links*. An SCN will largely rely upon optical links, both for the IOLs and for the ISLs. Due to the difficulty of implementing coherent optical links, with an analog interface, baseband operation appears to be a must, particularly for the interface between the ISL and the other payload sub-systems.

The CCSDS standard has been reviewed and it has been found that, by appropriate selection of parameters, there are no basic inconsistencies between it and the OBP operational mechanisms.

An OBP payload operating in an asynchronous network concept has been proposed; it utilises a Switching Fabric realised with the same techniques which will be used for the implementation of terrestrial broadband networks (B-ISDN). After a review of present technology and expected developments, the OBP has been tentatively sized masswise and powerwise. It was concluded that, by the next century, OBP will be implementable with neglectable impacts on the payload mass and power, while providing important benefits with regard to overall system efficiency.

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