Control and Management of Optical Inter-Satellite Network based on CCSDS Protocol (Invited)

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Abstract *A network control architecture and Advanced Orbiting Systems (AOS) frame switching scheme suitable for inter-satellite optical network are proposed and demonstrated. The proposed scheme will facilitate on-board data forwarding of resource and energy hungry satellite by avoiding unnecessary data packing and unpacking for bypass traffic.*

Introduction

Facing the increasing demands on the satellite communications data rate, communication technologies based on microwave cannot yet meet the demands. With the break though of key technologies in satellite laser communications, researchers have come to the conclusion that, optical communications must be used to implement satellite communications facing with the increasingly growing demands for a high data rate and a large communications capacity [1].

The use of multi-gigabit laser inter-satellite links (ISLs) is the enabling factor for routing traffic through the spare segment and creating a global space-based optical backbone network. Most of the work has been focused on the PHY and hardware design; the networking issues have not attracted comparable attention in the research community. Regarding to the space networking protocol, Consultative Committee for Space Data Systems (CCSDS) plays an important role in standard formulation. Within CCSDS protocol stack, Advanced Orbiting Systems (AOS) space data link protocol (a Layer 2 protocol) provides a framing layer between channel coding and higher-layer link multiplexing protocols such as CCSDS Encapsulation Service. Also, IP over CCSDS has attracted lots of attention since it embarrasses ubiquitous application of IP standard and lower cost for space flight adaptation. However, we still need conquer the following challenges caused by dynamically changed ISLs: (1) how to achieve routing convergence efficiently and keep service continuity while ISLs changed? (2) how to deliver traffic end-to-end avoiding unnecessary intermediate packing and unpacking process? (3) how to implement QoS for different services and other networking Operation, Administration and Maintenance (OAM) purpose policy.

Therefore, in order to investigate these problems, topology design and network control architecture, as well as a novel AOS label switching technology are addressed and demonstrated in this paper.

Network Topology Design

An optical satellite constellation network is formed by answering the following questions [1]:

- Decide the orbit LEO-MEO-GEO, and number of orbital planes and inclination
- Decide on launching policy π or 2π and "phasing" (i.e. spacing)
- Decide number of ISLs per satellite
- Decide which satellites will be linked with ISLs

In this paper, we focus on the last step for a given constellation with constraints of ISLs numbers. First, we obtain the visibility data of satellite constellation from Satellite Tool Kit (STK). And then, considering both the visibility of satellite and basic connectivity/robustness requirements of satellite networking topology, the time slot based topology design approach is proposed according to the principle of less topology reconfiguration. This is because lasers, different from RF antenna, need tracking and pointing system to establish the physical connection which is time consuming and will cause routing convergence. The detailed algorithm and some topology design results are shown in Fig. 1 and Fig. 2 respectively. This is a hybrid GEO-MEO-LEO constellation network.

Optical Inter-Satellite Networking Control and Management Architecture

As shwon in Fig.3, networking system includes the following three function planes: Management (i.e., topology construction and updating), Control (i.e., routing) and Data Plane (i.e., data encapsulation and forwarding).

To tackle the problem of routing and end-to-end service continuity caused by ISL dynamics, the protocol of control plane is proposed with the following novel strategies:

- Link-State Database Self-Updating: OSPF can update the link-state database according

Input	
Access_t	Link visibility at time t
$Link_{ij}$	link between satellite i and j
N	total number of satellites
T	the total time
N_1	the number of inter-orbit links on each track surface
N_2	the number of interlayer links on each track surface
Matrix	the adjacency matrix of the track surface
Output	
m	number of fixed topologies
G_{m}	the M-th fixed topology
G	the whole network topology

Algorithm:

while $t \leq T$

$\{Link_{ij}\} \leftarrow \mathrm{Access}_t \ \ (1 \leq \mathrm{i,j} \leq \mathrm{N}, \mathrm{i} \neq \mathrm{j})$

for each Link in $\{Link_{ij}\}$

Matrix ← Link

if Connect(Matrix)

$\{Link_{k1}\}/\{Link_{k2}\} \leftarrow \mathrm{Link}$

end

if $k1 \geq N_1$ && $k2 \geq N_2$

break

end

end

$T_m \leftarrow Min(\{Link_{k1}\} \cup \{Link_{k2}\})$

$G_{T_m} = \{T_m, \{Link_{k1}\}, \{Link_{k2}\}\}$

$t \leftarrow t + T_m$

end

$$\mathrm{G} = \{\{T_1, T_2, \ldots, T_m\}, \{G_1, G_2, \ldots, G_m\}\}$$

Fig. 1: Topology Design Algorithm

Slot Start (min)	Slot End (min)	Slot Dura. (min)	Link1	Link2	Link3	Link4	Link5
1	19	19	L513L418	L413M_18	L113L518	L313L218	L213L118
			Link6	Link7	Link8	Link9	Link10
			L306L404	L406M_24	L206M_24	L204M_36	L506L104
20	34	15	Link1	Link2	Link3	Link4	Link5
			L520L404	L420L304	L120L504	L320L204	L220L104
			Link6	Link7	Link8	Link9	Link10
			L313L411	L413L511	L213L311	L513L111	L113L211

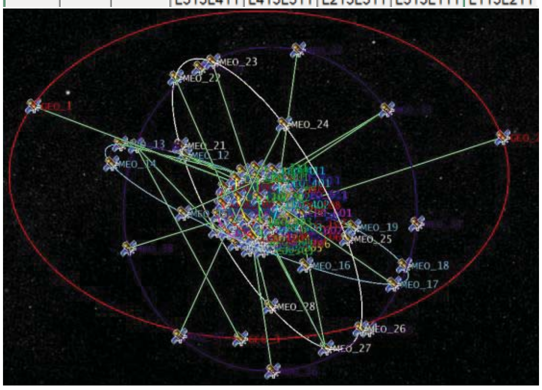

Fig. 2: Part of Topology Design Results and 3-D View of ISLs

to the ephemeris and planed ISLs reconfiguration strategy in the future. This could avoid neighbouring information flooding when ISLs changes.

- Algorithm Optimization: Routing algorithm is optimized to consider residual lifetime of ISLs (which can minimize the traffic interruption caused by ISLs reconfiguration) and CSPF is employed to achieve bandwidth guarantee.
- Employing one-way link: with classical OSPF, when bi-direction link goes one-way (such as broken laser), adjacency relations will be removed from both side and this one-way link will not be used which is a waste for precious ISLs. So, OSPF is modified with capability of maintaining one-way ISLs by deliver one-way notification from the node being able to receive message to the other side.

AOS Frame Switching Technology

In CCSDS framework, the AOS Space Data Link Protocol provides functions of transferring various data using a fixed-length protocol data unit called the Transfer Frame. In intermediate node, we could not switch AOS frame direcly and all the traffic will be unpacked and forwarded to uperlayer to do further process. Considering the bypass traffic, it will be packed in AOS frame again and transfered through optical ISLs. Along with the increasing of space data delivery demand, the switching requirements of satellite node will increase as well. Switching and data packing/unpacking approach are enengy and resource consuming especially for sateallite. So, based on discussion above and inspired by Multiprotocol Label Switching (MPLS) network, a control segment is added in AOS frame (Fig. 4) in oder to implement frame switching in intermediate satellite by avoiding uncessary uppacking and repacking apprach for bypass traffic. More specifically, label fileld is used to forward AOS frame according local Label Forwarding Information Base (LFIB) with support of Label Distribution Protocol (LDP). So, Data Communication Network (DCN) channel is added to deliever the required control and management information (e.g., routing protocol,). Furthermore, some OAM bits is reserved to conduct network

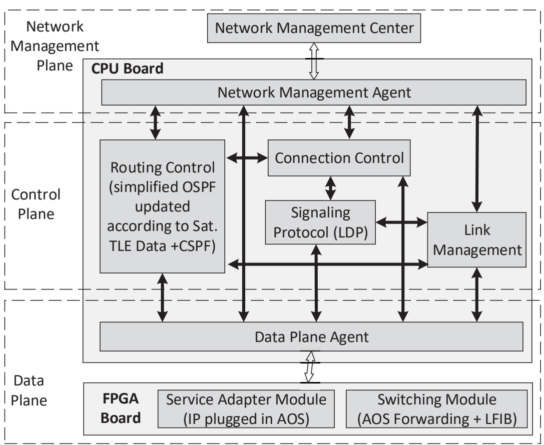

Fig. 3: The Control and Management Architecture

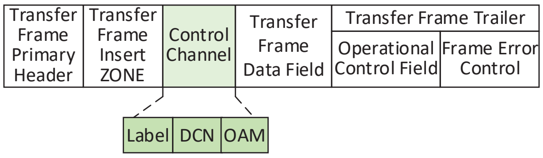

Fig. 4: The Concept of AOS Switching in AOS Frame

monitoring and detection function.

AOS Frame Swicthing Demonstration

As shown in Fig. 5, the platform consists of following three function modules:

- CPU Board: The hardware where control plane protocol, management plane agent and data plane agent are operated. It facilitates the path calculation, forwarding table update and control/management message processing.
- AOS Switch FPGA: This is a data plane emulator which perform frame assembler /dissembler and switch AOS frames according their labels and local LFIB (proof of concept in Fig. 6). Its LFIB is configured by control plane protocol (i.e., LDP). Low-Voltage Differential Signalling (LVDS) connector is used to interconnect other switch boards and serial port to connect with CPU board.
- Service Adapter: The adaptor could adapt different data (bit stream or IP packet) into AOS frames on one end so that they can be transported transparently across the system. And it also can transform the AOS frames to the corresponding services at the other end.

Generally, ground Network Management Center sends configuration message to NMA of a peer node on ground and then it is forwarded to Data Plane Agent (or TPA) which deliver message to FPGA switch (as presented in Fig. 7). If this is a message going to other satellite, it will be plugged in DCN channel of AOS frame and then delivered through RF or laser channel. With same FPGA logic and CPU resource consumption, the proposed label switching strategy could achieve 3.6 times faster than processing IPv6 packet and 2.9 time faster than IPv4 packet respectively, which means lower delay and energy consumption could be achieved while processing same amount of traffic.

Conclusion

For inter-satellite optical network, topology design approach is considered first. With the proposed control and management architecture, label switching technology for AOS frame is also demonstrated in order to avoid unnecessary disassembling for bypass traffic and therefore save energy and resource in intermediated node.

Acknowledgements

This work was funded in part by NSF of China (61622102, 61771074), State Key Lab. of Advanced Optical Communication Systems Networks (China).

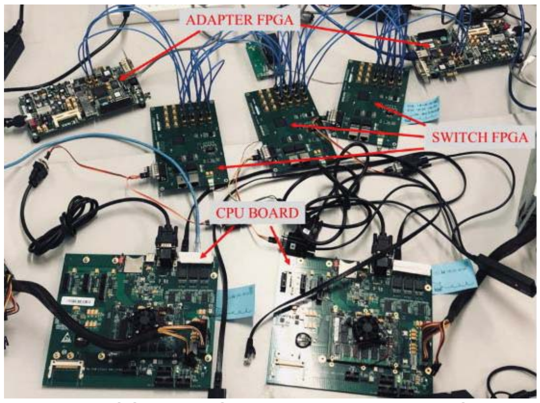

Fig. 5: AOS Frame Switching Demonstration Setup

Fig. 6: The POC of AOS Switching Board

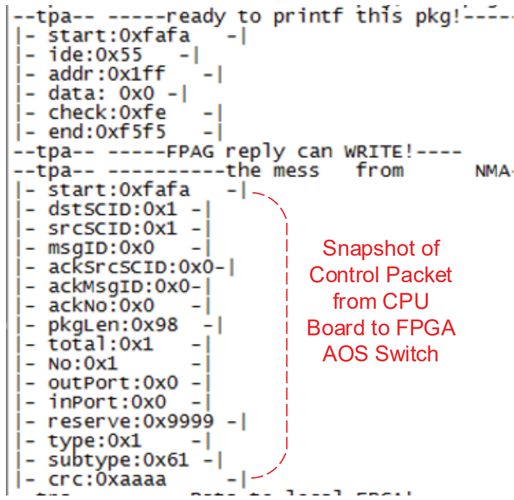

Fig. 7: Snapshot of Control Packet

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