# Design and Verification of a Novel Switching Architecture for Onboard Processing

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**Abstract.** To overcome the problems caused by conventional ground routing protocols applied in the satellite communication network, a novel switching architecture is proposed. The proposed architecture employs layer-2 switching for same port and IP routing for different ports. Furthermore, the onboard IP switching process is well designed. OPNET is applied to build a satellite network simulation environment based on onboard IP switching. Simulation results demonstrate that the switching architecture meets the requirements of onboard IP data packet switching for both inter-beam, between beams and between satellites.

**Keywords:** Space based backbone network · Switching architecture · Satellite communication

## 1 Application Scenarios

With the improvement of the processing ability of satellite platform and payload, communication satellites can realize not only bent pipe, but also data regeneration and even routing and switching technology. The development of satellite communication system based on IP packet switch extends the ground network to outer space. IP packet switch onboard can provide internet communication service for anybody at anywhere. Furthermore, satellite communication can stay connected if the ground-control system is breakdown or encounters failures, which improves the viability of satellite communication systems. The network structure of satellite communication system based on IP packet switch is shown in Fig. 1.

M. Jia et al. (Eds.): WiSATS 2019, LNICST 281, pp. 424–431, 2019.
https://doi.org/10.1007/978-3-030-19156-6_40

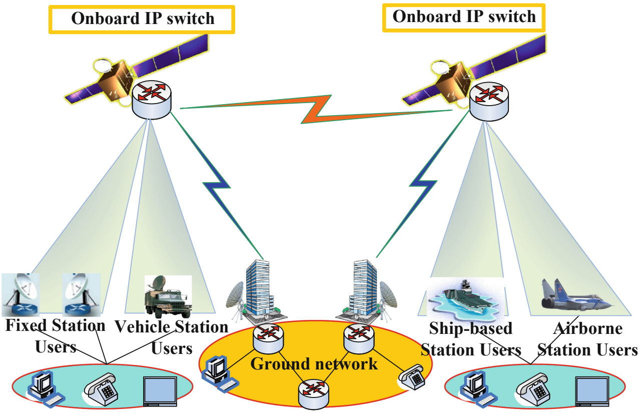


**Fig. 1.** Network structure of satellite communication system based on IP packet switch

## 2 Related Work

Typical satellite communication systems which are capable of onboard switching include SpaceWay system, IRIS system and TAST system. Among them, TSAT system [1] attempts to use onboard MPLS switching. However, due to the restrictions of funds and technologies, TSAT project ended in 2009.

- **SpaceWay System**

SpaceWay system [2] employs onboard fixed length packet switching method to implement IP packet routing and switching. Ingress flows and egress flows are of standard IP packets for both satellite terminals and ground equipment. In the satellite terminal, each IP packet is divided into one or more fixed length SpaceWay packets. The MAC layer addresses of the destination node and the downlink beam which the destination node located in are inserted in the SpaceWay packet header. Then, the SpaceWay satellite analyzes the packet header and extracts the two addresses to implement onboard switching. The transformation from IP addresses to SpaceWay addresses is achieved through a collaboration of satellite terminal and satellite network control center.

- **IRIS System**

IRIS system [3] attempts to develop space router based on radiation-resistant PowerPC CPU. With the help of this router, a series of IP-based applications, e.g. web and VoIP, can build the communication link directly without via the ground relay station, which decreases the Space-Ground communication delay (the delay for GEO satellite is about 250 ms). IRIS system installs a Cisco 18400 spaceborne IP router, which can be configured flexibly onboard according to ground control commands, to process routing and switching of IP packets. Satellite employs IP data packet to transmit data, which allows direct access to the network and achieves a faster communication.

## 3 Adaptability Analysis of Switching Architecture

The architecture [4] of a router can be divided into forwarding plane and control plane. Control plane maintains routing table and ARP table according to routing protocol (RIP, OSPF, etc.) and Address Resolution Protocol (ARP). Forwarding plane implements packet forwarding according to the forwarding table, which is generated by control plane based on routing table and ARP table (Fig. 2).

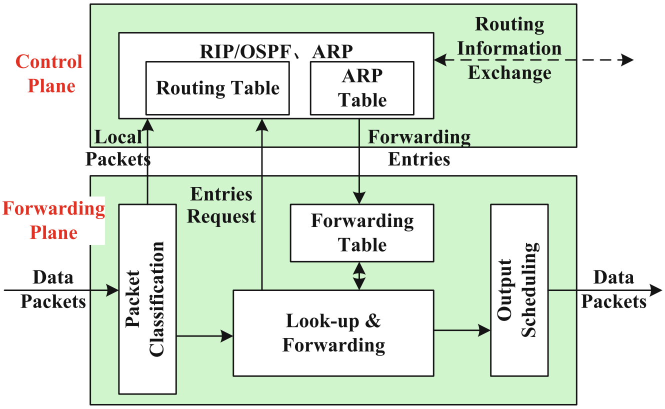


**Fig. 2.** Architecture of a router on ground

In the following of this section, the adaptability of switching architecture in satellite communication systems based on spaceborne IP switching is analyzed in the aspect of processing and switching for different kinds of data packets (IP unicast data packets, IP multicast data packets, ARP data packets).

### 3.1 IP Unicast Data Packet

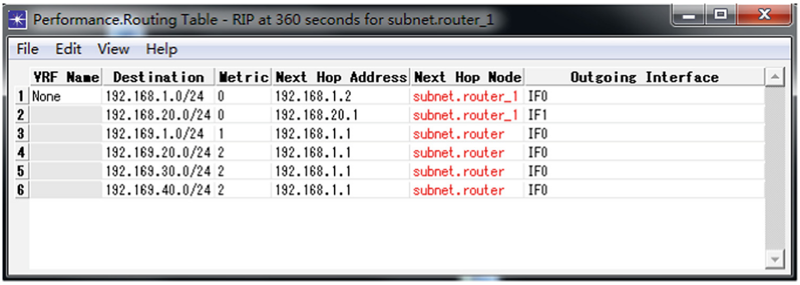
After receiving an IP unicast data packet, the forwarding plane decides whether the packet should be received locally according to the MAC address. Data packet with the router's MAC address is accepted. Otherwise, the data packet is discarded directly and will not be forwarded by the same port. Then, the data packet is classified according to its IP address. Data packet with local IP address is sent to control plane and data packet with non-local IP address is forwarded based on the matching results of forwarding table.

As a result, if the switching architecture of the ground router is adopted on the satellite directly, IP unicast data packets from two satellite terminals under the same beam cannot be transmitted correctly. Because the IP unicast data packet from the source terminal is discarded directly by the satellite router due to the MAC address of the packet is different from the MAC address of the satellite router.

## 3.2 IP Multicast Data Packet

IP multicast data packets can be divided into data packets and management packets. The switching architecture of data packet is the same as the IP unicast data packet, i.e. a router looks up multicast IP address in multicast routing table and forwards the packet. For management packets (applied in RIP [5], OSPF [6], etc.), a router decides whether the packet should be received locally according to the multicast IP address and will not forward the packet by the same port.

As a result, if the switch architecture of the ground router is adopted on the satellite directly, multiple ground routers under the same beam and the satellite router form a point-to-multipoint network. The routing information from one ground router will not be forwarded to other ground routers under the same beam, and ground routers cannot obtain the routing information of next hop. Figure 3 shows that ground router with RIP protocol can only obtain routing information from different beams if the switch architecture of the ground router is adopted on the satellite directly.



|  | VRF Name | Destination | Metric | Next Hop Address | Next Hop Node | Outgoing Interface |
|---|---|---|---|---|---|---|
| 1 | None | 192.168.1.0/24 | 0 | 192.168.1.2 | subnet.router_1 | IF0 |
| 2 |  | 192.168.20.0/24 | 0 | 192.168.20.1 | subnet.router_1 | IF1 |
| 3 |  | 192.169.1.0/24 | 1 | 192.168.1.1 | subnet.router | IF0 |
| 4 |  | 192.169.20.0/24 | 2 | 192.168.1.1 | subnet.router | IF0 |
| 5 |  | 192.169.30.0/24 | 2 | 192.168.1.1 | subnet.router | IF0 |
| 6 |  | 192.169.40.0/24 | 2 | 192.168.1.1 | subnet.router | IF0 |

**Fig. 3.** RIP routing information on ground router

## 3.3 ARP Data Packet

After receiving an ARP data packet, the forwarding plane classifies the packet according to its MAC address. Data packet with local address or broadcast address is sent to the control plane. Otherwise, the data packet is discarded directly and will not be forward by the same port.

As a result, if the switch architecture of the ground router is adopted on the satellite directly, the ARP data packets from two satellite terminals under the same beam cannot be processed properly. Because the MAC address of ARP data packet from the source terminal is broadcast address and the packet is sent to control plane rather than being forwarded to the destination terminal.

It can be seen from the above analysis that, if the switch architecture of the ground router is adopted on the satellite directly, forwarding of certain IP data packets or ARP data packets will be affected, which causes the routing protocol failing to converge. Therefore, it is necessary to provide adaptive design for the environment of onboard IP switch.

## 4 Switching Architecture Design for Onboard Processing

Considering layer-2 switching and IP routing in ground network, and taking into account the communication requirements among satellite terminals under the same beam and the limitation of the storage capacity of spaceborne IP switch payload, this paper proposes a novel switching architecture. In this architecture, layer-2 switching happens at the same port, and IP routing happens between different ports. Combined with the optimization design such as proactive forwarding entries distribution in routing table and ARP table self-learning, the proposed architecture meets the requirements of onboard IP data packet switching (Fig. 4).

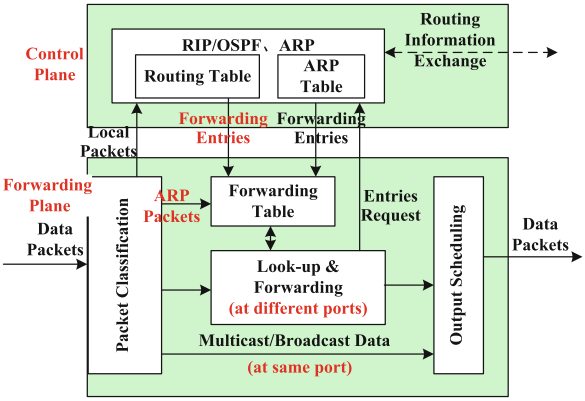


**Fig. 4.** Onboard IP switching architecture

- **Layer-2 Switching at the Same Port**

The following section illustrates the IP data switching process at the same port by taking satellite terminal 1 to visit satellite terminal 2 which is at the same port as an example. When satellite terminal 1 receives IP data packet, the layer-2 address of next hop (satellite terminal 2) is obtained by looking up the routing table according to the destination IP address. Satellite terminal 1 adds its layer-2 address and satellite terminal 2's layer-2 address as the header of IP data packet and encapsulated it into a satellite transmission frame before sending it to the onboard IP router.

After receiving the satellite transmission frame, the onboard IP router extracts the layer-2 address of data packet and determines this address is different from its own layer-2 address. Then, the frame is sent directly to the downlink interface for transmission and the onboard layer-2 switching process at the same port is accomplished.

Satellite terminal 2 receives the satellite transmission frame and determines the layer-2 address of the data packet is the same as its own layer-2 address. Then, the frame is accepted and the IP data packet is recovered. After that satellite terminal 2 sends the IP data packet to its corresponding user.

- **IP Routing and Switching among Different Ports**

The following section illustrates the IP data switching process at different ports by taking satellite terminal 1 to visit satellite terminal 2 which is at different ports as an example. When satellite terminal 1 receives an IP data packet, the layer-2 address of next hop (satellite terminal 2) is obtained by looking up the routing table according to the destination IP address. Satellite terminal 1 add its layer-2 address and the onboard IP router's layer-2 address as the header of IP data packet and encapsulates it into a satellite transmission frame before sending it to the onboard IP router.

After receiving the satellite transmission frame, the onboard IP router extracts the layer-2 address of data packet and determines this address is the same as its own layer-2 address. Then, the IP data packet is recovered and the corresponding IP address is extracted. The desired port is obtained by looking up the forwarding table according to the IP address. Then the IP data packet is encapsulated into a satellite transmission frame and is sent to the downlink interface for transmission. With this, the onboard layer-2 switching process at different ports is accomplished.

Satellite terminal 2 receives the satellite transmission frame and determines the layer-2 address of the data packet is the same as its own layer-2 address. Then, the frame is accepted and the IP data packet is recovered. After that satellite terminal 2 sends the IP data packet to its corresponding user.

## 5 Simulation and Verification

In order to test the ability of the above onboard IP switching architecture, OPNET is applied to build satellite network simulation environment. There is 1 onboard IP router and 6 earth stations (employing ground router and data terminal simulator), as shown in Fig. 5. Port 1 of onboard IP router connects earth stations 1, 2, 3 and port 2 of onboard IP router connects earth stations 4, 5, 6. The router uses RIP protocol to configure the communication service parameters under the same beam and different beams, so as to verify the routing convergence and data transmission performance with the proposed switching architecture.

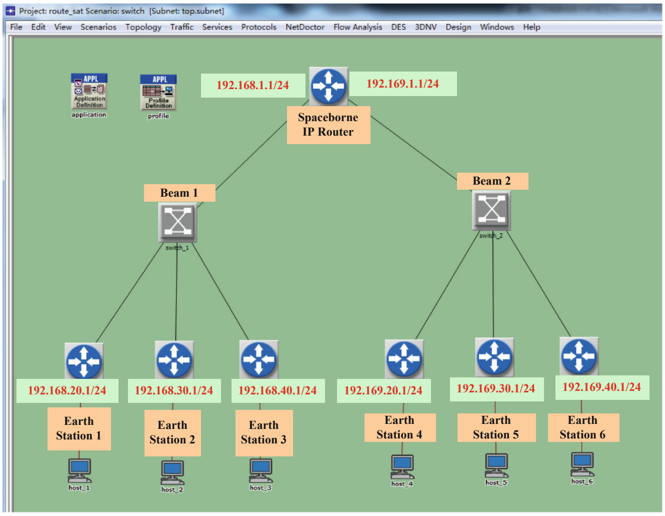
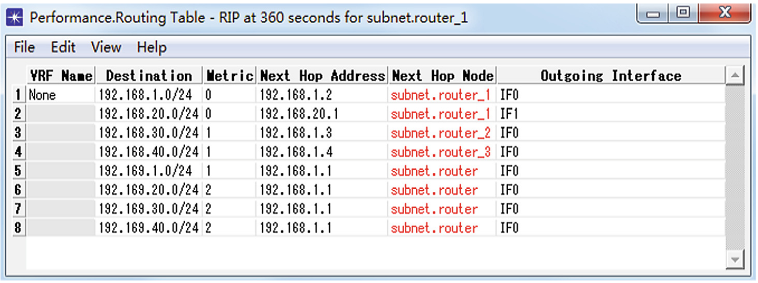


**Fig. 5.** Satellite network simulation environment with onboard IP switching architecture

Figure 6 shows the routing convergence results of ground router with RIP routing protocol. It can be seen that, by employing the proposed switching architecture, ground router can obtain the routing information under the same beam or different beams.



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| 3 | | 192.168.30.0/24 | 1 | 192.168.1.3 | subnet.router_2 | IF0 |
| 4 | | 192.168.40.0/24 | 1 | 192.168.1.4 | subnet.router_3 | IF0 |
| 5 | | 192.169.1.0/24 | 1 | 192.168.1.1 | subnet.router | IF0 |
| 6 | | 192.169.20.0/24 | 2 | 192.168.1.1 | subnet.router | IF0 |
| 7 | | 192.169.30.0/24 | 2 | 192.168.1.1 | subnet.router | IF0 |
| 8 | | 192.169.40.0/24 | 2 | 192.168.1.1 | subnet.router | IF0 |

**Fig. 6.** RIP routing information on ground router

The transmitting performance of earth terminals with the proposed switching architecture is given in Fig. 7. Simulation results show that data from earth station terminals can transmit data under the same beam or different beams.

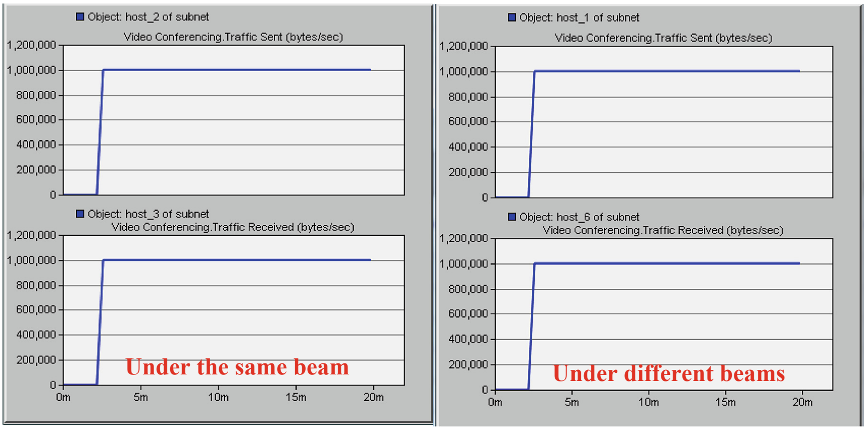

**Fig. 7.** Transmitting performance of earth terminals

## 6 Conclusion

A novel switching architecture suitable for satellite communication network application based on onboard IP switching is proposed. The traditional ground routing protocols will not converge and IP data packets will not be properly processed when applied in the onboard IP routers as downlink beam is broadcast in nature. The proposed architecture employs a hybrid switching strategy: layer-2 switching within same port and IP routing for different ports, combined with the optimization design such as proactive forwarding entries distribution in routing table and ARP table self-learning, to overcome the existing problems and enable routing convergence and data transmission. Simulation results show that the proposed architecture meets the requirements of onboard IP data packet switching.

## References

1. Everett, M., Haines, J., Touch, J., et al.: TSAT network architecture. In: Military Communications Conference, MILCOM 2008. IEEE (2008)
2. Whitefield, D., Gopal, R., Arnold, S.: Spaceway now and in the future: on-board IP packet switching satellite communication network. In: Military Communications Conference, MILCOM 2006. IEEE (2006)
3. Florio, M., Fisher, S.J., Mittal, S., Yaghmour, S.: Internet routing in space: prospects and challenges of the IRIS JCTD. In: Military Communications Conference, MILCOM 2007. IEEE (2007)
4. Aweya, J.: IP router architectures: an overview. Int. J. Commun. Syst. **14**(5), 447–475 (2001)
5. Malkin, G.: RIP Version 2. IETF RFC 2453 (Standards Track) (1998)
6. Moy, J.: OSPF Version 2. IETF RFC 2328 (Standards Track) (1998)