Design of an Electro-Optical Hybrid Switching Architecture for Satellite Internet

Zhenhua Zhang[1,2](✉), Siyue Sun[1,2], Xiangyu Gan[1,2], Yimeng Luo[1,2], Jian Wang[1,2], and Linchen Ku[1,2]

[1] Innovation Academy for Microsatellites of Chinese Academy of Sciences, Shanghai, China
nmwjasdf@163.com
[2] University of Chinese Academy of Sciences, Beijing, China

Abstract. The establishment of satellite Internet is a crucial step in the future development of the satellite communications industry. Therefore, in the current inter-satellite link environment where laser links and microwave links coexist, a new switching system architecture is needed. This paper summarizes the business capabilities that satellite Internet must meet based on the current development status of satellite communications, as well as the characteristics and transmission requirements of satellite Internet services. It also investigates and analyzes the current state of switching technology, summarizing the applicability of existing switching technologies in the construction of satellite Internet. Based on the analysis results, an end to end network on the satellite is constructed, leading to the design of a satellite optical-electrical hybrid architecture.

Keywords: Satellite Internet · Electro-Optical Hybrid Switching · Intersatellite link

1 Introduction

Satellite Internet is a satellite-based communication system that provides services such as processing, storing, and forwarding operational data through artificial satellites, enabling the interconnection and interoperability of air, sky, earth, and sea. Satellite Internet is not a new concept; from the inception of the Iridium system to today's Starlink, more than 30 years have passed. Early satellite communications primarily involved geostationary orbit (GEO) satellites, which used single satellites to relay data.

As satellite communication technology has evolved, the limitations of ground networks have become more apparent. For instance, high-speed mobile aircraft communication services struggle to maintain high communication quality, and extreme areas such as polar regions, deserts, and oceans remain uncovered. Lower satellite orbits, with their low cost, low latency, large scale, and high bandwidth, have garnered increasing attention from researchers [1].

H.-H. Chen and W. Meng (Eds.): WiSATS 2024, LNICST 605, pp. 111–124, 2025.
https://doi.org/10.1007/978-3-031-86196-3_10

Today's satellite communication systems are utilizing progressively lower orbits. Systems like O3b use medium Earth orbit (MEO), while the second-generation Iridium system, OneWeb, Starlink, and similar constellations use low Earth orbit (LEO). The advent of LEO satellite Internet has triggered a global surge in research and development.

Leveraging the research and development surge in satellite constellations, this paper aims to design a switching architecture that meets the current information transmission needs of satellite constellations and is scalable for future satellite Internet development. The paper first summarizes the business requirements and characteristics of existing satellite constellations based on the current state of satellite development. It then investigates various existing switching technologies, comparing their advantages and disadvantages to identify a switching form suitable for the future development of satellite Internet. Ultimately, this study proposes an Electro-Optical Hybrid switching architecture.

2 Status of Satellite Internet Development

Low orbit satellite communications initiated a significant boom as early as the 1990s, with Motorola's Iridium system being the most notable example. However, due to the high development costs and the rapid advancement of terrestrial cellular networks, the Iridium project ultimately went bankrupt. In recent years, the development of small satellites and the reduction in launch costs have highlighted the advantages of deploying low orbit satellites. As a result, nearly 30 companies worldwide are now engaged in deploying satellite Internet, with plans to launch more than 100,000 satellites globally . Among these, over 10 companies have proposed non-geostationary orbit (NGSO) satellite systems, involving approximately 80,000 satellites [1]. The main constellations are presented in Table 1.

Table 1. Satellite Internet Constellation.

Satellite Constellation	ballpark	frequency band	service
Iridium	66	L/Ka	voice communication
Starlink	42000	Ku/Ka/V	high speed Internet
OneWeb	882	Ku/Ka/V	high speed Internet
Kuiper	3236	Ka	Internet
HongYun	156	Ka	Internet
HongYan	324	L/Ka	Internet

Early satellite communications primarily utilized the transparent forwarding method for data transmission, with information processing mainly conducted at ground stations. This approach significantly limited the satellite information processing capacity. Additionally, using ground stations as forwarding nodes increased communication delays and adversely affected transmission quality. In recent years, the number of access users has risen, and the frequency of information interaction and sharing has increased. Consequently, the transparent forwarding method no longer meets the needs of the evolving communication industry. Therefore, there is a need to develop satellites with information processing capabilities, such as multimedia satellites.

At present, satellite communication systems primarily use microwave links for star to Earth connections, while laser links have been added for intersatellite connections alongside microwave links. However, microwave links are limited by frequency constraints, leading to bottlenecks in transmission rates and communication capacity, making it difficult to meet the demand for distributing and transmitting various types of services. In recent years, the continuous development of optical communication technology has provided a solution to the limitations of microwave links. On-planet laser links offer advantages such as large capacity, small equipment size, and strong anti-interference capabilities, which can effectively supplement microwave links for information transmission [3]. Therefore, the development of space laser communication is crucial for realizing satellite Internet. Table 2 shows the current status of satellite links.

Table 2. Satellite link status

Satellite orbit type	Link Type	transmission medium	single-port rate
intersatellite orbit	Same orbit, different orbits, cross-layer link building	Laser/Microwave	multirate 100 Mbps, 2.5 Gbps, 5 Gbps, 10 Gbps, 100 Gbps
access link orbit	Establishing links to users	Microwave	Multi-user, multi-band Wide range of rates (1 Mbps-20 Gbps)
Feeder link orbit	Implementing links	Microwave	Ka band 10 Gbps-20 Gbps

Satellite switching technology can effectively reduce the satellite system's dependence on ground stations and, at the same time, reduce communication delays. Currently, satellites mainly use microwave links to transmit information, and the primary switching method on satellite is electric domain switching. However, electric switching faces an electronic bottleneck, making it difficult to improve communication rates and capacity. Additionally, the electric switching devices on-satellite have a relatively large volume, which increases the design requirements of the satellite's interior. In contrast, optical switching devices are relatively smaller in volume and offer advantages such as large transmission capacity and good information confidentiality. Therefore, studying satellite optical switching will lay the foundation for improving satellite Internet performance in the future. The service model shown in Table 3 will further constrain the switching system of satellite Internet [4].

At present, the development of all optical switching is constrained by optical devices and other factors, making it difficult for available optical switching methods to flexibly handle multiple types and granularities of services on satellites. Therefore, to meet the service forwarding requirements of satellite Internet, it

Table 3. Satellite business model.

data type	Resource type	packet delay	packet loss	Guaranteed bandwidth
signaling	Non-GBR	100 ms	10^{-6}	shared bandwidth
conversational speech	GBR	100 ms	10^{-2}	shared bandwidth
Conversation videos	GBR	150 ms	10^{-6}	shared bandwidth
Non-conversational videos	GBR	300 ms	10^{-6}	shared bandwidth
multimedia video	Non-GBR	300 ms	10^{-6}	shared bandwidth
TCP, P2P file sharing	Non-GBR	300 ms	10^{-6}	shared bandwidth
Dedicated line business	GBR	100 ms		Exclusive bandwidth

is necessary to use optical-electrical hybrid switching on satellites. The application of optical-electrical hybrid switching combines the advantages of both optical and electrical switching. Electrical switching, with its flexible forwarding capabilities and mature technology, is used for handling a large number of transmissions with small information streams [5]. Meanwhile, high capacity optical switching is employed for dealing with a small number of transmissions with large information streams. This approach effectively meets the high efficiency transmission requirements of various types and granularities of services in space.

3 Current Status of Research on Switching Technology and Analysis of Its Applicability

3.1 Electrical Switching Technology

The Optical Transport Network (OTN) is based on wavelength division multiplexing technology within the optical layer of the network. Its standardization began in 1998. Prior to 2000, the design philosophy of OTN was similar to that of the Synchronous Digital Hierarchy (SDH) system. According to the principles of optical network layering, OTN was defined in terms of network node interfaces, physical layer interfaces, network jitter performance, and other aspects. The main standards for OTN were largely finalized by 2003.

The OTN is divided into two layers: the optical layer and the electrical layer, which together facilitate the transmission of services, as shown in Fig. 1. The optical layer primarily functions as a transmission pipeline for information, performing optical layer scheduling and enabling the cross scheduling of optical signals. The core unit for optical signal scheduling is the Reconfigurable Optical Add Drop Multiplexer (ROADM). The ROADM receives OTU optical signals and then routes these signals to specified egress points by creating internal optical cross paths, with each egress corresponding to a different line.

However, with the accelerating pace of informatization, various video services have been growing rapidly in recent years. These services are characterized by small bandwidth and large numbers, necessitating simple and fast flexible bandwidth adjustments. Traditional OTN technology has become insufficient

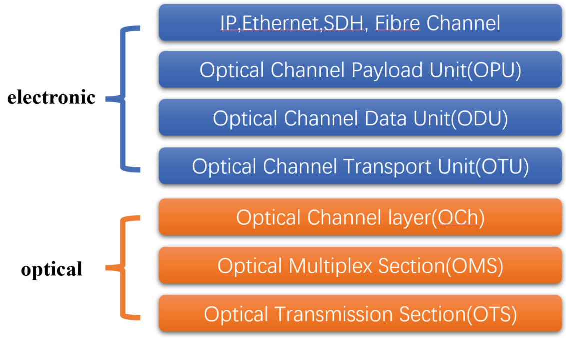

Fig. 1. OTN structure

for efficiently transmitting these types of services. Consequently, Optical Service Unit (OSU) technology was developed. In January 2020, the ITU-T adopted the Optical Service Unit path layer network (OSU) standard during a plenary meeting in Geneva to initiate standard research on OTN's capability to carry small granular services.

OSU, as a technological expansion of the optical transport network (OTN), can efficiently transmit small grained services on the ground with high technological maturity and well developed corresponding devices. However, in traditional terrestrial networks, completing end to end communication is more complex. First, the user terminal sends information to the access network. Then, through the wireless access network and IP IPRAN, information is transmitted to the core network, where the fiber optic channel completes the transmission of high capacity information. Finally, the information is processed and forwarded back through IP bearer in the core network. OTN, as a technology for bearing high traffic, long distance services, is only part of the ground network, whereas constructing a star network requires encompassing the entire ground architecture's content and function.

In a satellite network, there is no division into access network, bearer network, and core network. Services uploaded to the satellite require new routing and switching for transmission. Therefore, the use of OSU technology in satellite networks requires consideration of the functional design of core and access networks, which puts high demands on network protocol optimization and network planning, especially under the constraint of fast switching in satellite networks.

OSU technology is essentially a switching technology for optical layer transmission and electrical layer switching. The application prospects and efficiency of optical switching technology are higher than those of electrical domain switching. In the optical layer, OSU needs to establish channels in advance to meet end to end communication. The variety of business needs on the star require flexible network bandwidth for efficient transmission. While OSU pipeline switching has advantages in leased line business, it struggles to effectively respond to scenarios with a large number of user terminals requiring flexible access. Additionally, the delay and bandwidth utilization in pipeline establishment and dismantling are disadvantages compared to optical layer switching.

To summarize, OSU technology in the context of OTN is more reliable for star applications due to its mature application on the ground and the availability of well developed devices. However, future optical domain switching holds better development prospects.

3.2 Optical Switching Technology

At present, optical switching technology is mainly divided into: optical circuit switching, optical burst switching and optical packet switching. Among them, optical circuit switching has been studied the most and is relatively mature, optical packet switching inherits the characteristics of traditional electric domain packet switching, and optical burst switching is closer to the former two performance of the compromise program.

Optical Circuit Switching(OCS). Optical Circuit Switching, a mature optical switching technology, inherits the characteristics of traditional circuit switching. The transmission and exchange of services require a link building process, where each link is assigned a dedicated wavelength from the source to the destination. During the switching process, establishing a link necessitates a bidirectional bandwidth application to complete the request and response process. Once established, only the two parties involved can transmit information, and resources are released only after the link is dismantled.

Although OCS can transmit information at high speed and high capacity, it is not suitable for most current business types, such as video services, which require high frequency and low transmission capacity. OCS technology is more suitable for high capacity service transmission pipelines and has a significant advantage in transmitting on-satellite services that are not sensitive to large-granularity delay. Additionally, OCS can be used for some on-satellite private line services, where channel resources are individually allocated to ensure high reliability transmission. However, when handling small grained, delay sensitive services, OCS technology struggles to provide flexible and efficient transmission.

Optical Burst Switching(OBS). Optical Burst Switching is a technology in which the control packet enters the optical switching node first, followed by the data packet for forwarding. The switching unit of OBS, called an Optical Burst (OB), includes two parts: the Burst Data Packet (BDP) and the Burst Control Packet (BCP). The BDP is a re-encapsulation of the data in the network, based on attributes such as the destination address and QoS requirements. The BCP contains the routing information of the BDP, its length, offset time, priority, and quality of service. The BCP and the corresponding BDP are transmitted in separate optical channels, with the BCP leading the BDP by an offset delay [6].

This offset delay allows the reservation of the resources required by the BDP in the absence of optical caching and optical synchronization. By the time the

BDP arrives at the node, the corresponding optical path has been established, ensuring the efficient switching and transmission of the BDP [7].

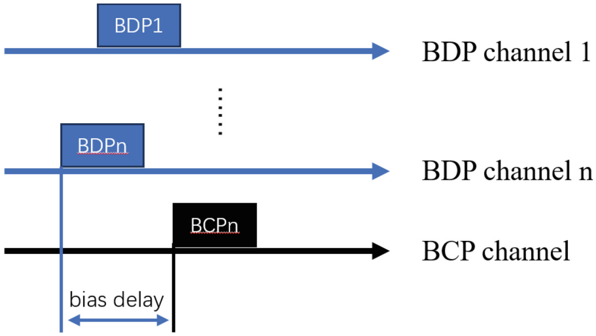

Fig. 2. OTN structure

As shown in Fig. 2, the OBS switching process requires setting an offset delay between the BCP and the BDP. The offset delay is configured to ensure that the BCP has reserved the necessary resources before any BDP arrives. This design allows for a unidirectional reservation process without needing a buffer for the switching technology [8]. However, once blocking occurs in the network, the packet loss rate increases. Different network structures can lead to blocking, making it difficult to guarantee transmission quality even with optical delay lines. Therefore, developing strategies to manage blocking is critical.

The switching granularity of Optical Burst Switching (OBS) can vary from a few IP packets to hundreds of IP packets, reducing control overhead. The separate transmission of burst data packets (BDPs) and burst control packets (BCPs) on the physical channel allows the switching node to reserve resources for the BDP after the BCP's arrival. This ensures that the BDP can be transmitted directly without undergoing optoelectronic conversion, facilitating the efficient transmission of high bandwidth services. However, when the frequency of service transmission is high, congestion and conflicts can prevent OBS from achieving high-reliability service transmission, which is unacceptable when such reliability is required.

Currently, the application of Optical Burst Switching (OBS) technology on satellites primarily needs to focus on the optical delay line and the optical switching matrix. OBS requires an anti-blocking design, and the design of the optical delay line significantly impacts the performance of the entire on-board network. The optical switching matrix is the core device of the OBS system, directly influencing the performance of the switching network. Presently, the typical structures of the optical burst switching matrix include spatial optical switching matrices and arrayed waveguide grating (AWG)-based optical burst switching structures.

The burst packet granularity of OBS technology is moderate, which can adequately support the transmission of small granularity services, such as video services on satellites. Additionally, OBS offers higher channel resource utilization since it does not require the traditional circuit switched form's chain building process and resource monopolization. Regarding delay, the primary delay in OBS arises from the processing and switching delay of the BCP at each node. Each node only needs to perform optoelectronic and optical (O/E/O) conversion for the BCP without analyzing the BDP.

In summary, OBS technology has a foundational level of engineering implementation for satellite use. While it is not as mature as Optical Transport Network (OTN) technology, which is better suited for satellite service transmission, OBS offers high bandwidth utilization. However, a reasonable anti-blocking strategy is necessary to optimize its performance.

Optical Packet Switching(OPS). Traditional packet switching employs the store and forward method, wherein messages sent from the source node are segmented into fixed format packets. Each packet is appended with the destination node's address in the packet header and transmitted using a virtual circuit. Upon receiving a packet, the network switch temporarily stores it, then searches for an available switching path within the network to forward the packet to its destination, as illustrated in Fig. 3. This approach significantly enhances line utilization [9].

Optical packet switching, a technology based on optical signal transmission, inherits the characteristics of electronic packet switching. Compared to traditional networks, optical packet switching networks exhibit higher resource utilization and better adaptability to sudden data and information surges [10]. OPS

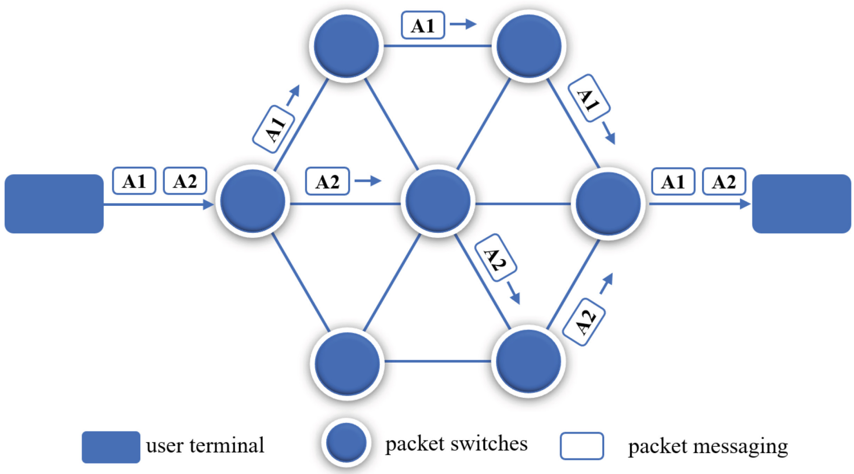

Fig. 3. OTN structure

technology, inherited from the domain of electric packet switching, can adeptly handle the corresponding services of satellite Internet due to its efficient and flexible information transmission capabilities. However, a primary challenge facing OPS technology lies in the absence of an efficient optical caching mechanism [11].

While terrestrial network's electrical switching technology can achieve electrical caching, replicated circuit block switching, and read-as-you-go functions, the current research on optical caching in optical networks primarily relies on optical delay lines for brief caching. Under ideal conditions, altering crystal lattice structures and increasing micro-ring resonance cavities can extend caching times to up to an hour, with caching rates reaching 1 Gbit/s. However, relying on optical delay lines for caching fails to effectively address cache contention issues, as this technology cannot ensure meeting the delay disparities inherent in the switching process.

In summary, due to the development of optical caching devices is not mature, want to complete the optical caching process can only use the optical delay line, so OPS technology, although in the theoretical level than the OBS and OCS technology is more efficient, more flexible, more suitable for the optical network as a switching technology, but subject to the immaturity of the physical level of the device is very difficult to be effectively applied to the network on the satellite [12].

Table 4. Switching Technology Comparison

Switching Technology	switching Form	Device Capabilities	capability	Satellite-based applicability
OSU	electrical	maturity	Better performance, but limited by electronic bottlenecks	applicable
OCS	optical	maturity	High transmission capacity, but inflexible	inapplicable
OBS	optical	comparatively maturity	Moderate business granularity and high transmission efficiency	applicable
OPS	optical	immaturity	Subject to the immaturity of the optical device can not meet the business requirements	inapplicable

As depicted in Table 4, at this juncture, while OSU technology exhibits viability within the electric domain for satellite Internet networking, it confronts electronic bottlenecks as communication capacity escalates. Conversely, the optical domain presently demonstrates proficiency in engineering OBS technology, rendering it more apt for satellite applications. Should mature development products for optical cache devices materialize in the future, OPS technology would emerge as a more fitting solution for the networking demands of satellite Internet.

4 Electro-Optical Hybrid Switching Architecture

At this stage, the construction of satellite Internet is primarily focused on low-orbit satellites. Consequently, numerous data transmission services have opted to utilize low orbit satellites, which facilitate easier acquisition of high resolution images and other data. These satellites are also suitable for measurement and control purposes. High-speed convergence business scenarios from space to the core network include applications such as general aviation aircraft networking and entertainment, rescue medical police aviation networking, broadband communications for ocean-going vessels, polar scientific research communications, and land emergency command communications. The data types transmitted in these scenarios encompass signaling, session-based voice, session-based video, and non-session-based video. Measurement and control services comprise remote control and telemetry services, where telemetry is predominantly employed for the centralized detection of dispersed or inaccessible objects, including those that are distant, in harsh environments, or moving at high speeds. Beyond fulfilling basic data transmission and measurement and control requirements, satellite Internet also necessitates network management and safeguard functions.

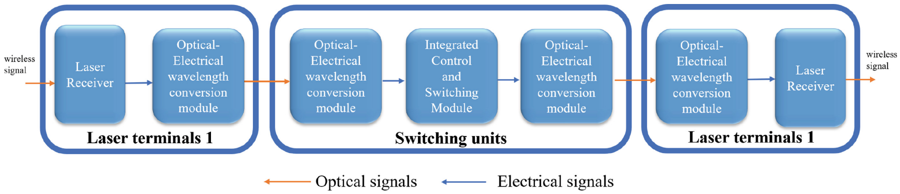

Fig. 4. Current satellite Switching processes

As shown in Fig. 4, laser links have been incorporated into current satellites to facilitate inter-satellite connections. However, due to the lack of optical wavelength conversion devices, six photoelectric conversions are necessary to complete the information processing at satellite switching nodes. While the use of laser links enhances the satellite's signal transmission capacity, the excessive photoelectric conversions significantly increase overhead and transmission delay. Consequently, this architecture is not an efficient switching solution.

Figure 5 depicts the ground optical switching model, where ground optical switching nodes utilize wavelength routing. This allows multi service flow switching across fibers carrying hundreds of channels, primarily serving backbone networks. The optical switching speed requirements for these networks range from seconds to milliseconds. However, in satellite networks, services are carried on a single wavelength, necessitating shorter response times for optical switching. Additionally, the diversity of data granularity in satellite networks requires precise and synchronized optical switching, which ground switching nodes struggle to achieve. Therefore, this paper proposes the following switching architecture

Figure 6 depicts the design of an optical and electrical hybrid architecture based on service type. This design features both an external electrical interface and an optical terminal capable of simultaneously establishing laser links and microwave links. The electrical interface supports microwave links across various frequency bands, while the optical terminal receives laser signals via an

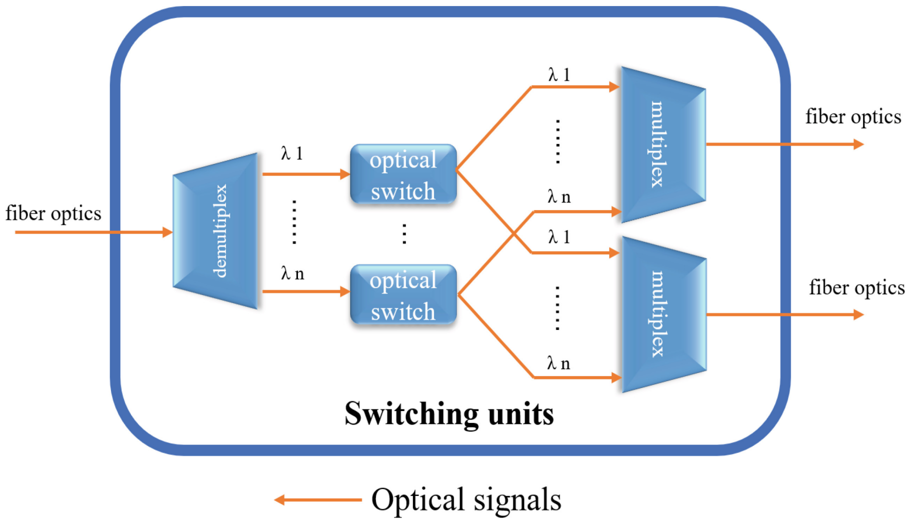

Fig. 5. Current satellite Switching processes

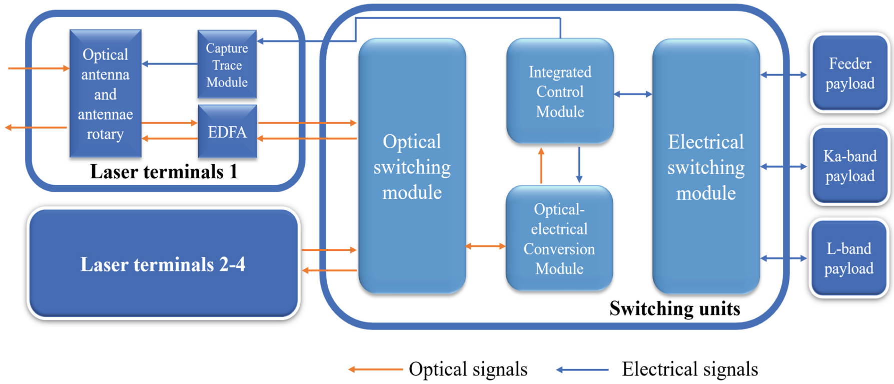

Fig. 6. Electro-Optical Hybrid Switching Architecture

optical antenna and manages the antenna using a capture and tracking module. The electrical switching module handles the monitoring and control of user-side access, the combination and splitting of packet-switched packets, and transmission control. The integrated control module's functions include packet classification, forwarding table generation and configuration, call processing, traffic control, routing, switching control, system configuration, and management. The Electro-Optical Switching module is primarily responsible for the convergence and divergence of optical and electrical signals, including optical-to-electrical and electrical-to-optical conversions. The optical switching module encompasses optical switching and protocol processing, ensuring the adaptation of light emitting signals, data generation and disassembly, and queue control.

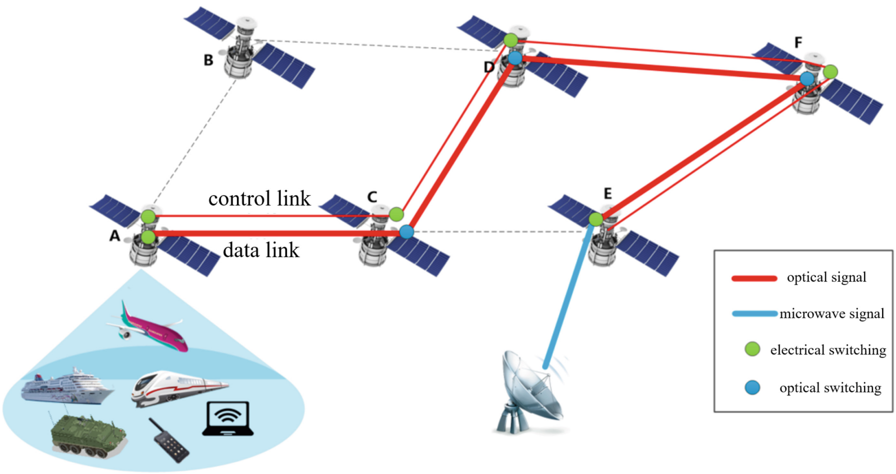

Fig. 7. switching unit works in a satellite internet

Figure 7 illustrates the working principle of a switching unit employing the optical burst switching regime in a satellite Internet system, utilizing both data and control channel transmissions. The control channel employs an electrical switching module to manage its forwarding, while the data channel directly uses an optical switching module for transmission. Additionally, both upstream and downstream feeder links utilize microwave links to facilitate transmission.

The introduction of the optical switching module enables signal transmission without requiring photoelectric conversion, thereby reducing overhead and transmission delay associated with multiple photoelectric conversions. Moreover, since the satellite laser link operates using a single wavelength transmission system, this architecture is compatible with the wavelength transmission of satellites, making it particularly suitable for constructing satellite Internet systems utilizing laser links. This approach allows the satellite Internet to move beyond the original satellite function of merely transparent forwarding, enabling some of the ground station's functions to be performed directly by the satellite's switching node. As a result, this reduces the reliance on ground stations.

5 Conclusion

Switching technology is crucial for building satellite Internet. In this paper, we first examine and analyze the switching requirements for satellite Internet. We investigate the current mainstream switching technologies and summarize the advantages and disadvantages of each when applied on satellite.

Electric domain switching, a mature technology, is well developed in terms of transmission systems and switching equipment, making it easier to implement at the application level. In contrast, optical domain switching, which can overcome electronic bottlenecks, offers superior performance and represents a future oriented technology. However, its implementation on satellites is currently hampered by underdeveloped devices and systems.

The adoption of hybrid switching in this paper is primarily based on previous research, current switching technology, satellite links, and existing data formats. Among switching technologies, optical switching is significantly constrained by the lack of engineered optical cache devices and optical wavelength conversion devices, making it challenging to construct fully optical switching nodes at the physical layer. Satellite communication links currently use both microwave and laser links; thus, introducing a hybrid architecture can accommodate these two forms of links to a certain extent, enhancing their efficiency. Moreover, given the variable types and granularity of services, the hybrid switching architecture can flexibly manage diverse service types. Therefore, this paper anticipates that optoelectronic hybrid switching will have a broader application prospect. Finally there are many more key elements worth studying for satellite internet

1 Design of transmission protocols in satellite constellations.
2 Engineering of optical caching devices and all-optical wavelength conversion devices.
3 Design of multi-wavelength laser terminals
4 Fast capture and tracking of inter-satellite laser links.

References

1. Chen, Q., Giambene, G., Yang, L., et al.: Analysis of inter-satellite link paths for LEO mega-constellation network. IEEE Trans. Veh. Technol. **70**(3), 2743–55 (2021)
2. Chaudhry, A.U., Yanikomeroglu, H.: Free space optics for next-generation satellite networks (2020)
3. Susilo, H.E., Suryana, J.: Research on LPWAN direct to satellite IoT: a survey technology and performance on LEO satellite. In: 2023 29th International Conference on Telecommunications (ICT), Toba, Indonesia, pp. 1–7 (2023). https://doi.org/10.1109/ICT60153.2023.10374072. keywords: Surveys;Satellites;Power demand;Low earth orbit satellites;Telecommunications;Internet of Things;Doppler effect;LEO Satellite;Internet of Things;Low Power Wide Area Network (LPWAN);Satellite-Based IoT,
4. Ding, R., et al.: 5G integrated satellite communication systems: architectures, air interface, and standardization. In: 2020 International Conference on Wireless Communications and Signal Processing (WCSP), Nanjing, China, pp. 702–707 (2020). https://doi.org/10.1109/WCSP49889.2020.9299757. keywords: Satellite broadcasting;5G mobile communication;Satellites;Protocols;Communication channels;Optical switches;Logic gates;Satellite-terrestrial networks;5G;air interface;satellite communications,
5. Zhou, W., Hong, T., Ding, X., Zhang, G.: LoRa performance analysis for LEO satellite IoT networks. In: 2021 13th International Conference on Wireless Communications and Signal Processing (WCSP), Changsha, China, pp. 1–5 (2021). https://doi.org/10.1109/WCSP52459.2021.9613680. keywords: Wireless communication;Satellites;Interference cancellation;Silicon carbide;Simulation;Low earth

orbit satellites;Mathematical models;Internet of Things;satellite IoT;LoRa;Uplink Performance;successive interference cancellation,

6. Papazoglou, C., Sarigiannidis, P.G., Papadimitriou, G.I., Pomportsis, A.S.: Techniques for improved scheduling in optical burst switched networks. In: International Symposium on Autonomous Decentralized Systems, vol. 2009, pp. 1–4 (2009). https://doi.org/10.1109/ISADS.2009.5207359
7. de Pedro, L., Aracil, J., Hernandez, J.A., Garcia-Dorado, J.L.: Analysis of the processing and sojourn times of Burst Control Packets in Optical Burst Switches. In: International Conference on Optical Network Design and Modeling, vol. 2008, pp. 1–3 (2008). https://doi.org/10.1109/ONDM.2008.4578393
8. Li, C.Y., Li, G., Wai, P.K.A., Li, V.O.K.: Optical burst switching with large switching overhead. J. Lightwave Technol. **25**(2), 451–462 (2007). https://doi.org/10.1109/JLT.2006.889427
9. Chen, K.S., Yang, C.C.: An application of spectral-amplitude-coding labels in optical signal buffering over optical packet-switching networks. IEEE Commun. Lett. **24**, 2020–2023 (2020)
10. Liu, W., Romeira, B., Li, M., et al.: A wavelength tunable optical buffer based on self-pulsation in an active microring resonator. J. Lightwave Technol. **34**(14), 1 (2016)
11. Ma, Y., Ma, Y.Z., Zhou, Z., et al.: One-hour coherent optical storage in an atomic frequency comb memory. Nat. Commun. **12**, 2381 (2021)
12. Zhang, Z., et al.: A survey of optical/electric hybrid switching technology for satellite Internet. Telecommun. Sci. **38**(11), 1–10 (2022)