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Investigation of frame mode unification and virtual channel multiplexing based on the multilayered satellite network OISLs interface

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ABSTRACT

In a multi-layered optical satellite network, a standardized data transmission is a reliable guarantee to efficiently process and transfer multi-service data for the space link. The transmission frame reframing unit (TFRU) is proposed to solve the problem of different service data having low transmission efficiency in the laser link. The TFRU uses a virtual channel (VC) technology to unify the format and rate of transmitted data using second encapsulation and VC scheduling for the service data. The Priority VC schedule algorithm is proposed to further improve multiplex efficiency. According to the principle of TFRU encapsulation and arrival rate of service data, the frame dynamic priority is defined by the VC priority and frame criticality. Furthermore, the Priority VC schedule specific method is provided. The simulation results show that the throughput increases to 3.0546 M, and the scheduling time delay reduces to 0.9183 s. Thus, the system performance has been greatly enhanced. The cache demands are satisfied because the laser terminal data transmission rate is larger than the sum of all service data rates. Using the dynamic schedule generated TFRU frames, the priority algorithm based on the TFRU ensures frame scheduling fairness in each VC.

1. Introduction

With the exploration of space and the development of inter-satellite laser link, building of optical satellite network becomes an inevitable trend for future space information network [1–2]. The multi-layered satellite network integrates various optical inter-satellite links (OISLs) and satellites, which at different orbit altitudes are divided into different layers. Each layer is used to provide a specific service, not only to support various demands of QoS (quality of service) but also to have a large number of optional links to transfer data [3–4]. The OISLs have a unified transmission mode in the identical satellite constellation. Meanwhile, the laser link between the backbone network satellite node and its managed satellite constellation has a fixed transmission mode.

According to the link characteristic, various OISLs use the specific link protocol and transmission mode [5–8]. Thus, during the multi-layered optical satellite network construction process, the various service data types, which have different frame formats and unfixed transmission rates, may need to be transmitted using the same link at the same time. This increases the data link control difficulty and reduces the transmission efficiency of the satellite nodes and laser links, and, possibly, results in lost frames. When the problem becomes more serious, the system performance worsens [9–11]. The multi-layered satellite network structure is an ideal option for constructing an optical satellite network. Based on the inter-satellite links and traffic types, the transmission frame reframing unit (TFRU) is proposed for the OISLs interface in the multi-layered optical satellite network. The TFRU, using second encapsulation of different service data frames in the data link layer, realizes the unification of frame formats and transmission rates for each laser link [12–14].

The TFRU uses the virtual channel (VC) technology to divide a physical channel into multiple independent logical channels, and each logical channel manages and multiplexes the data units from different services. Due to frame length and transmission rate differences between multiple services, it is necessary to schedule the generated TFRU frames from virtual channels using the multiplexing process. In a traditional priority algorithm (TPA) [15], the importance of service data is considered as the only standard for scheduling. By scheduling the important data, the TFRU frames generated from another VC, which has a lower priority, cannot be scheduled throughout. Thus, the algorithm has an inferior fairness. The frame criticality algorithm (FCA) [16] first schedules the TFRU frame that has the longest wait time. Therefore, the earlier

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generated frames are the first to be scheduled. The algorithm prevents the physical channel from monopolizing the VC with a high priority. However, the arrival rate influence on priority, which varies with time, is not reflected. Therefore, according to the TFRU encapsulation principle and the service data frame arrival rate, the Priority VC scheduling algorithm based on the TFRU is proposed to achieve a fair VC scheduling.

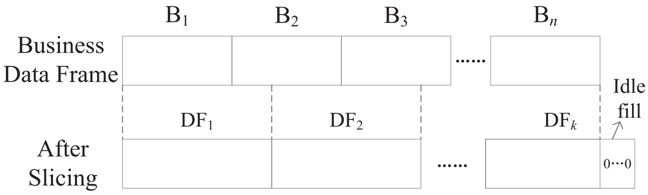

Fig. 2. Principle of slicing.

2. TFRU

2.1. TFRU design

In the multi-layered optical satellite network, a large number of data frames from different services needs to be transferred by each relay satellite node. Therefore, the strong data processing ability is the assurance that different types of data are reliably transmitted. To promote this, the data frames from different services undergo processing such as slicing, reframing and multiplexing. The process is defined as the transmission frame reframing unit (TFRU). Using second data encapsulation, the Transmission Frame Reframing Unit generates the TFRU frames that are suitable for transmitting using the optical satellite network. In conclusion, the TFRU is used to unify the frame format and transmission rate, and it is the key technology for improving the information processing and data transmission ability. The model is presented in Fig. 1.

Step 1: Data field extraction and header generation. Division of data frames from different services into blocks of data fields with L_{DF} lengths and generation of frame headers. The header includes the fields of service ID, VC ID and VC Counter. It can efficiently recover the original data frames at the receiver.

Step 2: Forwarding of error correction (FEC) coding. Encoding after combining headers and data fields in each VC. Choosing of suitable means to forward the error correction coding for the channel types.

Step 3: Interleave. Combining of the header, data field and the FEC field into a new code block. Interleaving the new code block and generation of the TFRU frame. Interleaving is used to solve the continuous burst error, which is caused by the deep fade. Interleaving reduces the information content relevance by changing the information structure. It is equivalent to dispersing burst error code words to make adjacent code words interfere with a lower possibility, and enhances the performance to answer the burst error.

Step 4: Additional Synchronization Marker (ASM) addition. Application of the ASM and reliance on the code word correlation to achieve frame synchronization of the transmitter and receiver to ensure the quality of communication.

Step 5: Virtual channel multiplexing. Scheduling the generated TFRU frames from multiple VCs, each frame takes up a time slot.

2.2. TFRU frame generation principle

According to the TFRU design, the service data need to be reframed after being mapped to virtual channels. Because the TFRU frame length is longer than the service data frames, a number of service data frames are divided into two parts. The process is called slicing, and it is depicted in Fig. 2.

The case of the arrived service frames obeys the Poisson distribution where λ is the arrival rate. $A(t)$ is the number of the arriving frames at time t. L_B is the service frame length. Slicing uses an efficient frame generating algorithm [17]. Thus, when the arriving frames fill the TFRU frame data field, the TFRU frame is input to the buffer and waits for scheduling. Thus, the service frame arrival probability N at time t is

$$P(A(t)=N)=\frac{(\lambda t)^N}{N!}e^{-\lambda t} \tag{1}$$

Then, the number of the TFRU frames $[N \cdot L_B/L_{DF}]$ is generated and put into the buffer to wait for scheduling, where $[X]$ is the largest integer less than X. Therefore, to generate J, the TFRU frames need to reach $[J \cdot L_{DF}/L_B]+1$ service frames. The probability of generating J TFRU frames at time t is

$$P(A(t)=\left[J\frac{L_{DF}}{L_B}\right]+1)=\frac{(\lambda t)^{\left[J\frac{L_{DF}}{L_B}\right]+1}}{\left(\left[J\frac{L_{DF}}{L_B}\right]+1\right)!}e^{-\lambda t} \tag{2}$$

The frame arrival time obeys the Gamma distribution with parameters (N,λ) [13]. Thus, the probability density function of time for N service frames to arrive is

$$f_N(t)=\lambda e^{-\lambda t}\frac{(\lambda t)^{(N-1)}}{(N-1)!} \quad N=0,\,1,\,2\cdots \tag{3}$$

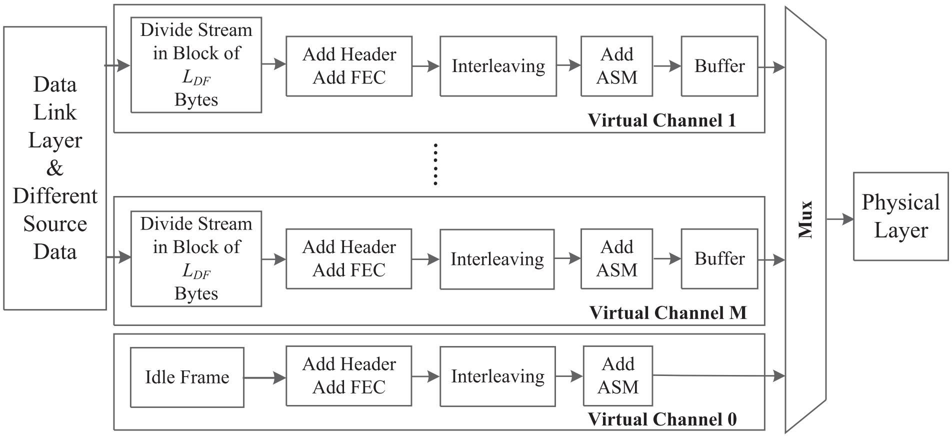

Fig. 1. TFRU framework.