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Research Article

A Scheduling Method of Cross-Layers Optimization of Polling Weight for AOS Multiplexing

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The core mechanism of Advanced Orbit System (AOS) mainly contains the packet channel multiplexing and the virtual channel multiplexing. The multiplexing efficiency and frame time directly affect the performance of the AOS and even the whole system. In this paper, in order to optimize AOS multiplexing performance, a scheduling method of cross-layers optimization of polling weight (CLOPW) is proposed. Different from single sublayer optimization such as the isochronous frame methods, the novel method focuses on factors related to AOS performance of two core sublayers, such as packet distribution, residual function, cache capacity, frame time, and multiplexing efficiency. We build a multiple factors framing model of finite buffer and deduce the formula of packet multiplexing efficiency based on the short correlation. Furthermore, we give the formula for the virtual channel utilization and delay of cross-layer optimization. The experimental results show that the novel scheduling method of cross-layers optimization of polling weight is higher utilization of virtual channel and lower average delay than the isochronous frame method.

1. Introduction

With the development of space technology, in order to meet the demand of differentiated communications for future multimedia space missions, better realize the sharing of ground and space communication resources, and improve the efficiency of real time, diverse, and dynamic task, it is necessary to extend the concept of ground Internet to space and build a flexible and efficient Space Internetwork. Consultive Committee for Space Data System (CCSDS) [1–3] is an international standard organization composed of multinational space organization, which establishes standardized communication architectures, communication protocol, and service for the next-generation space network. Advanced Orbit System (AOS) [4, 5] proposed by CCSDS is developed on the basis of Common Orbit System (COS) [6]. AOS is a data transmission and communication mechanism, which also is a data processing and management system of space-to-space, space-to-surface. Meanwhile, AOS can process larger capacity and higher rate data than those of COS and build a global, extensive network.

The multiplexing mechanism [4], namely, packet channel multiplexing (PCM) in Virtual Channel Link Control (VCLC) sublayer and Virtual Channel Multiplexing (VCM) in Virtual Channel Access (VCA) sublayer, is the core and basis of AOS. According to AOS protocol, the data with different rate and from heterogeneous information sources is normalized into CCSDS standardized packet. These packets are encapsulated into Multiplexing Data Units (M_PDU), which finally form Virtual Channel Data Unit (VCDU) [7]. M_PDU frame time (abbr. frame time) and efficiency directly affect the throughput performance of virtual channel in the next sublayer.

In order to analyze, design, and manufacture multiplexers for AOS, researches have done a lot of work on the scheduling method of frame generation and optimization such as the method of isochronous frame and high efficiency frame. The isochronous frame scheduling method [8] is to encapsulate the data packets from higher levels into a frame at a fixed interval time, whose disadvantage is mainly that the method will lead to a decline in multiplexing efficiency [9–11]. High efficiency frame optimization means that the data packets are not released until the arrival data packets fill up a whole M_PDU, whose multiplexing efficiency is almost 100%. But the method will increase the frame time and the packet delay [12, 13]. Y. Tian et al. [14] put forward an adaptive frame optimization model. In the model a threshold value is set. With the value, as soon as the arrival packets fill up a frame, a frame is generated. In another paper [15], the authors indicate that the adaptive model overcome long delay problems, which sometime cause the lower multiplexing efficiency than the isochronous frame optimization. In the paper [16], the authors proposed a virtual channels scheduling method with broad applicability based on movable boundary. In order to optimize the performance of AOS multiplexing, the authors establish a movable boundary between synchronous time slots and asynchronous ones in terms of types of date sources. Bie et al. [17] design a mixed multiplexing optimization mode by the analysis of data types. In the mode, it is changeable for the boundaries of VIP, synchronous, and asynchronous virtual channels.

In this paper, a scheduling method of cross-layer optimization of polling weight (CLOPW) is proposed. Different from single sublayer optimization such as the isochronous frame method and other methods [8–17], the novel scheduling method focuses on factors related to AOS performance of two core sublayers, such as packet distribution, residual function, buffer capacity, frame time, M_PDU efficiency, and virtual channel utilization, and builds recursion formula and numerical analysis model. Furthermore, in terms of input and output matching criterion of AOS, we give a computational method of optimized utilization and frame time based on the previous formula and model. The experimental results show that the proposed method on AOS performance, e.g., the virtual channel utilization and delay, is superior to the existing isochronous frame method. The major contributions of our work can be summarized as follows.

(a) A Novel Cross-Layer Optimization Scheme for Virtual Channel Scheduling of AOS. Different from the traditional scheme for local optimization in individual layer, the novel cross-layer optimization scheme focuses on factors related to AOS performance from VCLC layer to VCA layer. With integrating and analyzing the influence of upper factors, the cross-layer mapping relationship is established. Accordingly, AOS utilization and delay can achieve global optimization with the cross-layer optimization. It has important practical significance for analyzing, improving, designing, and manufacturing AOS systems in future work.

(b) A Computational Method of M_PDU Efficiency in Finite Buffer. According to CCSDS recommended standard, the performance is separately analyzed on respective sublayers. But the output of VCLC sublayer is taken as the input of VCA, whose multiplexing efficiency and frame time directly affect the performance of the VCA, and even the whole system. However, on the one hand, currently it is insufficient on researches of quantitative mathematical analysis and mapping expression between multiplexing efficiency and framing time. On the other hand, the existing studies are based on the ideal condition of infinite buffer. In this paper, we deduce the formula of packet multiplexing efficiency and frame time in finite buffer, which gives a computational method of M_PDU efficiency and provides the theoretic basis for cross-layer optimization and then improves future CCSDS recommendation.

(c) A Simulation Model Based on the Short Correlation Distribution and Matching Criterion of Virtual Channel Input and Output. In order to verify the validity of the packet channel multiplexing model and the scheduling method of CLOPW, we simulated the process of M_PDU multiplexing in VCLC and virtual channel scheduling in VCA. Furthermore, based on short correlation model, we compare the theoretical curves with the simulation results and then analyze the effectiveness.

The rest of this paper is organized as follows. Section 2 presents the overview of our AOS multiplexing mechanism including packet channel multiplexing and virtual channel multiplexing. Section 3 introduces our proposed method in detail. Based on AOS traffic model and assumption, the scheduling methods and formulas for CLOPW are proposed and derived, which improve M_PDU efficiency in limited cache, virtual channel utilization, delay, etc. In Section 4, there is the experimental result and analysis. Finally, Section 5 is conclusion.

2. The Mechanism of AOS Multiplexing

The AOS data link layer contains VCLC sublayer and VCA sublayer, which also provide two stages of multiplexing, i.e., packet channel multiplexing and virtual channel multiplexing [5, 18]. The AOS multiplexing process is shown in Figure 1.

The VCLC sublayer mainly provides two types of services to users, packet service, and M_PDU service. Data from upper layer comes into packet service unit and then is encapsulated into standard CCSDS packet. The M_PDU packet zone contains either payload packets or idle data. When insufficient packets are available at release time of an AOS transfer frame carrying M_PDUs, a M_PDU that contains idle data in its packet zone shall be generated. Meanwhile, the high rate data forms bit stream, which is encapsulated into Bitstream Protocol Data Unit (B_PDU). The B_PDU service provides transfer of a serial string of bits, whose internal structure and boundaries are unknown to the service provider. In virtual channel multiplexing unit, a physical channel is divided into separately logical channels, named Virtual Channel (VC). AOS can define 64 virtual channels at most. Each virtual channel is given a unique Virtual Channel Identifier (VCID). The mechanism of Virtual Channel allows a physical channel to be shared by multiple high-layer communication streams, each of which can have different service requirements.

The transformation of data structure of multiplexing is shown in Figure 2. Firstly, packet service provides the transformation from non-CCSDS packets to standard CCSDS packets, which is the foundation of transparent transmission between different applications or users on space network. Through packet transformation, some existing protocols and applications need not be redesigned or modified and can directly carry and transmit data. Secondly, the transformed

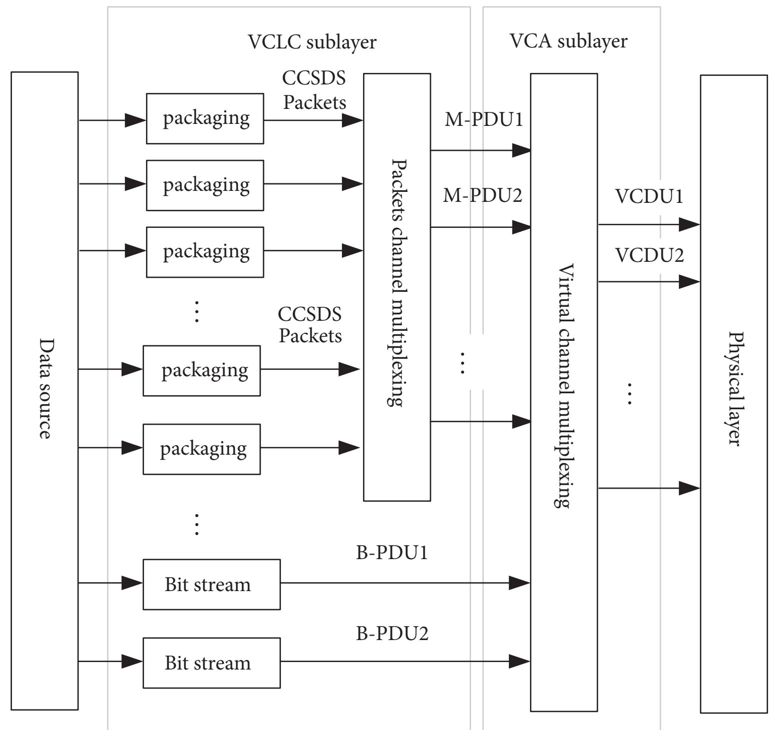

Figure 1: The AOS multiplexing process.

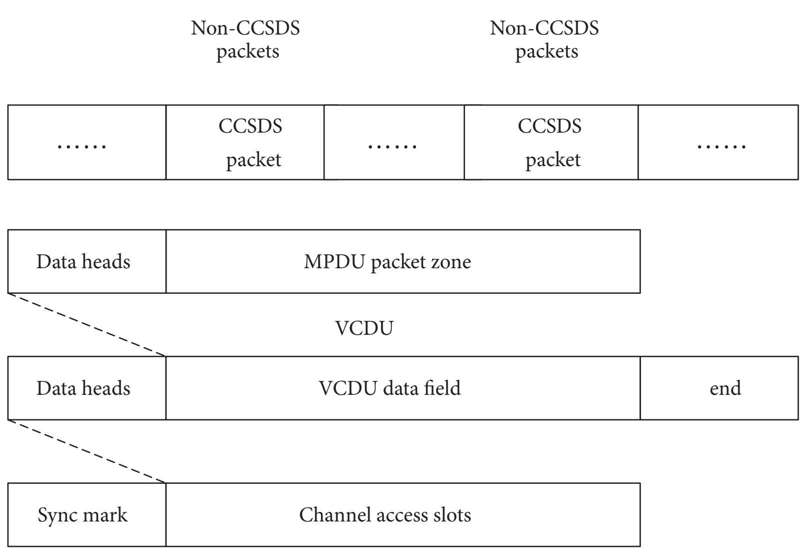

Figure 2: Transformation of data structure of multiplexing.

packets are inserted contiguously and in forward order into M_PDU packet zone. When insufficient packets are available at release time, idle packets are inserted into M_PDU packet zone. Thirdly, a M_PDU is inserted into VCDU data field. Since the length of the M_PDU is fixed by management for any particular Virtual Channel, VCDU data field fits exactly within the fixed-length M_PDU. Finally, the VCDU comes into the channel access slot and is transmitted in the physical channel.

For processing larger capacity and higher rate data in future multimedia space missions based on AOS, a lot of research results of the multiplexing and scheduling algorithms have been achieved [8, 9, 11, 12, 16, 17, 19–21]. Some of them are designed for specific missions and spacecrafts, and they cannot achieve broad applicability or excellent scheduling performance. Liu et al. [19] proposed a kind of scheduling algorithm based on the urgency function of VCs, which can achieve better performance than the

Table 1: the table of symbols.

symbols	*The meanings of a symbol*	*symbols*	*The meanings of a symbol*
λ_p	Arrival rate of Poisson	L_{mpdu}	M_PDU length
l_p	CCSDS packet length	N	Number of packets in a M_PDU
B	Cache capacity	$\eta_{mpdu}^{(i)}$	i order M_PDU efficiency
$p(n)$	Arrival probability of Poisson	$\xi^{(i)}$	Overflow probability in i^{th} gap
r	Number of residual packets	${\Phi_p}^{(j)}(r)$	the j^{th} order residual packets function
i	virtual channel number (from 1 to i)	α_i	Weight of the polling time
T_w	Average frame time	$v_{in}^{(i)}$	Input rate of VCDU frame in i^{th}
C	Total output channel capacity	$v_{out}^{(i)}$	Output rate of VCDU frame in i^{th}
R	Throughput of virtual channel	γ	Virtual channel utilization
D	Delay of virtual channel	$\overline{D}$	Average delay of virtual channel

classical scheduling algorithms. But the algorithm ignores the relevance and influence from upper layer. They only consider the urgency of each data frame in local layer. Therefore, the performance of these algorithms is limited in reality. Bie et al. [17] propose an improved algorithm, which considers the influence of the number of remaining frames in each VC when designing the scheduling decision function. However, this algorithm still does not distinguish the frame urgency from the different layers. In the article [20], a novel scheduling algorithm was designed. The scheduling method, estimating the VC urgency and the frame urgency separately, improves the scheduling performance. Further results are developed in [16] by introducing the movable boundary technology into the algorithm of [22], which can decrease the scheduling time delay and increase the channel utilization rate further. These methods of the above articles only focus on the influence factors of each individual sublayer to obtain local optimization. In this paper, we build a multiple factors framing model of finite buffer and propose a scheduling method of cross-layer optimization. We detailedly introduce our proposed method in the following section.

3. A Scheduling Method of Cross-Layer Optimization

For describing the mathematical model more systematic and easy to understand, I listed a table of symbols in Table 1.

3.1. A Computational Method of Packets Channel Multiplexing. A computational method of packet channel multiplexing is built on the following assumptions.

(a) The packets arrival model from different data sources obeys the Poisson probability distribution. The arrival rate is equal to λ_p.

(b) Supposing that M_PDU length was equal to L_{mpdu}, packet length is l_p. $L_{mpdu} = N \cdot l_p$, and N is an integer.

(c) The system is carried out in a batch process; i.e., together N packets are inserted into one M_PDU packet zone in a frame time T_w. When the amount of arrival packet is less than N, the idle packets are inserted into M_PDU packet zone.

(d) Let the cache capacity be B and $B > N$.

The presence of idle packets causes a decrease in M_PDU efficiency. If extending the frame time T_w to be used to wait for coming packets into buffer, the efficiency would increase, but the delay worsens.

Set M_PDU efficiency as η. In the first waiting gap (frame time T_w), the efficiency is expressed as follows, named 1 order M_PDU efficiency,

$$\eta_{mpdu}^{(1)} = \frac{1}{L_{mpdu}} \left[\sum_{n=0}^{N} n \cdot l_p \cdot p(n) + N \cdot l_p \sum_{n=N+1}^{B} p(n) \right] \quad (1)$$

where L_{mpdu} is the length of M_PDU and l_p is the length of CCSDS packet. T_w is the time gap. $p(n)$ is packet arrival probability with Poisson distribution.

$$p(n) = \frac{\left(\lambda_p T_w\right)^n e^{-\lambda_p T_w}}{n!} \quad (2)$$

The overflow probability in the first gap is as the following formula.

$$\xi^{(1)} = p(n > B) = 1 - \sum_{n=0}^{B} p(n) \quad (3)$$

Furthermore, the M_PDU efficiency in the second time gap T_w was considered. In the second gap, the residual packets from the first gap must be calculated. Let the residual packets probability be ${\Phi_p}'(r)$, named the first order residual packets function (abbr. 1-RPF), where r is the amount of residual packets.

$$\Phi'(r) = \begin{cases} \displaystyle\sum_{q=0}^{N} \frac{\left(\lambda_p T_w\right)^q e^{-\lambda_p T_w}}{q!} & r = 0 \\ \displaystyle\frac{\left(\lambda_p T_w\right)^{N+r} e^{-\lambda_p T_w}}{(N+r)!} & r = 1, 2, 3 \ldots, B - N \end{cases} \quad (4)$$

When arrival packets in the first time gap were less than N, there are no residual packets in the second gap T_w, and r is equal to 0. Otherwise, when $n > N$ in the first gap, r is the amount of residual packets and n=N+r. So the actual arrival probability is $p(N+r)$ in first gap T_w. The efficiency was expressed as follows:

$$p''(k) = \sum_{i=0}^{k} \Phi_p{}'(i) \cdot p(m = k - i) \quad k = 1, 2, \cdots, B \tag{5}$$

where k is the amount of packets in second gap, which include two parts. One part is the arrival packets with Poisson distribution. The other is the residual packets from the first gap T_w. Therefore, the 2-order M_PDU efficiency is expressed as follows.

$$\eta_{mpdu}^{(2)} = \frac{1}{L_{mpdu}} \left[\sum_{n=0}^{N} n \cdot l_p \cdot p''(n) + N \cdot l_p \sum_{n=N+1}^{B} p''(n) \right] \tag{6}$$

The second-order residual packets function (abbr. 2-RPF) is as follows.

$$\Phi_p{}''(r) = \begin{cases} \sum_{q=0}^{N} \sum_{i=0}^{q} \Phi'_p(i) \cdot p(m = q - i) & r = 0 \\ \sum_{i=0}^{N+r} \Phi_p{}'(i) \cdot p(m = N + r - i) & r = 1, 2, 3 \ldots, B - N \end{cases} \tag{7}$$

The overflow probability in the second gap is as the following formula.

$$\xi^{(2)} = p(n > B) = 1 - \sum_{n=0}^{B} p''(n) \tag{8}$$

From above the formulas, the recursion formula of j order M_PDU efficiency can be given,

$$\eta_{mpdu}^{(j)} = \frac{1}{l_{mpdu}} \left[\sum_{n=0}^{N} n \cdot l_p \cdot p^{(j)}(n) \right] + N \cdot l_p \sum_{n=N+1}^{B} p^{(j)}(n) \tag{9}$$

where $p^{(j)}(n)$, $\Phi_p{}^{(j)}(r)$, and $\xi^{(j)}$are as follows.

$$p^{(j)}(n) = \sum_{i=0}^{n} \Phi_p{}^{(j-1)}(i) \cdot p(m = n - i) \tag{10}$$

$$\Phi_p{}^{(j)}(r) = \begin{cases} \sum_{q=0}^{N} \sum_{i=0}^{q} \Phi_p^{(j-1)}(i) \cdot p(m = q - i) & r = 0 \\ \sum_{i=0}^{N+r} \Phi_p{}^{(j-1)}(i) \cdot p(m = N + r - i) & r = 1, 2 \ldots (B - N) \end{cases} \tag{11}$$

$$\xi^{(j)} = p(n > B) = 1 - \sum_{n=0}^{B} p^{(j)}(n) \tag{12}$$

3.2. A Scheduling Method of Cross-Layers Optimization of Polling Weight. The virtual channel number is, respectively, from 1 to i. The normalization of scheduling period is 1. α_i is weight of the polling time on VCA sublayer. The time slice allocated for each virtual channel is from α_1 to α_i. α_i satisfies the following formula.

$$\alpha_1 + \alpha_2 + \cdots + \alpha_i = 1 \tag{13}$$

We normalized the polling cycle of the whole virtual channel to 1. T_{w_i} represents the average frame time of generating a M_PDU (a M_PDU is encapsulated into a VCDU) on the ith virtual channel, i.e., average normalized time per a VCDU. The input rate of VCDU frame on the ith virtual channel is expressed as $v_{in}^{(i)}$.

$$v_{in}^{(i)} = \frac{1}{T_{W_i}} \tag{14}$$

If the total output channel capacity is represented as C, which stands for the maximum VCDU transmission rate in downlink channel, the time slice allocated for ith virtual channel is α_i. The output rate of ith virtual channel is $v_{out}^{(i)}$.

$$v_{out}^{(i)} = \alpha_i C \tag{15}$$

There are three situations of output and input rate of ith virtual channel.

(a) When the condition $v_{in}^{(i)} < v_{out}^{(i)}$ is met, i.e., the input rate of ith virtual channel is lower than the output rate, we need to insert idle packets, which will lead to the decline of virtual channel utilization.

(b) When the condition $v_{in}^{(i)} > v_{out}^{(i)}$ is met, i.e., the input rate of ith virtual channel is higher than the output rate, it can lead to a gradual increase in the cache and easily overflow.

(c) When the condition $v_{in}^{(i)} = v_{out}^{(i)}$ is met, i.e., the input rate of ith virtual channel is equal to the output rate, the best match between input and output is achieved.

$$v_{in}^{(i)} = v_{out}^{(i)} \tag{16}$$

From the formula (14), (15), (16), we can get the following:

$$\frac{1}{T_{Wi}} = \alpha_i C \tag{17}$$

That is

$$\alpha_i = \frac{1}{T_{Wi} C} \tag{18}$$

In a whole polling cycle, the throughput of virtual channel is represented as R,

$$R(T_w) = (\eta_1, \eta_2, \cdots, \eta_i) \cdot \begin{bmatrix} \alpha_1 C \\ \alpha_2 C \\ \vdots \\ \alpha_i C \end{bmatrix} \tag{19}$$

where $\eta_1, \eta_2, \cdots, \eta_i$ represent the M_PDU multiplexing efficiency, which can be obtained from formula (1).

Virtual channel utilization is defined as radio of valid data to total output. The utilization is represented as γ.

$$\gamma = \frac{R}{C} \tag{20}$$

From formula (19) to (20), we can get the following.

$$\gamma = (\eta_1, \eta_2, \cdots, \eta_i) \cdot \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \vdots \\ \alpha_i \end{bmatrix} \tag{21}$$

That is

$$\gamma = \eta_1\alpha_1 + \eta_2\alpha_2, \cdots, +\eta_i\alpha_i \tag{22}$$

From the formula (1) and (22), the first order utilization of virtual channel with the first order efficiency of M_PDU is represented as $\gamma^{(1)}$.

$$\begin{aligned} \gamma^{(1)} = & \left[\sum_{n=0}^{N} \frac{n}{N} \cdot \frac{(\lambda T_{W1})^n e^{-\lambda T_{W1}}}{n!} \right. \\ & \left. + \sum_{n=N+1}^{B} \frac{(\lambda T_{W1})^n e^{-\lambda T_{W1}}}{n!} \right] \alpha_1 + \left[\sum_{n=0}^{N} \frac{n}{N} \right. \\ & \left. \cdot \frac{(\lambda T_{W2})^n e^{-\lambda T_{W2}}}{n!} + \sum_{n=N+1}^{B} \frac{(\lambda T_{W2})^n e^{-\lambda T_{W2}}}{n!} \right] \alpha_2 \cdots \\ & + \left[\sum_{n=0}^{N} \frac{n}{N} \cdot \frac{(\lambda T_{Wi})^n e^{-\lambda T_{Wi}}}{n!} \right. \\ & \left. + \sum_{n=N+1}^{B} \frac{(\lambda T_{Wi})^n e^{-\lambda T_{Wi}}}{n!} \right] \alpha_{\mathrm{i}} \end{aligned} \tag{23}$$

In the i[th] virtual channel, the multiplexing efficiency of M_PDU in second time gap can be represented as $\eta_i^{(2)}$.

$$\begin{aligned} \eta_i^{(2)} = & \left[\sum_{n=0}^{N} \frac{n}{N} \cdot p''\left(n \mid T_f = T_{W\mathrm{i}}\right) \right. \\ & \left. + \sum_{n=N+1}^{B} p''\left(n \mid T_f = T_{W\mathrm{i}}\right) \right] \end{aligned} \tag{24}$$

So the 2-order utilization of virtual channel is $\gamma^{(2)}$.

$$\begin{aligned} \gamma^{(2)} = & \left[\sum_{n=0}^{N} \frac{n}{N} \cdot p''\left(n \mid T_f = T_{W1}\right) \right. \\ & + \sum_{n=N+1}^{B} p''\left(n \mid T_f = T_{W1}\right) \alpha_1 + \left[\sum_{n=0}^{N} \frac{n}{N} \right. \\ & \cdot p''\left(n \mid T_f = T_{W2}\right) \\ & + \sum_{n=N+1}^{B} p''\left(n \mid T_f = T_{W2}\right) \alpha_2 \cdots + \left[\sum_{n=0}^{N} \frac{n}{N} \right. \\ & \cdot p''\left(n \mid T_f = T_{W\mathrm{i}}\right) \\ & + \sum_{n=N+1}^{B} p''\left(n \mid T_f = T_{W\mathrm{i}}\right) \alpha_{\mathrm{i}} \end{aligned} \tag{25}$$

Furthermore, the j[th] order utilization of virtual channel is $\gamma^{(j)}$.

$$\begin{aligned} \gamma^{(j)} = & \left[\sum_{n=0}^{N} \frac{n}{N} \cdot p^{(j)}\left(n \mid T_f = T_{W1}\right) \right. \\ & + \sum_{n=N+1}^{B} p^{(j)}\left(n \mid T_f = T_{W1}\right) \alpha_1 + \left[\sum_{n=0}^{N} \frac{n}{N} \right. \\ & \cdot p^{(j)}\left(n \mid T_f = T_{W2}\right) \\ & + \sum_{n=N+1}^{B} p^{(j)}\left(n \mid T_f = T_{W2}\right) \alpha_2 \cdots + \left[\sum_{n=0}^{N} \frac{n}{N} \right. \\ & \cdot p^{(j)}\left(n \mid T_f = T_{W\mathrm{i}}\right) \\ & + \sum_{n=N+1}^{B} p^{(j)}\left(n \mid T_f = T_{W\mathrm{i}}\right) \alpha_{\mathrm{i}} \end{aligned} \tag{26}$$

In summary, the utilization is related to not only the multiplexing efficiency of M_PDU, but also the frame time T_{Wi} of VCLC sublayer and the distribution weight α_i of time slice of virtual channel on VCA sublayers. Suppose that the input rate of virtual channel is matched with the output. The j order utilization $\gamma^{(j)}$can be expressed as follows.

$$\begin{aligned} \gamma^{(j)} = & \left[\sum_{n=0}^{N} \frac{n}{N} \cdot p^{(j)}\left(n \mid T_f = T_{W1}\right) \right. \\ & + \sum_{n=N+1}^{B} p^{(j)}\left(n \mid T_f = T_{W1}\right) \frac{1}{T_{W1}C} + \left[\sum_{n=0}^{N} \frac{n}{N} \right. \\ & \cdot p^{(j)}\left(n \mid T_f = T_{W2}\right) \\ & + \sum_{n=N+1}^{B} p^{(j)}\left(n \mid T_f = T_{W2}\right) \frac{1}{T_{W2}C} \cdots \\ & + \left[\sum_{n=0}^{N} \frac{n}{N} \cdot p^{(j)}\left(n \mid T_f = T_{W\mathrm{i}}\right) \right. \\ & + \sum_{n=N+1}^{B} p^{(j)}\left(n \mid T_f = T_{W\mathrm{i}}\right) \frac{1}{T_{Wi}C} \end{aligned} \tag{27}$$

When $v_{in}^{(i)} = v_{out}^{(i)}$, α_i is the function of variable T_{Wi}. By changing the polling weight of time slice on VCA sublayer and making it match with M_PDU frame time,

Table 2: Simulation Parameters Table of AOS Virtual Channel.

VC No.	*Data type*	*Service type*	*Arrival rate (frame/s)*	*urgency*	*Transmission type*
VC1	surveillance Video	Bitstream	$5.15{\times}10^2$	0	SYN
VC2~3	Voice and Video	Bitstream	$6.76{\times}10^2$	0	SYN
VC3~6	System data	Path	$5.97{\times}10^2$	1	ASYNC
VC7~8	Telemetry of vital signal	Path	$3.78{\times}10^2$	2	ASYNC
VC9	Delay telemetry	Path	$4.26{\times}10^2$	3	ASYNC
VC10~12	Internet data	Internet	$2.57{\times}10^2$	4	ASYNC
VC13~14	Payload data	Path	$8.27{\times}10^2$	3	ASYNC
VC15~16	CCD images	Bitstream	$1.23{\times}10^3$	2	ASYNC

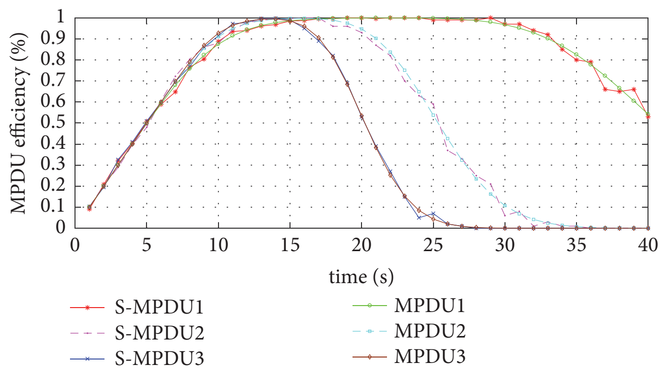

Figure 3: Relationship between the M_PDU efficiency and frame time.

the optimization of cross-layer on virtual channel utilization can be realized. The scheduling method is called cross-layer optimization of polling weight (abbr. CLOPW).

In terms of formula (19), we define delay of virtual channel as D, which is a function of framing time.

$$D = \frac{1}{R(T_w)} \tag{28}$$

Furthermore, the average delay of virtual channel is expressed as

$$\overline{D}\Big|_{L_{VCDU}=M} = \frac{1}{N}\sum_{k=1}^{N} D\left(t = T_W(k)\right) \tag{29}$$

where $D(t = T_v(k))$ represents the delay time under the condition that t is equal to different frame time $T_w(k)$, and k is from 1 to N. $\overline{D}|_{L_{VCDU}=M}$ represents the average delay time under the condition that the length of VCDU is equal to M.

4. Experimental Result and Analysis

In order to verify the validity of the packet channel multiplexing model and the scheduling method of CLOPW in Section 3, we simulated the process of M_PDU multiplexing in VCLC and virtual channel scheduling in VCA. We build a 16-channel simulation model, whose data is partly derived from [21] and extended on this basis. Simulation parameters of AOS Virtual Channel are shown in Table 2. Furthermore, based on short correlation model with Poisson distribution, we compare the theoretical curves with the simulation results and then analyze the effectiveness.

4.1. The Experimental of the Packet Channel Multiplexing. Based on the scheduling method of M_PDU efficiency (in Section 3.1) and the assumption (in Section 3.2), we simulated the process of M_PDU multiplexing in VCLC sublayer. Meanwhile, the simulation result is compared with the recursion formula. And the length of packets l_p is set to 1, $\lambda_p = 1$, $N = 10$, $B = 40$.

The relationship between the M_PDU efficiency and time is shown in Figure 3. We adopt Poisson distribution model to simulate the CCSDS packet arrival process. In terms of arrival packets in different simulation time, we plot the relation curve of M_PDU efficiency vs. time, named S-M_PDU1, S-M_PDU2, and S-M_PDU3. Serial numbers 1, 2, 3 indicate the order of simulation. Meanwhile, we use the proposed computational method of Packets Channel Multiplexing to get the efficiency-time function and plot the theoretical relation curve such as M_PDU1, M_PDU2, and M_PDU3, which, respectively, represent 1-order, 2-order, and 3-order M_PDU formula. It can be seen from Figure 3 that the theoretical relation curve is well fitting with the simulation curve, which shows that the computational method can depict multiplexing process well in VCLC sublayer. With the growth of the frame time, M_PDU efficiency increases first and then decreases. Because in the short frame time there are few arrival packets, MPDU packet zone is inserted into a

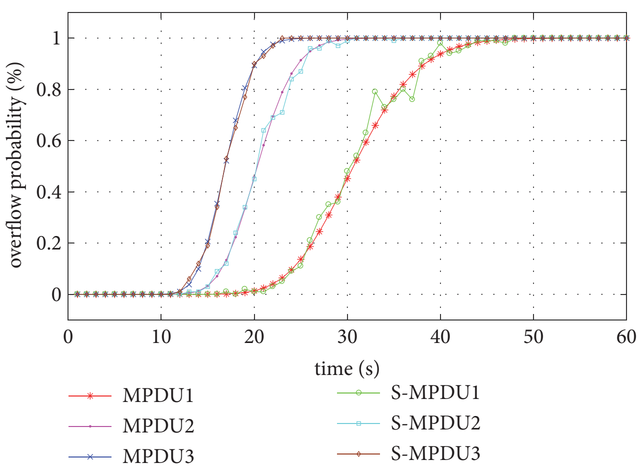

Figure 4: Overflow probability of AOS multiplexing.

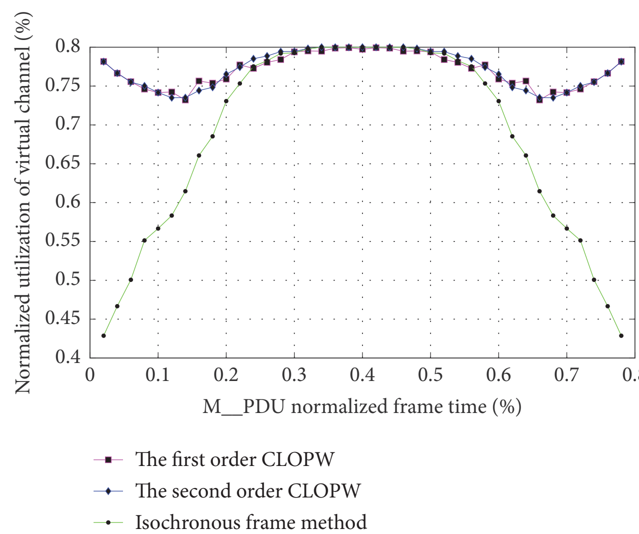

Figure 5: Comparison of normalized utilization of virtual channel.

large amount of idle packets, resulting in low efficiency. With the increase of arrival packets, idle packets drop and MPDU efficiency is growing. Yet due to limited cache capacity, with the continuous increase of frame time the overflow probability rises, which result in a decline of the M_PDU efficiency.

The overflow probability curve is shown in Figure 4. It can be seen from the curve that the 1~3-order MPDU formula is well fitting with the simulation data.

4.2. The Experimental of CLOPW. In order to analyze the performance for CLOPW, we compare the normalized utilization of virtual channel and average delay with isochronous frame method. Set virtual channel capacity C to 10000 frames/sec. Let the number of virtual channels be 16. We change M_PDU normalized frame time T_{v1}, T_{v2} of VC_1 or VC_2 and let $T_{v1} + T_{v2} = 0.8$. Meanwhile, we fix the other normalized frame time of the remaining VC_3~VC_{16} and let $T_{v3} + T_{v4} + \cdots + T_{v16} = 0.2$. For CLOPW, in terms of formula (18) $a_i = 1/(T_{vi}C)$, we let T_{v1} change from 0.02 to 0.78, and a_1, α_2 follow the change. For isochronous frame method, we use the fixed polling weights, i.e., $a_1 = \alpha_2$, which do not change with T_{v1} and T_{v2}. The 1-order and 2-order utilization of CLOPW are compared with those of isochronous frame method [14]. The experimental results are shown in Figure 5.

With isochronous frame method, as shown in Figure 5, when M_PDU normalized frame time T_{v1}, T_{v2} is relatively low or higher, the normalized utilization of virtual channel is low because less time T_{wi} leads to the low efficiency of M_PDU, which causes the decline of normalized utilization of virtual channel. On the other hand, a long frame time T_{v1} contributes to improving the M_PDU efficiency, but that would result in an overflow increase, which causes the decline of normalized utilization. When M_PDU normalized frame time T_{v1}, T_{v2} is relatively moderate, i.e., they are approximately equal $T_{v1} = T_{v2} = 0.4$, the normalized utilization reaches the maximum because in this time the fixed polling weights $a_1 = \alpha_2$ match frame time ($T_{v1} = T_{v2}$). The isochronous frame method is consistent with CLOPW. When the CLOPW is adopted, the

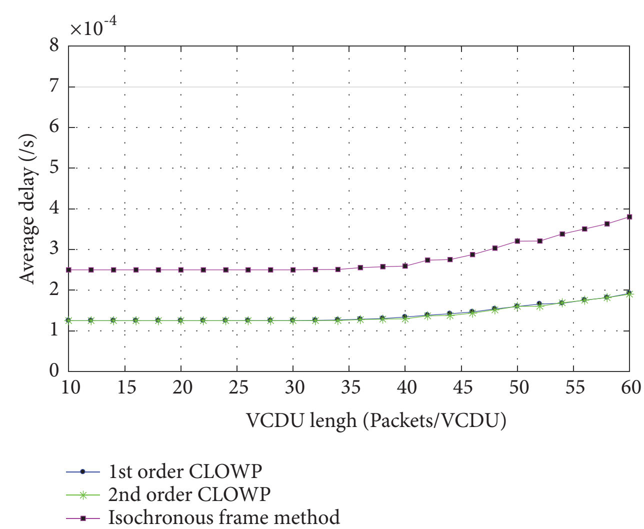

Figure 6: Comparison of average delay between CLOPW and isochronous frame method.

polling weight such as α_1, α_2 changes with the frame time T_{v1}, T_{v2}. The less frame time is allocated for short polling time slices, and the long frame time matches long polling time slices, which would improve normalized utilization of virtual channel. It can be shown in the Figure 5 that CLOPW method, whether it is of 1-order or 2-order, has higher normalized utilization than isochronous frame method as a whole.

Furthermore, the average delay is studied. Figure 6 shows the comparison of average delay between CLOPW and isochronous frame method under the change of the VCDU frame length.

As the length of the VCDU frames increases, the average delay of CLOPW and the isochronous frame method are slowly increasing. At the same VCDU length, the average delay of CLOPW is always lower than that of isochronous scheduling algorithm.

5. Conclusion

In the paper, we analyze the mechanism of the AOS multiplexing model in VCLC and VCA sublayer. We derive the M_PDU multiplexing efficiency under finite buffer, which is applied to cross-layer optimization. Furthermore, a scheduling method of cross-layers optimization of polling weighted, called CLOPW, is proposed. The novel scheduling method gives the formula for the virtual channel utilization and delay of cross-layer optimization. With fixed packet length of M_PDU under the condition of short correlation traffic model, CLOPW is more suitable for virtual channel multiplexing of AOS. The experimental results show that CLOPW is higher utilization of virtual channel and lower average delay than the isochronous frame method. The method can provide theoretical support for the construction and operation of AOS development.

Data Availability

The AOS traffic dataset of arrival packets from different data sources obeys the Poisson probability distribution, which is simulated and generated by MATLAB. We adopt MATLAB library function such as "poissrnd" to generate the Poisson traffic, which meets AOS requirement of short correlation traffic. The data is available.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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