The Performance Analysis of Satellite Virtual Channel Scheduling Algorithms Based on Stochastic Network Calculus

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***Abstract*—The use of scheduling algorithm in virtual channel multiplexing in CCSDS AOS affects the channel utilization of AOS space communication system. According to the traffic characteristics in AOS, the system model is established by using stochastic network calculus and Fractal Brown Motion (FBM) model which takes consideration into the self-similar characteristics of traffic. According to the characteristics of the FBM model, from the angle of delay performance and backlog, to compare first-come-first-serviced, static priority and Round Robin scheduling algorithms are focused and their influence on the performance is investigated. The results shed new insights for further research on virtual channel scheduling performance of AOS CCSDS spatial data systems, and have potentially significant and practical value to study the scheduling algorithm of traffic with strong self-similarity and burstiness in AOS space communication systems.**

***keywords*—AOS; Stochastic Network Calculus; self-similar; Virtual Channel; scheduling algorithm.**

I. Introduction

The Consultative Committee for Space Data Systems (CCSDS) is an international standardization organization, composed of multinational space agencies, whose aim is to specify standardized communication systems for space data system structure, communication protocol and business [1,3,4]. Advanced Orbit Systems (AOS) is a data link communication and transmission protocol, recommended by CCSDS. It may be used to serve space-to-space and space-to-surface data communications, and its measurement, control and management. AOS can deal with large capacity or high rate data and support multiple users with different requirements and simultaneous access. Because the source types of AOS space communication system are complex, if the traditional form of time-division multiplexing is used (i.e., the traffic is divided into data frames with fixed-length, and then fixed time slot will be allocated to data frame), it will reduce the system efficiency in data transmission. To improve the systems performance on this, the concept of virtual channel (VC) has been proposed in CCSDS AOS, where the scheduling algorithm used in VC is called VC scheduling algorithm.

VC scheduling algorithm has been one of the key research issues for AOS in space communication systems. VC multiplexing in AOS data link layer allows different traffic to share the same physical channel to transmit data. Besides, VC scheduling can support multiple VCs multiplexed on the same physical channel, each of which may have a certain reference value to meet the transmission performance of the related space information network data transmission and the overall transmission performance of the AOS system.

In this paper, satellite data transmission is divided into five categories, namely audio, video, image, command and general file. The physical channel is accordingly divided into six types of VCs [2,8], which respectively are audio VC, video VC, image VC, command VC, general file VC and idle frame VC. The purpose of this paper is to investigate VC scheduling algorithms, and analyze the data transmission performance of VCs.

The literature [2] analyzes manned spacecraft data types, determines the division of nine VCs according to the needs of business, and then illustrates the advantages and disadvantages of four scheduling algorithms including first-come-first-serviced, Round Robin, remaining quantity first and Static Priority. In addition, to meet the system delay performance and the buffer capacity demand, it also proposes a new dynamic priority scheduling strategy. In [3], in order to rationally allocate the ratio of synchronous or asynchronous traffic occupying the physical channel, it proposes a virtual dynamic scheduling method based on different data rate and the amount of residual data, which can meet the delay requirement of the synchronous data and the transmission rate requirement of the asynchronous data. In [4] and [28], the focused scheduling algorithms are respectively based on static priority and Round Robin. With static priority scheduling, when there is a large amount of data in the high priority VC, physical channel will be monopolized by such priority traffic; although Round Robin scheduling can solve this starvation problem, when the number of data types is more, it may lead to the phenomenon of large delay. [5,6] apply the superposition of ON/OFF model with heavy-tailed distribution to the source of self-similar traffic model and present a practicable model and then validate the LEO traffic is self-similar. In [7], combined with the characteristics of VC in AOS, a service guarantee mechanism that combines flow control and VC scheduling is proposed. This mechanism can ensure the high priority data obtaining service quality guarantee.

In these literature studies, Poisson traffic or Markov traffic models have mostly been adopted. However, such Markov models have some limitations: for example, they cannot reflect the self-similarity characteristic of traffic in AOS space communication system. In addition, when the buffer capacity is limited, the literature Markov model based analysis has few results to calculate the packet loss rate. In this paper, we use the Fractal Brown Motion (FBM) model in the analysis, which can reflect the traffic self-similarity characteristic in AOS. Moreover, we base our analysis on network calculus to provide results on both delay and backlog where the latter can be used to approximate loss rate when buffer capacity is limited. Network calculus is an analytical tool used for network performance analysis, which can be divided into two branches: deterministic network calculus (DNC) and stochastic network calculus (SNC). SNC is often used in network performance analysis of wireless communication systems. In this paper, the SNC [12] is applied for performance analysis of the AOS space communication system. In particular, performances under first-come-first-serviced (FCFS), static priority and round robin scheduling algorithms in AOS are compared. According to the delay requirements of different types of data services, for data transmission for satellite internal data link layer, we combine stochastic network calculus with AOS CCSDS VC parameters to analyze the effect of different scheduling algorithms on the performance of the AOS channel.

Specifically, a constant rate service model is selected, which has been used in the literatures, e.g.[13,14], for performance analysis of systems with FBM arrival model and service nodes with self-similarity characteristics. In addition, according to the characteristics of the FBM traffic model, we analyze the influence of first-come-first-serviced (FCFS), static priority and round robin scheduling algorithm on the delay and backlog performance of the AOS channel. This analysis sheds new light for further study of VC scheduling performance of CCSDS spatial data in AOS systems.

The rest of the paper is organized as follows. In Section II, we give an introduction of the basic knowledge about SNC. In Section III, we introduce AOS and VC scheduling algorithm. In Section IV, the system model for investigation is presented. In Section V, performance analysis is detailed, which includes numerical analysis of the arrival process and service process under each considered scheduling algorithm, and deduction of the corresponding formula of arrival curve and service curve. In Section VI, results are presented and discussed. Finally, we conclude this work with a short summary in Section VII.

II. STOCHASTIC NETWORK CALCULUS BASICS

Network calculus (NC) initiated by Cruz and Chang is a new tool for quantitatively analyzing the performance of queuing systems, which has two branches: Deterministic Network Calculus (DNC) and Stochastic Network Calculus (SNC) [9,10,11,12]. SNC, as a network traffic theory for service quality analysis, has two important concepts: Stochastic Arrival Curve (SAC) and Stochastic Service Curve (SSC). SAC characterizes the traffic behavior of an arrive flow. SSC characterizes the service behavior of the considered node or system.

The key of applying SNC for performance analysis of network quality of service is mainly to find the stochastic arrival curve characterization and the stochastic service curve characterization of the arrival model and the service model respectively, and then deduce stochastic delay bound and stochastic backlog bound for the system.

Assume that the discrete time model is t$\in N_0$={0,1,2,...}, let cumulative functions A(s,t), S(s,t) and D(s,t) denote the arrival, service and departure processes respectively in the interval (s,t]. For any $0 \leq s \leq t$, define $A(s,t) \equiv A(0,t) - A(0,s)$, $D(s,t) \equiv D(0,t) - D(0,s)$ and $S(s,t) \equiv S(0,t) - S(0,s)$, and assume that $A(0) = D(0) = S(0) = 0$, where $A(0,t)$, $D(0,t)$ and $S(0,t)$ are non-negative, increasing in t.

Definition 1: Arrival Curve and Service Curve

Definition 1.1 (Arrival Curve) If for any $0 \leq s \leq t$, there is a non-negative and non-decreasing function $\alpha(t)$, meeting

$$A(s,t) \leq \alpha(t-s) \tag{1}$$

then $\alpha(t)$ is called an arrival curve of $A(t)$. $\alpha(t)$ describes the upper bound of traffic arrival of $A(t)$, that is to say in the interval $(s,t]$, the arrival traffic $A(s,t)$ will not be more than $\alpha(t-s)$.

Definition 1.2 (Service Curve) Consider that the traffic $A(t)$ has departure process $D(t)$ after the service of a network node. If for $\forall t \geq 0$, there is a non-negative and non- decreasing function $\beta(t)$ meeting:

$$D(t) \geq A \otimes \beta(t) \tag{2}$$

where $\otimes$ expresses the min-plus algebra formulation, that is $A \otimes \beta(t) = \inf_{0 \leq s \leq t} \{A(t-s) + \beta(s)\}$, we then call $\beta(t)$ a service curve provided for traffic by the network service node.

The right hand side of inequality (2) also represents the departure process of traffic $A(t)$ through a reference service node with service process $S(t)$. An intuition of inequality (2) is that network calculus uses a linear service system to approximately describe, as a lower bound of the service process $S(t)$ of the node.

Definition 2: Delay and Backlog

Definition 2.1 (Delay) Delay refers to the time interval from service arrival to service completed. Suppose a communication stream $A(t)$ goes through a network node that provides the service $S(t)$ to obtain the output stream $D(t)$. For $t \geq 0$, delay is defined as:

$$d(t) = \inf \{s \geq 0 : A(t) \leq D(t+s)\} \tag{3}$$

With the definition of delay, for $\forall x \geq 0$, if $d(t) > x$ is true, then $A(t) > D(t+x)$ is also true, therefore,

$$\begin{aligned} pr\{d(t) > x\} &\leq pr\{A(t) - D(t+x) > 0\} \\ &\leq pr\left\{\sup_{0\leq\tau\leq t}\{A(\tau,t) - S(\tau,t+x)\} > 0\right\} \end{aligned} \tag{4}$$

Definition 2.2 (Backlog) Backlog is the sum of traffic which arrives in the network service node in a certain moment but has not be served. With arrival process $A(t)$ and service process $S(t)$, the backlog at time $t \geq 0$ is defined to be $b(t) = A(t) - D(t)$. With the definition of backlog, the following relation holds:

$$\begin{aligned} pr\{b(t) > x\} &= pr\{A(t) - D(t) > x\} \\ &\leq pr\left\{\sup_{0\leq s\leq t}\{A(s,t) - S(s,t)\} > x\right\} \end{aligned} \tag{5}$$

Theorem 1: Delay Bound and Backlog Bound

Let the moment generating function (MGF) [15] of stochastic arrival process and stochastic service process respectively defined as $\mathrm{M}_A(\theta,t)$ and $\mathrm{M}_S(\theta,t)$. Specifically, for $\theta \geq 0$,

$$M_A(\theta,t) = E\left[e^{\theta A(\mathrm{t})}\right] \tag{6}$$

In addition, define

$$\overline{M}_S(\theta,t) = M_S(-\theta,t) = E\left[e^{-\theta^{S(t)}}\right] \tag{7}$$

Suppose $A(t)$ and $S(t)$ are independent stochastic processes. Then, for an acceptable violate probability $\varepsilon \in (0,1]$, we have the following delay bound and backlog bound: for $\forall\theta \geq 0$,

$$\begin{aligned} d = &\inf_{\theta>0} \\ &\left[\inf\left[\tau : \tfrac{1}{\theta}(\ln\sum_{t=\tau}^{\infty}\mathrm{M}_A(\theta,t-\tau)\overline{M}_S(\theta,t) - \ln\varepsilon) \leq 0\right]\right] \end{aligned} \tag{8}$$

$$b = \inf_{\theta>0}\left[\frac{1}{\theta}(\ln\sum_{t=0}^{\infty}\mathrm{M}_A(\theta,t)\overline{\mathrm{M}}_S(\theta,t) - \ln\varepsilon)\right] \tag{9}$$

III. AOS Protocol and Virtual Channel Scheduling Algorithm

AOS is based on the OSI seven layer structure model. Its space data link (SDL) layer corresponds to the data link layer in the OSI model, and the SDL layer can be divided into two sub layers: VC Link Control (VCLC) sub layer, VC Access (VCA) sub layer [16,17]. AOS adopts package channel multiplexing based on the VCLC sub-layer, and VC multiplexing based on the VCA to realize that multiple users share the same physical channel. Its principle is shown in Fig.1.

AOS can classify and process different sources. In packet channel multiplexing, the VCLC sub-layer can cascade CCSDS packages to the same VC. In VC multiplexing, a physical channel is divided into six VCs and its function allows a physical channel to be shared by a variety of data streams.

To transmit different data types in satellite, we divide the physical channel into six VCs:

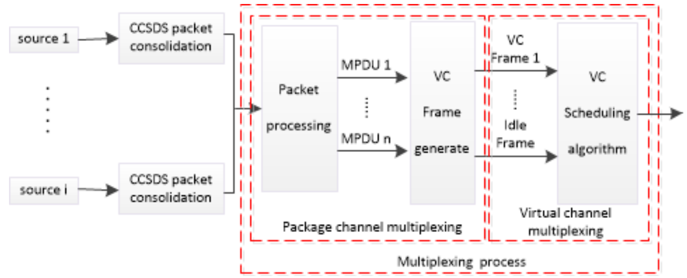


Fig. 1: AOS multiplexing mechanism model

VC1: transmitting audio data with bit-stream service.
VC2: transmitting video data with bit-stream service.
VC3: transmitting image data with bit-stream service.
VC4: transmitting command data with path service.
VC5: transmitting the general file data with path service.
VC6: filling idle data: produce and transport filling VCDU. At any scheduling time, if all the other VCs are empty, the data in VC6 will be transmitted through the physical channel.

The scheduling algorithms used in AOS VC in this paper include:

(1) First-Come-First-Served Scheduling Algorithm. First-Come-First-Served scheduling algorithm (FCFS) is the simplest scheduling algorithm of all the scheduling algorithms, which is also known as First-In-First-Out (FIFO) scheduling algorithm. It accords with the simple queue scheduling principle, and schedules according to the order of traffic to the service node [18,19,20].

(2) Static Priority Scheduling Algorithm. In Static Priority scheduling algorithm (SP), the higher the priority value is, the lower the priority is. The service node schedules the flows according to the priority level of the arriving traffic. Traffic with higher priority is scheduled preferentially to provide service [18,20], and then the traffic with lower priority is scheduled when the higher priority queue is empty. Therefore, in static priority scheduling strategy, when the higher priority queue is not empty, the lower priority data will have to wait for a long time and cannot be scheduled, which may be vulnerable to starvation.

(3) Round Robin scheduling algorithm. As one of the most classical scheduling algorithms, the Round Robin scheduling algorithm (RR) can be used in space network. In RR, the time slot size determines the length of time that each VC occupies the physical channel. Time slot scheduling is managed by physical channel, according to the traffic characteristic of a VC to allocate the same slot [18] to the VC, and chooses in turn each VC occupying the physical channel to transmit data frames, so that the VCs share the physical channel in their assigned time slot, and complete the delivery of the data frames. The delay performance of RR scheduling of data may not satisfy some real-time requirement if it is stringent: when a VC will transmit a real-time data frame but at this moment there is no allocation of the corresponding time slot, then it will have to wait till the next round for the turn of the allocated time slot, which may not violate the delay requirement of the

data frame to be transmitted.

In this paper, according to the basic theory of network calculus, we consider a VC model of the data link layer based on CCSDS AOS and investigate the delay performance of the model.

IV. System Model

Taking the self-similarity characteristic of data flows into consideration, this paper adopts the FBM model with significant self-similarity character as the self-similar traffic model [20,21,22]. For FBM traffic, we can find a stochastic arrival curve of the traffic, which characterizes the traffic under an exceeding probability of the arrival process over the curve. In addition, for a system, a stochastic service curve may be found, which lower-bounds the amount of the service that the system serves.

Based on these two tools, we can establish a model of the CCSDS AOS system and analyze its performance.

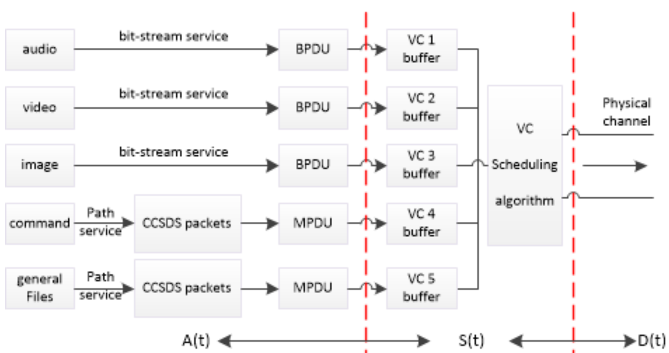


Fig. 2: Source model

The system model is illustrated in Fig.2. Specifically, the data arrived to each VC are stored in the queue, where the data are served in accordance with the first-in-first-out (FIFO) principle. As introduced earlier, A(t) is denoted as the arrival process of the data packet flow to the VC, and describes the amount of data to the virtual channel. A VC scheduling algorithm is used to schedule data for service, which is denoted by a service process S(t), describing the service provided by the VC. The final process of data transmitted through a physical channel is recorded as a departure process D(t), describing the amount of data leaving the VC.

We can abstract the model of Fig.2 into a single node network model shown by Fig.3, and use the structure that multiple data stream inputs share the link output, and the service node adopts a VC scheduling algorithm to serve. In this paper, stochastic network calculus is used to establish the traffic model and the service model and provide performance analysis of the system under different VC scheduling algorithms. Specifically, the investigated scheduling algorithms are FCFS, SP and RR.

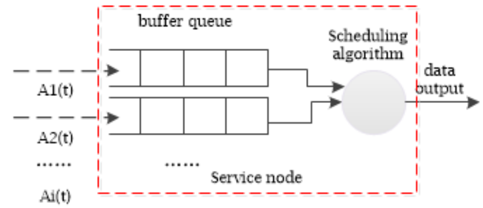


Fig. 3: Single node network model

V. Performance Analysis

A. FBM Self-Similar Model

In order to derive the performance under FBM traffic using stochastic network calculus, we adopt the moment generating function form of FBM [23,24,25].

In particular, the arrival process of FBM is a self-similar process with a stable increment [26,27], which can be written in the form $\mathrm{A}(0,t)$=v_at+σZ$_t$, and has the following properties:

- Z_t is a Fractal Gaussian process [21], continuous everywhere, and has stationary Gaussian increment, that is $Z_t - Z_s \sim Z_{t-s}$;
- For $\forall t \geq 0$, $Z_t = 0$ and $E\left[Z_t\right] = 0$;
- For $\forall t \geq 0, Var\left[Z_t\right] = \left|t\right|^{2H}$;
- The mean value is $E\left[A(0,t)\right] = v_a t$;
- $\forall t \geq 0, Var\left[A(0,t)\right] = \sigma^2 * Var\left[Z_t\right] = \sigma^2 t^{2H}$.

Consider the arrival process A(t): A(0,t)=v_at+σZ$_t$, where $\{\mathrm{A}(0,t) : t \geq 0\}$ is the sum of traffic of FBM within the time t; $v_a > 0$ is the average arrival rate for traffic of VC; $v_a = \lim\limits_{t\to\infty} \mathrm{A}(0,t)/t = \lim\limits_{t\to\infty}(v_a + k\sigma/t^{1-H}) = \inf\limits_{t\geq 1} \mathrm{A}(0,t)/t$; σ is the standard deviation of traffic per unit time, Z$_t$= $\int_0^t (t-s)^{H-0.5}$dB(s) is standard fractal Brownian motion with $H = \frac{1}{2}$ and the mean is zero [13].

We then obtain:

$$\hat{\mathrm{A}}(0,\mathrm{t}) = v_a t + \mathrm{k}\sqrt{\sigma^2 t^{2H}} = v_a t + \mathrm{k}\sigma t^{\mathrm{H}} \tag{10}$$

where k=$\sqrt{-2\ln\varepsilon_c}$, H is Hurst parameter, which represents the emergency degree of the self-similar traffic [14]. $\mathrm{H} \in (0.5, 1)$ means that the self-similar traffic has long-range dependency.

B. Service Model

For different scheduling algorithms, the corresponding service curve, backlog and delay performance provided by the system are derived as follows.

1) Under FCFS scheduling algorithm: The stochastic service curve based on FCFS scheduling algorithm is $S(t)$=$v_s t$, where $v_s = 150Mb/s$ is the service rate of AOS channel. Its form of MGF is expressed as:

$$\overline{M}_S(-\theta,t) = E\left[e^{-\theta^{v_s t}}\right] \tag{11}$$

In addition, for the FBM traffic, its MGF is as:

$$M_A(\theta,t) = Ee^{\theta\left[v_a t + \sqrt{-2\ln\varepsilon_c}\cdot\sigma\cdot t^{\mathrm{H}}\right]} \tag{12}$$

Based on Theorem 1, we can obtain the backlog bound under FCFS as

$$\begin{aligned} b_f &= \inf_{\theta>0}\left[\frac{1}{\theta}\left(\sum_{t=0}^{\infty}\ln \mathrm{E}e^{\theta\left[v_a t - v_s t + \sqrt{-2\ln\varepsilon_c}\cdot\sigma\cdot t^{\mathrm{H}}\right]} - \ln\varepsilon\right)\right] \\ &= \inf_{\theta>0}\left[\sum_{t=0}^{\infty}\mathrm{E}(\mathrm{v_a}t - v_s t + \sqrt{-2\ln\varepsilon_c}\cdot\sigma\cdot t^{\mathrm{H}}) - \frac{\ln\varepsilon}{\theta}\right] \end{aligned} \quad (13)$$

Similarly, a delay bound d_f under FCFS is found.

2) Under SP scheduling algorithm: If SP scheduling algorithm is applied, the service provided by the system is marked with $S(t)$, the service rate is a constant v_s. We consider a SP scheduler with p priority levels. Each VC is assigned a priority p with $0 < p \leq P$, and FIFO is applied in the same queue. Then, a stochastic service curve based on SP scheduling algorithm is:

$$\begin{gathered} S_p(t) = \left[v_s t - \sum_{q=1}^{p-1}\alpha_q(t) - \max_{p+1\leq m\leq n}\{B_m^{\max}\}\right]^+, \\ \varphi^+ = \begin{cases} \varphi, \varphi > 0 \\ 0, \varphi \leq 0 \end{cases} \end{gathered} \quad (14)$$

where $S_p(t)$ is the service curve of traffic with priority for p, $q < p$ means the priority of traffic p higher than traffic q. $\sum_{q=1}^{p-1}\alpha_q(t)$ refers to the sum of arrival traffic of $(p-1)^{th}$ traffic before the tagged traffic p is scheduled for transmission. The MGF of the algorithm follows as:

$$\overline{M}_S(\theta,t)=E\left[e^{-\theta\left[v_s t - \sum_{q=1}^{p-1}\alpha_q(t) - \max_{p+1\leq m\leq n}\{B_m^{\max}\}\right]^+}\right] \quad (15)$$

Based on Theorem 1, we can obtain a backlog bound b_s and a delay bound d_s.

3) Under RR scheduling algorithm: Assume that the size of the time slot is t_{slot}. According to the scheduling principle of RR scheduling algorithm, the ith VC will need to wait $(i-1)t_{slot}$ until being scheduled. A service curve is expressed as:

$$S_j(t) = v_s t - v_s\sum_{i=j}^{N}(i-1)t_{slot}, N= 1,2,....,5 \quad (16)$$

where $t* = (i-1)t_{slot}$, $t_{slot} = L_M/v_s$ shows the size of a time slot, and L_M shows the maximum length of data being stored in a single time slot:

$$S_j(t) = \sum_{i=j}^{N} v_s(t - t*) \quad (17)$$

The MGF of the algorithm follows as:

$$\overline{M}_S(\theta,t)=E\left[e^{-\theta\left[v_s t - \sum_{i=j}^{N}(i-1)L_M\right]}\right] \quad (18)$$

Applying Theorem 1, we can obtain a backlog bound b_r and a stochastic delay bound d_r.

VI. Results

In this section, we investigate the performance of the AOS system where the traffic is FBM. Specifically, with the performance bounds derived from the analysis presented above, we analyze the influence of Hurst parameter, violate probability and different scheduling algorithms on the performance of the system. MATLAB is used to experiment. The involved parameters' values are set as in TABLE I [2,29,30,31]:

TABLE I: Data Parameters In Each VC Setting

data types	v_a(Mb/s)	σ	H	B(bit)	P
audio	25	0.7	0.83	900	1
video	10	1.5	0.93	1500	2
image	39	0.62	0.76	500	3
command	5	0.77	0.78	300	4
general file	36	0.33	0.86	1000	5

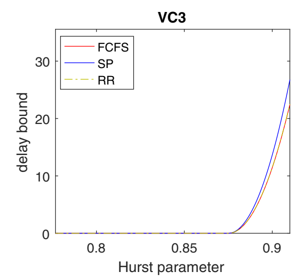
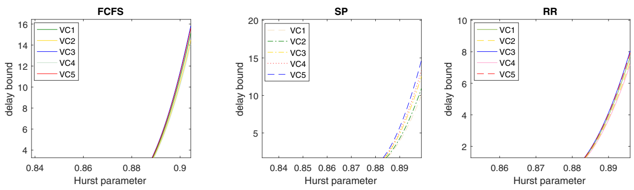


Fig. 4: The variation of Hurst parameter and delay under three kinds of scheduling algorithms

Take VC1 for experiments, $t = 0.4$, $\varepsilon_c = 1e{-}3$, $\varepsilon = 1e{-}6$, and use the parameters given in TABLE I above. Fig.5 shows the relationship graph of Hurst parameter and delay of VC1 under three kinds of VC scheduling algorithms. In the three scheduling algorithms, the delay is small when Hurst is less than 0.87. When Hurst ranges from 0.87 to 0.95, the delay grows sharply with the Hurst value increasing. This is because the self-similarity of the AOS traffic makes the burst enhancement and traffic can arrive with a large probability. The self-similarity of the arriving traffic reduces the delay performance of the channel, which causes the delay performance to degrade. With delay performance analysis, the network load can be selected according to the self-similarity of the traffic, so that the AOS VC scheduling performance can be improved or meet the requirement.

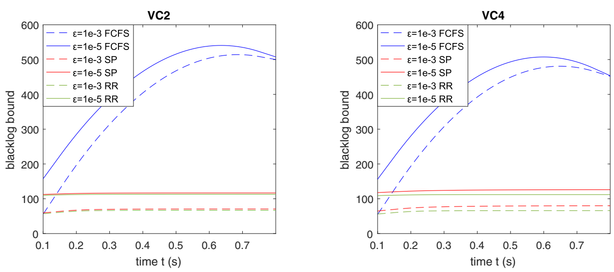
As shown in Fig.5, from the VC1 to the VC5, the delay performance varies with respect to the Hurst parameter values for each of the three VC scheduling algorithms.

In the three sub-figures in Fig.5, the latency increases sharply with the increase of self-similarity, which is due to the over-enhancement of self-similarity that makes the delay performance of the VC reduce. In the sub-figure (a) or (b), the latency performance of the higher VC is better than that of the lower priority VC when the self-similarity is increased. In the sub-figures (a) and (c), the trend of delay variation remains unchanged, since the RR algorithm in this paper does not prioritize the VC.



(a) (b) (c)

Fig. 5: The variation of delay under three kinds of scheduling algorithms



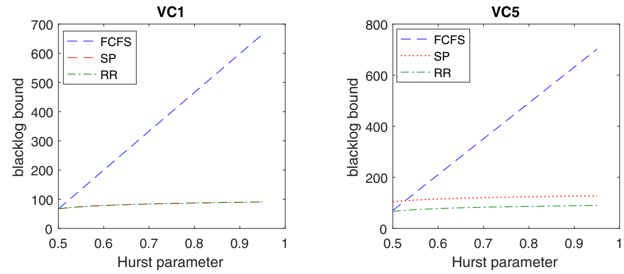
(a) (b)

Fig. 6: The backlog changes in VC2 and VC4

Fig.6 shows results for VC2 and VC4 respectively, and compares the variation of the backlog bound under three different scheduling algorithms (FCFS, RR, SP). Consider time $t = 0.8$, and the violation probability $\varepsilon = 1e-3$ or $\varepsilon = 1e-5$. Figs.6 (a), (b) show the influence of different violation probability on backlog under different scheduling algorithms. Under FCFS scheduling algorithm, when violation probability $\varepsilon = 1e-5$ and $t = 0.6$, the backlog arrives at the maximum; when violation probability $\varepsilon = 1e-3$ and $t = 0.65$, the backlog achieves the maximum value; with the time increasing, the backlog first increases and then decreases. This is because the node service rate is large and the traffic can be timely output.

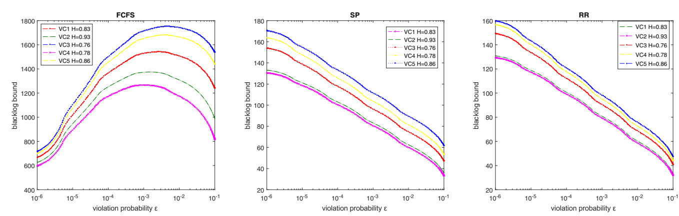
Compared with Fig.6 (a), (b), the time slot is set to $t_{slot} = L_M/v_s$, $L_M = 31.8kb$. In the SP scheduling algorithm, the VC2's priority is higher than the VC4's priority. Obviously, the traffic with higher priority (VC2) has a smaller backlog; the lower priority (VC4) traffic has a larger backlog. However, in the RR scheduling algorithm, the traffic with lower priority has a smaller backlog.

With parameters setting in TABLE I, the shift relationship graphics of self-similarity parameter Hurst and backlog of VC1 and VC5 are shown in Fig.7 (a) and Fig.7 (b). With FCFS scheduling algorithm, with the rise of Hurst, the backlog will rise in a linear manner, whose slope is slightly less than the burst of traffic in the current. With SP and RR scheduling algorithms, the backlog changes slowly. Fig (a) and Fig (b) compare the performance of different VCs. The changing of backlog is obvious in FCFS and SP scheduling algorithms, but in the RR scheduling algorithm, that is nearly invariable. This is because the RR uses the channel in a deprive way: it can allocate the same slot to each VC in the alternate order and the next slot will be scheduled once the current slot is using up, so it is without priority limitation.



(a) (b)

Fig. 7: The backlog changes in VC1 and VC5



(a) (b) (c)

Fig. 8: The backlog changes under different scheduling algorithms

Fig.8 (a), (b) and (c), respectively illustrate the relationship between backlog and violation probability ε in each VC under FCFS, SP, RR scheduling algorithms.

In Fig.8 (a), what we can observe is that when the violation probability ε changes from 1e-6 to 1e-1, the backlog rises first and then declines sharply. As shown in Fig.8 (b) and (c), when the violation probability varies from 1e-6 to1e-1, the backlog tends to linearly decline, that is to say the violation probability is the decreasing function of backlog. From the figure, we can know that the backlog in RR scheduling algorithm is better than that in FCFS and SP scheduling algorithm. When the violation probability is the same, the backlog of high priority traffic will be less than the backlog of traffic with low priority. That is because priority level is added into VC and then distinguishes one VC from another by using SP algorithm rule.

Through analysis of the above results, the model we used in this paper is able to reflect impact of the self-similarity characteristic of traffic on the system performance (such as shown in Figures 4, 5, 7).

VII. Conclusion

In this paper, we briefly reviewed the basic knowledge of stochastic network calculus, combining stochastic network calculus, self-similarity, and moment generating function, by using the self-similar traffic model. We also analyzed how it influences the system performance when the VC adopts different scheduling algorithms. The results showed that under the self-similar traffic model, Round-Robin scheduling algorithm makes the physical channel with higher utilization. VC multiplexing mechanism is the core of the CCSDS AOS two-level multiplexing mechanism, its performance can directly impact the transmission capacity of the traffic of CCSDS AOS. This article applied stochastic network calculus to analyze QoS (Quality of Service) performance, and it can provide theoretical support for building future space data systems. What is more, it provides a value for high quality and high reliable satellite network where service quality and QoS performance evaluation are desired.

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