Queue scheduling mechanism of integrative intelligent network based on information age

Jiangshan Zheng¹,², Li Yang³*, Chengsheng Pan⁴ and Huafeng Shi⁴

¹ School of Information Engineering, Dalian University, Dalian 116622, China
² Communication and Network Laboratory, Dalian University, Dalian 116622, China
³ School of Automation, Nanjing University of Science & Technology, Nanjing 210014, China
⁴ School of Electronics and Information Engineering, Nanjing University of Information Science & Technology, Nanjing 211800, China

*Corresponding author’s e-mail: yangli945@njust.edu.cn

Abstract. Aiming at the problems of deterministic transmission of delay-sensitive service flows and mixed transmission of different service flows in the integrative intelligent network, which can easily lead to network congestion collapse and excessive delay, a scheduling mechanism named SATAS based on information age is proposed. The service flows in the intelligent network aggregation node are classified into delay-sensitive and other types of service flows. Based on the idea of time division multiplexing, the service flow in the buffer queue is scheduled according to the gated list. Further, combined with the age of information, based on the multi-objective optimization decision-making theory, and according to the actual requirements of scheduling in the intelligent network, a suitable gate control list is obtained, thereby realizing the scheduling of business flows in the intelligent network. Finally, a simulation verification system is built to schedule different types of business flows. The simulation results show that the SATAS mechanism ensures the deterministic transmission of delay-sensitive service flows, while ensuring the mixed transmission of different service flows, reducing the queuing delay and frame loss rate.

1. Introduction

The integrative intelligent network is based on the ground network and extended by the space network, covering natural spaces such as space, air, land and ocean, and providing information guarantee for the activities of space-based, air-based, land-based and sea-based users Infrastructure [1].

The integrative intelligent network is the same as the integrative network, and its service flow has the characteristics of diversity and high speed. The diversity of business flows causes the network to guarantee different quality of services (QoS) [2] for different business flows. The high rate of service flow puts forward higher requirements on the scheduling capability of the network, otherwise it will cause problems such as congestion collapse and excessive end-to-end delay. As for seismic data and operational command data, business flows that require extremely high latency must be guaranteed on time and accuracy.

Therefore, it is urgent to implement a suitable queue scheduling algorithm in the integrative intelligent network, combining the diversity and high-rate characteristics of service flows, to ensure the
deterministic transmission of delay-sensitive service flows and the mixed transmission of different service flows.

2. Related work
Queue scheduling means that the sink node selects the next forwarded packet from the queue according to a certain rule, so that all input streams can share the output link bandwidth in a predetermined manner, occupy corresponding network resources, and meet their own required quality of service.

Currently, among the existing queue scheduling algorithms, there are the following algorithms that consider the mixed transmission of different service streams. Literature [3] proposes an adaptive fair dynamic resource scheduling algorithm (TWFS) based on the secondary structure model of service differentiation and QoS guarantee, so as to ensure the fairness, adaptability and quality of service of business flow during scheduling. Literature [4] introduced the token bucket mechanism based on the static priority scheduling algorithm (SP) [5] and the weighted round robin scheduling algorithm (WRR) [6], which improved the adaptability of the scheduling strategy to the network, while ensuring different QoS requirements for different business scheduling. Literature [7] designed a global dynamic weight polling algorithm (GDWRR), which dynamically adjusts the service threshold of each queue according to the current queue status to meet the QoS requirements of different service flows.

In addition, in order to solve the problem that delay-sensitive business flows require efficient and accurate scheduling, Time Sensitive Networking (TSN) [8] and Deterministic Networking (DetNet) [9] came into being. Literature [10] proposed a scheduling strategy based on Time Triggered Ethernet (TTE). Reduce business flow conflicts and dispatch multiple conflict-free business flows at the same time to meet the needs of high real-time applications. Literature [11] based on the time-aware shaping mechanism (TAS) [12], proposed a static scheduling algorithm (SSMT) based on the Satisfiability Modulo Theories. Determine the key function parameters in the TSN network and create constraints for offline scheduling based on the generalized configuration of these parameters to ensure the end-to-end delay of the deterministic service flow. Literature [13] proposed a comprehensive scheduling method based on TSN (SSTSN) by solving the problem of gated list calculation in TAS mechanism. Using the first-order array theory, the system constraints are formalized, and the SMT/OMT-based solver is used to solve the calculation, thereby ensuring the deterministic transmission of delay-sensitive business flows. Because some of these algorithms only consider the mixed transmission of different flows, and some only consider the deterministic transmission of delay-sensitive service flows, and do not combine the two. This is not conducive to solving the problems of Internet congestion collapse and excessive delay due to the rapid increase in business flow.

3. SATAS scheduling mechanism
The basic idea of the SATAS scheduling mechanism proposed in this paper is to consider the deterministic transmission of delay-sensitive service flows and the mixed transmission requirements of different service flows in view of the diversity and high rate characteristics of service flows in the integrative intelligent network, and establish a multi-objective decision-making model, calculate the weights of different service flows in the cost function according to different parameters of the service flow, determine the objective function and constraint conditions, and solve the gated list, thereby controlling the service flow transmission and scheduling via the SP scheduling algorithm.

3.1. Questions raised
The flow in the integrative intelligent network is characterized by diversity. All business flows are classified into delay-sensitive business flows and other business flows based on their QoS. The priority of all delay-sensitive service flows is n, where n is the number of queues in the buffer. Based on the idea of time division multiplexing, different delay-sensitive service flows enter the buffer queue class n in different time slots. Other types of service flows enter class 1~n-1 in turn, and according to their QoS, the priority of these types of service flows is 1~n-1.
On the basis of time division multiplexing, the service flow forwarding of each queue in the buffer queue is controlled by a transmission gate. When the transmission gate is opened, that is when the state is $1$, the service flow of the current queue can be forwarded. When the gate is closed, that is when the status is $0$, the service flow of the current queue cannot be forwarded. Combine all the transmission gate states at different times to form a gated list. In order to prevent the service stream from receiving interference from other service streams during transmission, when the transmission gate status is switched, only the transmitting queue is allowed to transmit the service stream within a certain time range. The service flow in the queue with the transmission gate opened will be scheduled by the SP scheduling algorithm, and the service flow with the higher priority will be forwarded first. The transmission process is shown in Figure 1.

![Gated list](image)

**Figure 1 SATAS logic diagram**

This article will conduct research on how to generate GCL based on the age of information.

### 3.2. Problem conversion

Assume that there are $n$ queues in the sink node, and the service flow in queue $i$ ($0 < i < n$) is waiting for scheduling. Time is divided according to equal time slices. It is assumed that the time when queue $i$ schedules and sends a service flow to the output port is a time slice. The probability of successful service flow scheduling in each queue is $p$.

AoI\(^{14}\) refers to the time elapsed since the last successful update of information. It can measure the "freshness" of the information received by a receiving node. At any time $t$, $U(t)$ is used to represent the sending time of the last successful packet received by the receiving node, and the information age $\Delta(t)$ is:

$$\Delta(t) = t - U(t)$$  \hspace{1cm} (1)

The cost function of a single AoI link is:

$$\overline{\Delta} = \lim_{T \to \infty} \frac{1}{T} \int_0^T \Delta(t) \, dt = \lim_{T \to \infty} \frac{1}{T} \sum_0^T \Delta(t)$$  \hspace{1cm} (2)

The smaller the value of $\overline{\Delta}$, the better the "freshness" of the link information, and the faster the link update frequency, that is, the current link transmits service flow. The average AoI of multiple links is the weighted sum of the average AoI of all links. Therefore, the problem to be studied in this paper is transformed from how to generate GCL to a multi-objective decision-making problem, that is, to find a scheduling algorithm whose cost function is the smallest under certain constraints.
In this article, AoI is the elapsed time since the last successful scheduling of the service flow by the sink node, and is used to measure the "freshness" of the service flow scheduled by the sink node. Since the service flow is sent once per time slice, at time $t$, if the service flow in queue $i$ is successfully scheduled, the information age of the queue at the next time is 1. Otherwise the information age at the next moment needs to be added to the information age at the current moment by 1. That is, at time $t+1$, the AoI update equation of queue $i$ is as follows:

$$\Delta_i(t+1) = \begin{cases} 1, & \text{Service stream transmission succeed} \\ \Delta_i(t) + 1, & \text{Service stream transmission failed} \end{cases}$$

Among them, when $t=0$, $\Delta(t) = 0$.

Compared with other types of service flows, delay-sensitive service flows have higher requirements for delay. Therefore, when calculating the cost function of multiple queue scheduling service flows in the convergence node of the integrative intelligent network, the weights of the AoI values of the two types of service flow queues should be separately considered. However, other types of service flows have no obvious distinction between QoS requirements, and at the same time, the service flows that GCL controls and selects for transmission will be scheduled again through the transmission selection algorithm. The scheduling algorithm here in this article selects the SP algorithm, which will strictly follow the priority of the queue during scheduling. Therefore, the weights of the AoI values for scheduling other types of service flow queues are not specially considered, and they are all $\frac{1}{n-1}$.

Therefore, the cost function $\sigma$ under any strategy $\pi_\sigma$ scheduling is:

$$\pi_\sigma \triangleq \limsup_{T \to \infty} \frac{1}{T} \left[ \alpha \sum_{t=1}^{n-1} g_i(t) \Delta_i(t) + \beta \frac{1}{n-1} E \left[ \sum_{t=1}^{n} \sum_{t=1}^{T} g_i(t) \Delta_i(t) \right] \right]$$

Among them, $n$ is the number of queues, $T$ is the time $t$ tends to $\infty$, $\alpha$ is the weight of the AoI value of scheduling delay-sensitive service flow queues, and $\beta$ is the weight of the AoI value of scheduling other service flow queues, $g_i(t)$ is the gate value in the gate control list corresponding to queue $i$ at time $t$, namely:

$$g_i(t) = \begin{cases} 0, & \text{Transmission gate closes} \\ 1, & \text{Transmission gate opens} \end{cases}$$

3.3. Weight calculation

For the selection of the weights $\alpha$ and $\beta$ corresponding to the AoI values of two different service flow queues in the cost function $\pi_\sigma$ under any strategy $\sigma$ scheduling, this article first uses the entropy method to weight the different parameters of the queues, and then the obtained weighted value is normalized to determine the two weighted values.

Suppose the priority of queue $i$ is $a_i$, the queue length at the current moment is $b_i$, the buffer length is $c_i$, and the probability of successful service flow scheduling in the queue is $p_i$.

Delay-sensitive service flows have higher requirements for delay than other types of service flows. The priority of this type of service flow is the highest, and the corresponding $a_i$ value is the largest; other types of service flows have different priorities according to their different requirements for QoS. The higher the priority, the larger the corresponding $a_i$ value. The lower the priority, the smaller the corresponding $a_i$ value.

If the queue length $b_i$ at the current moment is greater than the buffer length $c_i$ of the queue, the service flow in the queue will overflow and the frame will be lost, which will affect the "accuracy"
requirement in the service flow scheduling process. Therefore, this article will limit the queue length $b_i$ at any time to be less than or equal to the buffer length $c_i$ where the queue is located.

Since the queue length has been restricted to be less than the buffer length, the scheduling failure caused by queue congestion and frame loss can be ignored. Therefore, the probability $p_i$ of the successful scheduling of the service flow in the queue is related to the gated list value $g_i$ and the priority $a_i$ of the queue. which is:

$$P\left( (g_i(t) = 1) \cap (\max a_i(t)) \right) = p_i$$

(6)

According to equation (3), we can know:

$$\begin{align*}
P(\Delta_i(t) \rightarrow 1) &= p_i \\
P(\Delta_i(t) \rightarrow \Delta_i(t) + 1) &= 1 - p_i
\end{align*}$$

(7)

From the above analysis, it can be seen that the three parameters of queue priority, queue length at the current moment, and the probability of successful service flow scheduling are all positive parameters. That is, the higher the value of the three different parameters, the more priority the service flow of the corresponding queue is scheduled. Since these three parameters are three different attributes of the queue, the three parameters should be dimensionless before weighting. The dimensionless can eliminate the influence of different magnitudes between the parameters. The dimensionless equation is:

$$\overline{x_{ij}} = x_{ij} / \sum_{i=1}^{n} x_{ij}$$

(8)

Where $x_{ij}$ is the $j$-th parameter in the $i$-th queue, $0 < i < n$, $0 < j \leq 3$, and $n$ is the number of queues. $x_{i1} = a_i$, indicates the priority of the service flow. $x_{i2} = b_i$, indicates the length of the queue where the service flow is located. $x_{i3} = p_i$, indicates the probability of successful service flow scheduling. After dimensionless, $\overline{x_{ij}} \in [0,1]$ is obtained.

Three different parameters after the queue dimensionless are weighted: $\overline{a_i}$, $\overline{b_i}$, $\overline{p_i}$. The weighting equation is:

$$s_i = \sum_{j=1}^{3} \lambda_j \cdot \overline{x_{ij}}$$

(9)

Where $s_i$ is the weighted value obtained after weighting the three parameters, and $\lambda_j$ is the weight of the corresponding parameter, which will be calculated by the entropy method.

For each parameter after dimensionless, calculate its entropy $e_j$:

$$e_j = -K \sum_{i=1}^{n} \overline{x_{ij}} \ln \overline{x_{ij}}$$

(10)

Among them, $K = \max \left[ \sum_{i=1}^{n} \overline{x_{ij}} \ln \overline{x_{ij}} \right]$, $K > 0$, $e_i > 0$, $\overline{x_{ij}}$ represent the dimensionless value of the $j$-th parameter of the $i$-th queue.

Calculate the difference coefficient $d_j$ by equation (11):

$$d_j = 1 - e_j$$

(11)

Finally, the difference coefficient is normalized to obtain the weight:
4. Solve

After calculating the weights corresponding to the AoI values of the scheduling delay-sensitive service flows and other service flow queues, they are substituted into equation (4). Under certain constraints, when the cost function in equation (4) is the smallest, the list of \( g_i \) values corresponding to different time slots is the gated list corresponding to the optimal scheduling strategy under the constraint, and the scheduling strategy is the optimal scheduling strategy. Multi-objective decision-making problems can be solved by using dynamic programming [15] and other methods to obtain the optimal scheduling strategy.

The constraints are as follows:

\[ g_i \in \{0,1\} \]  
\[ 0 \leq \sum_{i=1}^{n} g_i < n-1 \]  
\[ 0 \leq b_i \leq c_i \]  

Among them, equation (15) constrains the gate value \( g_i \) to be 0 or 1. When \( g_i = 0 \), it means that the transmission gate is closed and the current service flow cannot be transmitted. When \( g_i = 1 \), it means that the transmission gate is in the open state. After the current service flow is scheduled by the transmission gate, it will be dispatched by the SP scheduling algorithm together with other service flows that also pass the transmission gate. \( g_i \) cannot take other values. Equation (16) restricts the number of gate openings for each transmission through the gate value. Since the transmission gate is opened, the value of \( g_i \) is 1, so the sum of the \( g_i \) values of all queues at any time is the number of transmission gates opened. Since the number of transmission gates is the same as the number of queues, there are \( n \) in total. If \( \sum_{i=1}^{n} g_i = n \), that is, all the transmission gates are opened, and all service flows are uniformly scheduled through the transmission gates through the SP scheduling algorithm, and the transmission gate control mechanism does not take effect. However, the various calculation processes in the process still exist, which will cause the scheduling mechanism to not obtain the advantages of the method but increase the complexity and cause serious waste of resources. If \( \sum_{i=1}^{n} g_i = 0 \), that is, all the transmission gates are closed, all service flows will not be scheduled, which can easily lead to queue congestion. If it does so for a long time, it may even cause frame loss. Equation (17) constrains that the length of the queue where the service flow is located must be less than or equal to the length of the buffer. If the
queue length is greater than the buffer length, frames larger than the buffer length will be lost, and the accuracy of scheduling cannot be guaranteed.

Sorting out equation (4), equation (15), equation (16) and equation (16), that is, the multi-objective decision-making problem is:

\[
\min \pi^\sigma \triangleq \lim_{T \to \infty} \sup_{t} \frac{1}{T} \left[ \alpha \sum_{i=1}^{T} g_n(t) \Delta_n(t) + \beta \frac{1}{n-1} E \left[ \sum_{i=1}^{T} \sum_{j=1}^{g_i} g_j(t) \Delta_j(t) \right] \right]
\]

\[
\begin{align*}
g_i & \in (0,1) \\
0 & < \sum_{i=1}^{n} g_i < n-1 \\
0 & \leq b_i \leq c_i
\end{align*}
\]

The specific process of the scheduling mechanism in this article is as follows:

Step1: The sink node receives delay-sensitive service flows and other service flows sent by other nodes, and prepares for scheduling.

Step2: All delay-sensitive service flows enter the queue based on the time-division multiplexing theory according to different scheduling time slots.

Step3: Other types of traffic still enter queues with different priorities after QoS classifies their priorities.

Step4: Obtain the information age of all queues and the priority of the business flow in the queue, scheduling success rate and queue length.

Step5: When the transmission gates are not all opened and not all closed, and the queue length is less than or equal to the buffer length, when the delay-sensitive business flow and other business flows weight the information age AoI value with the smallest cost function, the corresponding difference the list of time gating values is the gating list.

Step6: The transmission gate of the queue where the service flow is located is opened or closed according to the gate control list, corresponding to the service flow scheduling.

Step7: All service flows scheduled by the transmission gate are scheduled via the SP scheduling algorithm, and the scheduling is completed.

4. Simulation results and performance analysis

4.1. Simulation parameter setting

The simulation verification in this paper is based on the integrative intelligent network, and the network topology is constructed in NS2 simulation software. The network topology diagram is shown in Figure 2.
In Figure 2, A, B, and C are the three satellite source nodes in the integrative intelligent network, respectively, which transmit delay-sensitive service streams and other service streams to satellite node D. For the convenience of simulation, source node A sends the service stream as a VoIP call stream, which requires high delay. The source node B sends a service stream as a video stream, which has a lower latency requirement compared to a VoIP call stream. The source node C sends a service stream as a file transfer service stream, and this type of service stream has no obvious requirements for latency. Its priority is the lowest. For the three satellite source nodes, the specific parameter settings are shown in Table 1. Satellite node D is the sink node. After receiving the service flows from source nodes A, B, and C, the scheduling mechanism is designed according to this article, and the appropriate service flow is selected for scheduling and transmitted to satellite node E. Its service rate is 10Mbit/s. The satellite node E is the destination node.

Table 1 Source node parameter settings

| Source node | Business type   | Business flow               | Priority | Send rate  | Time interval |
|-------------|-----------------|-----------------------------|----------|------------|---------------|
| A           | delay sensitive | VoIP call streaming         | 3        | 4.7Mbit/s  | 20ms          |
| B           | others          | Video streaming             | 2        | 3.5Mbit/s  | 30ms          |
| C           | others          | file transfer streaming     | 1        | 2.3Mbit/s  | None          |
4.2. Simulation results and analysis
In order to reflect the advantages of the queue scheduling mechanism in this article, the SAAS mechanism proposed in this article is compared with the SSMT mechanism and SSTSN mechanism, and the performance of the queue delay and frame loss rate is analysed and compared.

4.2.1. Simulation and analysis of time delay
Time delay refers to the time required for the service flow to be transmitted from one satellite node to another satellite node, which generally includes transmission delay, queuing delay, processing delay and propagation delay. For queue scheduling algorithms, queuing delay has a greater impact on whether the queue will be congested, so this paper selects queuing delay as a performance indicator for analysis. The average queuing delay simulation results of the three scheduling mechanisms are shown in Figure 3.
As can be seen from the figure above, compared with the SSMT mechanism and the SSTSN mechanism, the average queuing delay of the service flows in the three queues is the lowest in this mechanism. For delay-sensitive service flows, the average queuing delay of this mechanism is reduced by 7.46% compared to the SSMT mechanism, and 6.49% lower than the SSTSN mechanism. This is mainly because this article is based on the time-sensitive network, introduces the information age, and confirms the gate control value of each queue through the information age, so as to decide whether to schedule the current service flow. At the same time, the subsequent SP scheduling algorithm of the gated control list will schedule limited delay-sensitive service flows with higher priority, reducing the queuing delay of such service flows. For other types of traffic, the average queuing delay of the mechanism in this paper is 2.61% lower than that of the SSMT mechanism, and 3.73% lower than the SSTSN mechanism. This is mainly because this article cites the idea of time division multiplexing, which maximizes the use of all time slots, so as to schedule as many service streams as possible and reduce resource waste.

4.2.2. Simulation and analysis of frame loss rate performance
The frame loss rate refers to the ratio of lost frames to the total number of transmissions when the service stream is transmitted from one satellite node to another. To ensure the accuracy of service flow scheduling, the frame loss rate should be reduced as much as possible. The simulation results of the frame loss rate of the three scheduling mechanisms are shown in Figure 4.
Frame drop rate curve

(a) Queue 1 frame loss rate

(b) Queue 2 frame loss rate
It can be seen from Figure 4 that compared with the SSMT mechanism and the SSTSN mechanism, the frame loss rate of this mechanism decreases with the increase of the buffer length, but in general, the frame loss rate of the mechanism is lower than that of the SSMT mechanism and SSTSN mechanism. For delay-sensitive service flows, this mechanism is 17.98% lower than SSMT mechanism and 21.69% lower than SSTSN mechanism. For other types of service flows, this mechanism is 11.82% lower than SSMT mechanism and 16.08% lower than SSTSN mechanism. This is mainly because when the information age is introduced in this article to determine the gate value, the weight determination parameters of different types of service flows include the queue length, and at the same time restricts the queue length to be less than or equal to the buffer length, which is useful for reducing the frame loss of service flows rate plays a very important role. The reduction of the frame loss rate ensures the accuracy requirements of service flow scheduling.

5. Conclusion
Based on the integrative intelligent network architecture, in order to ensure the mixed transmission of different service streams and the deterministic transmission of delay-sensitive service streams, the SAAS mechanism is proposed. This mechanism is based on the theory of time division multiplexing and controls the scheduling of service flows according to the gated list. Combined with the age of information, the entropy method is used to determine the weights of different types of service flows, and the gated list is determined according to the multi-objective optimization decision model, so as to determine the appropriate service flow to be scheduled via the SP scheduling algorithm. The simulation verification is carried out in this paper. The simulation results show that compared with other mechanisms, the queuing delay and frame loss rate during scheduling are reduced to a certain extent in this mechanism, which alleviates the problem of excessive congestion collapse and excessive delay in intelligent networks. Therefore, this mechanism guarantees the deterministic transmission of mixed transmission of different service flows and delay-sensitive service flows in the convergence node of the integrative intelligent network.
Acknowledgments
This work is supported by the National Natural Science Foundation of China under Grants 61722105, 61931004.

References
[1] SUN C H. Research Status and Problems for Space-based Transmission Network and Space-ground Integrated Information Network [J]. Radio Engineering, 2017,047(001):1-6.
[2] YANG L, SUN J, PAN C S. LEO multi-service routing algorithm based on multi-objective decision making[J].Journal on Communications, 2016,37(10):25-32.
[3] YANG L, WU Q L. Self-adaptive fair scheduling algorithm in wireless network[J].Journal on Communications,2012,33(001):102-106.
[4] ZHANG C F, QIAN X R. A new queuing scheduling algorithm for multi-service network[J].Microcomputer & Its Applications,2015, 000(019):24-26.
[5] GONG S L, WANG C, FENG Y G. Substation LAN communication queue scheduling strategy based on improved weighted fair queue [J]. Automation of Electric Power Systems, 2015,39(04):76-81.
[6] SHREEDHAR M, VARGHESE G. Efficient fair queuing using deficit round robin[J]. IEEE/ACM Transactions on Networking, 1996, 4(3):375-385.
[7] QIAN P F, QIAO L F, CHEN Q H. Design and Implementation of Queue Scheduler for Large-Capacity Switch Fabric That Can Provide QoS[J].Communications Technology,2018, v.51;No.323(11):133-139.
[8] CAO Z P, LIU Q R, LIU D P. Survey of time-sensitive networking[J/OL]. Application Research of Computers:1-10[2021-02-16].https://doi.org/10.19734/j.issn.1001-3695.2020.02.0026.
[9] HUANG T, WANG S, HUANG Y D. Survey of the deterministic network[J]. Journal on Communications,2019,40(06):160-176.
[10] LI J L, ZHANG W, LIU Q A. A Large-Scale Time-Triggered Deterministic Network[J]. Journal of University of Electronic Science and Technology of China,2019,48(06):815-822.
[11] Silviu S. Craciunas,Ramon Serna Oliver,Martin Chmelik, Wilfried Steiner. Scheduling Real-Time Communication in IEEE 802.1Qbv Time Sensitive Networks[P]. Real-Time Networks and Systems,2016.
[12] IEEE 802. 1Qbv-2015. Standard for Local and metropolitan area networks-Bridges and Bridged Networks-Amendment 25: Enhancements for Scheduled Traffic [S]. Piscataway, NJ: IEEE Press, 2016.
[13] Oliver R S , Craciunas S S , Steiner W . IEEE 802.1Qbv Gate Control List Synthesis using Array Theory Encoding[C]// IEEE Real-Time and Embedded Technology and Applications Symposium (RTAS). IEEE, 2018.
[14] Kauls, Yatesr, Gruteser M. Real-time status: how often should one update? [C]//2012 Proceedings IEEE INFOCOM. Orlando: IEEE, 2012. DOI: 10.1109/INFCOM.2012.6195689.
[15] Kinsky M A, Cho M H, Shim K S, et al. Optimal and heuristic application-aware oblivious routing[J]. IEEE Transactions on Computers, 2013, 62(1): 59-73.