Research on Improved Earliest Deadline First Scheduling Strategy of Networked Control System

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Abstract: How to design an effective scheduling strategy to improve the performance of tasks in a networked control system, optimize the quality of data transmission and improve the adaptability of tasks with dynamic attributes is of great significance. Considering that the overall performance of networked control system is closely related to the time attribute of transmission task and channel environment, this paper improves the classic earliest deadline first strategy. Starting from the schedulable condition, the dynamic time interval of the task is precisely processed, and the distribution function of the schedulable condition is obtained by using the distribution function of each attribute, and the precise value of the schedulable variable that meets the requirements is determined, so as to obtain the accurate execution time and cycle value of the task attribute. The simulation experiment is carried out on the True Time platform. In the simulation, the scheduling effect of three loops networked control system is compared in ideal environment, with different packet loss rate and interference rate, and in the case of execution time and cycle change dynamically. The results show that the proposed improved earliest deadline first scheduling strategy overcomes the shortcomings of the standard earliest deadline first scheduling strategy, which leads to the degradation of system performance. It improves the output quality of the system, and improves the adaptability of the system to packet loss and interference factors.

Keywords: networked control system, scheduling, earliest deadline first, packet loss, interference.

1. Introduction

1.1 Research background

With the rapid development of communication means and computer related technology, network technology has been increasingly penetrated and popularized, and its application scope is very wide and has a great influence. Traditional control technology, such as distributed control or centralized control, is difficult to meet the requirements of social development and system control. With the increasing complexity of control technology, the guarantee of control effectiveness has become an inevitable factor in the introduction of a control system into network application. Networked control system (NCS) is through the introduction of information network, so that a large number of control laws can directly act on the controller object through the communication network, and can quickly feedback back to the control center through the network, to achieve the goal of data exchange and control accurate and timely (Gautam et al., 2021; Wang et al., 2016). The basic structure of NCS is shown in Fig. 1, which has the advantages of high reliability, good flexibility, low cost and distributed processing (Ferrari et al., 2021). In recent years, NCS has been developed unprecedentedly, and has been developed rapidly and widely used in many fields.

In NCS, the system performance not only depends on the choice of control strategy, but also has a close relationship with the allocation of resources in the network, that is, scheduling strategy plays an important role in performance control (Tian et al., 2018). Compared with the point-to-point direct communication between the device nodes in the traditional control system, data transmission in the shared network is the most important difference between the NCS and the traditional control system. The significance of studying the scheduling strategy of NCS is to optimize the network information transmission, solve the congestion and conflict in the control process, and try to achieve a satisfactory level of overall performance, so as to reduce the network delay, increase the manageability and predictability of the system, and improve the overall operation stability. In this paper, the scheduling strategy in NCS is studied.

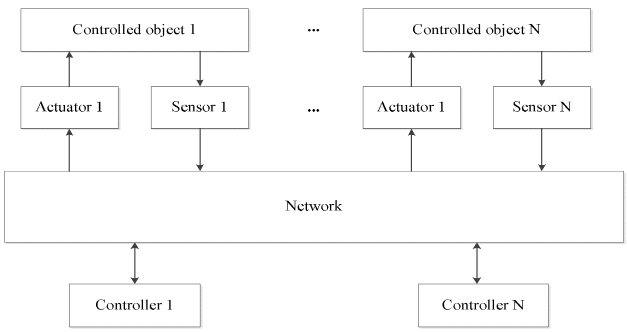


Figure 1. The basic structure of NCS

1.2 Literature review

In recent years, many scholars have carried out corresponding research on the scheduling problem of NCS, and achieved some results. The most classic scheduling strategy of NCS is static scheduling strategy. The static scheduling strategy allocates resources before the whole system is executed. The bandwidth and priority of each network node are set in advance according to the time constraints and time characteristics of information. During the operation, it is implemented in accordance with the above requirements without any deviation in scheduling. When the time interval of the system is constant, the stability can be guaranteed. In the implementation problem, we can use token mode, polling or other methods. Static scheduling strategy is based on a certain system model, and its fairness can be guaranteed, so it is widely used in real-time systems. Among the static scheduling algorithms, the typical ones are rate monotonic (RM) algorithm (Gao et al., 2012), fix priority (FP) algorithm (Kim et al., 2014), and so on. But there are many shortcomings in static scheduling strategy. (a) The scheduling efficiency of aperiodic information is not high. Static scheduling simply regards all information as periodic tasks, and defines the period of aperiodic information with the minimum arrival time interval. Therefore, the static scheduling strategy has some idealism. (b) Lack of adaptability to change. The addition and deletion of nodes become more complex, and if the key nodes leave the system by mistake, the operation of the whole system must be stopped, resulting in the lack of universal adaptability and flexibility of the system. (c) The utilization rate of resources is low. Static scheduling strategy determines various characteristics and parameters of the system in advance, so it is necessary to consider the worst case in resource allocation, so as to set the running cycle of the system, which will inevitably lead to the waste of system resources in different degrees and the situation of invalid allocation.

Due to the deficiency of static scheduling strategy, dynamic scheduling strategy has been widely used. Considering the information characteristic of time-varying in the network channel, the dynamic scheduling strategy is based on the actual demand and resource allocation, and constantly adjusts the bandwidth proportion or priority order between nodes. Compared with the static scheduling strategy, which needs to be set before execution and cannot be changed after execution, its most obvious advantage is that it has good adaptability to system changes, and can make more full use of channel resources. Typical dynamic scheduling algorithms include earliest deadline first (EDF) algorithm (Kalaivani and Kalaiarasi, 2019), maximum error first try once discard (MEF-TOD) algorithm (Zhou et al., 2019), etc.

In recent years, many scholars have proposed some new scheduling algorithms and strategies for NCS based on dynamic scheduling strategy. In the study, in order to improve the performance of the NCS, a deadband feedback-based scheduling approach for the NCS with a variable sampling period is proposed. A NCS with five control loops is used as the simulation object and carried out by True Time toolbox. The simulation results show that the proposed scheduling approach can improve output control performance of the system, reduce integral absolute error value of the control loops, and improve network utilization (Tian 2021). The authors proposed a modified media allocating model of multifunction vehicle bus for the train NCS. Under the premise of ensuring the stability of the control system, and taking into account the impact of transmission jitter on the dynamic performance of the closed-loop control, their proposed collaborative design strategy can minimize the network resource occupancy rate of the subsystem. The numerical simulation and experimental tests illustrate the effectiveness of the strategy (Yan et al., 2021). In their study (Zhao and Ji, 2021), a novel model-dependent scheduling scheme is proposed for the networked control systems with time-delay, disturbance, and medium access constraints. The designed scheduler calculates the error between the ideal dynamic and the real system, and selects the states that make the stability of the system better to access the network. The illustrative examples are given to demonstrate the affectivity of the proposed scheduling method and the co-design scheme. By using a gain scheduler within the packet-based control framework and fitting the delay-dependent gains into a time-delay system model, a less conservative self-triggered approach is proposed to determine the sampling update, which consequently enables the design of two network scheduling algorithms to reduce the communication usage. The simulation results show the proposed approach reduces greatly the communication usage while maintaining satisfactory control performance (Zhao et al., 2021). In their study (Fan et al., 2020), a dual-way scheduling algorithm is finally proposed for distributed NCSs with different types of transmitted data packets. Experiments are conducted on a remote teaching platform to verify the effectiveness of the proposed dual-way scheduling mechanism. Results demonstrate that, with the stability time-delay bound considered within the scheduling process, the proposed mechanism is effective for NCS time-delay reductions while addressing the stability, control accuracy, and settling time issues efficiently. In their study (Kundu and Quevedo, 2020), a scheduling method under which global asymptotic stability of each plant in the NCS is proposed. The simulation results verify the feasibility of the proposed scheduling strategy. In the literature (Yan et al., 2020), a dynamic bandwidth resource allocation model of the overall control system for optimal performance is proposed. A simple example is included to illustrate the performance of proposed scheme. The authors extend the notion of try-once-discard. The numerical simulations are performed for variety of system parameters and NCS set-ups to strengthen our stability claim as well as illustrating performance bounds (Mamduhi and Hirche, 2019).

From the above research results, the scheduling strategy of NCS has made some progress. However, many scheduling strategies are too complex, although they can achieve good performance in simulations; the complexity of the algorithm greatly limits the application of these scheduling strategies in practice. Furthermore, these scheduling strategies have many assumptions for network data transmission and controlled objects. If these conditions are not met, the scheduling effect will be greatly reduced. As the most classic dynamic scheduling algorithm, EDF has many advantages. The most important thing is that EDF is the dynamic optimal scheduling strategy. When the dynamic scheduling algorithm is feasible, EDF scheduling must be satisfied, and theoretically, the network utilization can reach 100%. Therefore, it is more important to improve the classical EDF scheduling strategy for its practical application.

1.3 Main contributions

Considering that the overall performance of NCS is closely related to the time attribute of transmission task and channel environment. This paper improves the classic EDF strategy. The main innovations are as follows.

1. Based on the schedulable condition, the dynamic time interval of the task is processed accurately, and the distribution function of the schedulable condition is obtained by using the distribution function of each attribute.

2. According to the two rules of possibility and necessity, the precise value of schedulable variable is determined, and the exact execution time and cycle value of task attribute are obtained.

3. In the simulation, the task transmission performance under different packet loss rate and interference rate is verified. The simulation results are closer to the actual situation.

The rest of this paper is organized as following. Section 2 designs improved EDF scheduling strategy. The simulation results are given in Section 3. The conclusions and future work are presented in Section 4.

2 Improved EDF scheduling strategy

In the actual implementation of NCS, there are many influencing factors, such as delay, packet loss, preemption and so on, which will seriously affect the stability of the system. In the theoretical task transmission, the traditional scheduling algorithm is based on the ideal conditions, such as the execution time of each task transmission is completely independent, and it is assumed that all the network communication delays are predictable in the whole working process. However, in practice, the execution of tasks and processing time are closely related to the processor operation of the system. Under full load and light load, due to the different bandwidth, the actual execution time is also different. At the same time, emergencies, clock accuracy and other factors may also affect the attributes of tasks in the system. These factors bring changes to the original ideal system. In this paper, the network data transmission is improved, and the preemptive EDF scheduling algorithm with time precision processing is used to solve the problem of attribute dynamic change in the system work. Through certain constraints, the dynamic change is transformed into determination, and the determined attributes are used for scheduling, so that the system can get a satisfactory scheduling effect, and the stability is guaranteed.

2.1 Processing of dynamic change of task execution time

Considering that the execution time of tasks in NCS is dynamic, this paper analyzes the basic EDF scheduling strategy from two aspects: the scheduling condition and the scheduling strategy.

A. Schedulable condition

In the classical EDF scheduling algorithm, the schedulability of the system needs to meet the following conditions (Sharma et al., 2020):

$$U = \sum_{i=1}^{n} \frac{c_i}{h_i} \le 1, \left(i = 1, 2, \cdots, n\right) \tag{1}$$

where c_i is the execution time of the task, h_i is cycle of task, n is the number of tasks. In the standard EDF scheduling algorithm, the execution time c_i is an accurate value. In this paper, the task execution time of the research object is changed to a non fixed value, that is, dynamic. Therefore, the formula (1) satisfying the scheduling condition is modified adaptively, that is, a variable W is used to replace U in the formula.

$$W = \sum_{i=1}^{n} \frac{c_i}{h_i} \tag{2}$$

Two condition parameters are used to explain this W, possibility condition $M(W \le 1)$ and necessity condition $N(W \le 1)$. And define a distribution function about W, denoted as $\varphi_w(w)$, to constrain and determine the above two parameters. Suppose a transmission task T_i, whose execution time is c_i, a distribution function $\varphi_w(w)$ related to time variable is defined. The value of the distribution function is related to the dynamic variable time $c_1, c_2, \cdots, c_n$, and its distribution function is as follows.

$$\varphi_w\left(w\right) = \min_{\substack{t_1, t_2, \cdots, t_n \\ w = \sum \frac{t_i}{h_i}}} \left\{\varphi_{c_1}\left(t_1\right), \varphi_{c_2}\left(t_2\right), \ldots, \varphi_{c_n}\left(t_n\right)\right\} \tag{3}$$

where w is an independent variable of W. The function $min\left(\cdots\right)$ is the minimum value of the distribution function of the schedulable variable W when all execution time c_i has the same distribution function value. The two conditional parameters M and N satisfy the following conditions.

$$M\left(W \le 1\right) = Sup\left(\varphi_w\left(w\right)\right), w \le 1 \tag{4}$$

$$N\left(W \le 1\right) = 1 - M\left(W > 1\right) = 1 - Sup\left(\varphi_w\left(w\right)\right), w > 1 \tag{5}$$

where $Sup()$ is the minimum upper bound function, which indicates the maximum value of variable w when the distribution function $\varphi_w(w)$ of W takes a certain value.

B.Scheduling strategy

The original intention of providing feasible scheduling criteria for the transmission of system tasks is to select the best among all feasible schemes. On this basis, when multiple tasks are transmitted in the system, the task can have a higher possibility of transmission. The dynamic execution time of tasks mostly changes in an interval. There are two special endpoint time values in the task distribution function, namely the minimum and maximum execution time. Corresponding to these two cases, in the case of choosing different time values, there are two different scheduling strategies. The dynamic execution time is replaced by the maximum or minimum endpoint time, which is the precise processing of the dynamic execution time attribute. The improved EDF scheduling strategy in this paper makes a corresponding supplement and adjustment to the classical EDF algorithm, accurately calculates the value of the possibility condition and necessity condition under the schedulable condition, and calculates the accurate time value of all tasks in the execution, so as to achieve the goal of dynamic time precision processing. In the scheduling of multiple tasks, the schedulable condition W depends on the feasibility condition and necessity condition.

1.When the value of $\varphi_w(w)$ is the maximum, w is greater than 1. In the current situation, the possibility and necessity of scheduling need to be met $0 < M(W \le 1) = \alpha < 1$, $N(W \le 1) = 0$. At this time, it is considered that the task execution time in the current transmission is closer to the minimum. In this case, each task with the minimum execution time can guarantee that the scheduling strategy has the possibility of α. Meantime, corresponding to the possibility value, that is, under the condition of $\varphi_{c_i}(t)$ is α, the execution time of each task corresponds to two endpoint time values, and the smaller value is taken as the accurate time. In addition, if the feasibility condition is $M(W \le 1) = 0$, the transmission process is considered to be non schedulable.

2.When the value of $\varphi_w(w)$ is the maximum, the independent variable w is less than 1. In the current situation, the possibility and necessity conditions of scheduling should be met as $M(W \le 1) = 1$ and $0 < N(W \le 1) = 1 - \beta \le 1$. At this time, it is considered that the task execution time in the current transmission is closer to the maximum. In this case, the maximum execution time of each task can ensure the necessity of scheduling $1-\beta$. At the same time, corresponding to the possibility value, that is, the two endpoint time values corresponding to the execution time of each task under the condition of $\varphi_{c_i}(t) = \beta$, take the larger value as the accurate time. In addition, if the necessary condition $N(W \le 1) = 1$ is satisfied, the transmission process is considered schedulable. The improved EDF scheduling strategy selects a larger execution time for each task under this condition, and all tasks can be transferred and completed before the deadline.

3.When the value of $\varphi_w(w)$ is the maximum, the independent variable w is equal to 1. In the current situation, the conditions of scheduling possibility and necessity are $M(W \le 1) = 1$ and $N(W \le 1) = 0$. The time corresponding to $\varphi_{c_i}(t) = 1$ is the exact execution time of each task.

The following is an example of the process of precise processing of task execution time. Suppose there are three tasks in the NCS, T_1, T_2 and T_3, their task cycles are 0.01, 0.02 and 0.03. The execution time is 0.004, 0.005 and 0.006. And the fluctuation range is set to 0.001, which indicates that the execution time changes dynamically in the interval. According to the principle that the maximum and minimum values are accurate in the scheduling strategy, a more appropriate triangular distribution function is used for processing. Fig. 2 shows the distribution function diagram of each task.

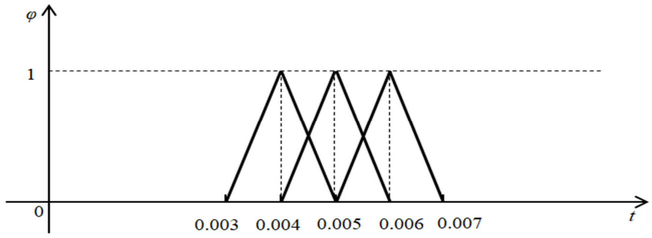


Figure 2. Distribution function of execution time of each task under dynamic execution time

The distribution function of W can be obtained by calculating the formula of schedulable variable, as shown in Fig. 3. According to the second case of scheduling strategy, $M(W \le 1) = 1$, $N(W \le 1) = 1 - \beta = 9/11$ and $\beta = 2/11$ can be obtained. In this case, the precise value of execution time is taken as $N(W \le 1) = 1 - \beta = 9/11$, The maximum value of the distribution function of each task is used as the precise time, namel $c_1 = 0.0048$, $c_2 = 0.0058$ and $c_3 = 0.0068$. Then, the execution time of dynamic change is processed.

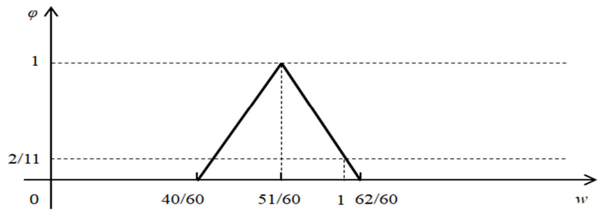


Figure 3. Distribution function of schedulable variable W under dynamic change of execution time

2.2 Processing with uncertain execution time and period

Define a distribution function $\varphi_{h_i}(t)$ about sampling period, and set an intermediate attribute variable to represent the ratio of task execution time and task cycle, which is expressed as $p_i = c_i / h_i$. The distribution function of p_i is defined as

$$\varphi_{p_i}(p) = \varphi_{c_i/h_i}(p) = \min_{t_2>0, t_1/t_2=p} \left(\varphi_{c_i}(t_1), \varphi_{h_i}(t_2)\right) \tag{6}$$

Then, the distribution function of schedulable variable W is obtained

$$\varphi_w(w) = \min_{\substack{z_1, z_2, \cdots, z_n \\ w=\sum z_i}} \left\{\varphi_{p_1}(z_1), \varphi_{p_2}(z_2), \ldots, \varphi_{p_n}(z_n)\right\} \tag{7}$$

Similarly, a brief example is given to illustrate the process of the precision processing. Suppose the system has three tasks, T_1, T_2 and T_3, and their execution time and fluctuation range are 0.004 ± 0.001, 0.006 ± 0.001, and 0.007 ± 0.001. The cycle time and fluctuation range are 0.01 ± 0.001, 0.02 ± 0.002 and 0.03 ± 0.003. The triangle distribution is selected as the distribution function of task time according to the principle of accurate maximum and minimum value in scheduling strategy. Fig. 4 shows the distribution function of each task.

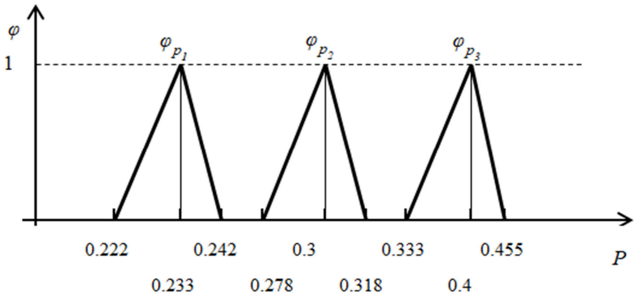


Figure 4. The distribution function of p under dynamic changes of both execution time and cycle

The distribution function of schedulable variable W can be obtained by calculation, as shown in Fig. 5. Obviously, when the value of distribution function is the maximum value of 1, the corresponding value of independent variable w is less than 1. $M(W\le1)=1$, $N(W\le1)=1$, and $\beta=0.405$. Let $\varphi_{c_i}(t)=\beta=0.405$, the maximum value of the distribution function of each task is taken as the precise time. We can get the execution time of three tasks as 0.0046, 0.0066 and 0.0082. The cycle times are $h_1=0.0106$, $h_2=0.0212$ and $h_3=0.0318$.

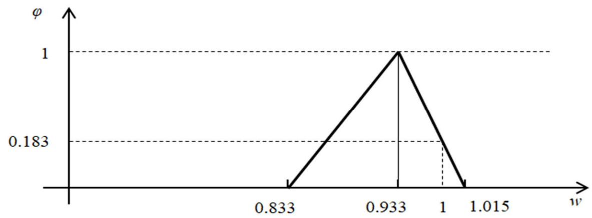


Figure 5. Distribution function of schedulable variable W under changes of both execution time and cycle

3 Simulation

In this paper, True Time is chosen as the simulation platform. Multi loop NCS is adopted. The whole system consists of network communication module, sensor, controller, actuator and interference node. The driving mode of the sensor is clock driving mode. The data is sampled periodically and sent to the controller through the network. The controller and actuator are event driven mode. The transmission tasks performed by each sensor are scheduled in the application layer, and the transmission order is allocated through a certain scheduling strategy, so that the task packet transmission of the whole network can be carried out orderly and stably. The following transfer function model is selected for the controlled objects of the three loops.

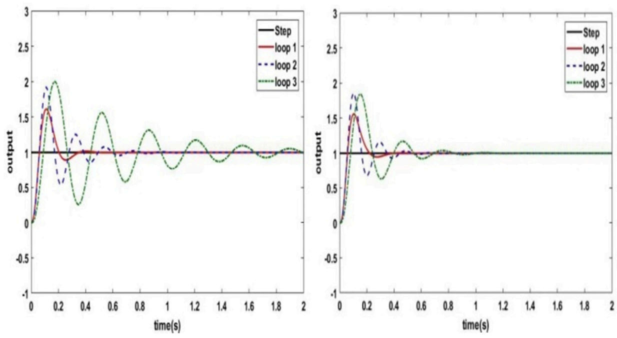
$$G(s)=\frac{1000}{s^2+s} \tag{8}$$

Because the main problem of this paper is the scheduling strategy of NCS, the most classic PID controller is adopted. The parameters of PID controller are as follows $K=0.95$, $T_i=0.07$, $T_d=0.05$, $N=100$ and $h=0.01$. The sampling periods of the three loops are 0.04s, 0.05s, 0.07s. CAN network is chosen as the communication network in the simulation.

According to the above dynamic example of execution time, the classic EDF scheduling strategy and the improved EDF scheduling strategy are used for task transmission. Under this dynamic condition, considering the influence of packet loss and interference in the network channel, the transmission of tasks and the scheduling of each execution loop in the network are observed. In order to discuss the output curve of network transmission and the scheduling of each loop task under the influence of interference and packet loss, the following simulation schemes are selected.

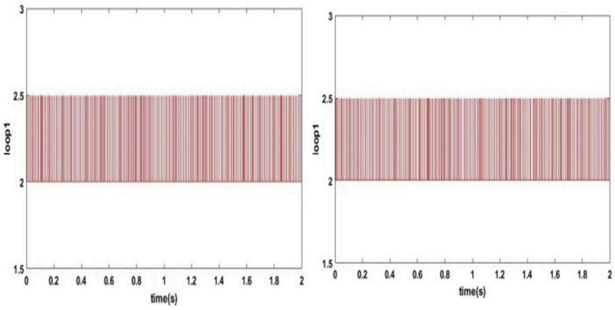
A.Simulation scheme I: interference rate is not 0, packet loss rate is 0

Under the condition of system interference, the output and scheduling of the system will be affected to a certain extent, which cannot be ignored. In the simulation, the scheduling of the system with different interference rate is studied. Fig. 6 shows the output response curves of the three loops under standard EDF and improved EDF scheduling strategies when interference rate is 0.2 and packet loss rate is 0. Figs. 7 to 9 show the scheduling of the three loops under standard EDF and improved EDF scheduling strategies. It can be seen from the comparison in these figures that there is oscillation in the system output under the traditional EDF strategy, and it takes a certain time to reach the stable state. The improved EDF scheduling strategy can suppress the system oscillation. After improving the EDF scheduling strategy, the task scheduling situation maintains a relatively good level.



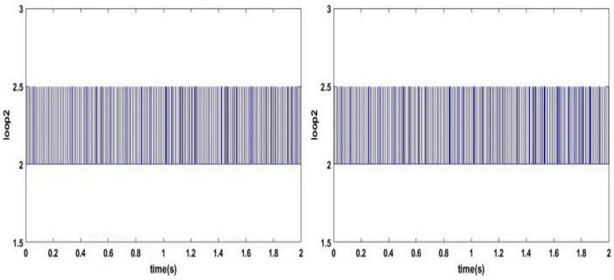
a standard EDF b improved EDF

Figure 6. Output under interference rate 0.2 and packet loss 0



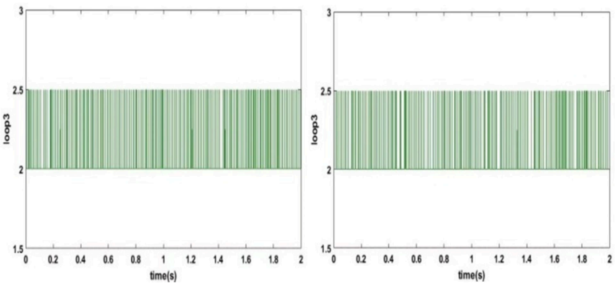
a standard EDF b improved EDF

Figure 7. Scheduling of loop 1 with interference rate 0.2 and packet loss 0



a standard EDF b improved EDF

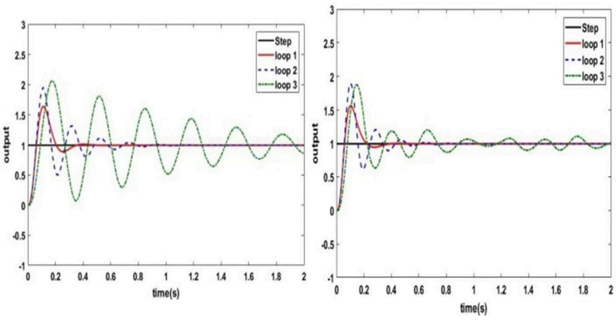
Figure 8. Scheduling of loop 2 with interference rate 0.2 and packet loss 0



a standard EDF b improved EDF

Figure 9. Scheduling of loop 3 with interference rate 0.2 and packet loss 0

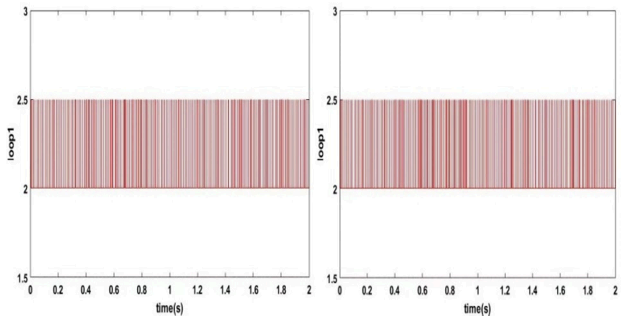
The interference rate of the system is increased to 0.3, Fig. 10 shows the output response curves of the three loops under standard EDF and improved EDF scheduling strategies.



a standard EDF b improved EDF

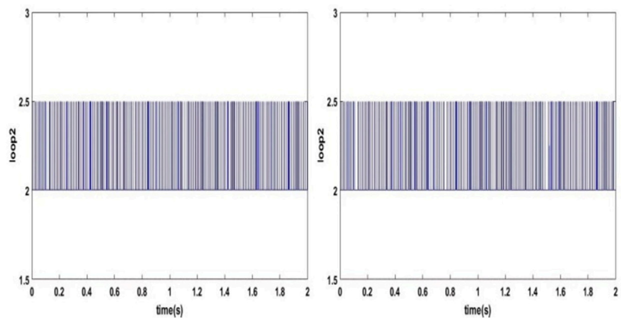
Figure 101. Output under interference rate 0.3 and packet loss 0

Figs. 11 to 13 show the scheduling of the three loops under standard EDF and improved EDF scheduling strategies. Through the comparison of simulation results, it can be seen that the increase of transmission channel interference makes the output quality of the traditional EDF scheduling strategy decline significantly. Although the oscillation amplitude gradually narrows and tends to be stable, the adjustment time becomes longer and the transmission performance of the system declines. Under the control of the improved EDF scheduling strategy, the system output oscillation is significantly suppressed, the invalid priority competition under the dynamic execution time is reduced, and the system output is significantly improved. And from the scheduling of each task, the execution of each task has been better allocated, and the task transmission is still controllable.



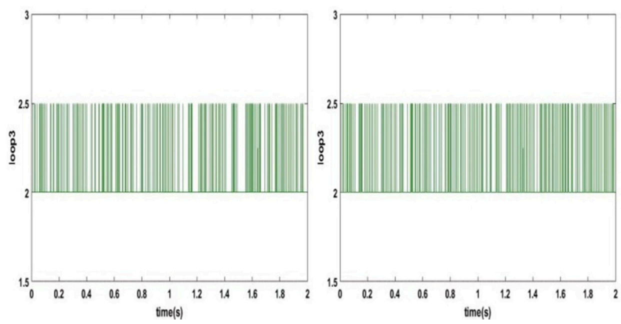
a standard EDF b improved EDF

Figure 11. Scheduling of loop 1 with interference rate 0.3 and packet loss 0



a standard EDF b improved EDF

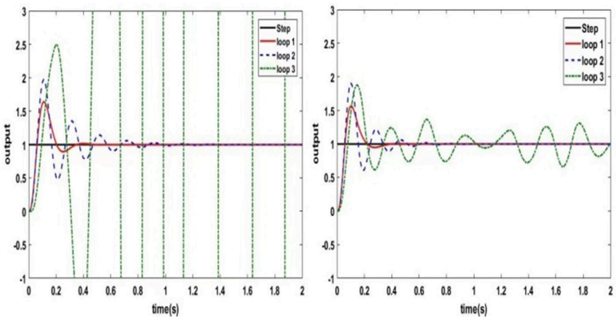
Figure 12. Scheduling of loop 2 with interference 0.3 and packet loss 0



a standard EDF b improved EDF

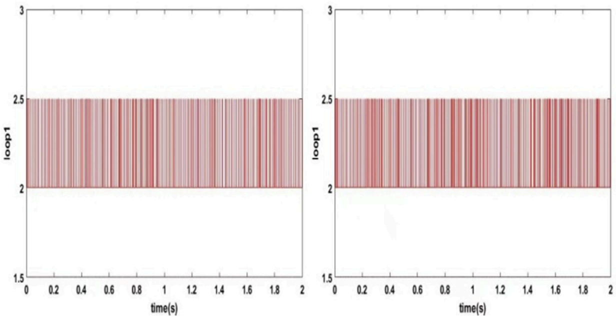
Figure 13. Scheduling of loop 3 with interference 0.3 and packet loss 0

The interference rate of the system is increased to 0.4, the corresponding simulation results are shown in the next four figures. It can be seen that under the traditional EDF strategy, the quality of task transmission drops sharply, individual loop oscillation becomes uncontrollable, the scheduling effect becomes worse, and the system gradually loses stability. The improved EDF strategy, because it solves the problem of priority competition confusion caused by uncertain time attributes, significantly improves the tolerance of the loop to external disturbance factors. Under the same disturbance, the transmission results after accurate processing still oscillate, but maintain in the same controllable range, and the task scheduling and system stability are significantly improved.



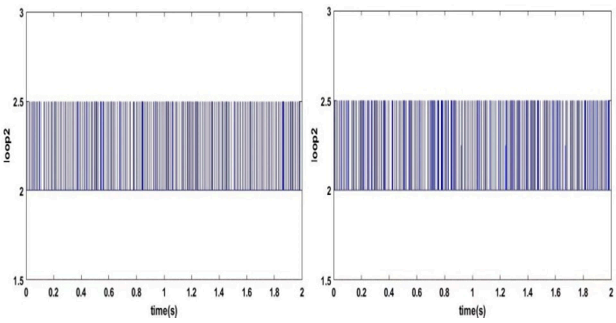
a standard EDF b improved EDF

Figure 14. Output under interference 0.4 and packet loss 0



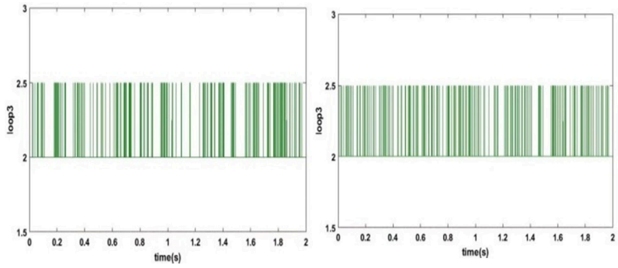
a standard EDF b improved EDF

Figure 15. Scheduling of loop 1 with interference 0.4 and packet loss 0



a standard EDF b improved EDF

Figure 16. Scheduling of loop 2 with interference 0.4 and packet loss 0



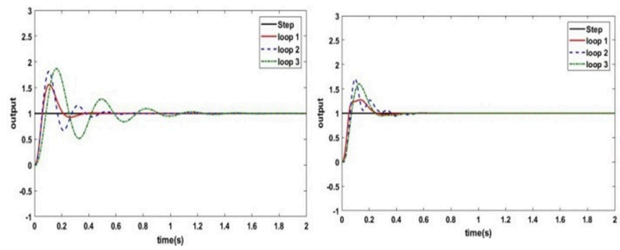
a standard EDF b improved EDF

Figure 17. Scheduling of loop 3 with interference 0.4 and packet loss 0

B.Simulation scheme II: packet loss rate is not 0, interference rate is 0

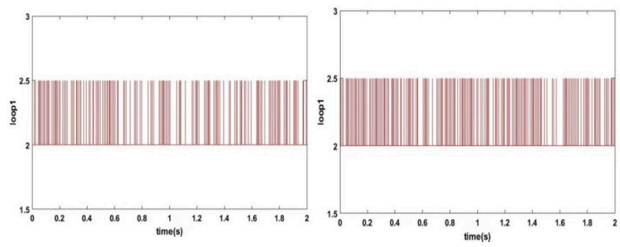
In this simulation scheme, packet loss rate is not 0, interference rate is 0. Under this situation, there is not interference in the network. Network task conflict, channel preemption and other situations will lead to packet loss. The packet loss rate is related to channel load and congestion. Therefore, packet loss rate can influence the performance of NCS.

Fig. 18 shows the output responses of the standard EDF scheduling strategy and the improved EDF scheduling strategy when there is no interference but the packet loss rate is 0.1. Figs. 19 to 21 show the comparison of the scheduling of the three loop tasks under the two scheduling strategies. Compared with the output and task scheduling before and after the improvement, it can be seen that the output scheduling before and after the improvement is controllable in the case of low packet loss level, the output oscillation of the system under the improved EDF strategy is improved, and the system stability is relatively good.



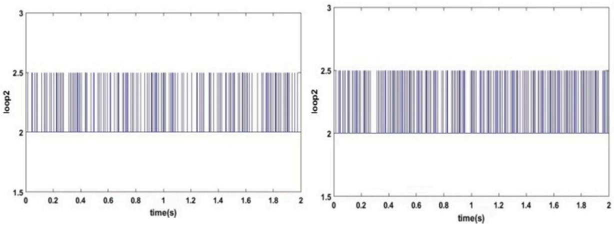
a standard EDF b improved EDF

Figure 18. Output under packet loss rate 0.1 and interference rate 0



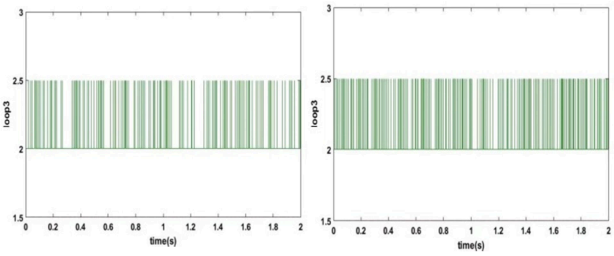
a standard EDF b improved EDF

Figure 19. Loop 1 scheduling based on packet loss rate 0.1 and interference rate 0



a standard EDF b improved EDF

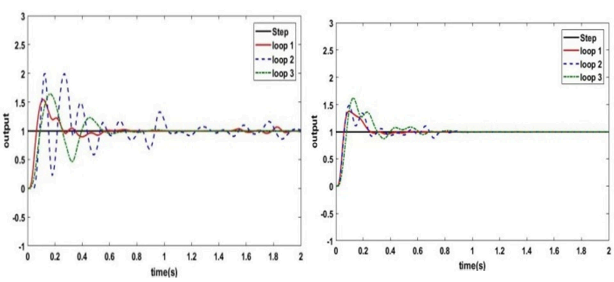
Figure 20. Loop 2 scheduling based on packet loss rate 0.1 and interference rate 0



a standard EDF b improved EDF

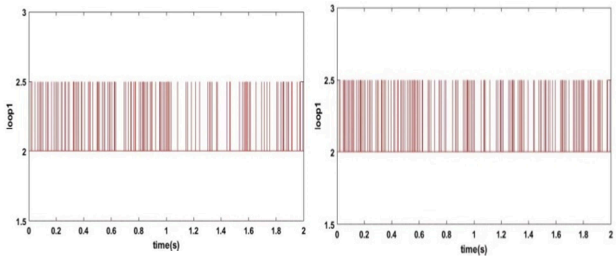
Figure 21. Loop 3 scheduling based on packet loss rate 0.1 and interference rate 0

The packet loss rate is increased to 0.15, and the scheduling effect of the two scheduling strategies is compared. Fig. 19 shows the output responses of the standard EDF scheduling strategy and the improved EDF scheduling strategy when there is no interference but the packet loss rate is 0.15. Figs. 22 to 24 show the comparison of the scheduling of the three loop tasks under the two scheduling strategies. From the simulation results, it can be seen that under the traditional EDF strategy, the output oscillation amplitude of the system begins to increase, the time from output to stable state becomes longer, the system performance begins to decline and the scheduling quality also gradually declines. Because of dealing with the uncertainty execution time, the improved EDF scheduling strategy reduces the factors that have adverse effects on the system performance, so the output situation is significantly improved, and the oscillation is reduced. When the task is transmitted in the network, the channel resources are used more effectively, and the scheduling effect is restored to a certain extent. The stability of the whole system is also improved.



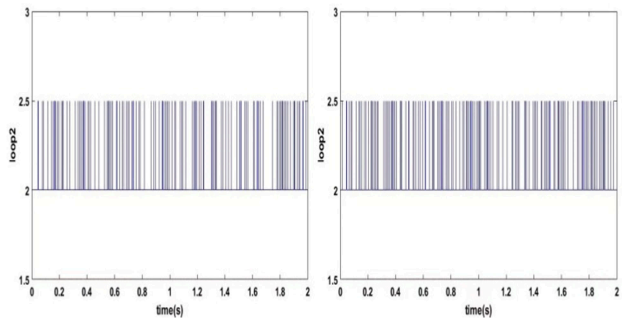
a standard EDF b improved EDF

Figure 22. Output under packet loss rate 0.15 and interference rate 0



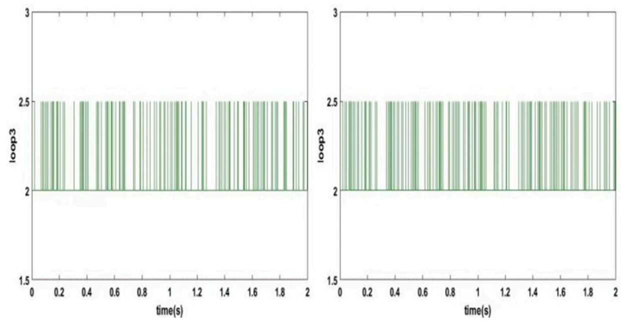
a standard EDF b improved EDF

Figure 23. Loop 1 scheduling based on packet loss rate 0.15 and interference rate 0



a standard EDF b improved EDF

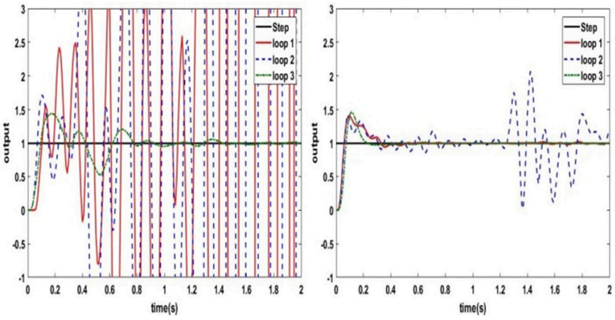
Figure 24. Loop 2 scheduling based on packet loss rate 0.15 and interference 0



a standard EDF b improved EDF

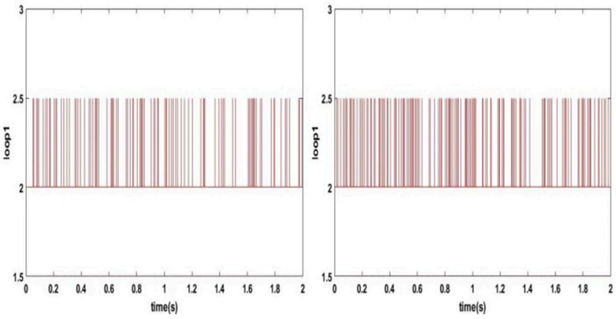
Figure 25. Loop 3 scheduling based on packet loss rate 0.15 and interference 0

Furthermore, the packet loss rate is increased to 0.2. Similarly, the simulation results are shown in the Fig. 25 & 26. From the simulation results, it can be seen that under the standard EDF scheduling strategy, the transmission quality of system tasks drops sharply due to the increase of packet loss rate, and the output oscillation amplitude of multiple tasks is too large to be stable. At the same time, it can be seen that compared with the channel disturbance, the impact of task packet loss on system transmission is more obvious. When the packet loss rate is too high, the system will lose balance. Under the improved EDF strategy, the system can accept a certain proportion of the packet loss rate, increase the fault tolerance of the transmission process, improve the system performance and transmission quality, and improve the scheduling of each task loop.



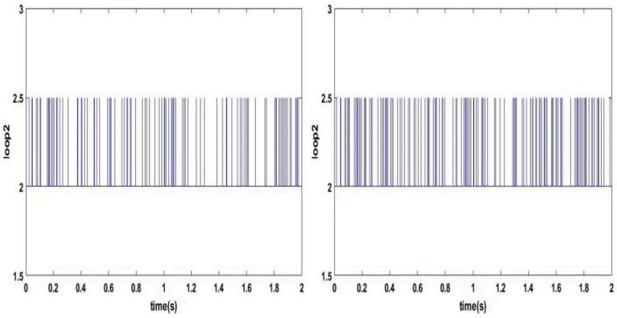
a standard EDF b improved EDF

Figure 26. Output under packet loss rate 0.2 and interference rate 0



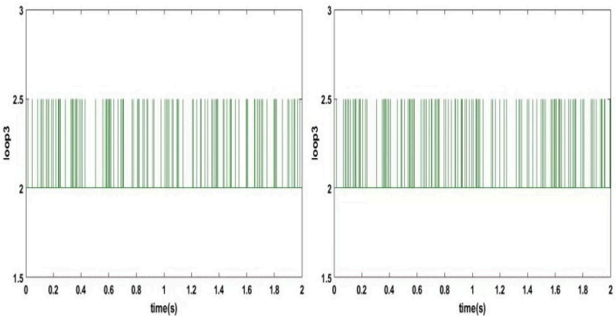
a standard EDF b improved EDF

Figure 27. Loop 1 scheduling based on packet loss rate 0.2 and interference rate 0



a standard EDF b improved EDF

Figure 28. Loop 2 scheduling based on packet loss rate 0.2 and interference rate 0

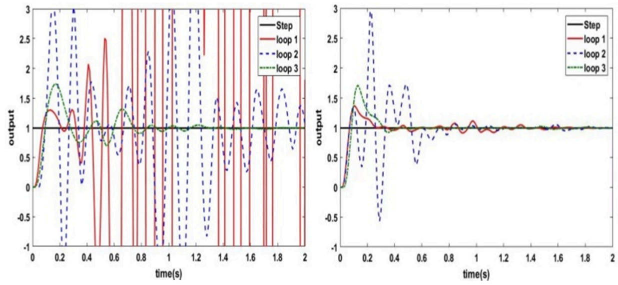


a standard EDF b improved EDF

Figure 29. Loop 2 scheduling based on packet loss rate 0.2 and interference rate 0

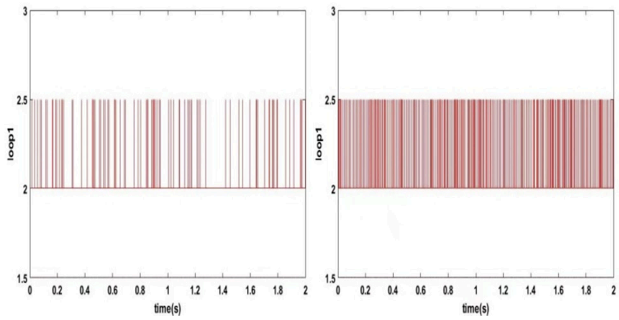
C. Simulation scheme III: packet loss rate is not 0, interference rate is not 0

In this simulation scheme, the packet loss rate and interference rate exist at the same time to verify whether the scheduling strategy is effective. The packet loss rate is set as 0.15 and the interference rate is set as 0.3. The relevant simulation results are shown in Figs. 30 to 33. From these traditional EDF scheduling strategies, due to the presence of packet loss and interference factors in the NCS, and the dynamic change of execution time, the competition is more intense when the transmission of each task is occupied by a large number of channels by external factors. In contrast, the improved scheduling strategy makes the task transmission can be carried out orderly, which improves the system's tolerance of adverse factors, improves the data transmission quality and system stability.



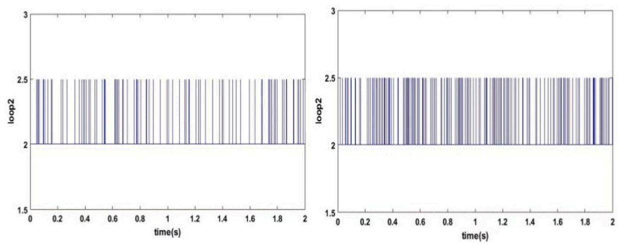
a standard EDF b improved EDF

Figure 30. Output under packet loss rate 0.15 and interference rate 0.3



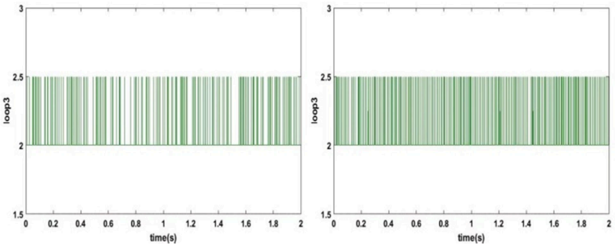
a standard EDF b improved EDF

Figure 31. Loop 1 scheduling based on packet loss rate 0.15 and interference rate 0.3



a standard EDF b improved EDF

Figure 32. Loop 2 scheduling based on packet loss rate 0.15 and interference rate 0.3

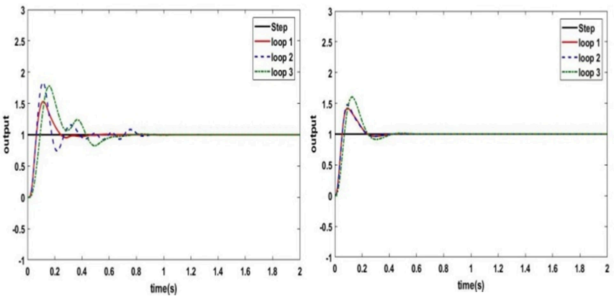


a standard EDF b improved EDF

Figure 33. Loop 3 scheduling based on packet loss rate 0.15 and interference rate 0.3

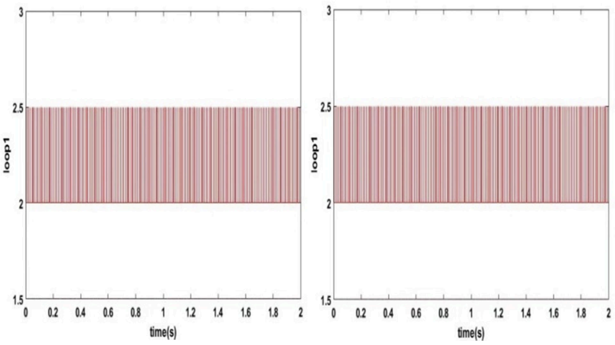
D.Simulation scheme IV: packet loss rate is 0, interference rate is 0

In this simulation scheme is the ideal state of NCS, that is, no interference rate and packet loss rate. The relevant simulation results are shown in Figs. 34 to 37 below. The simulation results show that the standard EDF scheduling strategy achieves better scheduling effect without interference and packet loss in NCS. In contrast, under this condition, the output curve fluctuation of each task in NCS is significantly reduced after the improved EDF scheduling strategy accurately processes the event execution time. During the scheduling period, the task can be transmitted in a certain order. The network task scheduling performance is better, the data transmission is ideal, and the system is more stable.



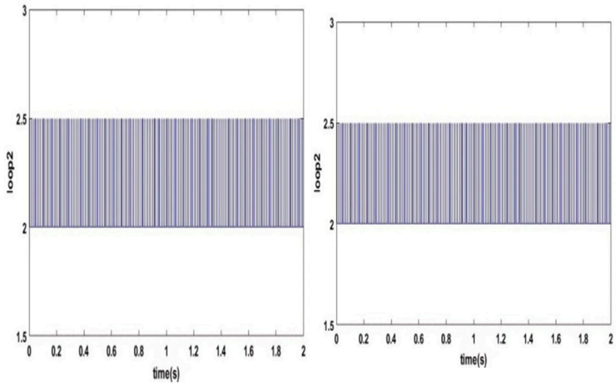
a standard EDF b improved EDF

Figure 34. Output under packet loss rate 0 and interference rate 0



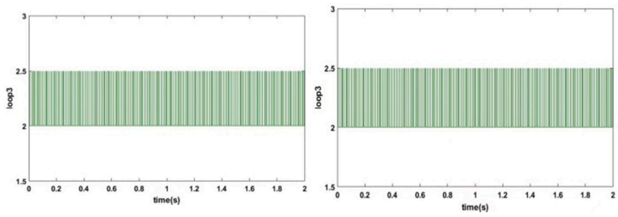
a standard EDF b improved EDF

Figure 35. Loop 1 scheduling based on packet loss rate 0 and interference rate 0



a standard EDF b improved EDF

Figure 36. Loop 2 scheduling based on packet loss rate 0 and interference rate 0



a standard EDF b improved EDF

Figure 37. Loop 3 scheduling based on packet loss rate 0 and interference rate 0

E.Simulation scheme V: execution time and cycle change dynamically

The above four simulation schemes start from the packet loss and interference that affect the NCS, and analyze the influence of various factors on the transmission and stability of the system. The simulation results show that the improved EDF scheduling algorithm can effectively improve the transmission efficiency and system stability of multi task NCS, and improve the adaptability of the system to other adverse factors. The performance of NCS is analyzed when the execution time and cycle change dynamically. Since the influence of data packet loss and interference factors on this situation is basically the same as that in the previous analysis, we will not repeat the elaboration. Here we only analyze the output and scheduling of each task of the NCS without interference and packet loss. The output response of the three loops under the standard EDF and the improved EDF scheduling strategy is shown in Fig. 38 and Fig. 39. The task scheduling of the three loops is shown in Figs. 40 to 42. From the comparison of simulation results, it can be seen that under the condition that the execution time and cycle attributes of tasks are dynamically changing, and the standard EDF scheduling strategy is adopted, the scheduling time of each task in the network cannot be determined due to the competition rules, and the task transmission cannot be carried out in an orderly manner, resulting in the poor schedulable of network tasks, It makes the task unable to complete the normal execution, the time for the system to reach the stable state becomes longer, and the transmission quality of the whole network control system is also seriously reduced. After using the improved EDF scheduling strategy, the time attribute of each task is determined, and the priority determination is relatively more effective. From the output response image and the scheduling situation of each task, the data transmission effect is restored, and the stability of the system is guaranteed.

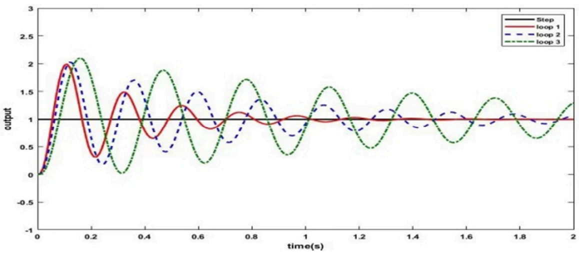


Figure 38. Output under standard EDF when execution time and cycle change dynamically

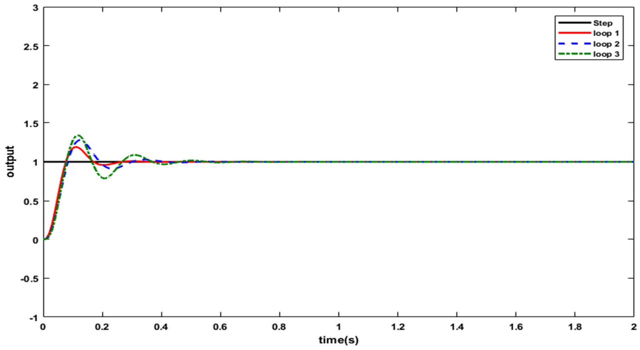
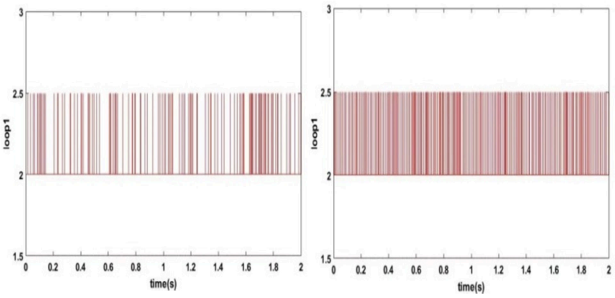
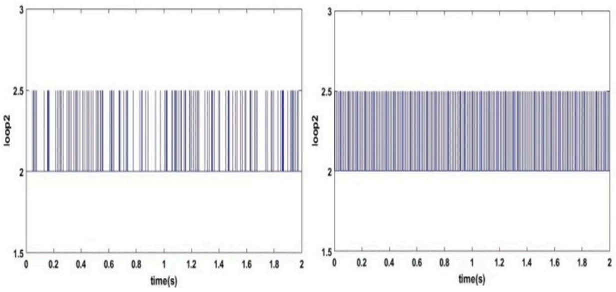


Figure 39. Output under improved EDF when execution time and cycle change dynamically



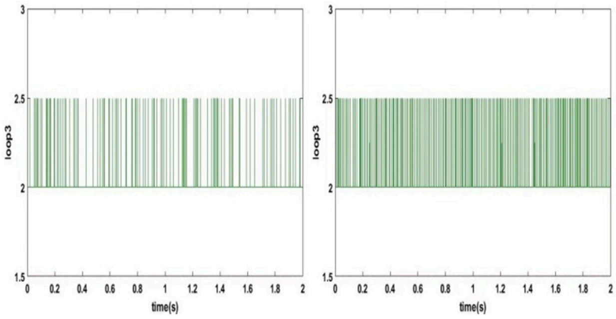
a standard EDF b improved EDF

Figure 40. Loop 1 scheduling when execution time and cycle change dynamically



a standard EDF b improved EDF

Figure 41. Loop 2 scheduling when execution time and cycle change dynamically



a standard EDF b improved EDF

Figure 42. Loop 3 scheduling when execution time and cycle change dynamically

It can be seen from the above dynamic scheduling results that in the NCS, in the process of multi task data transmission, in order to compete for the priority of transmission, each task competes to occupy the channel resources on the network. The dynamic change of the attributes of the transmitted tasks makes it difficult to find an effective transmission order in the transmission, which leads to the chaos of the scheduling management in the system and makes the efficiency of information transmission unsatisfactory. The improved EDF scheduling strategy, which can accurately process the task attributes, can make each task transmit data according to the set rules and reasonable time, so the bandwidth of the system can be effectively allocated, the execution of each task can be well managed, and the data transmission of the system can be carried out efficiently and orderly. The stability of the system is effectively guaranteed.

4 Conclusions

The focus of this paper is to improve the practical applicability of network transmission, improve the transmission efficiency of the network and the stability of the system. The traditional EDF scheduling strategy has clear attribute requirements for tasks in execution, such as an accurate execution time and cycle, which are often difficult to meet in reality. Or because of a series of uncontrollable factors, such as the heavy load of tasks, special emergency tasks, the delay of the process of sensor sending and receiving information and so on, the attributes of the transmitted tasks may change dynamically in the network control system, which makes it difficult to get the ideal effect. At the same time, the standard EDF scheduling strategy cannot adapt to different tasks and environments, which makes the execution of the system more difficult to satisfy. In this paper, the standard EDF scheduling strategy is improved, and can bus communication network is selected. This paper introduces the factors of packet loss and external interference, and improves and optimizes the schedulable conditions and scheduling strategy, so that the cycle and execution time of tasks can be accurately identified. The simulation results on the true time platform show that the improved EDF scheduling strategy can significantly improve the data transmission and scheduling of the system, and the adaptability to bad network transmission environment with packet loss and interference is also significantly improved.

Due to the complexity and variability of NCS, the proposed scheduling strategy still needs to be further optimized. In this paper, when dealing with the uncertain time range, the interval fluctuation is constrained to a fixed value through the distribution function. Whether this value can accurately represent the characteristic information of the task itself needs to determine a standard to measure its compliance in the future research. On the other hand, because of the complexity of NCS, the simulation environment is not completely the same as the actual transmission environment, so the simulation will idealize some other problems, such as the actual control object may not be a fixed model, the data packets in the transmission process may be disordered, etc., which still need to be further considered in the future.

Acknowledgement

This work is partially supported by the Doctoral Scientific Research Foundation of Liaoning Province (Grant No. 20180540050).

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