A New PID Active Queue Management Method Based on Immune Algorithm

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Abstract

To find the optmized parameters of PID controller is very difficult in the active management algorithm(AQM), this paper proposed an improved immune algorithm based to optmize the parameters of PID controller, and then apply the PID controller to AQM algorithm to achive the stable queue length, and meanwhile reduce the packet loss ratio. Using the performance index function of the PID controller as the objective function of the immune algorithm, the proposed method can fast obtain a set of PID controller parameters that minimizes the performance index function by searching in the given controller parameter space. The improved immune algorithm uses the immune memory mechanism and the elite crossover strategy which makes the algorithm having fast convergence speed, and the wavelet mutation id adopted, which makes the algorithm take into account the global search as well as local search, so the network can quickly reach the stable state. The Simulation result of Matlab shows that compared with traditional active queue management method, the queue length of our algorithm can be quickly coverged to the expected queue length, and the packet loss probablity is reduced.

Keywords

Artificial immune algorithm, pid controller, active queue management,immune memory, elite crossover.

1. Introduction

As the increasing of users, applications, and the types of network, the network traffic grows at the rapid speed, and network congestion is becoming more seriously. How to guarantee the service quality and reduce the packet loss probability is the key problem for the performance of network. Active Queue Management (AQM) [1] method is the main method of network congestion avoidance, and its basic idea is to smooth the network traffic by using average queue length. The main representative of the active queue management algorithm is: RED [2], BLUE[3], PI[4], PID[5] and so on. In view of the shortcomings of the RED, BLUE and other algorithms, such as lacking fairness of parameter settings, and queue length fluctuation, the paper [4] proposed an active queue management algorithm based on PI controller. Although this method has solved the problem of fairness and queue fluctuation of the traditional active queue management algorithms, the PI controller has the problem of slow response delay. Therefore, the research on the active queue management method is proposed based on PID controller.

The main goal of the PID active queue management method is that the queue length is quickly stable at the expected queue length, so that the fluctuation of the queue length can be minimized, so as to reduce the packet loss probablity and the network system can achieve the stable state. Many scholars have carried out deep research on the PID parameter tuning method, and put forward a lot of parameter setting method. The parameters setting method of Ziegler-Nichols frequency response method is proposed by [6]. But in the dynamic changing network environment, it is difficult to obtain the critical amplification factor and the critical period of the network system based on the experience, so it can't be used to set the parameters of the PID controller. A parameter tuning method based on the stability margin is proposed in the paper [7].This method is the lack of monitoring network system of amplitude margin and the phase margin formula is very complex, so it is difficult to obtain the optimal effect. The PID parameter optimization method for minimum square error integral is proposed by [8]. These PID parameters setting method is in the premise of determining the controlled object, finding PID parameters to optimize the state of network system in a performance index, only to achieve a PID controller in which a parameter optimized, the optimal parameter combination of the PID can't be obtained, so it is difficult to achieve the optimal network state.

In view of the problem that the PID controller parameters are difficult to set up in the active queue management algorithm, this paper proposes an PID active queue management method based on the improved immune algorithm. First, the improved immune algorithm is used to optimize the parameters of PID controller. The performance index function of PID controller is used as the target function of immune algorithm to get the optimal parameter combination. The PID controller is applied to the network active queue management system the immune memory mechanism and the concentration inhibition mechanism of the immune system are introduced in this paper, and the optimization ability and the convergence speed of the algorithm are improved by using the elite crossover strategy and wavelet mutation operator. The simulation results of Matlab show that compared with the conventional PID active queue management method, the proposed method can control the queue length and achives fast queue-lengh convergence to the desirable target in two cases of the normal TCP traffic flow and the burst TCP traffic flow.

2. The Principle of PID active queue management method

PID active queue management method is to calculate the packet loss probability by comparing the difference Δq between the actual output of controlled object q and the reference queue length q_0, and Δq is used as the input of the controller. q is the actual queue length,and p is the output control signal of PID controller,which is on behalf of the packet loss probablity. The basic block diagram is shown in Fig.1.

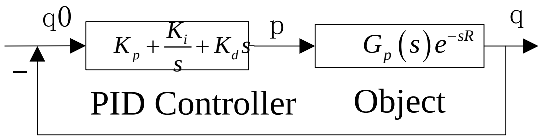


Fig.1 The queue control model based on PID

Where K_p is the proportional coefficient, K_i is the integral coefficient, and K_d is the differential coefficient of PID controller respectively. By discrete processing the above process, the sampling period T is divided into k equal time slots, so the discrete expression form is as follows.

$$p(k)=K_p e(k)+K_i\sum_{j=0}^{k}e(j)+K_d\frac{\left[e(k)-e(k-1)\right]}{T} \tag{1}$$

Where $e(k)=q(k)-q_0\cdot q(k)$ is the sampling value of queue length for K moments. And p(k) is the packet loss probability for K moments. T is the sampling period.

V Misra[6] et al. proposed a nonlinear differential equation of the TCP congestion control mechanism based on the analysis of the network continuous data flow. In order to facilitate the system analysis, the C.Hollot[7] uses the small signal theory to the local linearization in the steady state operating point, and carries on the Laplace transformation, then obtained the simplified TCP/AQM model. And the expression of transfer function of controlled object in the model can be written as follows.

$$G_p(s)=\frac{K}{(T_1s+1)(T_2s+1)} \tag{2}$$

Where $K=\frac{(R_0C)^3}{4N^2}, T_1=R_0, T_2=\frac{R_0{}^2C}{2N}$. C is the link capacity(Packets/s), R_0 is the round trip time(RTT), N indicates the number of connections for TCP.

Based on the above analysis, the key of the PID active queue management method is to set the three parameters of the PID controller, so that the target queue length can track the expected queue length, and the queue length can be fast and stable to reduce the delay and optimize the packet loss probability. Because the immune algorithm uses immune memory,elite crossover, mutation and antibody selection operation to realize the iterative and optimization operation, it has a fast convergence speed and can be used to adjust the parameters of PID controller, which can help to speed up the network state fast and stable.And it has strong anti-interference ability, so that the queue length, packet loss rate, and throughput can be in a better state.

3. The parameter tuning method of the PID controller

First of all, the method of optimizing the parameters of PID controller based on immune algorithm (IAIS) is proposed. The basic design idea is as follows. First, the size of each antibody is encoded as the size of K_p, K_i K_d, and the total length of each antibody is the sum of the encoding three parts of K_p, K_i, K_d. The performance index function J (see formula (3))of the PID controller is taken as the antigen, and use the detected system error e calculating each antibody produced by the antigen, and then calculate the matching degree between the antibody and antigen, that is the degree of affinity until producing the ideal antibody or meeting the termination condition of algorithm.The parameter setting method of the PID controller is as follows.

Step1 Determine the antigen and antibody of the immune algorithm. The performance index function J (see formula (3)) of PID controller is taken as the target function of the immune algorithm, which is regarded as the antigen ,and the coefficient of the PID controller is considered as the antibody.

Because the optimization target of PID controller parameters is to make the control error of the active queue management system close to 0, which has a fast response speed and smaller response error. The performance index of error absolute value time integral ITAE is used as the performance index function for PID parameter optimization. In order to avoid control energy too large, the square term of the control input is added to the objective function. In order to avoid over regulation, the penalty function is used. Namely, once the overshoot, it will be adjusted as one of the best indicator. As shown in formula(3), the performance index function of the PID controller is represented by the following equation.

$$J=\int_0^\infty \left(w_1|e(t)|+w_2u^2(t)+w_4y_E(t)\right)dt+w_3\cdot t_u \tag{3}$$

Where $e(t)$ is the system error. $u(t)$ is the output of the controller. t_u is the rise time. And w_1, w_2, w_3, w_4 are respectively weighted value, and $w_4 \gg w_1$, $y_E(t)=y_{out}(t)-y_{out}(t-1)$, $y_{out}(t)$ is the output of the controlled object.

Step 2 By using real number coding generate the initial antibody group $P_i(x_{i1}, x_{i2}, x_{i3})$. The PID controller parameters (K_p, K_i, K_d) are combined together. The encoding length is 3 bits. The initial population is generated randomly according to the parameters range $[a_1, b_1]$, and the memory bank contains N antibodies.The coding method ia as follows: $x_{id}=a_1+r\times(b_1-a_1)\quad d=1,2$ .Where r is a random number between 0 and 1.

Step 3 Calculate the affinity between antigen and antibody.

Because the error of the system is used as an affinity evaluation function, the algorithm needs to calculate the system response at every combination of K_p, K_i and K_d, so the affinity function of this paper is as follows:

$$fit_k = 1/\left(B + J\left(ITAE\right)\right) \tag{4}$$

Where B represents a constant that more than 0, by adding B it avoids overflow that the denominator is close to 0. The smaller the target function J, the higher the affinity degree of the antibody fit_k, so the higher the fitness function of antibody. After calculating the affinity of M antibodies, according to the affinity degree in descending order, N antibodies of high affinity degree into the memory unit are updated. After running the end of the algorithm, the antibody of the highest affinity in the memory element is the optimal parameter combination.

Step 4 Determine whether the algorithm to reach the maximum evolutionary algebra Gmax, if it is satisfied, then terminate the algorithm, and output the antibodies of the maximum affinity in the memory unit, and that is the optimal PID controller parameters. If the algorithm does not reach Gmax, go to step 5.

Step 5 We use the King crossover strategy[11] and the given cross probability Pc to cross each antibody in the elite individual and population, to improve the population structure and improve the convergence rate of the algorithm.

Step 6 In order to maintain the diversity of antibodies, the paper needs to carry on the wavelet mutation operation[12], and its adaptive mutation probability is as follows.

$$p_m = \begin{cases} k_3 \dfrac{f_{\max} - f}{f_{\max} - \overline{f}}, & f \geq \overline{f} \\ k_4 & f < \overline{f} \end{cases} \tag{5}$$

Among them, $k_3, k_4 < 1.0$. And $f_{\max}$ indicates that the largest fitness of the current population, $\overline{f}$ represents the average affinity degree of the population, and f is the affinity of the individuals involved in the variation. By using the adaptive mutation probability, higher than the antibody of average affinity in the population with the increasing of the affinity mutation probability is decreased, and increase mutation probability that lower than antibody of the population average affinity, so it can keep antibody diversity to produce more excellent antibodies by mutation operation.

Step 7 Based on the affinity degree and concentration, in accordance with the formula (6) we calculate the selection probability[13] and perform roulette wheel selection operation.Where β is a constant and $fit(i)$ is the affinity agree between antibody.

$$P_{si} = \alpha \frac{fit(i)}{\sum_{i=1}^{pop} fit(i)} + (1-\alpha)\frac{1}{pop} e^{-\frac{C_i}{\beta}} \tag{6}$$

Antibody concentration is the proportion of the similar antibodies in the population. The expression is as follows: $C_i = \sum_{i=1}^{pop} S_{i,j} \Big/ pop$ .T is the affinity threshold of the antibody. $S_{i,j} = \begin{cases} 1, S_{i,j} > T \\ 0, others \end{cases}$, $S_{i,j}$ is the affinity between the antibody and the antibody. $S_{ij} = 1/\left(1+d_{ij}\right)$, d_{ij} is the Euclidean distance between the two antibodies. According to the formula (6), we can know that the higher the affinity degree of individual, the greater the selected probability of the antibody, and the greater the concentration of the antibody, the smaller the selected probability of the antibody. This not only encourages the antibody of the high affinity degree, but also inhibits the antibody of the high concentration, thereby ensuring the individual diversity. In the immune algorithm, on one hand it can make the lower affinity and the higher concentration of antibodies to be suppressed, with a smaller probability to be chosen to enter the next generation; on the other hand, it can make the higher affinity and lower concentration of antibodies, with a larger probability to be chosen to enter the next generation to maintain the diversity of antibodies.

4. The improved active management method

In the third part, after the improved immune algorithm is used to obtain the parameters of the PID controller, a set of PID parameters for minimize the performance index function of the PID controller is obtained. The group of the optimal parameters are used in the PID active queue management model, in which the active drop the packet ahead of the overflow of the buffer queue, and the queue management is finally realized.

Firstly we use the improved immune algorithm to optimize the 3 Parameters of PID controller, the PID active queue management model is set.Initialized the parameters of the improved immune algorithm, such as the size of the antibody population pop, the current number of iterations g, the maximum number of iterations Gmax, and memory size N. Secondly start the queue management module, so that the current sampling time $k=1$, and sample the current queue length. Then calculate the deviation of the input variables, and the formula is as follows: $e(k)=q(k)-q_0$. Then according to the formula (2), the packet loss rate in the buffer queue at K time is calculated. We use the formula (7) to update the error of the queue length and packet loss rate

$$\begin{cases} p(k-1)=p(k) \\ e(k-1)=e(k) \end{cases} \tag{7}$$

In the end the routing node takes the packet loss probability, and randomly drop packets in the buffer queue, avoiding the packet loss with buffer overflow.

5. Experimental Simulation

In order to verify the effectiveness of the proposed algorithm in the Matlab environment, the experimental simulation is carried out. Considering the high throughput, low latency and low jitter can be obtained when the queue length is close to the reference value q_0 [14], the experiment will take the queue length as the main observation target. In all experiments, the reference queue length $q_0=200$, and the cache size of the router is 300packet/s.

In the experiment, 30 TCP flows share a bottleneck link, namely N=30, C=10^5 packet/s and the transmission delay of the bottleneck link capacity (i.e. the round-trip delay, mainly including the propagation delay, queue delay, etc.) is 0.03s[14]. The transfer function of the TCP network can be written as follows.

$$G_p(s)=\frac{7.5\times10^6}{(0.03s+1)(1.5s+1)}e^{-0.03s} \tag{8}$$

The parameters in IAIS are set as follows: the maximum evolutionary algebra is set to 200. The population size is 100. The affinity between the antibody and the antibody is 0.9, and the memory cell size is 20.The initial mutation probability is 0.06, and the crossover probability is 0.85. The ranges of three parameters of PID are [0,20], [0.1], [0,1]. $w_1=0.999$, $w_2=0.001$, $w_4=100$, $w_3=2.0$. Simulation time is 30s.

Fig. 2 shows the convergence curve of the fitness function values in the iterative process. The optimal PID controller parameters are obtained by using IAIS. $K_p=2.867\times10^{-6}$, $K_i=2.423\times10^{-6}$, $K_d=1.98\times10^{-7}$.

In the Matlab/Simulink, the PID active queue management method based on Ziegler-Nichols (Z-N)[14] and IAIS is simulated. The simulation results are shown in Fig. 3 and Fig.4. When the network condition is constant, that is, TCP flow number, link capacity, and round-trip time are not changed, the immune algorithm and Z-N method are used to optimize the queue length, and the change plot of the queue length is as follows.

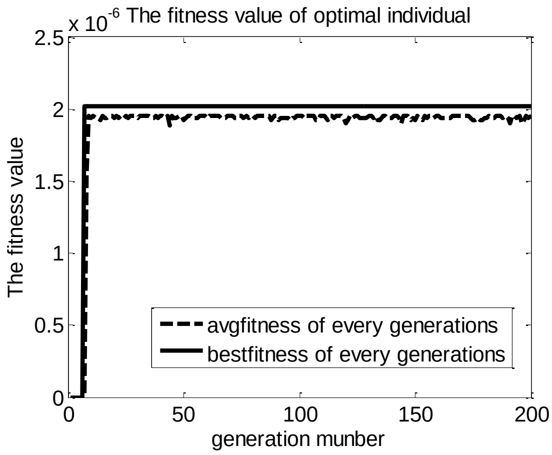
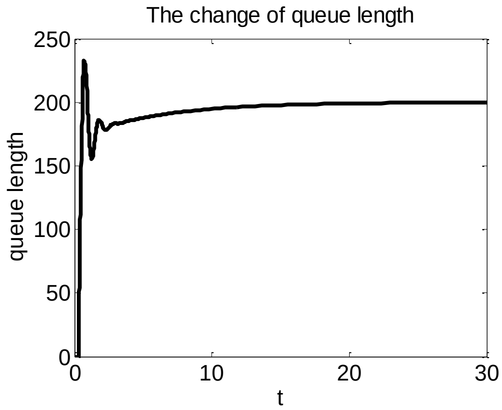


Fig.2 The change of optimal fitness of antibody



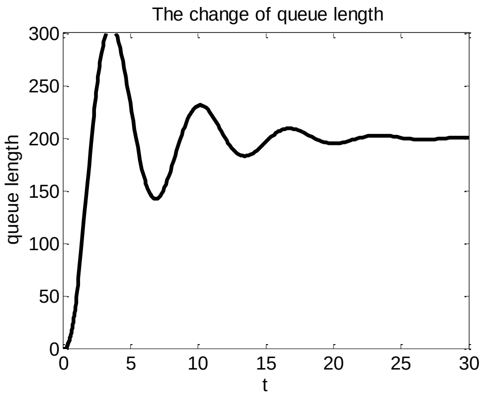
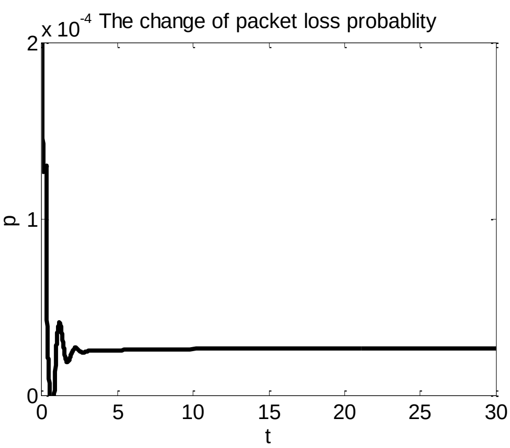


Fig.3 the queue length under the IAIS   Fig.4 the queue length under conventional PID



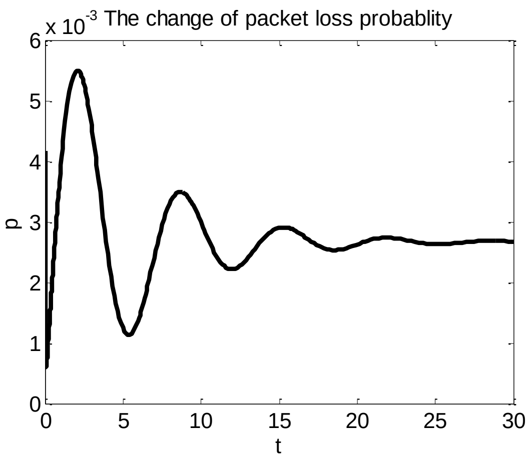


Fig.5 the loss probability under the IAIS   Fig.6 the loss probability under conventional PID

When the network condition is constant, the PID active queue management method based on immune algorithm has faster convergence rate, and the overshoot is less, and the error is less than the classic Z-N method. From Fig.3 we can see the fluctuation of queue length with the immune algorithm is small, and the queue length of the PID controller with the Z-N empirical formula method has larger fluctuation.

Fig.5 and Fig.6 show the change plot of the network packet loss rate under the action of the immune algorithm and the conventional PID. Under the action of immune algorithm, the network packet loss rate is stable around 0.00002, while the loss probablity of the network is stable at 0.00003 with the classical Z-N empirical formula method. From the graph, we can see that there is a certain relationship between the network packet loss probablity and queue length. When the fluctuation of the queue length occurs, the packet loss probablity is unstable. When the queue length is stable, the packet loss probablity remains constant. From the simulation results we can see that the PID active queue management method based on the improved immune algorithm has fast convergence speed, and its dynamic performance is better, at the same time the packet loss probablity is small.

Because the purpose of the active management method is to control the queue length of the router to stable at the desired queue length, and avoid the severe turbulence and the overflow of buffer queue in order to reduce the packet loss probablity, and deal with the TCP traffic flow fairly. The performance of the two active queue management methods is compared by increasing 30 TCP flows in 10s.The round-trip time is still 30ms, the link capacity is 10^5 packet/s. Simulation results are shown in Fig.7 andFig. 8. As we can be seen from Fig.7, the PID active queue management algorithm based on immune algorithm can converge to the reference value more quickly than the conventional PID active queue management algorithm. This is due to the improved immune algorithm has faster response speed, strong adaptive ability, and can be applied to real-time dynamic system control. Meanwhile, the algorithm can be used to stabilize the queue length faster than the conventional PID active queue management algorithm.

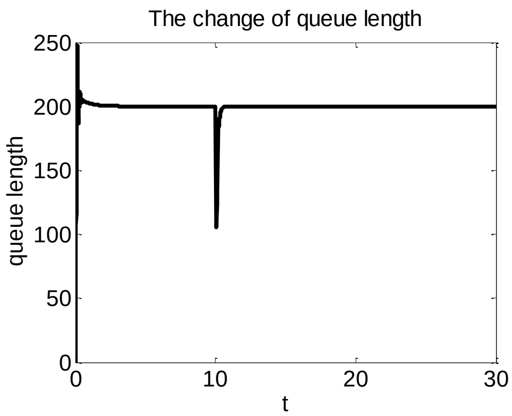


Fig.7 the queue length under the IAIS-PID

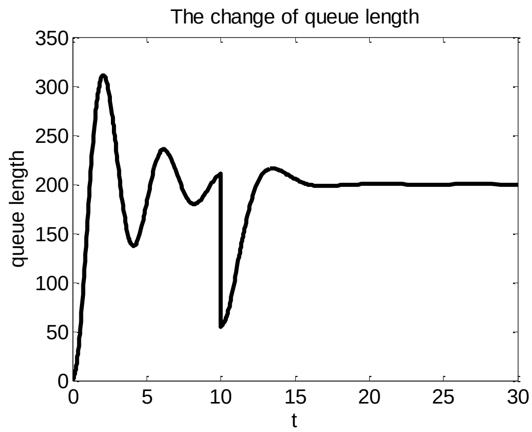


Fig. 8 the queue length under conventional PID

Fig. 9 shows the change of packet loss probablity under the condition of changing network. As it can be seen from the graph, the packet loss probablity increases with the increase of TCP flow. However, the packet loss probablity of the improved PID active queue management method is stable at 0.00015, and the loss probablity of the conventional PID active queue management method is stable around 0.01.

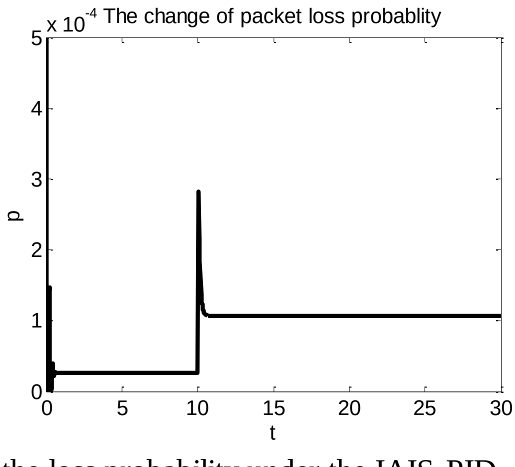


Fig.9 the loss probability under the IAIS-PID

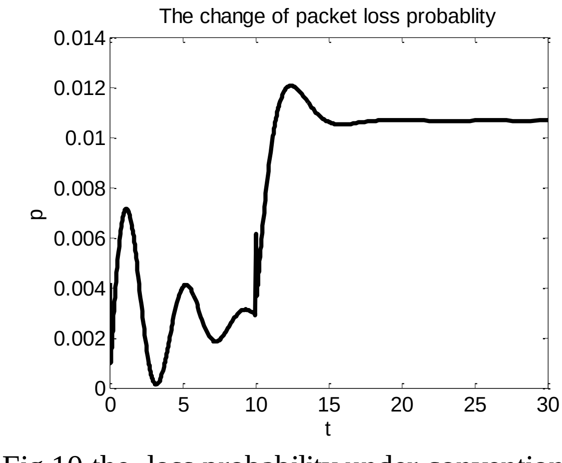


Fig.10 the loss probability under conventional PID

6. Conclusion

Aiming at the problem that the PID controller parameters are not optimized in the existing PID active queue management method, the improved PID parameter tuning based on the improved artificial immune algorithm and active queue management method is proposed. Using the improved immune algorithm to optimize the parameters of PID controller in a given search space, a set of PID controller parameters is quickly found to minimize the system performance index function. The PID controller is used in active queue management system. The Simulation result of Matlab shows that compared with traditional active queue management method, the queue length of this improved active queue management method can be quickly stable at the expected queue length in the two cases of the normal TCP traffic flow and burst TCP traffic flow, and the packet loss probablity is reduced.

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