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Echo-state-network classification based multi-services awareness in high-speed optical passive networks①

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Abstract

With the challenge of great growing of services diversity, service-oriented supporting ability is required by current high-speed passive optical network (PON). Aimed at enhancing the quality of service (QoS) brought by diversified-services, this study proposes an echo state network (ESN) based multi-service awareness mechanism in 10-Gigabite ethernet passive optical network (10G-EPON). In the proposed approach, distributed architecture is adopted to realize this ESN based multi-service awareness. According to the network architecture of 10G-EPON, where a main ESN is running in OLT and a number of ESN agents works in ONUs. The main-ESN plays the main function of service-awareness from the total view of various kinds of services in 10G-EPON system, by full ESN training. Then, the reservoir information of well-trained ESN in OLT will be broadcasted to all ONUs and those ESN agents working in ONUs are allowed to conduct independent service-awareness function. Thus, resources allocation and transport policy are both determined only in ONUs. Simulation results show that the proposed mechanism is able to better support the ability of multiple services.

Key words: 10-Gigabite ethernet passive optical network (10G-EPON), multi-services awareness, echo state network (ESN), reservoir computation

0 Introduction

With decades of rapid evolution from the ethernet passive optical network (EPON) to 10G-EPON or even 40G-EPON, great development has been achieved to optical access network technologies driven by constantly emerging multiple services[1,2]. Great effort has been made to support multiple services with the increasing demand on network capability, flexibility and reliability, etc. To better achieve the quality of service (QoS), 10G-EPON must be active to support diversified services. Thus, the service awareness ability shows great importance for the 10G-EPON to match different types of services with high efficiency. The service awareness means 10G-EPON must be fully aware of characteristics and requirements of multiple services.

In fact, the service awareness has already become an important issue in many fields, including network design, network management, and network security, etc[3-5]. Great efforts have been made on analyzing and classifying technologies of services. Deep research on the relation between statistic characteristics and service protocols has been done in Refs[6,7]. However, those approaches are not so accurate for service-layer protocol. As furthering research, series researches on data-traffic identification and classification mechanism have been reported in Refs[6-8], which is based on the packet length, arrival time interval and arrival sequence. As one solution, a Bayesian classifier based service-awareness (BC-SA) has been presented in Ref.[8]. This also implies that more pattern recognition algorithms also have great potential to realize service-awareness. However, there exist several problems in current neural network algorithms, including consuming time and computational complexity and so on. The echo state network (ESN)[9] is a strong candidate to better service-awareness performance, as ESN has great advantages to enhance reliability, to improve accuracy, and reduce complexity[10,11]. Considering the architecture of 10G-EPON, there still exist great problem to make ESN suitable for the 10G-EPON system, which is composed by optical line terminal (OLT) and a number of optical network units (ONUs). The OLT-

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ONUs architecture also makes it unfeasible to allocate the whole ESN only in OLT, since ONUs fail to benefit from original ESN based services-awareness.

With the aim at solving this problem, this study proposes an ESN based multi-services awareness (ESN-MSA) scheme for 10G-EPON. In the approach, the so-called "Main ESN" module is embedded and running in OLT with the whole function of ESN, while the "ESN Agent" works with sampled functions in each ONU. Main ESN is responsible for initiating and training ESN to form the reservoir and provide the reservoir information to all ONU through broadcast. And each ESN agent directly uses this reservoir information from OLT to form its ESN and independently conduct distributed multi-services awareness.

1 Echo state network based classification

As Fig. 1 shown, the architecture of the echo state network (ESN) is divided into three layers, input layer, reservoir and output layer[9-13]. There is a great number of neurons in this dynamical reservoir with quite strong learning ability. Assume that there are L input units, M output units and N units in the reservoir. Generally, the connection weight matrix is represented as $\boldsymbol{W}_{in}$ of the input layer, while its corresponding unit in the reservoir is $\boldsymbol{W}$. Thus, the dynamical learning ability and reliability of ESN can be ensured. In addition, $\boldsymbol{W}_{out}$ is the connection weight matrix of the output layer and is the goal of data training in ESN.

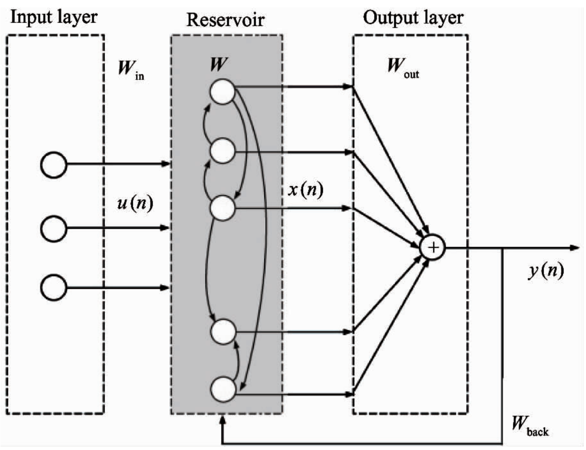

Fig. 1 ESN structure

The basic idea of ESN is that: the reservoir is triggered by the input signal to produce continuous state-variable within this reservoir. And the output value of ESN can be obtained by using linear regression algorithm between state-variable and output value. The state of reservoir and output are updated using Eqs(1) and (2).

$$x(n+1) = f(\boldsymbol{W}_{in}u(n+1) + \boldsymbol{W}x(n) + \boldsymbol{W}_{back}y(n)) \tag{1}$$

$$y(n+1) = f_{out}(\boldsymbol{W}_{out}u(n+1) + \boldsymbol{W}x(n+1) + \boldsymbol{W}_{back}y(n)) \tag{2}$$

where, $u(n)$, $x(n)$ and $y(n)$ represent individually the input variable, state variable and output variable. And $f(\ )$ and $f_{out}(\ )$ are the activation functions of processing units of the reservoir and the output unit.

Generally, ESN has been widely used in time series field and shows great potential in classification[13-16]. The basic idea of ESN classification is given in Eq. (3) and that means input signals must be kept without change until state variables are quite stable. This method still keeps the advantage of ESN in which the training is fast and simple, and shows great performance in classification.

$$\begin{cases} x(n+1)^{(i)} = \boldsymbol{W}_{in}u(n+1) + \boldsymbol{W}x(n+1)^{(i-1)} \\ x(n+1)^{(0)} = 0 \end{cases} \tag{3}$$

However, the reservoir of ESN is generated randomly in this approach. Therefore, this ESN classification approach still fails to gain the classification result with nice targeting and to satisfy the classification requirement for diversified services.

2 ESN classification based multi-services awareness mechanism

2.1 Working principle

As types of new services traffics soar, intelligent service-aware ability is required for 10G-EPON. According to the classification demands of service in 10G-EPON, key parameters to identify the type of service include: packet length, packet arrival rate and service-procession time. Those parameters of service characteristics can be gained through independently different methods. Aimed at better obtaining the targeting ability of existing services-awareness approaches and to make the ESN suitable for the architecture of 10G-EPON, an ESN based multi-service awareness (ESN-MSA) mechanism is proposed to be one feasible approach.

In fact, types of services are already depicted in this article. And QoS of these multi-services can be mainly divided into three categories: packet-loss-rate, time delay and jitter, where each category is with three classes: high-level, middle-level and low-level. That means, the ESN computation can be greatly simplified.

In this paper, the multi-services awareness is realized by allowing each ONU to independently perform ESN based services awareness with low complexity and by centralized complex ESN training in the OLT. To achieve this goal, Main ESN module is responsible for providing ONUs with well-trained ESN from the view of the whole 10G-EPON system, which implies that Main ESN is a complex one. Main ESN must complete the initiation and training of the ESN and provide this completed ESN to all ONUs. Before the ESN classification training begins, all parameters of ESN must be well set by Main ESN, including the number N of units in reservoir, spectral radius R of the internal connection weights matrix $\boldsymbol{W}_{in}$, etc, and the inter-connection weight matrix $\boldsymbol{W}$ is generated. Thus, the ESN Agent in each ONU just only needs to obtain ESN and to directly perform service-awareness using this ESN. It will abstract service-characteristics parameters from newly arriving services and to compute classification results for ONU to conduct schedule operation.

In fact, the ESN based service-classification function greatly depends on the selection of input parameters. This paper seletcts these kinds of parameters as input variables of the ESN: the length of data packet $u_L(n)$, the arriving rate of packets $u_A(n)$, the during time of packet $u_T(n)$, the source address $u_S(u)$, and the destiny address $u_D(n)$, as given by

$$u(n) = (u_L(n), u_A(n), u_T(n), u_S(n), u_D(n)) \tag{4}$$

2.2 The ESN initiation and training in OLT

In the proposed mechanism, the ESN initiation and training are centralized in the OLT, in order to make sure the consistency of services awareness among ONUs. After this training is fully completed, the information of the well-prepared reservoir is distributed to all ONUs. The detailed procedure of ESN initiation and training in OLT is depicted as follows:

Step 1: Set the processing units number N, and the number k of pioneer nodes according to types of services;

Step 2: Distribute k initial nodes randomly within 1×1 space, and record their position in this space;

Step 3: Generate a new node U within the space randomly, which belongs to the pioneer node with the shortest distance.

Step 4: Compute the distance related probability $P(U, V_i)$ between the new node U and known node V_i using Eq. (5) and determine whether the connection between them exists by judging the maximal value of their distance related probability reaches;

$$P(U, V_i) = \alpha e^{-\gamma d(U, V_i)} \tag{5}$$

Step 5: Repeat Step 4 until the number of nodes reaches N;

Step 6: Set all necessary parameters of ESN, including the internal connection weight radius R and the number of output units;

Step 7: Initiate the input matrix $\boldsymbol{W}_{in}$ and generate the internal connection weight matrix $\boldsymbol{W}$ using the method mentioned above;

Step 8: Input the training sample into the ESN that has already been initiated fully;

Step 9: Use Eq. (3) to collect state variables and input these variables into the activation function of processing units in reservoir to obtain final state variables;

Step 10: Get the well-trained main ESN structure using the output the pseudo inverse algorithm to deal with the output matrix $\boldsymbol{W}_{out}$.

Through the initiation and the training procedures, the Main ESN is well-prepared in OLT. Later, the detailed information of Main ESN will be broadcast by the OLT to all ONUs, which will draw this information to form their ESN Agents and conduct ESN based distributed multi-services awareness independently.

2.3 The ESN classification based multiple services awareness in ONUs

Generally, the service scheduling of 10G-EPON system is realized under the combination of the dynamic bandwidth algorithm (DBA) and intra-ONU scheduler[17-20]. In the proposed based multi-services awareness mechanism, ONUs directly play key roles to be aware of decertified services and to perform schedule function according to awareness results.

For implement, the ESN agent classifier module is embedded into ONU and its task is to perform multi-services awareness together with the scheduler in ONU under the control of DBA in 10G-EPON. On receiving the detailed information of the main ESN from OLT, each ONU immediately conducts its services-awareness initiation and constructs the ESN agent module the same with the well-trained main ESN according to the detailed information. After all ONUs finish this initiation, the ESN based multi-services awareness starts to work. And the scheduling process in each ONU is depicted in Fig. 2.

In Fig. 2, services packets arrive with different priorities, and their characteristics parameters are abstracted and transformed into $u(n)$ set of the input-layer of ESN for classification computation. And according to output results of the ESN, these services are

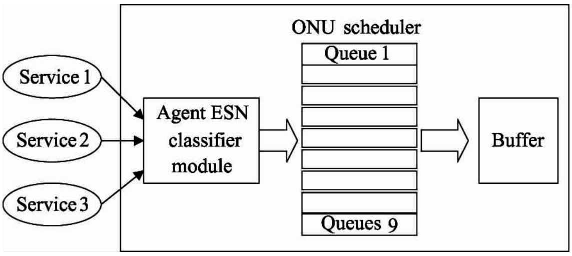

Fig. 2 ESN based services-awareness process in ONU

classified by the ESN agent module and put into corresponding queues. Then, the scheduler of ONU will move some packets according to their priorities into the buffer which would send these packets to the OLT.

The complexity of ESN classification is one of key issues, which must be low enough for implement. According to the ESN model, it only needs two times of multiply operation to deal with one kind of classification parameter, where the complexity is $O(1)$. If the number of classification parameters reaches m, the complexity is just $O(m) \times O(1)$ for the ESN classification computation in each ONU.

3 Simulation results and analysis

In order to evaluate the performance of the proposed mechanism, a software simulation platform of 10G-EPON system with 32 ONUs is built using NS2 simulation software. The "ESN Agent" module is running in each ONU, while the "Main ESN" module works in the OLT. In this simulation, three classes of services are set to produce traffic load, and requirements of services to network are represented by three parameters: average packet delay, packet loss rate and jitter. Moreover, each kind of services is divided into three levels in term of priority: Class 1 with the highest level, Class 2 with mediate level and Class 3 with the lowest level. Additionally, the Class 1 service and the Class 2 service are both set to be 20 % respectively, and the Class 3 service is 60%. The traffic load of each class service follows the Passion distribution. In the initiation of reservoir, $N = 100$ and IS (input unit scales) is set to be 4.

In fact, service-awareness performance is derectly determinded by the classification accuracy rate, which is depicted by Table 1. It can drawn from Table1 that the ESN-MSA has better accuracy than the BC-SA. Under conditions of full enough trainning, the ESN-MSA can achieve accuracy rate up to 92.8%, while the BC-SA has worse performance with accracy rate of 89.2%.

Table 1 Comparision of classification accuracy

Trainning times / Classification algorithm	1500	2000	2500	3000
BC-SA	80.2%	84.7%	87.3%	89.2%
ESN-MSA	85.3%	88.1%	90.4%	92.8%

Thus, futher comparison is also made between the BC-SA and the proposed ESN-MSA, from aspects of time delay, packet loss rate and jitter. These comparisons results are given from Fig. 3 to Fig. 5.

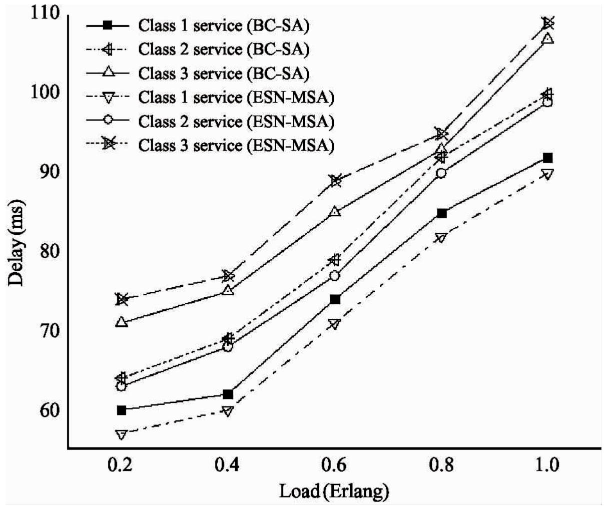

Fig. 3 Comparison of time delay

The delay time of delay-sensitive service is given in Fig. 3. Obviously, delay time of all services soars as the traffic load increases. Under the same traffic load condition the Class 1 service and Class 2 service with ESN-MSA show the value better than their corresponding ones with BC-SA, while the Class 3 service with ESN-MSA gets the worst value. Because the Class 3

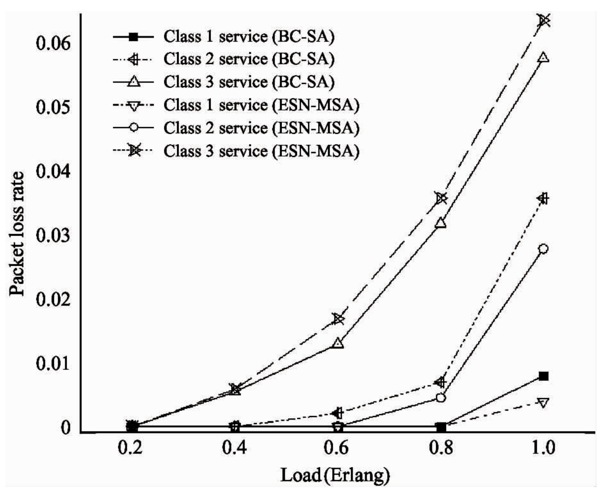

Fig. 4 Comparison of packet loss rate

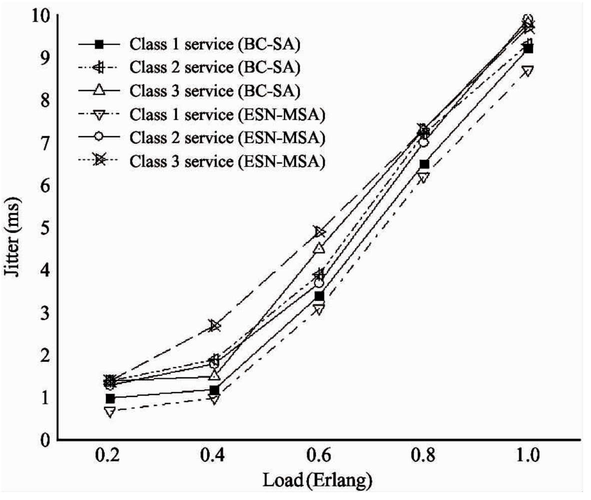

Fig. 5 Comparison of jitter

service has the lowest requirement on delay time, it is tolerant to this time-delay performance. Additionally, the Class 1 service in ESN-MSA can achieve the best performance.

Fig. 4 shows the comparison of packet loss rate for packet-loss sensitive services, and these services are also divided into three levels (Class 1, Class 2 and Class 3). Overall, the packet loss rate of all services soars as the traffic load becomes heavy. Similar to the comparison result of network delay time, the Class 1 service and Class 2 service with ESN-MSA show lower packet loss rate than BC-SA. And the Class 3 service with ESN-MSA still gets the worst result, since it has the lowest requirement on packet loss rate. From comparison, the packet-loss-rate of ESN-MSA is more reasonable than BC-SA. With the ESN-MSA scheme, differences among those services are more obvious. Thus, requirements of different classes of services on packet loss rate can be all further satisfied by using the ESN-MSA mechanism.

Comparison result in Fig. 5 shows that the BC-SA and the ESN-MSA has similar performance in terms of jitter. Generally, the jitter is caused mainly by the limited queue or buffer. Benefitting from greatly stronger hardware of the 10G-EPON system, the difference between BC-SA and ESN-MSA is not so obvious on jitter performance.

Combining these comparison results from Fig. 3 to Fig. 5, the ESN-MSA can obtain better performances comprehensively. And the ESN-MSA approach is able to enhance matching degree between services demands and 10G-EPON ability, with better time delay and more reasonable packet loss rate. Therefore, the ESN-MSA is more suitable for the architecture of 10G-EPON, since ONU is the one to face multiple services and to perform services-awareness directly with higher efficiency.

4 Conclusions

As ever-increasing multi-services has brought great challenge with demand of high matching degree between services and optical access networks, the high-speed PON is required to be actively aware of the characteristics of those services and to provide support with not only greater capacity but also better efficiency. In order to cope with this challenge, this article proposes an echo state network based multi-service awareness (ESN-MSA) mechanism in 10G-EPON, which introduces the echo state network into the 10G-EPON and makes full use of advantages of ESN. With this ESN-MSA scheme, more efficient resources scheduling is able to be conducted in 10G-PON system. Simulation results show that the ESN-MSA scheme is able to match requirements by multiple services with higher efficiency.

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