Abstract—In this paper, we propose an intelligent inter-ring route controller, called fuzzy inter-ring route control with PRNN predictor (FIRC-P), for the bridged resilient packet rings (BRPR). The FIRC-P contains three functional blocks implemented by fuzzy logic systems or pipeline recurrent neural networks (PRNN): fuzzy bridge-node congestion indicator (FBCI), PRNN downstream-node fairness predictor (PDFP), and fuzzy route controller (FRC). The determination of the FIRC-P is based on the load balancing principle, in which the CW or CCW ringlet with lower congestion degree and higher service rate will be chosen. Simulation results show that the FIRC-P improves the performance by about 10% and 220% in packet dropping probability, by about 13% and 18% in average packet delay, and by about 6% and 19% in throughput over the queue length threshold route controller (QTRC) and the shortest path route controller (SPRC), respectively.

Index Terms—resilient packet ring (RPR), route control, fairRate, congestion control, fuzzy logics, pipeline recurrent neural networks (PRNN)

I. INTRODUCTION

The resilient packet ring (RPR) is a dual-ring based network for high-speed metropolitan area networks (MANs) and is constructed by several pairs of two unidirectional links between stations [1]. A RPR network consists of a clockwise (CW) and a counter-clockwise (CCW) ringlets, giving each station on the ring a full duplex connection to its neighbors. More than one RPRs can be interconnected by a bridge to form a bridged RPR (BRPR) network. A spatially aware sublayer (SAS), which is a part of the MAC layer, in the bridge is used to decide which ringlet interface the packet should be routed to [1], [2]. Current research on SAS, including the IEEE 802.17b Working Group, is mainly focusing on how to modify this sublayer in order to avoid flooding the entire bridged network when transmitting inter-ring packets [1]-[3].

The shortest path route controller (SPRC) was widely considered for metro rings [4], [5] as it can maximize the spatial reuse and thus the achievable packet throughput for uniform traffic. However, as traffic load increases, incoming call requests could pile up at a node before being processed, and these would result in a potential bottleneck in network performance [5]. Intuitively, the route selection would be closely related with the congestion degree of the ringlet so as to follow the load balancing principle. Generally, RPR uses a queue length threshold to detect the congestion and a node’s adding rate limitation to avoid the network congestion [1]. Therefore, an intuitive queue-length threshold route controller (QTRC) would be better than the SPRC. However, the correlation function between the congestion degree and these variables is nonlinear and complicated.

Recently, intelligent techniques such as fuzzy logics and neural networks have been widely applied to control nonlinear, time-varying, and well-defined systems for that fuzzy logic and neural network control can provide effective solutions with small computational complexity. Fuzzy and neural fuzzy implementations of the two-threshold congestion control and the equivalent capacity admission control were once studied in the literature [6]. Results have shown that the proposed fuzzy logic and neural network approaches significantly improve system performance. Moreover, fuzzy logic and neural network systems are easily implemented in a chip.

Therefore, we propose an fuzzy inter-ring route control with PRNN predictor (FIRC-P) for BRPR. Either CW or CCW ringlet at bridge will be properly chosen for an incoming new call request from one RPR to the other RPR. The selection is based on the load balancing principle which is in the sense that the selected ringlet would be with lower congestion degree and higher service rate [7]. The FIRC-P contains a fuzzy bridge-node congestion indicator (FBCI) to detect the congestion degree of bridge, and a pipeline recurrent neural networks (PRNN) downstream-node fairness predictor (PDFP) to predict the mean received fairRate. Besides, the FIRC-P consists of a fuzzy router controller (FRC) to determine preference values of route of CW and CCW ringlets according to the congestion indication provided by FBCI, the predicted mean received fairRate provided by PDFP, the number of hops to destination, and the service rate of the bridge. A ringlet with a larger route preference value would be more proper to be selected. Simulation results show that the FIRC-P can effectively attain the load balancing property and improve the packet dropping probability (throughput) by 10% and 220% (6% and 19%) over QTRC and SPRC [4], respectively, in a scenario.

II. SYSTEM MODEL

Fig. 1 shows a bridge node connecting $R_0$ and $R_1$ RPR rings, where each ring contains a pair of CW and CCW ringlets and $M$ nodes. Assume that the fiber link capacity is $C$ Gbps and the distance between each two consecutive nodes is the same. The proposed FIRC-P is installed in a spatially aware sublayer (SAS). As a new call request coming from one ring to the other, the FIRC-P will determine an appropriate ringlet for the inter-ring new call request. Also, the SAS forwards packets of existing calls to their interface in the bridge node based on the determined route. The bridge node has one interface associated each ringlet, and as shown in Fig. 2, each interface has two transit buffers: the ringlet and ingress buffers. The packets to the same ring are stored in the ringlet buffer, and those to the other ring are buffered in the ingress buffer. Each buffer contains a primary transit queue (PTQ) and a secondary transit queue (STQ). The high- (low-) priority packets, such as voice packets and video packets of I-frame (video packets of B- or P-frames, and data packets), are stored in the PTQ (STQ). The bridge node always reserves bandwidth for the high-priority packets. The scheduler in the bridge first serves the PTQs exhaustively with the round robin policy, and then serves the two STQs with the proportional round robin policy associated with their queue lengths.

For simplicity, we adopt the AM fairness algorithm, proposed in IEEE 802.17 [1], in each node for simulations and it is
III. Intelligent Inter-Ring Route Controller

The fuzzy inter-ring route control with PRNN predictor (FIRC-P) is to determine a proper ringlet for an incoming inter-ring new call request at bridge. The determination is based on the load balancing principle, in which the CW or CCW ringlet with lower congestion degree and higher service rate will be chosen. The congestion may come from the bridge node or the CW (CCW) downstream node. The former is related with the two STQ lengths of the associated interface in the bridge. As shown in Fig. 3, the FIRC-P designs a fuzzy bridge-node congestion indicator (FBCI) to intelligently detect this congestion. The latter is related with the received fairRate from the downstream node of the associated ringlet. Therefore, the FIRC-P designs a PRNN (pipeline recurrent neural networks) downstream-node fairness predictor (PDFP) to predict the CW or CCW downstream-congestion degree. Finally, the FIRC-P designs a fuzzy route controller (FRC) to determine a proper ringlet for the incoming inter-ring new call request. It receives the congestion indication from FBCI, denoted by \( C_I \), and the predicted mean received fairRate from PDFP, denoted by \( \bar{R}_f \), as input linguistic variables. Also, it considers the service rate of the CW or CCW ringlet at the bridge, denoted by \( R \), and the number of hops between the bridge and the destination, denoted by \( H \), as input linguistic variables. Notice that the ringlet service rate at the bridge node, \( X \), and the number of hops between the bridge node and the downstream node, \( H \), are related with the received fairRate from the downstream node, \( Y \), as the proper ringlet route for the incoming inter-ring new call request.

A. Fuzzy Bridge-Node Congestion Indicator (FBCI)

The FBCI considers four measures, which are STQ length in the ingress buffer (\( Q_{SI} \)), STQ length in the ringlet buffer (\( Q_{SR} \)), the amount of the reserved bandwidth for high class traffic (which are stored in PTQ) (\( B_A \)), and the equivalent capacity of the incoming inter-ring new call [8] (\( E_c \)), as the input linguistic variables to determine the congestion degree of the bridge node at the CW or CCW interface. Note that the equivalent capacity for a new call can be estimated from its traffic description parameters: the peak rate, mean rate, and peak rate duration of packets [6], [8]. Among the four measures, the two STQ lengths are the more essential measures to indicate the degree of the congestion in the RPR bridge. The \( B_A \) occupancy is highly correlated with the STQ due to the fact that the system bandwidth is allocated to high priority traffic first. Also, the amount of \( E_c \) can cause the increment of the STQ length. The output linguistic variable of the FBCI is the congestion degree of the CW or CCW interface of the bridge, denoted by \( C_I \). Term sets for the four input linguistic variables and the output linguistic variable are defined as \( T(Q_{SI}) = \{ \text{Short} (S), \text{Medium} (M), \text{Long} (L) \} \); \( T(B_A) = \{ \text{Few} (F_W), \text{Many} (M_L) \} \); \( T(E_c) = \{ \text{Small} (S), \text{Large} (L) \} \), and \( T(C_I) = \{ \text{Very Low} (V_L), \text{Low} (L), \text{Medium} (M), \text{High} (H), \text{Very High} (V_H) \} \).

Membership functions for each term \( T \) in the term set of input/output linguistic variable \( X \), denoted by \( \mu_T(X) \), should be defined with a proper shape and position. The determination for the membership function is subjective in nature; however, it cannot be selected arbitrarily [9]. Usually, a triangular function \( f(x; x_0, a_0, a_1) \) or a trapezoidal function \( g(x; x_0, x_1, a_0, a_1) \) is chosen as membership function because they are simple and thus suitable for real-time operation [6]. The two functions are given by

\[
f(x; x_0, a_0, a_1) = \begin{cases} \frac{x-x_0}{a_0} + 1, & \text{for } x_0 < x < x_0 + a_1, \\ 0, & \text{otherwise}, \end{cases}
\]

and

\[
g(x; x_0, x_1, a_0, a_1) = \begin{cases} \frac{x-x_0}{a_0} + 1, & \text{for } x_0 < x < x_0 + a_1, \\ \frac{x-x_1}{a_1} + 1, & \text{for } x_1 < x \leq x_1, \\ 0, & \text{otherwise}, \end{cases}
\]

where \( x_0 \) in \( f(\cdot) \) is the center of the triangular function; \( x_0 \) (\( x_1 \)) in \( g(\cdot) \) is the left (right) edge of the trapezoidal function; and \( a_0 \) (\( a_1 \)) is the left (right) width of the triangular or the trapezoidal function. The center, edge, or width of the triangular or trapezoidal membership function is set intuitively but based on the characteristics of the linguistic variables.

Membership functions for \( S, M \) and \( L \) in \( T(Q_{SI}) \) are expressed as \( \mu_S(Q_{SI}) = g\left(\frac{Q_{SI}}{L_s}; 0, \frac{L_s}{4}, \frac{2L_s}{4}\right) \) and \( \mu_M(Q_{SI}) = f\left(\frac{Q_{SI}}{L_m}; \frac{L_m}{4}, \frac{2L_m}{4}, \frac{3L_m}{4}\right) \) and \( \mu_L(Q_{SI}) = g\left(\frac{Q_{SI}}{L_h}; l_h, 1, \frac{2L_h}{4}, 0\right) \), where \( L_s \) is the STQ queue size, and \( l_h \) is the threshold in percentage. Membership functions for \( S, M \) and \( L \) in \( T(Q_{SR}) \) are similar to \( S, M \) and \( L \) in \( T(Q_{SI}) \), respectively. Membership...
functions for $F_w$ and $M_a$ in $T(B_A)$ are defined as $\mu_{F_w}(B_A) = g(B_A; 0, \frac{2}{5}, 0, \frac{3}{5})$, and $\mu_{M_a}(B_A) = g(B_A; \frac{1}{5}, C, \frac{3}{5}, 0)$, respectively, where $C$ is the link capacity. Membership functions for terms in $T(E_r)$, are $\mu_{F_s}(E_r) = g(E_r; 0, R_{ws}, 0, R_{wa})$, and $\mu_{L}(E_r) = g(E_r; 10R_{ws}, C, R_{wa}, 0)$, where $R_{ws}$ and $R_{wa}$ are the minimum demand of the mean rates of the voice and video traffic, respectively. Membership functions for terms of output linguistic variable $C_l$ are defined as $\mu_{L}(C_l) = f(C_l; 0.1, 0, 0.5, 0)$, $\mu_{M}(C_l) = f(C_l; 0.3, 0, 0.5, 0)$, $\mu_{H}(C_l) = f(C_l; 0.75, 0, 1, 0)$, $\mu_{H}(C_l) = f(C_l; 1, 0, 1, 0)$.

As shown in Table I, there are 24 fuzzy rules for FBCI, where the notation "X" in this table represents "don’t care" of the linguistic variable. The order of significance of the input linguistic variables for the FBCI would be $Q_I$, $Q_{SR}$, $B_A$, and $E_r$ in sequence. The bridge will be in high degree of congestion if its two STQ queue lengths are close to or longer than the threshold (the corresponding terms of $Q_{SR}$ and $Q_{SI}$ are Medium or Long). 

FBCI adopts the max-min method for fuzzy inference. In Table I, there are the 4th, 5th, 10th, 11th, and 12th rules which have the same output congestion indication $C_l = L$. The provisional results after applying the min operation on rule 4 for inference is

$$w_4 = \min(\mu_{S}(Q_{SI}), \mu_{M}(Q_{SR}), \mu_{L}(B_A), \mu_{L}(E_r)).$$

Similarly, provisional results of $w_5$, $w_{10}$, $w_{11}$, and $w_{12}$ can be obtained. According to these provisional results, the max operator is applied to yield fuzzy inference result of the output indication $C_l = L$, denoted by $w_L$, by

$$w_L = \max(w_4, w_5, w_{10}, w_{11}, w_{12}).$$

The fuzzy inference results of the output indication $V_L$, $M$, $H$, and $V_H$, denoted as $w_{V_L}$, $w_{M}$, $w_{H}$, and $w_{V_H}$, respectively, can be obtained by the same way. Finally, the fuzzy inference results of FBCI are defuzzified to become a crisp value. The defuzzification method adopted is the center of area defuzzification method. Thus the crisp value of the congestion degree $C_l$ is obtained by

$$C_l = 0.1 \times w_{V_L} + 0.3 \times w_L + 0.5 \times w_M + 0.75 \times w_H + 1 \times w_{V_H},$$

where the coefficient for $w_M$ denotes the center value of the term $T$’s triangular membership function, and the term $T$ is $V_L$, $L$, $M$, $H$, or $V_H$; $0 \leq C_l \leq 1.$

B. PRNN Downstream-Node Fairness Predictor (PDFP)

The bridge uses the received fairRate from associated ringlet of downstream node to discern the congestion degree of the downstream node. However, by the AM considered in this paper, the high variation of the received fairRate would make the bridge not easily detect if its downstream node is in congestion or not. Thus, we originally choose an average received fairRate over the past $m$ periods from the current $n$th period, denoted by $\overline{R}_f(n)$, as the input variable, where $m$ is the size of the observation window, $m \geq 1$. The $\overline{R}_f(n) = \sum_{i=n-m+1}^{n} R_f(i)$ could be appropriate to detect the congestion situation of the downstream nodes during a period, and it is expressed by where $\overline{R}_f(n)$ is the received fairRate at time $n$. Also, since the bridge routes the traffic flows call by call, the next-step mean received fairRate could be more appropriate to determine the route for an accepted new call. Here, a pipeline recurrent neural networks (PRNN) [10] is adopted to design the PRNN downstream-node fairness predictor (PDFP). The fairRate with one-step prediction as a function of $p$ received fairRates and $q$ previously predicted fairRate, denoted by $\hat{R}_f(n+1)$ or $\hat{R}_f(i)$ for convenience, is given by

$$\hat{R}_f(n+1) = H(\overline{R}_f(n), \overline{R}_f(n-p+1); \overline{R}_f(0); \overline{R}_f(n-q+1)),$$

where $\hat{R}_f(i)$ is the previously predicted mean fairRate at $i$th period, $n - q + 1 \leq i \leq n$, and $H(\cdot)$ is an unknown nonlinear function to be determined. The PRNN prediction is a fast, low-complexity, and non-linear one that can approximate the function $H(\cdot)$ [10]-[11]. If a PRNN contains $q$ modules and $M$ neurons per module, the computational complexity would be $O(qM^2)$. However, when the system is in operation and the PRNN has determined each parameter by learning, the computational complexity is reduced to $O(1)$ [11].

C. Fuzzy Route Controller (FRC)

The FRC is to determine the route preference values, $P_s$, for both of CW and CCW ringlets according to themselves $C_I$, $\overline{R}_f$, $R_s$, and $H$. The higher value $P_s$ of a ringlet means that the ringlet is more suitable to accept the incoming new call request. Term sets for the input and output linguistic variables are defined as $T(C_I) = \{\text{Low} (L_c), \text{Medium} (M_c), \text{High} (H_c)\}$, $T(\overline{R}_f) = \{\text{Small} (S_f), \text{Medium} (M_f), \text{Large} (L_f)\}$, $T(R_s) = \{\text{Low} (L_s), \text{High} (H_s)\}$, $T(\overline{H}) = \{\text{Few} (F_s), \text{Many} (M_s)\}$, and $T(P_s) = \{\text{Unsuitable (U)}, \text{Weakly Unsuitable (WU)}, \text{Weakly Suitable (WS)}, \text{Suitable (S)}\}$.

Membership functions for terms of $L_c$, $M_c$, and $H_c$ in $T(C_I)$ are defined as $\mu_{L}(C_I) = f(C_I; 0.1, 0, 0.5, 0)$, $\mu_{M}(C_I) = f(C_I; 0.3, 0, 0.5, 0)$, $\mu_{H}(C_I) = f(C_I; 0.75, 0, 1, 0)$, $\mu_{H}(C_I) = f(C_I; 1, 0, 1, 0)$.

Membership functions for terms of $S_f$, $M_f$, and $L_f$ in $T(\overline{R}_f)$ are defined as $\mu_{S}(R_f) = g(R_f; 0, 0, 0, 1)$, $\mu_{M}(R_f) = g(R_f; 0.5, 0, 0, 1)$, $\mu_{L}(R_f) = g(R_f; 1, 0, 0, 1)$, where $\nu$ denotes the unused bandwidth for the low priority traffic at the bridge and $v = C - B_A$. Membership functions for terms of $F_s$ and $M_s$ in $T(H)$ are defined as $\mu_{F}(H) = g(H; 0, 0, 0, 1)$, $\mu_{M}(H) = g(H; 0.5, 0, 0, 1)$, and $\mu_{H}(H) = g(H; 1, 0, 0, 1)$, where $C$ is the total capacity of the fiber link. Membership functions for terms of $F_s$ and $M_s$ in $T(P_s)$ are defined as $\mu_{F}(P_s) = f(P_s; 0.1, 0, 0)$, $\mu_{M}(P_s) = f(P_s; 0.4, 0, 0)$, and $\mu_{H}(P_s) = f(P_s; 1, 0, 0)$.

As shown in Table II, there are 21 fuzzy rules. The notation "X" in Table II represents "don’t care" of the linguistic variable. The rules are designed according to the load balancing principle for FRC, and the order of significance of the input linguistic variables for the FRC is $C_I$, $\overline{R}_f$, $R_s$, and $H$. The low congestion degree of ringlet interface ($C_I = L_c$) and the large or medium predicted mean received fairRate ($\overline{R}_f = L_f$ or $M_f$) would make the inter-ring new call have more chance to enter the interface. However, the low congestion degree of ringlet interface ($C_I = L_c$), but the small predicted mean received fairRate ($\overline{R}_f = S_m$) which means that the downstream nodes may incur congestion, and the high ringlet service rate ($R = H_s$) would make the variable of the number of hops to destination $H$ significant. If $H$ is Few, the new call will be weakly suitable for the ringlet, while if $H$ is Many, the new call will be weakly unsuitable for the ringlet. On the other hand, the high congestion degree of ringlet interface ($C_I = H_c$) and the small predicted mean received fairRate ($\overline{R}_f = S_m$) would make the inter-ring new call have less chance to enter the interface. However, the high congestion degree of ringlet interface ($C_I = H_c$), but the large predicted mean received fairRate ($\overline{R}_f = L_f$) which means that the downstream nodes are free of congestion, and the high ringlet service rate ($R = H_s$) would similarly make the variable of the number of hops to destination $H$ significant. The fuzzy inference algorithm also adopts the max-min inference method, and the defuzzification method is the center of area defuzzification method.

IV. SIMULATION RESULTS

Simulations are here conducted to compare the performance of proposed FIRC-P, and SPRC [4]. Also, an intuitive queue-length
threshold route controller (QTRC) is included, which determines a proper ringlet depending on the shorter STQ length of ingress buffer. Traffic flows from $R_1$ to $R_0$ at the bridge are considered. Referring to Fig. 1, assume that there are $M = 16$ non-bridges on $R_0$, the link capacity is $C = 10.0$ Gbps, and sizes of the two PTQs (STQs) are 40 Mbyte with threshold $I_{th} = 1/4$. The parameter, $R_{co}$ ($R_{ci}$) is set to 64k/lps (640k/lps). The traffic calls of voice, video, and data are considered in the system. The two-state Markov chain is used to model packet traffic flow of calls with two different arrival rates and two state transition rates. Then the peak rate $R_p$, the mean rate $R_m$, and the mean burst period $T_p$ with the four priori rates can be computed [8].

For voice packet generation process, during the ON (talkspurt) state with state transition rate $4 \times 10^5$, the voice packet size is fixed at 70 bytes and generates with the constant bit rate (CBR) $21 \times 10^2$, and during the OFF (silence) state with state transition rate $8 \times 10^5$, no packets are generated. Thus, the arrival process of a voice source is assumed that $R_p = 21 \times 10^2$, $R_m = 7 \times 10^2$, and $T_p = 1.3s$. Two kinds of video packet generation processes are assumed: the intraframe and interframe generation processes. The intraframe (I-frame) generation process is similar to the voice packet generation process with generating rate $5 \times 10^2$, and a transition rate of $4 \times 10^5$ $(8 \times 10^5)$ of the ON (OFF) state. The arrival process of the I-frame source is assumed that $R_p = 5 \times 10^2$, $R_m = 1 \times 10^2$, and $T_p = 0.1s$. The interframe (B- and P-frames) generation process includes B-frame-bit-rate and P-frame-bit-rate video services. Their generation was characterized by Bernoulli processes with rates $\theta_B = 0.1$ and $\theta_P = 0.02$. The arrival process of the B(P)frame-source is assumed that $R_p = 2 \times 10^2$ $(10^2)$, $R_m = 2 \times 10^3$ $(2 \times 10^4)$, and $T_p = 0.01s$. The data packet generation process includes high-bit-rate and low-bit-rate data services. Their generation are also characterized by Bernoulli processes with rate $\theta_1 = 0.1$ and $\theta_2 = 0.02$. For high(low)-bit-rate of data source, it is assumed that $R_p = 7 \times 10^3$ $(3.5 \times 10^2)$, $R_m = 7 \times 10^3$ $(7 \times 10^2)$, and $T_p = 0.03s$. The I-frame packet size is fixed at 1000 bytes and generated with CBR; the B(P)-frame and data packet sizes are uniformly distributed over 100 and 1518 bytes and is generated with the variable bit rate (VBR).

Fig. 4(a), (b), and (c) show the average packet dropping probability, the average packet delay, and the throughput, respectively, versus the bridge traffic intensity in an unbalanced scenario. Here, the probability of destination of nodes for new calls is non-uniformly distributed, where node 1 (9) to node 8 (16) are with the same probability $\frac{1}{7} (\frac{1}{15})$. It is found that the packet dropping probabilities and the average packet delays of CW and CCW ringlet by FIRC-P and QTRC are still almost the same, while these by SPRC are quite different. We can deduce that the FIRC-P can indeed perceive the congestion degree of CW and CCW ringlets and sophisticatedly achieve the load balancing by overall considering the congestion degree, the received fairRate, the ringlet service rate, and the number of hops to destination. QTRC could avoid enlisting a longer STQ length of the ingress buffer due to its routing policy. Moreover, FIRC-P improves by about 10% (220%) in packet dropping probability, and by 13% (18%) in average packet delay, by about 6% (19%) in throughput in heavy traffic intensity over QTRC (SPRC). The SPRC gets a worse throughput because it routes most calls via the CCW ringlet for most destinations of incoming new calls are on the up.

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**TABLE I**

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Fig. 4. The performance comparison for FIRC-P, SPRC, and QTRC in the balanced scenario

Fig. 5. The performance comparison for FIRC-P, SPRC, and QTRC in the unbalanced scenario

side of the bridge.

V. CONCLUSIONS

This paper proposes a fuzzy inter-ring route control with PRNN predictor (FIRC-P) for bridged resilient packet rings (RPRs). The FIRC-P uses not only the two STQ lengths but also the reserved bandwidth for highest priority traffic and the equivalent bandwidth of an incoming new call to indicate the congestion degree of the interface of the bridge. It specially predicts the mean received fairRate to detect the congestion degree of downstream-node. Moreover, FIRC-P further considers the number of hops to destination and the service rate of the bridge, besides the indication of the congestion degree of bridge-node by FBCI and the prediction of the mean received fairRate by PDFP, to decide a route preference value of the interface by FRC. The rule structure of FRC is based on the load balancing principle. Finally, the FIRC-P chooses a ringlet with higher preference value of route to forward the call to the destination. Simulation results show that the FIRC-P effectively follows the load balancing principle and achieves the better performance than the queue length threshold route controller (QTRC) and the shortest path route controller (SPRC). These justify that the FIRC-P is sophisticatedly configured and well designed in choosing the input linguistic variables, defining membership functions, and designing rule base to determine a proper ringlet for an incoming new call. The design philosophy of FIRC-P can be applied to any kind of bridged optical packet rings. Moreover, the FIRC-P is feasible for real applications for that the computational complexity and the cost of FIRC-P are simple and effective, respectively.

REFERENCES