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「支援下一代無線與 FTTx 擷取之光纖都會網路技術」
(Optical Metro Core Network Transport Supporting Next Generation Wireless and FTTx Access Technology)
子計畫三：
「光纖擷取網路技術之分析研究 (Optical Access Networking Technology)」

計畫編號：NSC 92-2213-E-009-119
執行期限：92 年 8 月 1 日至 93 年 7 月 31 日
主持人：張仲儒教授 國立交通大學電信工程學系暨研究所
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一、中文摘要

光纖迴路（FITL, Fiber in the Loop）包含以光纖為傳輸媒體的高頻寬光傳輸系統與以此系統為提供服務之傳輸媒體. 隨著各設備發展廠商在光電通訊技術與技術標準化的發展, 以及網際網路(Internet)的快速發展全球資訊網(World Wide Web)的風行，以及數位多媒體內容的增加, 大眾對高速網路的網路頻寬需求呈倍數般爆量成長, 須提高對於寬頻光纖網路系統與光網路的建置, 提供更多更快的數位網路服務。

在 EPON 的媒介接取控制層規約與排程控制機制方面，本計畫已針對 EPON MAC Control Layer 進行研究與電腦模擬(Emulation)，以及對此層的 OAM 功能做法進行研究，並完成 MPCP for EPON link performance 探討與電腦模擬。

在 EPON 排程控制機制方面，本計畫針對「IPACT」方法加以改良，利用預測器（Predictor）預測 traffic 在 ONU Waiting Queue 中之長度，經由演算將 ONU 所需之時槽大小算出後送至 OLT, 決定下一次 OLT 同意 ONU 所能傳送之時槽大小。但此時槽大小將受到限制，不得大於預設之最大時槽大小（Pre-Defined Maximum Timeslot Size），亦即 ONU 所能傳送之資料最多不會超過此最大時槽大小。

本計畫研究在 EPON 網路架構中加入預測器，對 ONU 所需之時槽大小作動態之配置及以 QLP, LQF 方式傳送，且利用模擬方式分析，討論此方法對於封包延遲（Packet Delay）及頻寬利用率（Bandwidth Utilization）之改善情況，並與前述之方法做比較，以求得最佳之預測器設定，達成在 EPON 中公平及有效率（Fair & Effective）資料傳送之目的。

關鍵字：乙太被動型光纖網路(EPON)、媒介擷取控制(MAC)、多點控制通訊協定(MPCP)、光纖線路終端(OLT)、光網路(終端)元件(ONU)

Abstract

For the excellent performance of silica fiber, such as wide bandwidth, low transmission loss, lightweight, and immunity to interference, it is broadly deployed in long haul trunk and is gradually migrated into the access network to form the Fiber-In-The-Loop (FITL) architecture. Many efforts have been made to overcome the economic barrier for the mass deployment of FITL systems since it can improve the quality of the network and enhance the flexibility to provide the new broadband services. The rapid spread of the World Wide Web and increasing applications of digital contents have significantly increased the demand for high-speed Internet access. The networking of company LANs for intranets and extranets has also been increasing. They all need the broadband fiber access system and optical network to provide such high bandwidth and services.

We have studied the IEEE 802.3ah EPON MPCP protocol, and design the EPON model for the simulation. We have developed six different scheduling mechanisms for the EPON network, and made the comparison of the system performance during specific traffic.

We designed the linear prediction algorithm to improve the bandwidth utilization and minimize the packet delay of the EPON system. The linear predictor effectively improves some

efficiency of the utilization when the system approaches high traffic loading. The QLP and LQF mechanism have also used in our simulation. Finally, some simulation results is showed.

Keyword: EPON, MAC, MPCP, OLT, ONU.

二、Motivation and Objectives

1. Study of EPON MAC Layer Protocol

THE IEEE 802.3 Ethernet LAN protocol is a peer-to-peer communication transmission architecture. But, the Ethernet over Passive Optical Networks (EPON) adopts shared media access architecture (because of many ONUs commonly shared one single fiber). Thus, EPON needs a MPCP to manage the ONU upstream messages.

The IEEE 802.3 Ethernet in the First Mile (EFM) Task has been set up an improved MAC Control Sublayer (Multi-Point Control Protocol, MPCP) to support the PON physical interface. There are three types:

a) The upstream and downstream link between OLT and ONUs use different fiber as transmission media. The downstream traffic is TDM, and the upstream uses TDMA.

b) Use Full-Duplex transmission by one fiber between OLT and ONUs. No CMA/CD.

c) All customers' services are switched by way of OLT. Messages from each ONU can't link directly.

2. Design of Prediction-Based Scheduling Algorithm for EPON

EPON could provide diversified services such as Voice Communications, Broadcast Video, Video Conferencing, and Data. The concept of optical Ethernet has popped up toward the access network. The Ethernet over Passive Optical Network (EPON) will become a dominant technology for those services offered by EPON may range from simple telephony to multimedia communication.

While the backbone network bandwidth grows tremendously, the access network still remains the bottleneck. Ethernet passive optical networks (EPONs), which represent the convergence of low-cost Ethernet equipment and low-cost fiber infrastructure, appear to be one of the best candidates for the next-generation access network.

In the upstream direction, an arbitration mechanism is required at the ONUs to share the capacity without collisions. It can be achieved by allocating timeslots to each ONU, fig. 1 shows a concept of timeslot allocating scheme in the upstream direction. Each timeslot is capable of carrying several Ethernet packets. An ONU should buffer packets received from a subscriber until its timeslot arrives. When a timeslot arrives, the ONU transmits its packets at full channel speed. The duration of timeslot may be fixed (static) or variable (dynamic). Thus, the timeslot duration of ONUs is our design focus to improve the performance of the EPON system.

三、Approach

The objective of this project in the first year focuses on the performance evaluation of EPON scheduling in EPON MAC Layer MPCP Protocol, and design a gated-based and Prediction-based Scheduling algorithm. To achieve this purpose, the approaching methods and procedures are described as following:

- **Study of EPON MAC Layer Protocol**
  - Collect and study the newest IEEE/ITU-T standards, related EPON paper and documentations, e.g., IEEE 802.3ah D3.3 Specification, Ethernet over point-to-multipoint protocol.
  - Study the architecture of Ethernet over active/passive optical networks.
  - Analyze the priority setting/provisioning of differentiate service of EPON.
  - Design the simulation programs to emulate the EPON model for the performance of the scheduling.
- **Design of Prediction-Based and QLP-LQF Scheduling Algorithm for EPON**

We have studied six types of scheduling mechanism for the EPON upstream transmission, including the prediction-based algorithm. Besides, we found several methods to deal with Packet Delay, Bandwidth Utilization, and Fair & Effective parameters, simultaneously.

- ◆ Study the IEEE 802.3ah D3.3 Specification MPCP. Made a comparison with APON/GPON.
- ◆ Collect and study the traffic pattern and user behavior to establish the real voice/data traffic.
- ◆ Following the above procedure, study a predictor mechanism for the upstream transmission.

We have finished the following work:

- ● **Study of EPON MAC Layer Protocol**
  - ◆ Finished the study of IEE 802.3ah D3.3 Specification, and ITU-T standards.
  - ◆ Finished the research of the architecture for Ethernet over active/passive optical networks.
  - ◆ Finished the analysis of the priority setting and timeslot provisioning in differentiate service of EPON.
  - ◆ Achieved the simulation programs for emulating the scheduling performance of the EPON network.
  - ◆ Finished a dynamic Bandwidth Allocation Algorithm Design for EPON.
- ● **Design of Prediction-Based Scheduling Algorithm for EPON**

We have finished four scheduling algorithms for the EPON upstream transmission, and compared to the TDMA, IPACT algorithm [3] to explore the impact of different scheduling algorithms on EPON performance.

- ◆ Finished study of the IEEE 802.3ah D3.3 Specification MPCP, and made a comparison with APON/GPON.
- ◆ Established the real voice/data traffic of massive user in ONUs.
- ◆ Achieved a predictor mechanism for the upstream transmission.

The scheduling of EPON defined in IEEE 802.3ah is IPACT (Polling scheme based) [1-6]. We have finished six types of scheduling algorithms, and compare the performance by simulation. The following scheduling methods are depicted: (1) TDMA, (2) IPACT, (3) IPACT + Prediction, (4) DBA, (5) DBA with MTW, and (6) DBA with MTW. + Prediction. The methods (4) to (6) are the proposed Dynamic Bandwidth Allocation (DBA) algorithms:

(1) Fixed_Length Timeslot (TDMA): OLT sends Grant to each ONU by fixed length, for example, 1 ms for every ONU, maximum for 4 Grants (4 ms) in one ONU.

(2) Poll_Request (IPACT): OLT polls each ONU sequentially, and every ONU responds his queue length back to OLT. ONUs send REPORT MPCPDU to OLT, and OLT assigns the ONUs’ bandwidth in the next cycle time according to the former request in REPORT MPCPDU. The minimum transmission window assigned by OLT to each ONU is 0.0064 ms (64 kbits), and the maximum one is 4 ms. Those asking REPORT values with 1 ~ 4 ms will be assigned by its request value.

(3) IPACT + Prediction: following IPACT for the normal GRANT procedure and appending a prediction window (by Linear Predict Algorithm) after GRANT for the total ONU transmission length in next cycle time.

(4) Dynamic Bandwidth Allocation (DBA): OLT assigns the ONU Grand according to the ONU requests with no upper bound.

(5) DBA with Maximum Transmission Window (MTW): OLT assigns the ONU Grand according to the ONU requests but sets the maximum MTW value as 12 ms. The lower bound is 64 kbits.

(6) DBA with MTW + Prediction: Besides setting the maximum MTW value as 12 ms, OLT assigns the ONU Grand according to the ONU requests accompany with the

prediction results through Linear Predict Algorithm.

The Linear Predict Algorithm is depicted as following:

a) Predictive window reservation is set at OLT site.

b) ONU asks bandwidth by the REPORT packet.

c) OLT assigns Grant and bandwidth to ONUs by (REPORT + Prediction).

d) Predict value (P): represents the number of packet arrivals during grant cycle time interval. The prediction window is set between 64 kbits to 1 Mbits and increases every 64 kbits.

e) Trend value (T): set the variation between different cycles of R as Trend.

f) (R, T) set: when R is increasing, it means that the Trend is going UP and packets are accumulating at the ONU queue, therefore the P value should be increased.

   We say that (R, T) is positive correlation and P will be the correlation coefficient of R and T. $0 < P < 1$.

   Otherwise, decreasing P to basic window size immediately. We say that (R, T) is negative correlation. $-1 < P < 0$.

g) R=0 processing: when R=0 first time, set P=Min_Window (which equals 64 kbits length); R=0 again, set P=0; R=0 for the third times and the after, set P=Min_Window by way of exponential backoff algorithm.

h) Time_out setting: when R=0 for sometime (> 10 min or 10000 counters), set ONU deregister and share its bandwidth to other ONUS until that ONU gets back (re-register).

i) When P is approaching precision, R should be closed to Min-Tx_window (for our model, it is 4 ms for Fixed_length algorithm, and 1 ms for IPACT algorithm).

j) When P is a worse prediction, it will waste upstream bandwidth. So, it needs to adjust R and P value simultaneously.

k) Using ARMA (p, q) model to count the P value:

$$Z_t = a_0 + a_1 \cdot Z_{t-1} + a_2 \cdot Z_{t-2} + \ldots\ldots + b_1 \cdot Q_{t-1} + b_2 \cdot Q_{t-2} + \ldots + b_t$$

   p → Auto Regressive (AR) model

   q → Moving Average (MA) model

● Design of QLP-LQF Scheduling Algorithm for EPON

We consider an EPON access network consisting of an OLT and N ONUs (fig. 2) [7-11]. Inside the ONU, We adopt independent priority queues to support different class of services. The mechanisms of each queue are simply buffering the incoming packets and sending these packets out based on the decision of queue manager which is the arbitrator of ONU. The functions of queue manager are receiving and decoding GATE message, fetching and transmitting appropriate amount of packets from each queue to OLT, and generating REPORT message after transmitting user information.

The Decision Maker inside the OLT is an arbitrator in EPON access network. It has the ability to decide the start and end of transmission of each ONU. The decision mechanism is based on our scheduling algorithms which consider queue occupancy, packet delay, and fairness among all ONUs. We will discuss the detailed algorithms later.

The proposed scheduling scenarios are gated-based and predicted-based schemes. The inputs of the scheduler (fig. 3) are the information stored in RAM, including the updated RTT of N ONUs and the predicted additional occupancies of all 3N queues. For real-time services, i.e. voice and video service, the packet delay must be bounded so that the quality of service can be maintained. For non-real-time service, i.e. best-effort service, the goal of our scheme is to avoid packet blocking under bursty condition and to maintain delay fairness between best-effort-data queue.

For real-time service, we define the

predicted queue occupancies of voice service are $Q_{11}, Q_{21}, ...,$ and Q_{N1} , video service are $Q_{12}, Q_{22}, ...,$ and Q_{N2} . Then the capacity allowed transmitting for each voice and video queue are:

$$G_{i1} = f_{voice}(Q_{i1}) = \min(L_{\max}, Q_{i1}) \text{ , } i = 1, 2, ..., N$$

$$G_{i2} = f_{video}(G_{i1}, Q_{i2}) = \min(L_{\max} - G_{i1}, Q_{i2}) \text{ , } i = 1, 2, ..., N$$

where L_{max} is the maximum allowable transmission capacity of real-time services during one cycle. And then we can derive the residual available capacity R as follows:

$$R = (T_{\max} - N \cdot b) \times R_N - \sum_{i=1}^{N} (G_{i1} + G_{i2}) \text{ ,}$$

where T_{max} is the maximum cycle time, b is the guard time, and R_N is the line rate of the EPON.

For best-effort data service, there is no packet delay criterion, but there are two important issues which must be taken into account, one is the packet blocking probability, the other is the fairness of packet delay among all ONUs. Due to the bursty property of self-similar traffic, the queue occupancies of best-effort data service may be quite different. Under this condition, we want to maintain the fairness of packet delay of all ONUs, so that the best-effort data users will have the same quality. In addition, we also want to maintain the fairness of packet blocking probability.

We define the fairness index for packet delay and packet blocking probability as follows:

$$I_D = \frac{\left[\sum_{i=1}^{N} D_i\right]^2}{N \times \sum_{i=1}^{N} (D_i)^2} \quad \text{and} \quad I_{\mathrm{B}} = \frac{\left[\sum_{i=1}^{N} P_{\mathrm{B},i}\right]^2}{N \times \sum_{i=1}^{N} (P_{\mathrm{B},i})^2}$$

where D_i and $P_{B,i}$ are the average packet delay and average packet blocking probability of ONU_{i}. Then, the overall fairness index F can be defined as:

$$F = x \cdot I_D + (1 - x) \cdot I_B \text{ ,}$$

where x is a weighting factor.

We propose two scheduling schemes to achieve the goal of fairness. The first one is Hybrid Longest Queue First – Queue Length Proportional (Hybrid LQF – QLP) scheme, the other is Hybrid Equal Queue Length – Queue Length Proportional (Hybrid EQL-QLP) scheme. Both schemes have a queue length threshold. For Hybrid LQF-QLP scheme, if all the queue occupancies are lower than queue length threshold, then bandwidth assign to each queue is proportional to the corresponding queue occupancy (QLP). If any queue occupancy exceeds queue length threshold, then the queues with larger queue occupancies will be assigned more resource (LQF+QLP).

Similarly, for Hybrid EQL-QLP scheme, if all the queue occupancies are lower than queue length threshold, then QLP scheme is adopted. But if any queue occupancy exceeds queue length threshold, then EQL is adopted. EQL scheme tries to balance the queue occupancy of each queue.

四、Conclusion and Discussion

The performance of DBA algorithm is showed in fig. 4, and detailed transmission packets between OLT and ONUs is listed in table 1. Our assumption is that packets generated by Poisson distribution with changing rate from 50 pps (packet per second) to 20,000 pps.

The greedy DBA (algorithm (4)) algorithm has the maximum transmission rate but with a fairness problem for greedy ONUs. TDMA (algorithm (1)) algorithm has the worst performance compared to the other algorithms. The IPACT (algorithm (2)) gets better performance than TDMA, but the prediction-based algorithm gets even better since it can make good guess of the arrivals in one cycle time interval.

By adopting the proposed QLP-LQF Scheduling Algorithm, the fairness of packet delay and packet blocking probability can be taken into account simultaneously. Fig. 5 and fig. 6 show the packet blocking probability fairness index and packet delay fairness index of data service. The LQF and EQL scheme can achieve better performance in packet blocking probability fairness, but lose packet delay fairness. On the contrary, the QLP scheme has better fairness in packet delay, but weak in packet blocking probability. If we consider these two indexes together, i.e. overall fairness index, the hybrid schemes would be better than LQF, EQL and QLP scheme.

五、Next-year Work

We will continue the project according to results of this year. In the Study of AON MAC Layer Protocol and scheduling, we will study the ITU-T ASON/ATON, and PON standards; Discuss the service priority of AON architecture; Simulate the bandwidth utilization and packet delay of AON/EPON networks; Enhance the DBA scheduling algorithm.

In the enhanced Prediction-Based Scheduling Algorithm for EPON, we will check the EPON final standard to our simulation model; Making a new traffic control mechanism to meet the IEEE 802.3ad requirements; developing a new LAN traffic pattern for the self-similar packets; applying the optimum traffic pattern to the simulation programs to get the optimum results; enhancing the effective prediction algorithm to improve the minimization of packet delay and maximization of bandwidth utilization.

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七、Appendix

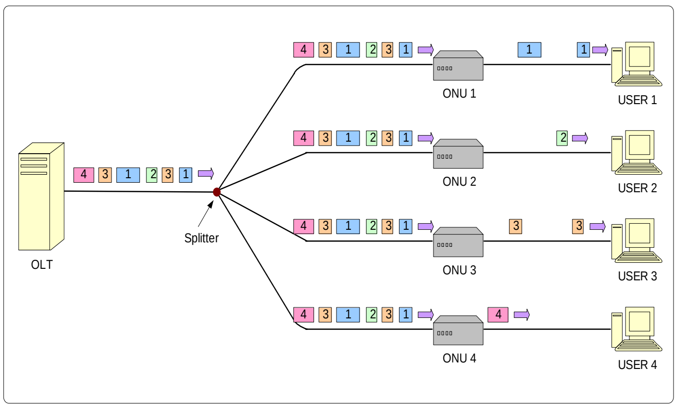

Figure 1: Upstream transmission in EPON

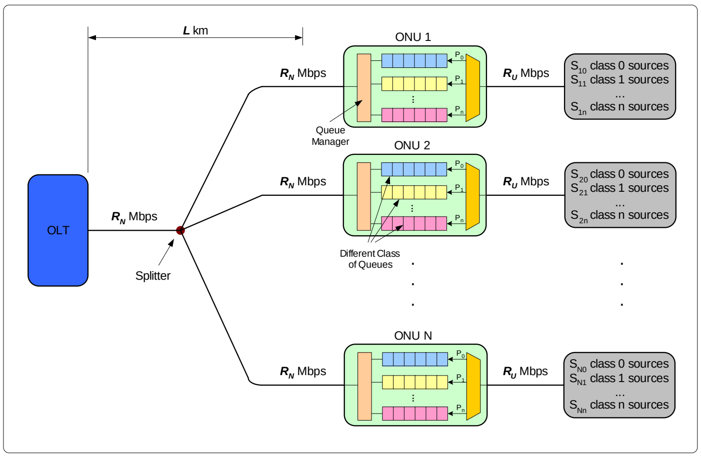

Figure 2: EPON system model

SS rate (p	TDMA	Polling	Polling + F	Dynamic	Dynamic_M	Dynamic+I
50	0.006257	0.006257	0.005358	0.004336	0.004336	0.005358
100	0.013595	0.011223	0.013427	0.012361	0.012372	0.013427
200	0.027733	0.025331	0.027317	0.027357	0.02738	0.027317
400	0.050654	0.051574	0.052035	0.048193	0.051978	0.052035
800	0.105219	0.113021	0.11144	0.113305	0.11351	0.11144
1600	0.218639	0.236812	0.238558	0.222064	0.237191	0.238558
3200	0.43792	0.432891	0.449104	0.446201	0.447207	0.449104
6400	0.896334	0.878908	0.894724	0.846028	0.88833	0.894724
10000	0.922983	0.935899	0.936812	0.657031	0.929962	0.938347
20000	0.95188	0.944185	0.943181	0.962104	0.953535	0.953631

Table 1: Detailed transmission packets of simulation of six scheduling algorithm in EPON

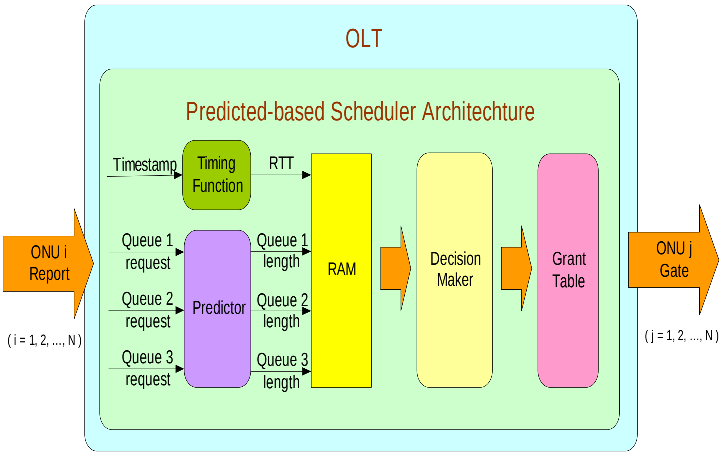

Figure 3: Scheduler architecture

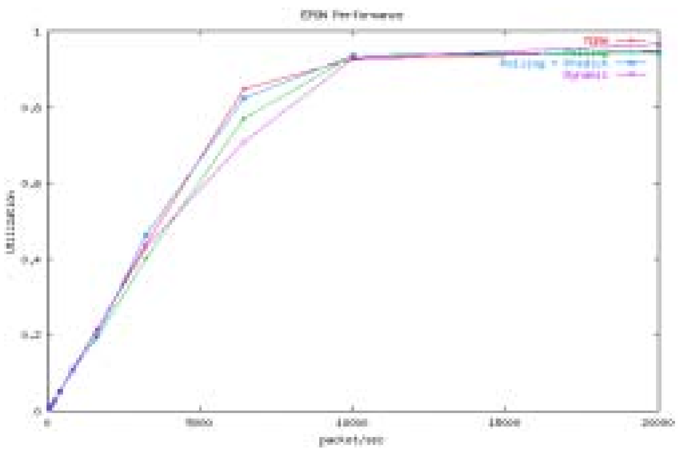

Figure 4: Upstream performance of six scheduling algorithm in EPON

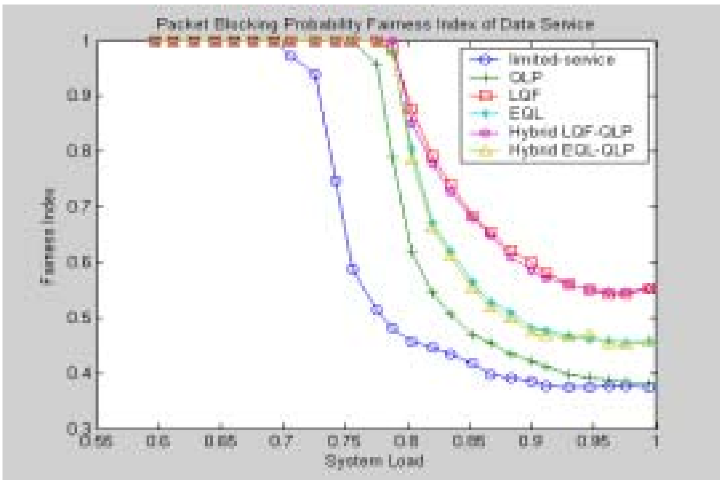

Figure 5: Packet blocking probability fairness index

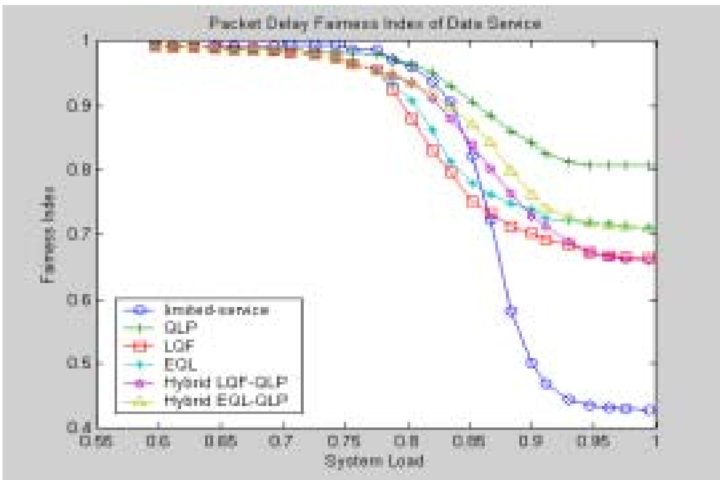

Figure 6: Packet delay fairness index