Performance Evaluation of Standard IPACT for Future Long Reach Passive Optical Networks (LR-PON).

A. M. Ragheb[1], M. Elnamaky[2], H. Fathallah[3] , and H. T. Mouftah[4]
[1,3]Electrical Engineering Department, - King Saud University, Saudi Arabia
[2] PSATRI - King Saud University, Saudi Arabia
[4] School of Information Technology and Engineering, University of Ottawa

Abstract. Ethernet Passive Optical Networks (EPONs) have been regarded as one of the best choices for next generation access networks. Many algorithms have been suggested to boost the efficiency of EPON. Interleaved Polling with Adaptive Cycle Time (IPACT) algorithm was one of the first solutions to dynamically allocate bandwidths. In this paper, modeling and simulation of Ethernet Passive Optical Networks (EPONs) have been developed using new Matlab Simulink tool *SimEvents* considering the IPACT algorithm as the dynamic bandwidth allocation (DBA) scheme. Models for low span area with moderate network load and long span area (Long-Reach PON) have been investigated. Simulation results show a consistent performance of the IPACT scheme. Results also show that the implementation of IPACT algorithm is not preferable for long span area (LR-PON).

Keywords : Ethernet Passive Optical Networks, EPON, Interleaved Polling with Adaptive Cycle Time, IPACT, *SimEvents*.

Introduction
In recent years, the demand on bandwidth capacity of telecommunication networks and the speed of local-area networks (LANs) have rapidly increased. With the ever-increasing users demand for various broadband applications, the subscriber access networks covering the "last mile" areas are still considered as the bandwidth bottleneck in today's telecommunication infrastructure (Zheng, 2009). To get rid of this bottleneck, passive optical networks (PONs) have been viewed as a smart solution to implement the subscriber access networks as fiber-to-the-home (FTTH), fiber-to-the-curb (FTTC), and fiber-to-the-building (FTTB) (Zhu, 2006).

Ethernet passive optical networks (EPONs) have received a great attention as one of the promising solutions because of its advantages over the traditional access networks. Larger bandwidth capacity, longer operating distance, lower equipment and maintenance cost, and easier update to higher bit rates were the main merits of the EPON networks (Zheng, 2009) & (Kramer, 2001). In an EPON system all *Optical Network Units* (ONUs) access the shared fiber channel to reach the *Optical Line Terminal* (OLT) through 1: N passive splitter/combiner, as shown in Fig.1. In the downstream direction (from OLT to ONUs), data frames are broadcasted to all ONUs. Each ONU extracts its information based on MAC address basis. In the upstream direction (from ONUs to OLT), data from ONUs are transmitted over the same fiber channel to reach the OLT in dedicated timeslots. Thus, it is a point-to-multipoint system in the downstream direction and a multipoint-to-point system in the upstream direction (Zhu, 2006) & (Song, 2009).

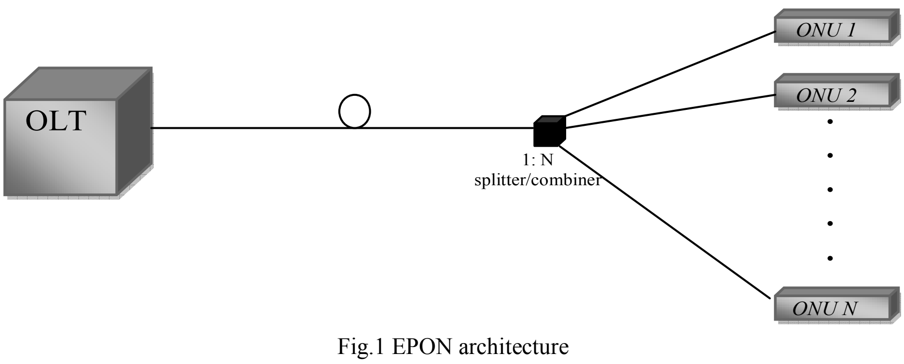

Fig.1 EPON architecture

In order to share the medium by different ONUs, many multiple access schemes based on dynamic bandwidth allocation (DBA) algorithms have been developed. Interleaved Polling with Adaptive Cycle Time (IPACT) scheme is widely regarded as a pioneer solution to dynamically allocate bandwidth to different ONUs in EPONs networks

(Zhu, 2008). In this scheme, the OLT polls each ONU for the number of bytes each ONU has to transmit. After receiving the *requests* from all ONUs, the OLT uses the DBA algorithm to *grant* the appropriate bandwidth (timeslot) to each ONU. Since the polling of each ONU is interleaved, where the next ONU is polled before the transmission from previous one has arrived at the OLT, this scheme provides a statistical multiplexing for ONUs and results in efficient upstream channel utilization (Song, 2009).

Based on this scheme, many dynamic bandwidth allocation (DBA) schemes have been developed to improve the performance of the EPON network. In (Byun, 2003), Byun *et al.* proposed an estimation-based dynamic bandwidth allocation algorithm to keep the queue length of each ONU low and to improve the packet delay on the EPON network. In addition, (Zhu, 2008) proposed the IPACT with Grant Estimation (IPACT-GE) scheme, which can achieve shorter average packet delay by estimating the amount of new packets arriving between two consecutive polls and grant ONUs with additional bandwidth. Moreover, (Song, 2009) proposed a multi-thread polling algorithm for Long-Reach PON (LR-PON), which can extend up to 100 km or higher. Song based his algorithm on having multiple polling processes running simultaneously in order to reduce the average packet delay.

In this study, the EPON network has been modeled and successfully simulated using new Matlab simulink tool *SimEvents*. Then, the performance of IPACT algorithm has been analyzed in both traditional EPON and Long-Reach PON (LR-PON) networks. This paper is organized as follows. Section II reviews the Multi-Point Control Protocol (MPCP). Interleaved Polling with Adaptive Cycle Algorithm (IPACT) is explained in section III. System modeling using Matlab *SimEvents* and simulation results are described in section IV. Section V concludes the study.

Multi-Point Control Protocol

Multi-Point Control Protocol (MPCP), developed and standardized by the IEEE 802.3ah Task Force, is a signaling protocol that facilitates the transmission of multiple ONUs (IEEE 802.3ah, 2009) & (Zheng, 2006). MPCP has been used as a bandwidth negotiation tool in EPON networks to exchange information between OLT and ONUs. Each ONU reports its bandwidth demand to the OLT, which in return sends bandwidth allocations to each ONU (Zheng, 2009).

There are two operation modes of the MPCP; auto-discovery mode and normal mode. Auto-discovery mode is responsible of discover newly connected ONUs, calculate associated round trip time (RTT), and get the MAC address of that ONU (Kramer, 2005). In this mode of operation, the MPCP relies on three Ethernet control messages, REGISTER, REGISTER_REQUEST, and REGISTER_ACK. In normal mode, the MPCP depends on two 64-bytes Ethernet control messages; REPORT and GATE. The REPORT message is generated by each ONU and piggybacked at the end of data timeslot to inform the OLT about ONU's queue status. Upon receiving the REPORT message, the OLT starts allocating bandwidths and sends its bandwidth allocations back to each ONU in the form of GATE messages, as shown in Fig.2.

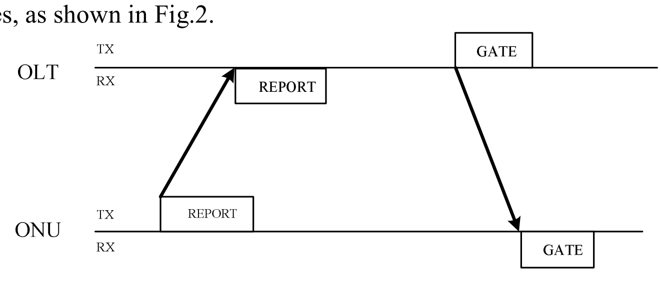

Fig.2 REPORT & GATE messages flow.

Interleaved Packet with Adaptive Cycle Time

In this section we will give an overview on the Interleaved Packet with adaptive Cycle Time (IPACT) algorithm and how the scheduling of the control messages is achieved.

A. IPACT Algorithm. For simplicity of illustration, we assume that we have an EPON network with three ONUs as shown in Fig.3 (Kramer, 2002):

1. Assume that at time t_0 OLT knows exactly how many bytes buffered at each ONU and the round trip time (RTT) to each ONU. OLT stores this information on its polling table and starts sending a GATE message to ONU1. The GATE message should contain the ID of ONU1 as well as the size of the granted window.
2. Once ONU1 receives its GATE message, it starts sending its buffered data up to the granted window size - 8000 bytes in this example. At the end of the transmission window, ONU1 will generate and send its REPORT control message, which allows the OLT to know exactly the newly requested window size for the next cycle - 600 bytes in this example.
3. Since the OLT knows exactly the round trip time (RTT) of ONU1 and how many bytes this OUN will send, it can schedule the control GATE message of ONU2 so that there will be no data collision.
4. Upon receiving data and REPORT message from ONU1, the OLT updates its polling table for the next polling cycle.
5. Similarly, the OLT can schedule the transmission of ONU3 GATE message as it knows the RTT of ONU2 and how many bytes ONU2 will send.

Polling Table

ONU	Bytes	RTT
1	8000	200
2	3000	150
3	2000	100

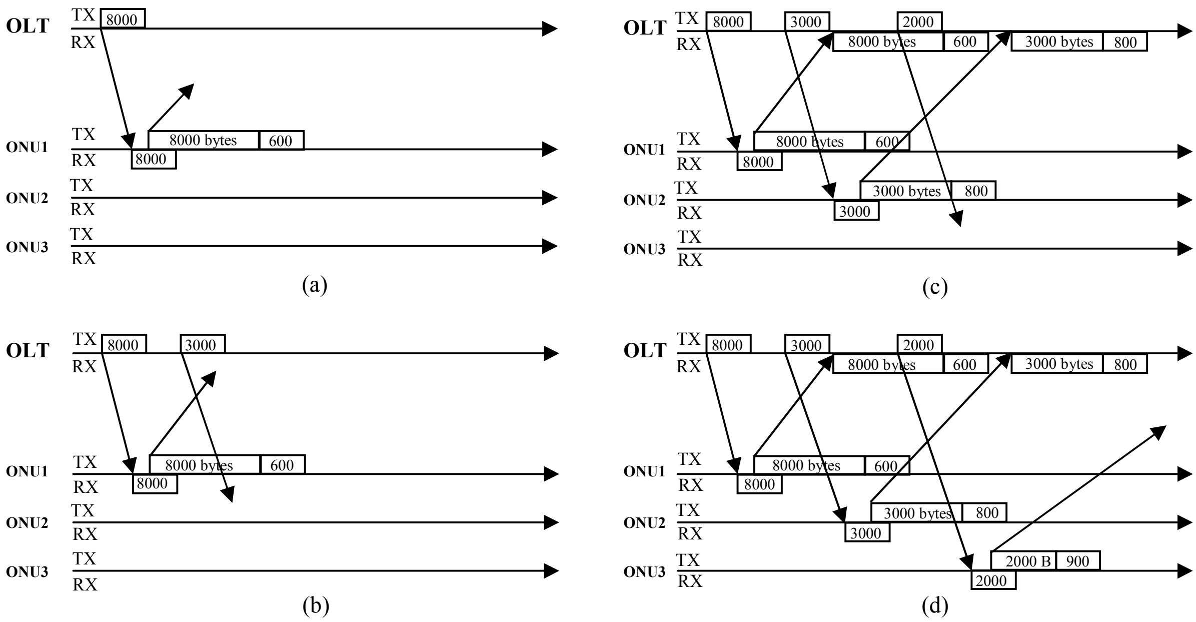

Fig.3 Steps of the IPACT algorithm.

B. GATE Messages Scheduling. GATE messages for different ONUs are being scheduled using the following formula (Kramer, 2002):

$$G_j^{[i+1]} = \max \begin{cases} G_j^{[i]} + r^{[i]} + r^{[i+1]} + \dfrac{W_j^{[i]}}{R_U} + B \\ G_{j-1}^{[i+1]} + r^{[i+1]} \end{cases} \tag{1}$$

where:

$G_j^{[i]}$ is the time when j^{th} grant to i^{th} ONU is transmitted

$r^{[i]}$ is the round trip time for the i^{th} ONU

$W_j^{[i]}$ is j^{th} the window size for i^{th} ONU

R_U is the transmission speed (bit rate)

B is the guard time between data received from ONUs (in μs)

The top line in Eq. (1) states that the GATE message scheduled to ONU_{i+1} such that its *request* arrives after a guard band starts at the end of the transmission window from ONU_i , as shown in Fig.4. The bottom line states that the GATE message cannot be sent before the previous *request* from the same ONU is received, i.e., the interval between two successive GATE messages to the same ONU is at least the round-trip time to that ONU. This is because the GATE message needs information contained in the previous *request* (Kramer, 2002).

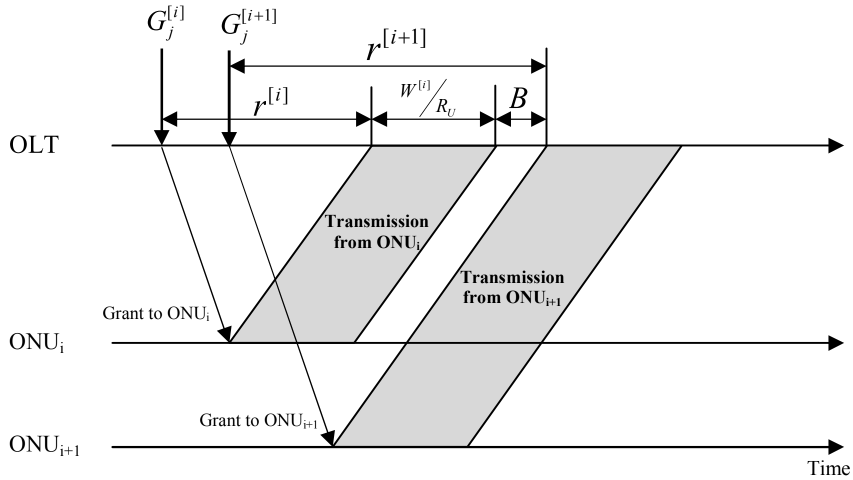

Fig.4 GATE messages Scheduling

System Modeling & Simulation Results

SimEvents software extends Matlab Simulink software with a discrete-event simulation (DES) model of computation. With *SimEvents* software you can develop activity-based models of systems to evaluate system parameters such as congestion, resource contention, and processing delays (Mathworks, 2009). Discrete-event simulations typically involve discrete items of interest. These items are called entities in *SimEvents* software. Entities can pass through a network of queues, servers, gates, and switches during a simulation. Entities can carry data, known in *SimEvents* software as attributes. One can configure entities with user-defined attributes, and then aggregate entities and attributes to model data hierarchy and transport in different applications such as; packet-based networks, mission planning, supervisory control, real-time operating systems, and computer architecture.

Using this powerful Simulink tool, *SimEvents*, an experimental model has been developed for the EPON network to evaluate the performance of the IPACT algorithm. As shown in Fig.5, the model is consisting of a single OLT and 16 ONUs. Both OLT and ONUs are consisting of two parts, transmitter and receiver. Each ONU is assigned a downstream and an upstream propagation delays. The upstream and downstream propagation delays have been selected randomly with a uniform distribution over the interval of [50 μs, 100 μs]. These values correspond to a coverage distances ranging from 10 to 20 *km* between OLT and ONUs. The transmission data rate in the downstream direction and upstream direction is set to be 1000 Mbps. The maximum transmission window size from a single ONU is set to 15000 bytes, which is equivalent to a maximum cycle time of 2 *ms* with a guard band of 5 μs. ONUs packet sizes are uniformly selected between 64 bytes and 1518 bytes according to IEEE 802.3 standards.

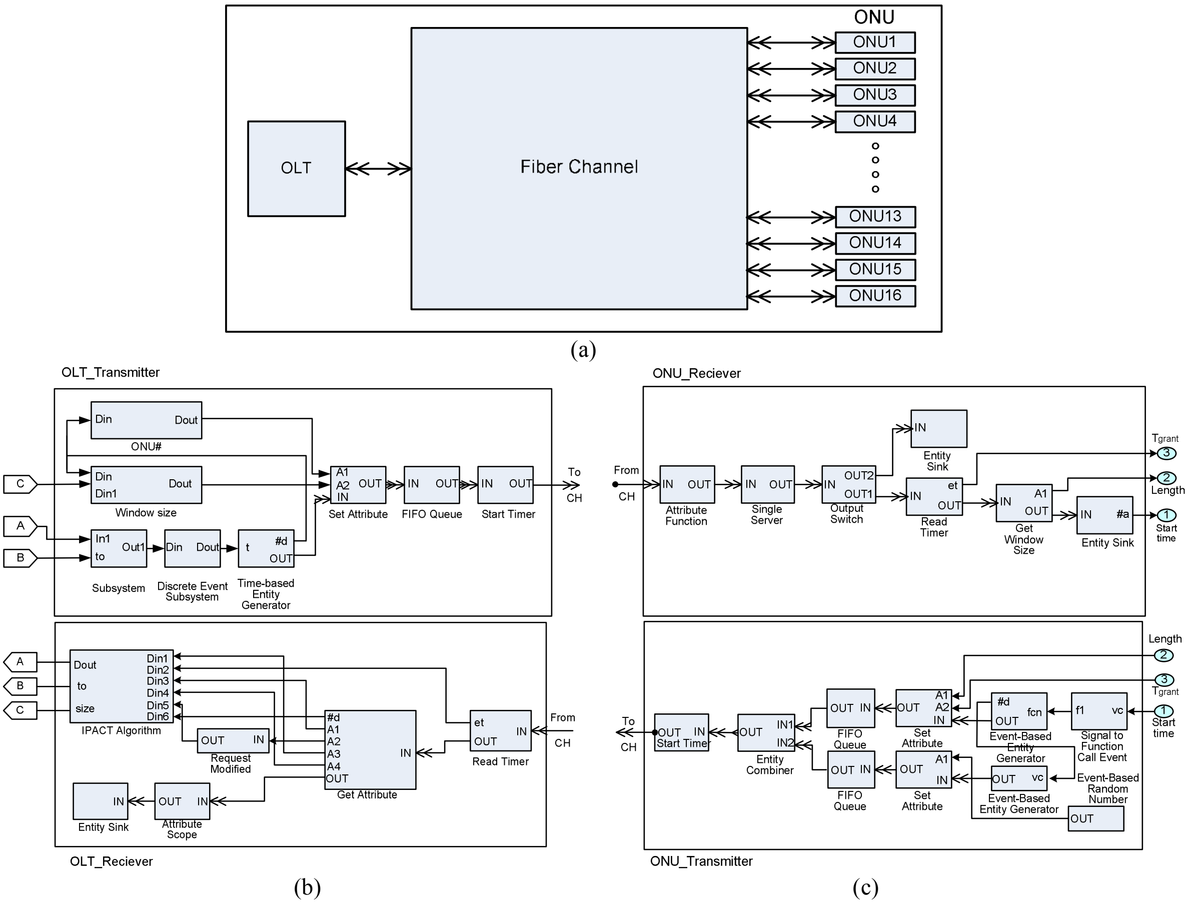

Fig.5 EPON model using Matlab *SimEvents*; (a) System model (b) OLT transmitter and receiver (c) ONU transmitter and receiver.

Fig. 6 shows the change in polling cycle time (adaptive cycle) with different ONU loads ranging from about 0.2 *ms* for minimum network load up to 2 *ms* for maximum network load. That figure shows the adaptation of cycle time according to network load; illustrating the main advantage of the IPACT algorithm, that makes it preferable for Ethernet Passive Optical Networks (EPON) over the traditional time-division multiple access (TDMA) algorithms with fixed cycle time.

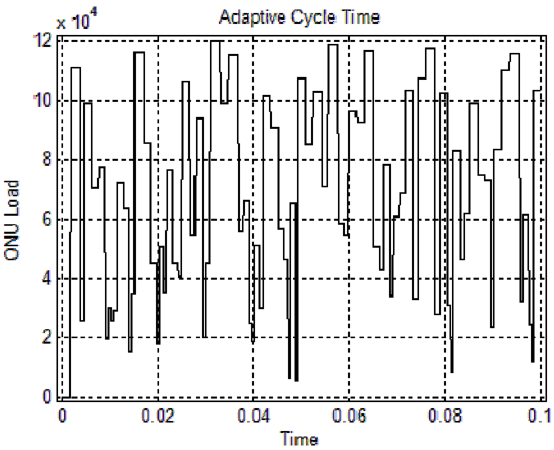

Fig. 6 Change in cycle time with ONU load

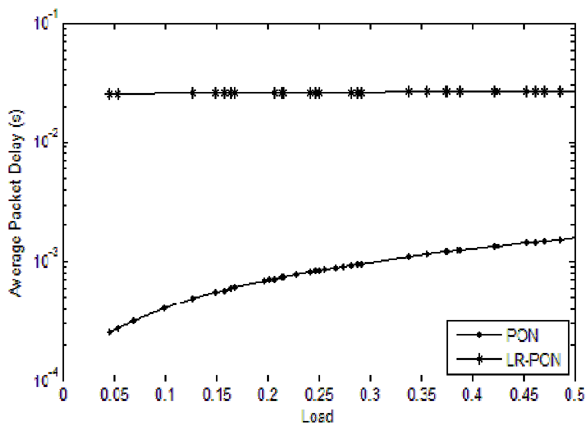

Fig. 7 Average packet delay with 20 *km* and 120 *km* span

Fig. 7 shows the average packet delay when ONUs are located in 10-20 *km* range (traditional PON) and 100-120 *km* range (LR-PON) from the OLT. For 20 *km* span, the polling algorithm has a good performance in terms of average packet delay. Simulation results show that the average packet delay is less than 2 *ms* when network load is not very high (0-0.5) with a small RTT, approximately 0.2 *ms*. On the other hand, for 120 *km* span, the performance of polling algorithm is not preferable even in light network load, since the average packet delay can reach up to 30 *ms* with RTT of 1.2 *ms*.

Conclusion

In this paper we have proposed the use of new available Matlab Simulink tool *SimEvents* in order to model EPON systems. The IPACT algorithm has been tested under small coverage area and large coverage area. Simulation results show a consistence performance of our Matlab *SimEvents* based model. Results also show that the implementation of the IPACT algorithm for Long-Reach PON is not preferable. In the next stage of our work, we will propose and investigate a new polling protocol for LR-PON to simulate the multi-thread polling exiting algorithms.

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