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FEASIBILITY ANALYSIS OF STARGATE NETWORK WITH INTEGRATION TO ETHERNET BASED PASSIVE OPTICAL NETWORK

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Abstract

The performance of a stargate network, which provides all-optical integration of Ethernet based wavelength division multiplexing passive optical networks (WDM PONs) with metropolitan area networks, has been extensively studied in this research. This network provides transparent connections at wavelength and sub-wavelength granularity. This network is cost effective with single hop and reuses wavelengths by exploiting multiple free spectral ranges (FSRs) of arrayed waveguide grating (AWG). The simulation has been performed in Optsim™ and results have been shown as eye diagrams and BER plots obtained at the receiver end.

Keywords: Wavelength Reusability; Free Spectral Range; Optical Bypassing; Wavelength Division Multiplexing; Space Division Multiplexing; Passive Optical Networking

1. Introduction

STARGATE is a proposed network architecture which integrates to hybrid ring-star based metro network. The emergence of new bandwidth hungry applications and services impose the network upgrades of current time-division multiplexing passive optical networks (TDM PONs) to their upgraded successor wavelength division multiplexing (WDM) PONs. Access network has to overcome the first/last mile bandwidth bottleneck between the high bandwidth demand at user end and high speed backbone network. In current access networks like fiber to the home (FTTH) and fiber to the premises (FTTP), asynchronous transfer mode (ATM) and Ethernet based PONs are widely deployed because of their access length, smaller attenuation and high bandwidth. A WDM STARGATE network with optical by-passing for all optical communication through arrayed waveguide grating (AWG) and integration with WDM EPON access network is proposed as a solution to the current first/last mile bandwidth bottleneck problem [1]. The STARGATE network providesa single hop communication between all optical network units (ONUs) through star topology with AWG and passive star coupler (PSC) working parallel as central routers. So packet latency is reduced with a considerable amount while the throughput is increased. With described superior characteristics of STARGATE, no physical layer feasibility was proved so far. In this paper we have shown the physical feasibility of STARGATE by means of computer simulation.

In this research work, performance analysis of the WDM STARGATE network through simulation in Optsim^{TM} was done comprehensively.

2. Literature Review

Passive optical networks (PONs) are point-to-multipoint networks. These are longer distance, high bandwidth, low cost with broadcasting ability access networks. PONs can be based on ring, bus or tree topologies, with or without redundancy [2]. There exist different types of PONs such as Asynchronous Transfer Mode (ATM) based PONs (APONs), Broadband PONs (BPONs), Gigabit PONs (GPONs) and Ethernet based PONs (EPONs). Most of these use time division multiplexing [3]. Out of three basic WDM networks topologies star, ring, and bus, star topology gains much research attention. A passive star coupler (PSC) based single hop star network with wavelength reuse and the AWG based single hop star network with a hybrid medium access control (MAC) protocol has been discussed in literature [4]. STARGATE is a proposed network architecture which integrates Ethernet based PON access networks to hybrid ring-star based metro network. It provides low cost and pay as grow upgrades to existent WDM networks. A comparison has been developed between slotted ring and AWG based metro WDM star networks by Yang, et. al., and has been concluded that AWG based star networks clearly outperformed the ring based networks in terms of throughput, packet loss, and delay [5].

I. WDM EPON

Current access networks mainly consist of time division multiplexing (TDM) PONs with single upstream wavelength and a single downstream wavelength. The wavelength channel is shared by PON nodes by means of time division multiplexing. This presents a simplified network with a single common type network transceiver. Due to increase in the number of end users and the bandwidth demand, the current single channel TDM PONs need to be upgraded. WDM EPON provides a cautious upgrade with addition of different wavelength channels. WDM upgrade can be applied to those nodes only which require high bandwidth by installing multiple fixed tuned or tunable transceivers, while nodes with low bandwidth demand can be left unchanged. In optical line terminal (OLT) of WDM EPON network, there is an array of fixed-tuned transceivers operating on the wavelength channels in use. Each of these fixed-tuned transceivers is dedicated for a single wavelength channel. This proposed upgrade of EPON do not impose any particular WDM optical network unit (ONU) architecture, thus allowing the decision to be made by network operator on basis of economics, technology and service provider preferences [2]. An AWG based WDM EPON architecture has been presented in [6]. The AWG allows spatial wavelength reuse in both upstream and downstream direction with direct communication between ONUs. This architecture is based on bidirectional tree topology, in which OLT is connected to AWG with dual fiber and resides in central office (CO), where it connects the access network to metro network.

II. STARGATE

STARGATE network is proposed to all optically integrate Ethernet based access networks like EPONs to metro networks [1]. STARGATE is based on three fundamental principles:

i) SDM upgrade: As the bandwidth demand from end users is increasing due to many new emerging multimedia applications and services, we need to upgrade the existing access networks to provide enough bandwidth to each end user. Installation of long run multifiber cables cost almost same as cables containing single or few cables [7]. The standard IEEE 802.3ah supports not only point-to-multipoint (P2MP) topology but also a hybrid EPON topology consisting of point-to-point (P2P) links in conjunction with P2MP links. In STARGATE, a separate P2P or P2MP fiber link to connect OLT with subset of one or more ONUs for downstream direction is being deployed. In this way, space division multiplexing (SDM) to cope with extensive traffic demands have been used.

ii) Optical bypassing: In STARGATE network architecture, optical bypassing shown in Figure.1 is used to avoid optical-electronic-optical (OEO) conversion done in OLTs.

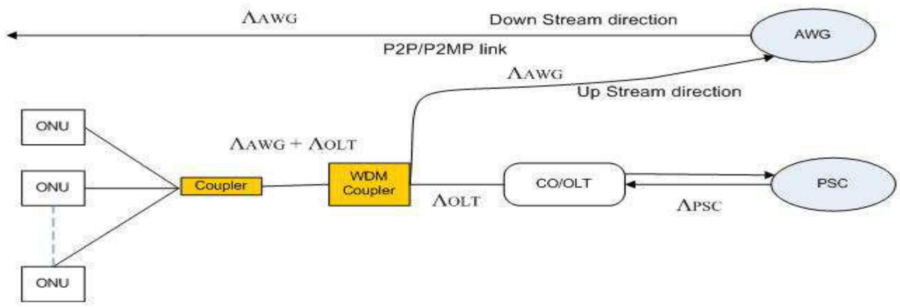


Figure 1: Optical bypassing [1]

The wavelength channels which are meant for all optical communication are directly routed to AWG after bypassing the OLT through a WDM coupler. This WDM coupler separates channels on the basis of wavelengths selection. Thus by avoiding the OEO conversion we are able to cut the cost and have achieved the passive all optical end to end communication. Through this optical bypassing we also achieve the single-hop communication between ONUs, so the packet latency is reduced by considerable amount.

iii) Passive optical networking: STARGATE uses AWG and PSC as wavelength channel routers to ensure the passivity of network. AWG requires no temperature control and monitoring of wavelength shift, so network management is simple and cost is reduced[1].

a). Architecture

The network architecture of STARGATE is shown in Figure. 2. It consists of a Resilient Packet Ring (RPR) metro edge ring that interconnects multiple WDM EPON tree networks among each other as well as to the Internet and server farms. The P (P is an arbitrary number) Central Offices (COs) are connected through single-hop WDM star subnetwork whose hub is based on wavelength-broadcasting PxP PSC in parallel with an athermal wavelength-routing PxP AWG. Λ OLT denotes the number of wavelengths in upstream and downstream direction in WDM EPON. Λ AWG are wavelengths passing through the AWG router, while Λ PSC are wavelengths passing through the PSC router. Λ AWG wavelengths are bypassed from OLT and CO with WDM coupler and directly routed to AWG in upstream direction. In this way, optical bypassing to avoid O-E-O conversion has been achieved successfully. While in downstream direction Λ AWG wavelengths are carried through P2P or P2MP link from AWG to the subset of attached ONUs. The CO in the upper right corner of Figure2 is assumed to be attached to the Internet and a number of servers through a common router. This CO is called hot-spot CO. This hot-spot CO communicate on any of the Λ AWG wavelengths, hence able to send and receive data all-optically through single-hop AWG based star network. NRZ is the modulation format used for simulation.

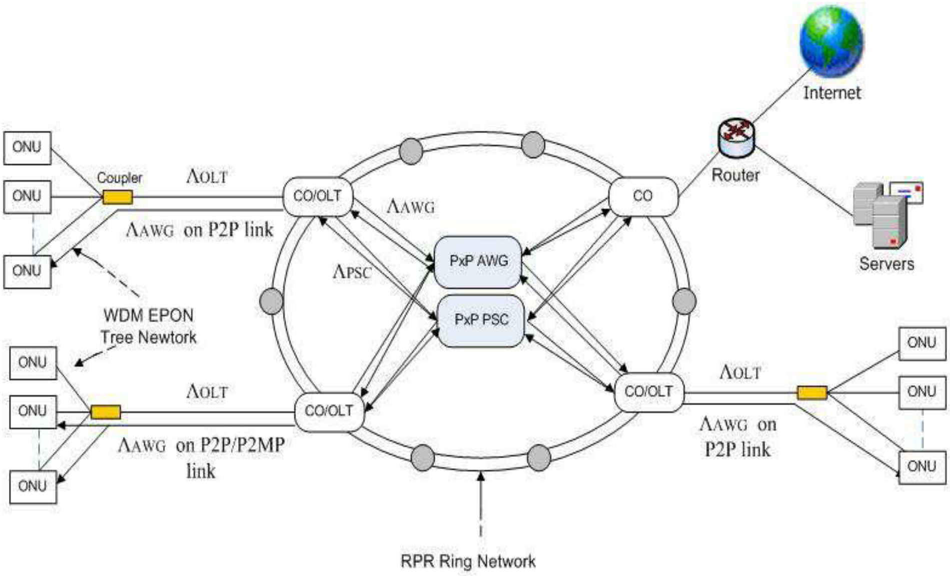


Figure 2. STARGATE architecture [1]

b). Significance of AWG

A conventional WDM metro star network is usually based on N x N PSC, which can be connected to only N nodes. This is due to the limitation of available ports and wavelengths. Since N x N coupler has splitting loss of 1/N so the number of ports cannot be increased beyond a specific number. Also in PSC based networks, one wavelength can be used for only one node[8].

AWG can be used as optical router to route a large number of wavelength channels with routing function performed on individual wavelengths. The AWG guides light on a planar light wave circuit into an array of waveguides that provide dispersion to separate different wavelengths [9]. The AWG allow us to reuse the wavelengths so that we can apply same wavelengths at different ports of AWG[10]. In Figure.3, a 2x2 AWG is shown in which same six wavelengths are applied to two input ports of AWG. Each FSR contains two wavelengths since AWG routes every second wavelength to same output port. Generally FSR of an AWG is the period of wavelength response and we can have D wavelengths in each FSR of a D x D AWG. In other words the degree of wavelengths is same as the number of wavelengths in each FSR[6]. Wavelength reusability is achieved by exploiting these FSRs. The AWG routes wavelengths such that no channel collision occurs at the AWG output ports[4]. In STARGATE network AWG is used as wavelength router which allows ONUs to communicate all-optically with low latency due to single-hop architecture.

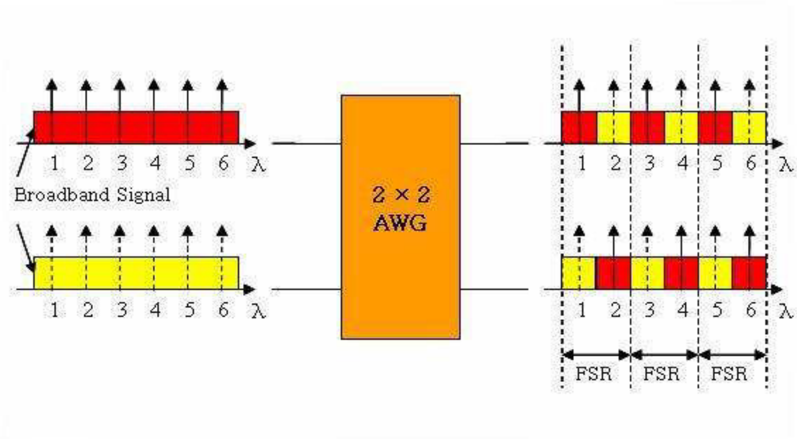


Figure 3.Wavelength routing of 2x2 Arrayed Waveguide Grating (AWG)

3.Numerical Results

The STARGATE network architecture has been simulated in optical communication systems software Optsim TM. Important parameters and values are listed in the Table1.The 10 Gbps logical data signal is generated by using a Pseudo Random Bit Sequence (PRBS) generator. This logical data signal is converted into a NRZ electrical signal. The continuous wave laser with a peak optical power of 10 mW is externally modulated in accordance with this generated data signal by a Mach Zehnder modulator.

Table1: Parameters used in the simulation

Parameter	**Value**
Number of ONUs (both at transmitting side and receiving side)	8+8
Degree of AWG and PSC	2x2
Transmission distance	34 Km
LD input power	10mW
Wavelength channels used	6
Channel spacing	0.8nm
Number of Λ AWG	2 (1549.2, 1550 nm)
Number of Λ PSC	4 (1551.6, 1552.4, 1553.2, 1554 nm)

The simulated architecture is shown in Figure4, eight ONUs at transmitting end and eight ONUs at receiving end have been used.

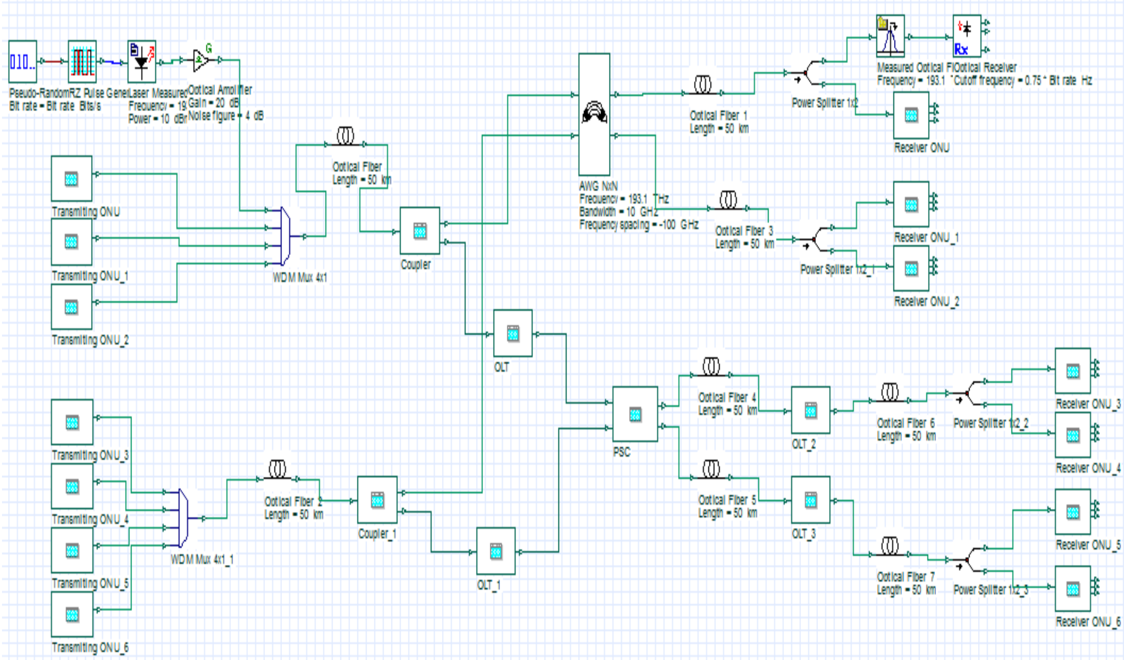
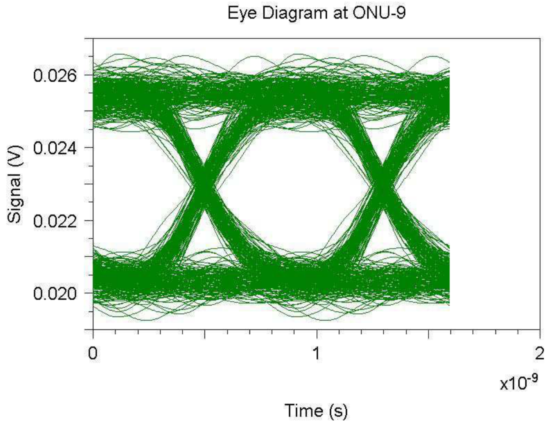


Figure 4: STARGATE network architecture simulated in Optsim^{TM}.

Six wavelength channels have been used. Out of these 6 wavelengths, 2 are Λ AWG i.e. those pass through the AWG router. By using, AWG, one can specially reuse the 2 wavelengths for 4 ONUs working on Λ AWG. The other 4 wavelengths are used by the 4 ONUs which are working on Λ PSC. In this architecture, we have 4 OLTs which connects 8 ONUs at both transmitting and receiving ends. The eye diagrams of received signal at ONU-9 and ONU-15 at receiving side are shown in Figures5 and 7, respectively. In Figure6 and 8, the BER plots obtained at ONU-9 and ONU-15 are shown with the function of the transmission distance. L1 is distance from transmitter to AWG/PSC and L2 is distance from AWG/PSC to receiver. The value of both L1 and L2 is 17 km each, so total transmission distance for network is 34 km. After this 34 km, a BER of 10^{-14} at ONU-9 and BER of 10^{-27} at ONU-15 have been attained, which are very much acceptable for communication systems. ONU-9 is one of the ONUs which are working on the Λ AWG wavelengths, i.e., it is communicating all-optically to other ONUs in the network through AWG router. Note that there is no OEO conversion in the communication path of these ONUs and signal needs no amplification for at least 34 km. As shown in Figure 6, BER at the ONU-9 is around10^{-14}, which is quite higher than one obtained at ONU-15 but still an acceptable one in communication systems. In Figure 5, the eye diagram obtained at ONU-9, the received peak-to-peak signal amplitude is 5 mV, which is low but acceptable as compared to the one received at ONU-15, as shown in Figure 7.



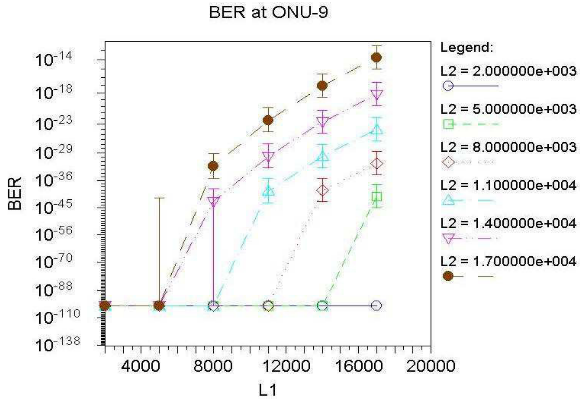
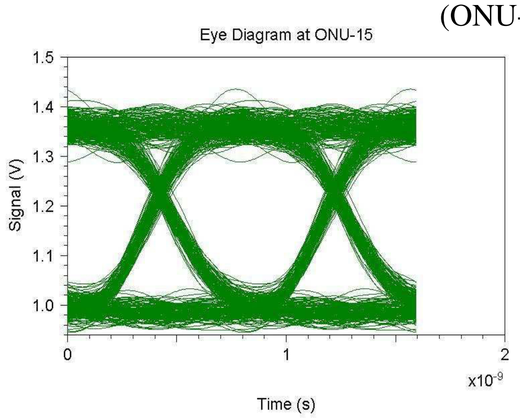


Figure 5: Eye diagram at receiver side (ONU-9) Figure 6. BER plot at receiver side (ONU-9, L1 and L2 both span 17km maximum)



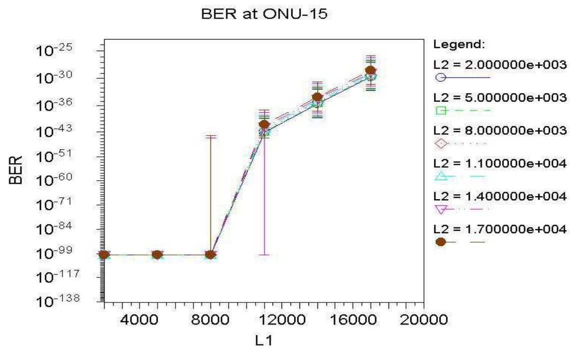


Figure 7: Eye diagram at receiver side (ONU-15) Figure 8. BER plot at receiver side (ONU-15, L1 and L2 both span 17km maximum)

The ONU-15 is one of the ONUs which are working on the ΛPSC, i.e., signal coming to this ONU through PSC router has experienced OEO conversion and amplification through the post-amplifier installed in each OLT. So a BER value of 10^{-27} has been obtained, as shown in Figure 8, which is smaller as compared to one obtained at ONU-9 against same distance of 34 km. However, installation of optical amplifier in each OLT is required otherwise the received signal would have much higher BER value, which may not be suitable for any communication system. Similarly the high peak-to-peak signal amplitude of 35 mV at ONU-15 is because of signal amplification in the communication path.

4. Conclusion

The physical feasibility of the STARGATE network has been thoroughly investigated in this research work. STARGATE is a network which allows all-optical integration of

EPONs to metro networks. Thesimulational analysis revealedthat the STARGATE architecture is a simple and cost effective architecture with minimum hop count between transmitting and receiving ends. Low packet latency, high throughput, wavelength reusability and cautious upgrades to current optical networks are the salient features of this STARGATE architecture. TDM PONs serves as the current access networks solution. Due to new emerging multimedia applications and services, TDM PONs need to be upgraded to satisfy the huge upcoming bandwidth demands from end users. Future networks should be able to provide enough bandwidth to the highly demanding users in an efficient and cost effective manner.

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