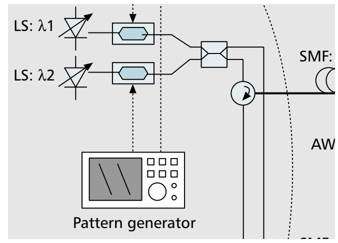

SUCCESS-HPON: A NEXT-GENERATION OPTICAL ACCESS ARCHITECTURE FOR SMOOTH MIGRATION FROM TDM-PON TO WDM-PON

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ABSTRACT

Optical access networks are considered to be a definite solution to the problem of upgrading current congested access networks to ones capable of delivering future broadband integrated services. However, the high deployment and maintenance cost of traditional point-to-point architectures is a major economic barrier. Current TDM-PON architectures are economically feasible, but bandwidth-limited. In this article we first discuss the possible role of WDM in access networks and investigate the associated issues. We then present the Stanford University Access Hybrid WDM/TDM Passive Optical Network (SUCCESS-HPON), a next-generation hybrid WDM/TDM optical access architecture that focuses on providing a smooth migration path from current TDM-PONs to future WDM-PONs. The first testbed for this architecture is described, along with the experimental results obtained, including feasibility of bidirectional transmission on the same wavelength on the same fiber for access networks and ONU modulation of upstream data on continuous waves provided by the OLT, eliminating the need for tunable components at the ONUs. The development of a second testbed and the issues it will address, including the implementability of the SUCCESS-HPON MAC protocol and scheduling algorithms, are also described.

INTRODUCTION

Optical access, including fiber to the home/curb/node (FTTX), has long been considered a definite solution to the problem of upgrading current congested access networks to ones capable of delivering future broadband integrated services. Optical fibers can provide bandwidths other transmission media (e.g., wireless or copper) cannot. Because of this, they have already been used in backbone networks, WANs, MANs, and even LANs successfully. The use of fiber in access networks would be the last needed step to the future all-optical network revolution.

Traditional optical access solutions based on point-to-point architectures are expensive: besides fiber deployment costs, they need maintenance for the outside plant active systems. These systems consist of many electrical-to-optical (E/O) and optical-to-electrical (O/E) components prone to failure, which prevents their large-scale deployment. To address these issues and expedite the introduction of FTTX, time-division multiplexing passive optical networks (TDM-PONs) have been developed, including broadband PON (BPON), gigabit PON (GPON), and Ethernet PON (EPON). These solutions are based on similar passive tree topologies, but have different transfer technologies. TDM-PON architectures can break through the economic barrier of traditional point-to-point solutions [1]. They are internationally standardized and currently being deployed in the field by network service providers in several places around the world.

Once TDM-PONs are deployed, upgrading optical access networks will be a challenge when user demand outgrows the existing network capacity. TDM-PONs have only one wavelength for downstream data and one for upstream data, thus limiting the average bandwidth per user to a few tens of megabits per second [2]. The very high available bandwidth of a single fiber is thus mostly wasted. Moreover, the tree topology of current-generation TDM-PONs prevents features such as protection and restoration.

Wavelength-division multiplexing (WDM) technology has been considered an ideal solution to extend the capacity of optical networks without drastically changing the fiber infrastructure. Many architectures incorporating WDM into access have been proposed by both academia and industry (e.g., [3, 4]). However, how to migrate from TDM-PON to WDM-PON still requires further investigation.

The rest of the article is organized as follows. The following section discusses the need for WDM in optical access networks, its issues and enabling technologies. The third section introduces the Stanford University Access Hybrid WDM/TDM PON (SUCCESS-HPON) architecture [5], which provides a smooth migration path from TDM-PON to WDM-PON in a scalable and flexible manner, and can also provide protection and restoration capabilities. The fourth section discusses the first testbed that has been implemented for SUCCESS-HPON and the experimental results obtained from it, including feasibility of bidirectional transmission on the same wavelength on the same fiber for access networks and optical network unit (ONU) modulation of upstream data on continuous waves (CWs) provided by the optical line terminal (OLT), eliminating the need for tunable components at the ONUs. It also describes a second testbed on which we are currently working and the issues it addresses. We then summarize and conclude this article.

	Capacity	Cost	Upgradability	Reliability
Point-to-point	Best	Highest	Easy	Good
TDM-PON	Good	Low	Difficult	Best
WDM-PON	Better	Higher	Easy	Better

Table 1. *Comparison between point-to-point, tdm-pon, and wdm-pon access solutions.*

WDM IN OPTICAL ACCESS NETWORKS

A paradigm shift in next-generation optical network architectures, ranging from WAN [6] to MAN [7] to access [8], has been observed: from fixed static optical networks toward more flexible, dynamically reconfigurable networks. The driving forces behind this shift are:

- A mismatch between current on-demand service/usage models and static network infrastructures
- An imbalance between backbone networks (waste of bandwidth) and access networks (lack of bandwidth)

In the particular case of access networks, Table 1 summarizes a comparison of current point-to-point, TDM-PON, and WDM-PON architectures [9]. Even though point-to-point networks provide the highest capacity, they are usually too expensive for home and small business users; their reliability is also usually low due to the use of active systems (e.g., multiplexers or switches) in the distribution network. Access networks require inexpensive solutions due to their low number of users to share the cost. TDM-PONs (i.e., BPON, GPON, and EPON) do not have the best capacity or upgrade possibilities, but their low cost and use of passive components make them the current architectures of choice. WDM will be needed in next-generation access networks in order to offer higher bandwidths and have more flexible, dynamically reconfigurable networks. However, how to migrate from TDM-PON to WDM in access networks is not yet clear.

Some of the design issues for WDM in optical access networks include:

- Backward compatibility: The potentially large plant of TDM-PON equipment that will be deployed in the next couple of years makes it important for new architectures to be backward compatible and to minimize the upgrade impact on current users.
- Frame formats: Current frame formats include asynchronous transfer mode (ATM), Ethernet, and GPON Encapsulation Method (GEM). The general trend is shifting from ATM to Ethernet; GEM is a specific PON frame format that can encapsulate various other types of frames. Next-generation WDM-PONs may be frame-agnostic, facilitating upgradability, or need their own frame formats to do, for example, in-band control.
- Medium access control (MAC) protocols and scheduling algorithms: If shared resources are used (i.e., tunable components or shared wavelengths), there will be a need to develop specific MAC protocols and scheduling algorithms to coordinate the allocation of these resources.
- Coarse WDM (CWDM) vs. dense WDM (DWDM): The trade-off between these two technologies is between the cost of components and the spectral efficiency achieved. DWDM offers much higher spectral efficiency, but usually requires expensive temperature-stabilized components.
- Light sources: Especially for the equipment at the customer's premises, inexpensive tunable capabilities are needed. Some WDM ONU alternatives being considered are tunable laser diodes, injection-locked Fabry-Perot lasers, broadband light sources with spectral slicing, or the use of only modulators that operate on a CW provided by the OLT.
- Video broadcasting: WDM allows the amount of bandwidth available for video transmission to be increased. There are two non-mutually-exclusive ways to transmit video: using analog RF on subcarrier multiplexed (SCM) channels or digitalization (e.g., with MPEG4) and transmission via IP packets. Depending on the network architecture and users' demands, one method may be preferable to the other, or a combination of both may be needed.
- Protection and restoration: Current tree topologies make it hard to provide protection and restoration. Changing to a ring metro/access topology, for example, could provide protection and restoration for home and small business users.

The architecture and testbed described in this article intend to address most of these issues and provide a practical and cost-efficient migration path from TDM-PONs to WDM-PONs.

SUCCESS-HPON: A NEXT-GENERATION OPTICAL ACCESS ARCHITECTURE

SUCCESS-HPON is a next-generation hybrid WDM/TDM optical access architecture, based on a ring plus distribution trees topology, fast centralized tunable components, and novel scheduling algorithms. The starting point in designing the SUCCESS-HPON architecture was "how to efficiently and smoothly upgrade TDM-PONs to enabling technologies in the future." The major design objectives were:

- Backward compatibility: Guarantee the coexistence of current-generation TDM-PONs and next-generation WDM-PONs in the same network.
- Easy upgradeability: Provide smooth migration paths from TDM-PON to WDM-PON.
- Protection/restoration capability: Support both residential and business users on the same access infrastructure.

ARCHITECTURE OVERVIEW

The overall architecture of SUCESS-HPON, including TDM-PONs and WDM-PONs as its subsystems, is shown in Fig. 1a. A single-fiber collector ring with stars attached to it formulates the basic topology. The collector ring strings up remote nodes (RNs), which are the centers of the stars. The ONUs attached to the RN on the west side of the ring talk and listen to the transceiver on the west side of OLT, and likewise for the ONU attached to the RNs on the east side of the ring. There is a point-to-point WDM connection between the OLT and each RN. No wavelength is reused on the collector ring. When there is a fiber cut, affected RNs will sense the signal loss and flip their orientation.

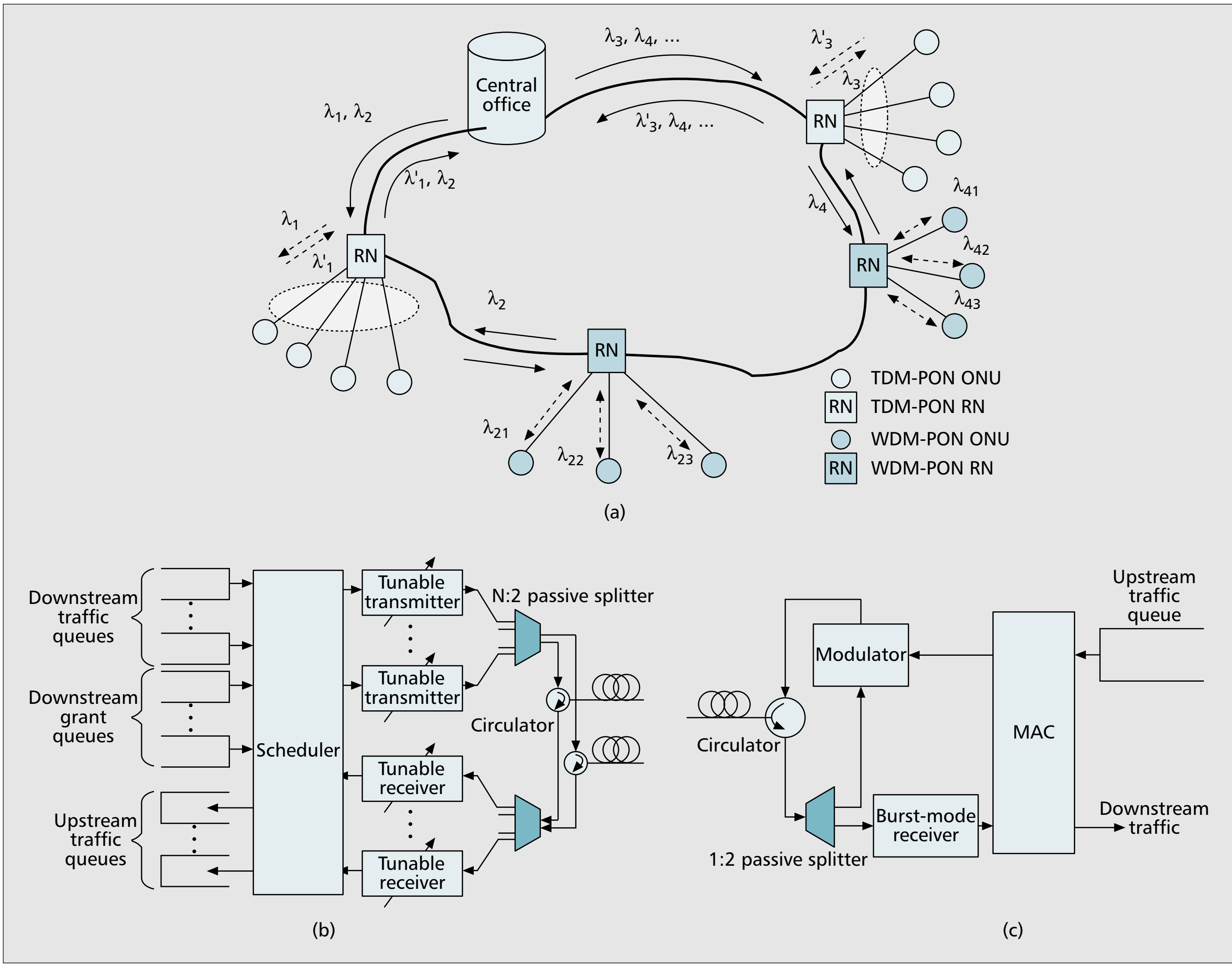

FIGURE 1. SUCCESS-HPON: a) overall architecture; b) OLT block diagram; and c) WDM-PON ONU block diagram.

A TDM-PON RN has a pair of CWDM band splitters per PON to add and drop wavelengths for upstream and downstream transmissions, respectively. A WDM-PON RN has one CWDM band splitter, adding and dropping a group of DWDM wavelengths within a CWDM grid, and a DWDM multiplex/demultiplex (MUX/DEMUX) device (e.g., an arrayed waveguide grating, AWG). Each WDM ONU has its own dedicated wavelength for both upstream and downstream transmissions on a DWDM grid to communicate with the OLT. Since the insertion loss of an AWG is roughly 6 dB regardless of the number of ports, one with more than eight ports can be used to enjoy a better power budget than with a passive splitter. Each RN generally links 16–64 WDM-PON ONUs.

Figure 1b shows the logical block diagram for the WDM-PON portion of the SUCCESS-HPON OLT. Tunable components such as fast tunable lasers and tunable filters are employed. Since the average load of access networks is generally low, using tunable components minimizes transceiver count and thus minimizes total system cost. This arrangement is also good in terms of scalability: as more users join the network, or their traffic increases, more tunable lasers and receivers are added at the OLT. Upstream optical signals are separated from the downstream signals by circulators. The scheduler controls the operation of both tunable transmitters and tunable receivers.

Note that the tunable transmitters at the OLT generate both downstream frames and CW optical bursts to be modulated by ONU for upstream data. With this configuration, half duplex communication is possible at the physical layer between each ONU and the OLT. Compared to a similar architecture [4] with a two-fiber ring, two sets of light sources, and two sets of MUX/DEMUX to perform full-duplex communications, the SUCCESS-HPON architecture dramatically lowers costs. As a trade-off, it needs carefully designed MAC protocol and scheduling algorithms to provide efficient bidirectional communication.

Figure 1c shows the logical block diagram for the WDM-PON portion of the SUCCESS-HPON ONU. The ONU has no local optical source and uses instead an optical modulator to modulate optical CW bursts received from an OLT for its upstream transmission. A semiconductor optical amplifier (SOA) can be used as an amplifier/modulator for this purpose with the assumption that its integration with electronics would decrease its production costs when mass produced.

Note that the ONU does not need a tunable receiver. The AWG in the remote node removes extraneous wavelengths and allows only a specific wavelength to reach each WDM-PON ONU.

The receiver at the ONU just needs to have enough optical bandwidth to receive any DWDM channel used in the network. Note as well that the MAC block in the ONU not only controls the switching between upstream and downstream transmissions but also coordinates with the scheduler at the OLT through polling and reporting mechanisms.

For further implementation details of the SUCCESS-HPON, especially at the physical layer, readers are referred to [5].

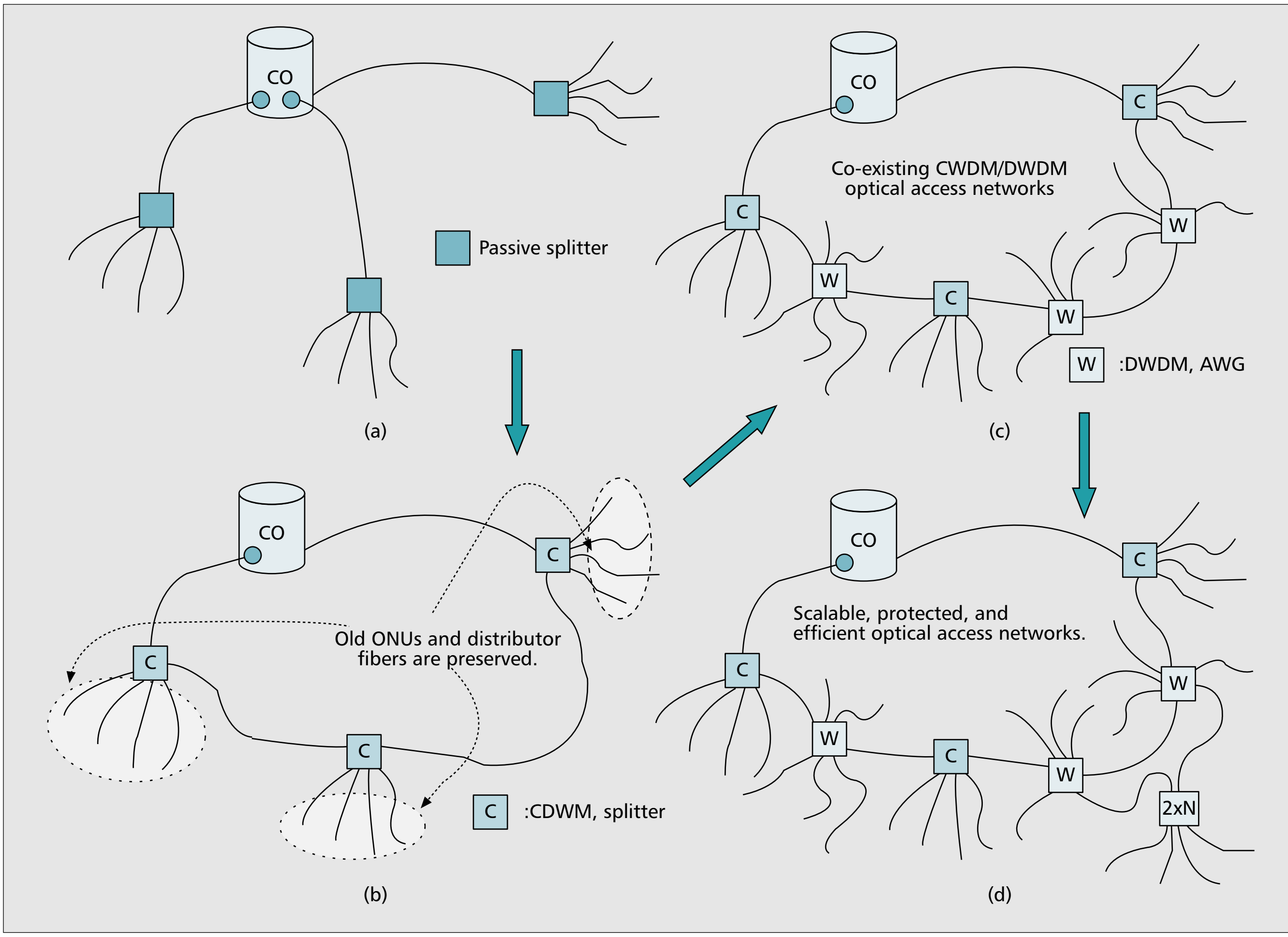

FIGURE 2. Migration path from TDM-PONs to full SUCCESS-HPON architecture.

NETWORK MIGRATION PATH

Figure 2 demonstrates the network migration scenario of optical access networks based on the SUCESS-HPON architecture. Figure 2a shows the existing tree TDM-PONs connected to the same central office (CO). Each TDM-PON has its own cabling and OLT inside the CO. Figure 2b shows the first migration step of the existing network infrastructure. The passive couplers of the PONs are replaced with RNs that consist of passive couplers and thin film add/drop filters to introduce CWDM. The feeder fibers of a PON are replaced with a single fiber ring that strings the RNs served by this CO. Note that distribution fibers are untouched during this migration. From the ONU's point of view, the functionality of the optical access network is exactly the same; only a short downtime for upgrade is needed. Therefore, existing TDM-PON ONUs can virtually work the same as before without a major upgrade.

Figure 2c describes the second phase of migration. As more users demand high bandwidth for future broadband applications, RNs that contain an AWG as DWDM multiplexer/demultiplexer can be inserted in the network. In this case, there is a dedicated DWDM channel between each ONU and the OLT. If protection and restoration functionality is implemented in the existing RNs using semi-passive switches, inserting a new RN in the network will not disturb the network operation in general.

Figure 2d shows the possible extension of the network. Since there is a dedicated wavelength at the output of the AWG, it is possible to use the collector ring as a backhaul for the PON with tree topology. The two feeder fibers of the PON can connect to different RNs to form a protection path. To upgrade the capacity even further, the SOA-based modulator can be replaced by a stabilized laser source to perform full-duplex operation.

The SUCCESS-HPON architecture smoothly upgrades the network from pure TDM-PONs to WDM-PONs in an economical manner.

MAC PROTOCOL AND SCHEDULING ALGORITHMS FOR WDM-PON

In the SUCCESS-HPON architecture, all tunable transmitters and receivers are located at the OLT. The sharing of these tunable components to service all the ONUs, and their use for both upstream and downstream data transmission pose a great challenge in designing an adequate scheduling algorithm. Such an algorithm has to keep track of the status of all shared resources (i.e., tunable transmitters and tunable receivers), ONU wavelength assignments, and round-trip times, and arrange them properly in both the time and wavelength domains for both downstream and upstream data transmissions.

Extensive work has been done on developing scheduling algorithms for SUCCESS-HPON, as described in [5, 10, 11]. Here we briefly describe the best scheduling algorithm thus far, Sequential Scheduling with Schedule-Time Framing (S^3F). This algorithm has relatively low computational complexity and can provide high throughput and low delay.

We consider a SUCCESS-HPON WDM-PON system with W ONUs (therefore W wavelengths), M tunable transmitters, and N tunable receivers. Because the tunable transmitters are

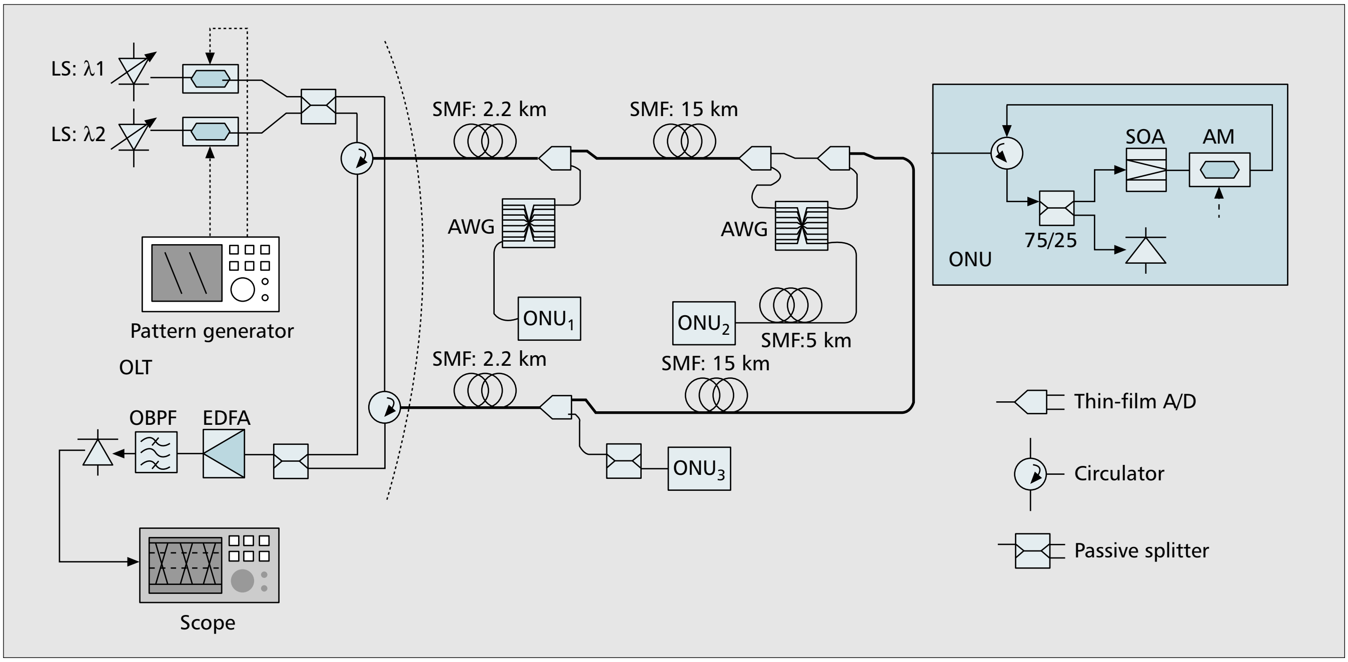

FIGURE 3. First version testbed setup.

used for both upstream and downstream traffic but the tunable receivers are only used for upstream traffic, it will usually be the case that $W \geq M \geq N$. A guard band (tens of ns) between consecutive frames takes into account the effects of unstable local ONU clock frequencies and tuning times of tunable transmitters and receivers at the OLT.

Like in B/G/EPON systems, the SUCESS-HPON OLT polls to check the amount of upstream traffic stored inside ONUs and sends grants (with appended optical CW bursts in this case) to allow the ONUs to transmit upstream traffic. Since there is neither a separate control channel nor a control message embedding scheme using escape sequences as in [12], the SUCCESS-HPON WDM-PON MAC protocol employs in-band signaling and uses frame formats with *Report* and *Grant* fields defined for polling and granting, respectively. A *Frame Type* field in the downstream frame header indicates whether the frame is to be used for upstream data or not. If it is going to be used for upstream data, the frame has appended a CW long enough for the granted data to be modulated onto it.

The S^3F algorithm operates as follows. At the end of each SUCCESS-HPON frame transmission or when a payload frame (e.g., Ethernet) arrives at an empty virtual output queue (VOQ):

1) Select the earliest available transmitter and receiver.
2) Taking into account the transmitter and channel availability times, schedule the next transmission time for data in this VOQ; if the VOQ is for upstream grants, take into account the receiver availability and ONU round-trip times as well.
3) Encapsulate queued data (e.g., Ethernet frames) into a SUCCESS-HPON frame; the maximum size of the latter is determined by the VOQ's downstream transmission counter.
4) Update the status variables for transmitter, receiver, and channel availabilities, and the downstream traffic counter.

The downstream transmission counter in step 3 ensures fairness among downstream and upstream traffic. The counter is increased based on the corresponding VOQ length when upstream traffic requests arrive and decreased as downstream traffic leaves. It is ensured, though, that downstream traffic can be sent even in the absence of upstream traffic. This counter, and the fact that there are separate VOQs for each ONU in each direction (downstream and upstream) ensures fairness between downstream and upstream traffic. For a more detailed description of the S^3F algorithm, please see [11].

Future work regarding the MAC protocol and scheduling algorithm will deal with the important issue of fairness among ONUs and the possibility of batch mode scheduling. In this mode, every batch period all the frames that can be scheduled are considered simultaneously, which allows for some optimization. Two tradeoffs are of importance in this case:

- Better throughput might be achieved, but at the expense of possibly higher average delays due to the batch period
- A higher computational complexity and memory is needed, which may affect the implementability of the algorithm.

SUCCESS-HPON Testbed and Experimental Results

The SUCCESS-HPON testbed serves several purposes:

1) Demonstrate the feasibility of bidirectional transmission of upstream and downstream traffic on the same wavelength for access networks.
2) Demonstrate the possibility to modulate upstream data onto CWs provided by the OLTs.
3) Demonstrate the functionality of the MAC protocol and scheduling algorithms.
4) Explore possible SUCCESS-HPON implementation issues.

In this article we describe the first version of the SUCCESS-HPON testbed and the experimental results obtained, mostly related to objectives 1 and 2. We are currently working on a second version of the testbed, in which several subsystems will be improved and objectives 3 and 4 above will be addressed.

First Version Testbed

The first testbed is shown in Fig. 3. The key components used in this testbed are:

- OLT transmitting end: two tunable lasers (Agility 4245), two Mach-Zehnder modulators (MZ, SDL 2.5 Gb/s), one pattern generator (HP70843A), one programmable board (not shown in the figure, developed in-house with an Altera APEX 20K FPGA), one coupler, and one circulator

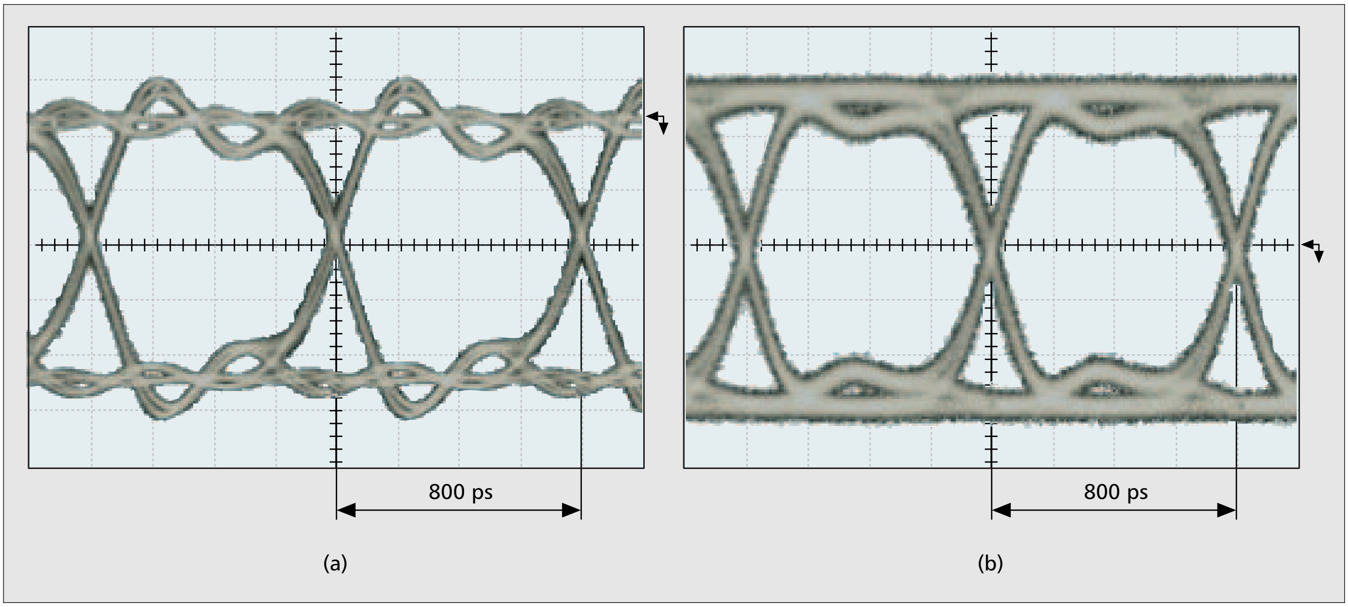

FIGURE 4. Eye diagrams for continuous transmission between OLT and ONU2: a) downstream traffic; b) upstream traffic.

- OLT receiving end: one circulator, one coupler, one erbium doped fiber amplifier (EDFA, developed in-house), one optical band pass filter, one photodiode (HP11982A), and one oscilloscope (HP54120)
- Distribution network: standard single mode fiber (SMF), two AWGs (Lucent X1450F), and four thin-film add/drop WDM filters
- Each ONU: one circulator, one coupler, one photodiode, one SOA (Genoa LOA), one MZ modulator (as above), and one programmable board (not shown, as above)

At the OLT transmitting end, two tunable lasers use different wavelengths to communicate with ONU_1 and ONU_2; these wavelengths are determined by the distribution network components as explained below. The pattern generator and the programmable board control the MZ modulators to generate downstream data at a 1.25 Gb/s rate and/or CW bursts. Downstream traffic and CW bursts pass through ports 1 and 2 of the circulators to enter the ring.

The collector ring is composed of four standard SMF sections of 2.2, 15, 15, and 2.2 km. Each remote node has at least one thin-film CWDM add/drop filter, and two of them have an AWG with a channel spacing of 100 GHz. Since no athermal AWGs were available at the time, we used conventional temperature-stabilized ones. The combined wavelength characteristics of the add/drop filters and the AWGs at each remote node determine the wavelength assigned to a particular WDM-PON ONU and are used by the OLT to communicate with it. A single wavelength for each ONU, as mentioned before, is used for both downstream and upstream communication. The total distances from the OLT to the ONUs are 2.2, 22.2, and 2.2 km, respectively.

Each ONU connects to its fiber through port 2 of its own circulator. Downstream data and CWs are received through port 3, while upstream data (which has been modulated on the CW) is sent through port 1. An optical power splitter is used: 25 percent goes to the receiver, while 75 percent goes to the SOA and MZ. The power budget for the downstream signal is enough to achieve error-free transmission. The splitter allocates more power for the upstream transmission since it needs to travel back to the OLT. Since the electronic driver circuitry to modulate the SOA is currently unavailable, and the SOA is not designed for fast switching, the SOA only amplifies the CW in our testbed. The modulation is then performed by an external MZ modulator that has a 6 dB loss. This MZ modulator again is controlled by a programmable board, different from the one at the OLT. When the ONU is receiving downstream data, the modulator is turned off to prevent upstream interference.

Upstream traffic enters the receiving end of the OLT through ports 2 and 3 of the circulators. Note that this traffic comes from CWs sent by the OLT transmitting end, which were then amplified by the ONUs, modulated, and sent back. The receiving end at the OLT has an erbium-doped fiber amplifier (EDFA) as a pre-amplifier, an optical band pass filter to remove the noise of the EDFA and a photodiode.

All fiber links are either fusion spliced, or connected with angled connectors to minimize reflection and avoid serious Rayleigh back scattering (RBS). This phenomenon introduces interference on bidirectional optical transmission when the two signals have the same wavelength.

EXPERIMENTAL RESULTS

Bidirectional Transmission on the Same Wavelength on the Same Fiber — We first send continuous data from the OLT to ONU2 at a 1.25 Gb/s rate. The laser's output optical power is set at 5 dBm, and a pseudo-random bit sequence (PRBS) with a $2^{23} - 1$ word length is used for MZ modulation. After leaving the OLT, the signal traverses 2.2 km of SMF, an add/drop filter, 15 km of SMF, a second add/drop filter, an AWG, and 5 km of SMF, and reaches ONU2. The total power loss from the OLT's laser to ONU2 is approximately 20 dB. Figure 4a shows the downstream eye diagram for the data received at ONU2. The ripples (distortion) of the eye diagram are due to the frequency response of the post-detection electrical filter.

The transmitter at the OLT is then set to generate a CW optical carrier for ONU2, also at an optical power of 5 dBm. The CW reaches the ONU following the same path described above, with an optical power of approximately –15 dBm. The circulator, 75/25 percent coupler, and MZ modulator at ONU2 add an additional loss of approximately 7.5 dB, but the SOA amplifies the CW by 20 dB, making the final output power approximately –2.5 dBm. The MZ units modulate the data onto the CW, using again a $2^{23} - 1$ word PRBS sequence. The modulated data is sent back through the ONU's circulator and follows a similar upstream path to the OLT, where it reaches the OLT's receiving end. The loss caused in the upstream direction reduces the received power level to approximately –22.5 dBm. Figure 4b shows the eye diagram for the upstream data. As can be seen, both figures show clear eye diagrams. The eye diagram for downstream data is clearer than the one for upstream data, mostly because of the high noise figure of the SOA.

Modulating Packets onto CW Bursts at the ONU — In this part of the experiment, we demonstrate the possibility to modulate upstream data onto CWs provided by the OLTs. For this we use two separate ONUs, which communicate to the OLT through different wavelengths. For both downstream and upstream data we use a $2^{23} - 1$ word PRBS sequence.

The two lasers at the OLT transmit at the 1550.92 nm (λ_1) and 1550.12 nm (λ_2) wavelengths, assigned to ONU1 and ONU2, respectively. The MZ modulators at the OLT are controlled by a programmable board, generating downstream traffic and CW bursts piggybacked together within a 1 ms frame, as shown in Fig. 5a and b.

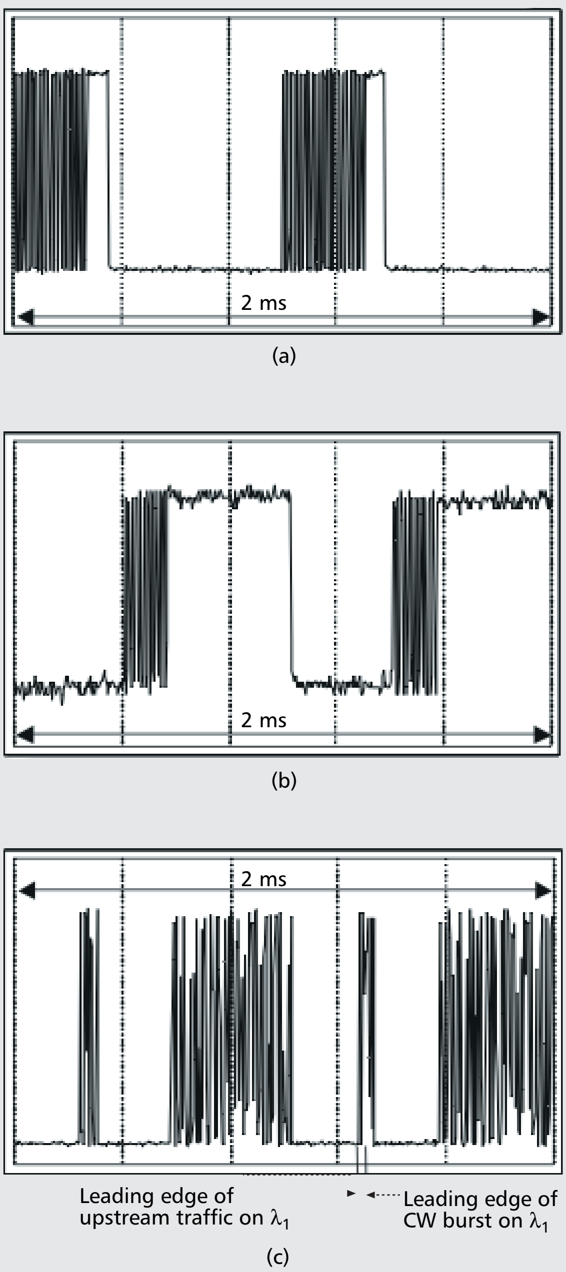

FIGURE 5. Timing diagram of packetized transmissions: a) downstream packets and CW bursts on λ_1; b) downstream packets and CW bursts on λ_2; and c) upstream traffic received at the OLT.

The add/drop filters and AWG assignments at the RNs ensure that λ_1 is received by ONU1 and λ_2 by ONU2. The MZ modulators at the ONUs are controlled again by a programmable board that turns them off while receiving downstream traffic (or in idle state) and turns them on when receiving the CW to modulate the data onto it.

The receiver at the OLT detects the upstream traffic on both λ_1 and λ_2. In this experiment, since the CWs in two different wavelengths do not overlap each other, there is no need for tunable receivers; the second version of the testbed, described in the next section, will implement tunable receivers to allow CWs to overlap. Figure 5c shows the upstream traffic pattern retrieved by the oscilloscope at the OLT receiving end. Note that the timing of downstream and upstream traffic on λ_2 are aligned; however, there is a forward time shift of the upstream traffic on λ_1 compared to the downstream data on λ_1. The reason is that the distance between the OLT and ONU1 is shorter; thus, so is the corresponding round-trip time. This factor is taken into account by the MAC protocol.

Toward the Second Version Testbed

The first version of the SUCCESS-HPON testbed demonstrated the feasibility of bidirectional transmission on the same fiber on the same wavelength for access networks and modulation of upstream data from the ONUs onto CWs provided by the OLT. The second version of the testbed will demonstrate the functionality of the MAC protocol and scheduling algorithms, and explore possible implementation issues.

Regarding the implementation of the scheduling algorithms, one of the main issues is their currently high computational complexity given the need to schedule frames at very high speeds. Current network processors may not be capable of scheduling all the incoming packets at the rates that are needed using these algorithms. We are thus currently working on finding simplified versions of the proposed scheduling algorithms that can achieve similar throughputs, with much lower computational complexity. A similar problem is faced in packet switch scheduling algorithms, and in this case randomized algorithms have proven to be very appropriate [13]. We are therefore exploring this option, among others.

In the second version of the testbed, several subsystem improvements will be made as well. In addition to implementing tunable receivers at the OLT, custom-designed reflective SOAs (RSOAs), which eliminate the need for a circulator at the ONUs, will be used in a similar approach to the one described in [14]. The SOAs that were available to us before (Genoa-Finisar G111 Linear Optical Amplifiers) have a high time domain reflectivity on the on/off input port, which made it impossible to modulate the data on the CWs adequately. These new RSOAs can be modulated at 1.25 Gb/s; they will need, however, special circuitry to modulate and switch from receiving data mode to transmitting (modulating) data mode according to the Frame Type field.

Summary

The mismatch between current on-demand dynamic service/usage models and static network infrastructure together with the huge imbalance in capacity between backbone and access networks is a major driving force behind the paradigm shift in optical networking. This shift is toward flexible and dynamically reconfigurable optical networks, where WDM plays an important role. Rapid developments in tunable optical components, WDM, and burst-mode receivers make such dynamically reconfigurable optical networks feasible.

Advances in architectural research push those enabling technologies toward the edge of the network.

SUCCESS-HPON is a research initiative for a next-generation optical access architecture that exploits the benefit of flexible, dynamically reconfigurable optical networks in access. It guarantees a smooth transition from current TDM-PONs to future WDM-based optical access. SUCCESS-HPON provides an upgrade path from pure TDM-PON to WDM-PON in an economical manner.

The first SUCCESS-HPON testbed demonstrated the feasibility of bidirectional transmission on the same wavelength on the same fiber for access networks and modulation of upstream data from the ONUs on CWs provided by the OLTs, thus eliminating the need for laser sources at the ONUs. The second version of the testbed will allow us to experiment with fast-switching RSOAs as modulators and study implementability issues of the MAC protocol and scheduling algorithms developed.

Acknowledgments

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