Reliable Architectures for Next-Generation Broadband Access Networks (RANGBAN) [Invited Paper]

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ABSTRACT

Future access network architectures should exhibit reliability while providing broadband Internet services. Progress on research and development of reliable wired and wireless access networks is discussed in this paper. Some emerging access network architectures and their reliability issues are explained.

Keywords: Broadband Access, Passive Optical Network, Long Reach, Optical Access, Wireless Access, Reliability.

1. INTRODUCTION

During the past decade, the backbone network has experienced enormous growth in capacity and reliability, mainly due to major developments in optical networking. During the same time, bandwidth demands of technology-savvy end users for broadband services such as media-rich applications have also increased at an unprecedented rate. However, the access network (commonly referred to as the "last-mile" network) still remains a bottleneck for providing bandwidth-intensive services to customers. Therefore, future "last mile" access infrastructure should support high capacity along with operational efficiencies. An access network should be able to scale in terms of number of users and data rate; so optical technologies are attractive for future access networks due to their high capacity.

1.1 Passive Optical Network (PON)

By employing passive optical components, an inexpensive transport mechanism can be created. This leads to the Passive Optical Network (PON) for building next-generation access networks. A PON uses a single trunk fiber that extends from the Optical Line Terminal (OLT) at a Central Office (CO) to a passive optical splitter, which then fans out to multiple optical drop points (Optical Network Unit (ONU)) connected to access (i.e., subscriber) nodes. While various flavors of PON exist (such as APON, BPON, GPON), Ethernet in the First Mile (EFM) is an attractive Layer-2 option for building the access network because of Ethernet's ubiquity and low cost. This gives rise to the Ethernet PON (EPON), which is designed to carry Ethernet frames at standard Ethernet rates.

1.2 WDM in PONs

Although the PON provides higher bandwidth than traditional copper-based access networks, there exists the need for further increasing the bandwidth of the PON by employing wavelength-division multiplexing (WDM) so that multiple wavelengths may be supported in either or both upstream and downstream directions. Such a PON is known as a WDM-PON. Architectures for WDM-PONs were proposed as early as the late-1980s. However, these ideas have not yet met commercial success because of: immature device technologies and a lack of suitable network protocols and software to support the architecture. A comprehensive review of WDM-PON technologies – devices, architectures, and protocols – which have been proposed by the research community over the past several years can be found in [1]. How to use WDM effectively in a PON so that the PON can become "data-burstiness-aware" is an important problem for its commercial viability (instead of fixed bandwidth allocation using dedicated wavelengths to users as in a traditional WDM-PON).

1.3 Hybrid Wireless-Optical Broadband Access Network (WOBAN)

The concept of a hybrid wireless-optical broadband access network (WOBAN) is a very attractive one. This is because it may be costly in several situations to run fiber to every home (or equivalent end user premises) from the CO; also, providing wireless access from the CO to every end user may not be possible because of limited spectrum. Thus, running fiber as far as possible from the CO towards the end user and then having wireless access technologies take over may be an excellent compromise. How far should fiber penetrate before wireless takes over is an interesting engineering design and optimization problem. In WOBAN, a PON segment starts from the CO and consists of an OLT at its head end. Each OLT can drive several ONUs which form the tail end of the PON. These ONUs support wireless routers in the wireless front-end of a WOBAN. The wireless routers directly connected to the ONUs are known as gateways.

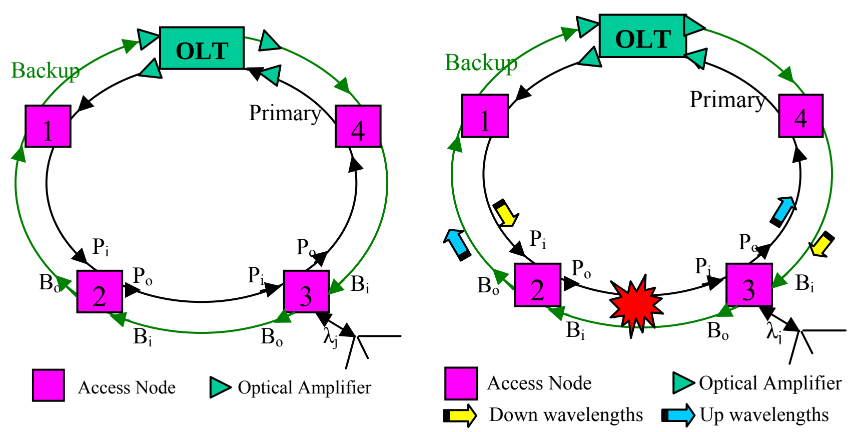
Therefore, the front-end of a WOBAN is a multi-hop Wireless Mesh Network (WMN) with several wireless routers and a few gateways. The wireless front-end may employ standard wireless technologies such as WiFi or WiMAX.

1.4 Long-Reach Broadband Access

Advances in optical technology have led to more wavelengths to be multiplexed on a fiber, and each wavelength can support a high transmission rate, e.g., up to 40-100 Gbps soon. The geographical span of a PON is a linear distance of 10-20 km. However, the fiber capacity is much larger than the typical bandwidth needs of users served by such a PON. To serve more users, the reach of the PON can be extended to 100 km and beyond without incurring the complexity of traditional metro networks, i.e., keep the network architecture simple; and they are referred to as SuperPON in the literature. We refer to them as Long-Reach (LR) Broadband Access Networks because, strictly speaking, the network is not passive (and hence not a PON) any longer because it may need some simple (but few) active elements, e.g., optical amplifiers. Thus, many COs can be consolidated, reducing the network's Capital Expenditure (CapEx) and Operational Expenditure (OpEx). Some architectures for Long-Reach Broadband Access have been proposed; they focus on how to provide long reach access, high transmission rate, etc. But their tree-and-branch topology inherited from the basic PON architecture cannot provide good coverage and reliability to users in metro area (100 km), so alternate network architectures such as "ring-and-spur" need to be developed which are more suitable for "two-dimensional" coverage.

2. RELIABILITY OF WIRED ACCESS NETWORKS

Figure 1 shows the operation (and protection support) of a wired access network using a "ring-and-spur" architecture (unidirectional access ring) and structure of a ring node (called access node here). The wired access network connects to the CO with an OLT, linking the access network to the backbone network. As shown in Fig. 1(a), two fiber rings connect the OLT and access nodes which add and drop wavelength(s). The primary ring carries network traffic in normal operation, and the backup ring provides survivability in case of a failure. In this illustration, in normal state, the primary ring transmits on downstream wavelengths from the OLT in one direction, e.g., counter clockwise. A set of wavelengths are assigned to each access node. Downstream traffic destined for node *i* is dropped from its wavelengths at node *i*, and then node *i* reuses these same wavelengths (after remodulation at the reflective ONU) to send its upstream traffic along the primary ring back to the OLT. This is possible by using an Optical Add-Drop Multiplexer (OADM) at the access node, where the OADM can be reconfigurable as well (i.e., a ROADM) to support dynamism in network configurations and to accommodate traffic variations. In normal operation, the backup ring transmits the downstream wavelengths from the OLT in the opposite direction, e.g., clockwise, but this signal is ignored. Each access node bypasses the downstream wavelengths on the backup ring and does not add upstream wavelengths onto the backup ring.



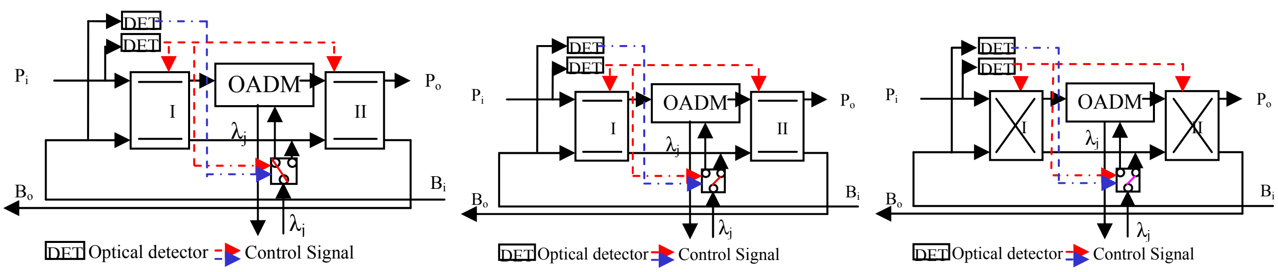
(a) Normal operation (b) Protection operation

Fig. 1. Operation of a robust wired access network using the "ring-and-spur" architecture.

Figure 1(b) shows the operation of the "ring-and-spur" wired access network after a failure between nodes 2 and 3. Now downstream traffic is sent to nodes 1 and 2 via the primary ring and to nodes 3 and 4 via the backup ring. Upstream traffic is sent from nodes 1 and 2 to the OLT on the backup ring, while nodes 3 and 4 use the primary ring to send data to the OLT. Below, we outline the hardware support needed to quickly detect failures and to reroute traffic as necessary.

Figure 2(a) shows the structure of an access node in normal operation. It contains two 2x2 optical switches, a 3-way optical switch, an OADM, and an optical detector array. The optical detector detects a network failure by monitoring signal strength on its attached port, and outputs 0 for normal state and 1 for failure. The output (0 or 1) controls the 2x2 optical switches and the 3-way optical switch, as shown by dashed lines. In normal state, the detector detects normal traffic signal on its attached port P_i. Its output 0 keeps the two 2x2 optical switches in "bar" state and sets the 3-way optical switch. Thus, downstream wavelengths on the primary ring arrive at port P_i, "drop and add" through an OADM, and continue to the next access node through port P_o; and downstream wavelengths on backup ring arrive at port B_i and are bypassed to the next access node through port B_o.

When a failure occurs (see Fig. 2(b)), the access nodes detect signal loss at their input ports (P_i for nodes 3 and 4; and B_i for nodes 1 and 2). At nodes 1 and 2, the detector on port B_i outputs 1 to set the 3-way switch, while detector on port P_i outputs 0 to keep the two 2x2 optical switches in "bar" state, as shown in Fig. 2(b). Thus, downstream wavelengths on the primary ring are dropped and upstream wavelengths are added onto the backup ring. At nodes 3 and 4, detector on port P_i outputs 1 to set the two 2x2 optical switches in "cross" state and also sets the 3-way switch (Fig. 2(c)). Thus, downstream wavelengths on the backup ring are dropped and upstream wavelengths are added onto the primary ring.



(a) Access node in normal operation (b) Access nodes 1 and 2 in protection (c) Access nodes 3 and 4 in protection

Fig. 2. Operation of the access node.

3. RELIABILITY OF WIRELESS ACCESS NETWORKS

Wireless access networks are gaining popularity, but they need to be made robust to deal with network failures. Wireless access architectures supported by high-capacity optical backhaul are envisioned to meet future untethered, reliable, and mobile end-to-end broadband access. One such architecture is Wireless-Optical Broadband Access Network (WOBAN). In a typical WOBAN, end users with wireless devices are scattered over a geographic area (Fig. 3). They may connect to a wireless gateway through either single-hop (under WiFi or WiMAX scenarios) or multi-hop wireless communication (under WiFi cenario). The access network is "anycast", i.e., an end user can connect to any one of the wireless routers in its proximity, and then route its traffic to a suitable gateway (through the fixed mesh of wireless routers) to access the rest-of-the-Internet (RoI).

WOBAN adds more robustness and fault-tolerance capability to the traditional wireline access network and can restore operation from network failure scenarios. In a traditional optical access network, due to a fiber cut, ONUs may fail, resulting in no connectivity for end users until the failure is fixed. Moreover, component failures in an optical network (e.g., OLT, ONU, etc.) also lead to less or no connectivity for end users. But, in WOBAN, the wireless connectivity may be able to adapt itself during failure so that affected users find a neighboring live gateway through which they may be able to redirect their traffic towards the CO. In case of congestion, it is also possible to redirect traffic through alternate less-congested wireless routers to reduce information loss. Thus, WOBAN provides better load balancing and fault tolerance compared to a wired access network. Moreover, WOBAN can "self organize" itself in case of router and gateway failures by using the adaptation capability of wireless front-end.

There exist proposals to make a WOBAN-like architecture more robust and reliable. Risk-and-Delay Aware Routing Algorithm (RADAR) [3] has been proposed to cope with failures in a WOBAN. RADAR can handle multiple failure scenarios. RADAR differentiates each gateway in the WOBAN by maintaining a hierarchical risk group that shows which PON group (ONU and OLT) a gateway is connected to. Each gateway is indexed, which contains its predecessors (ONU and OLT indices as well) to maintain the tree-like hierarchy of WOBAN. ONUs and OLTs are indexed similarly.

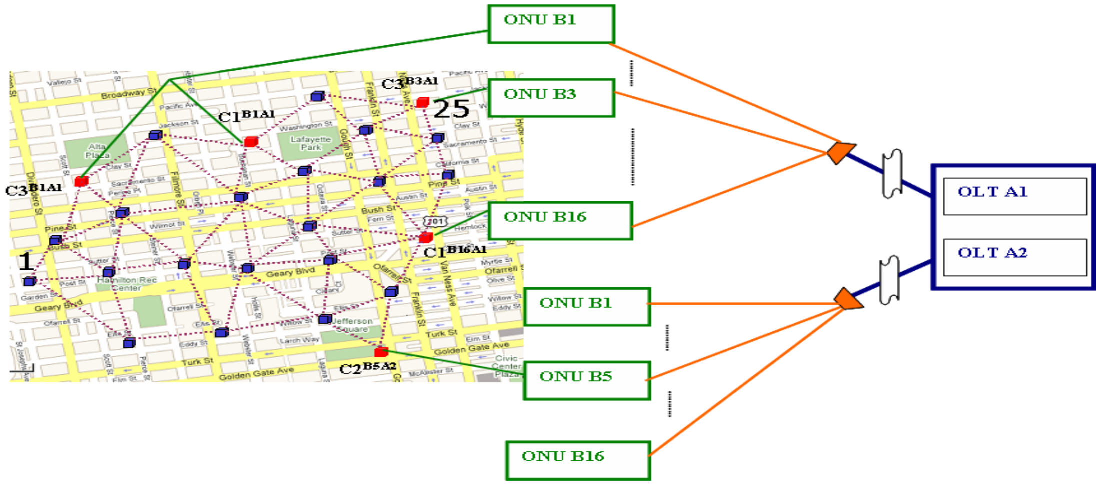


Fig. 3. WOBAN architecture with wireless front-end and PON backhaul.

In RADAR, to reduce packet loss, each router maintains a "Risk List (RL)" to keep track of failures. An RL in each router contains six fields, viz., path number (PN), Primary Gateway Group (PGG), Secondary Gateway Group (SGG), Tertiary Gateway Group (TGG), path status (PS) ("live" or "stale"), and corresponding path delay (PD). The primary gateway for a router is the gateway with the minimum delay path. PGG contains paths with the primary gateway and the gateways connected to the same ONU as with the primary gateway. SGG contains paths with gateways that are connected to different ONUs but the same OLT as with the PGG. TGG contains paths with gateways that are connected to a different OLT (and consequently a different ONU). In the no-failure situation, all the paths are marked "live". Once a failure occurs, RL will be updated and paths that lead to the failed gateway(s) will be marked "stale". If all links adjacent to PGG go down, and that of SGG and TGG are "live", then routers can infer that either both gateways connected to PGG have failed simultaneously or their parent ONU has failed. Then, packets will be rerouted through SGG and TGG paths. If all links adjacent to PGG and SGG go down, then TGG paths should take care of the packets. Thus, while forwarding packets, the router will only choose a "live" path. In this way, RADAR can provide protection for multiple front end and back end hierarchical failure scenarios.

Note that wireless access's reliability is constrained by less-reliable radio-frequency paths among routers. An end-to-end connection with all wireless hops exhibits decreasing reliability as number of wireless hops increases. Intelligent gateway placement in wireless access can reduce the wireless end-to-end connection hops and increase reliability of the network. For an end-to-end wireless connection, if one can reroute the traffic from one wireless end point to another end point through the wired backhaul, end-to-end connection reliability will increase due to the robustness of wireline network. This routing strategy may increase the path length of the connection, but network reliability gets enhanced.

4. CONCLUSION

Reliable access network should be an integral part of the next-generation network architecture to provide end-to-end broadband services. Reliability of both wired and wireless broadband access networks can be enhanced by careful network design. This paper explained some of the techniques to increase the reliability of an access network.

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