DIGITIZATION OF OPTICAL DISTRIBUTION NETWORKS (ODN) FOR PON

February 21, 2023

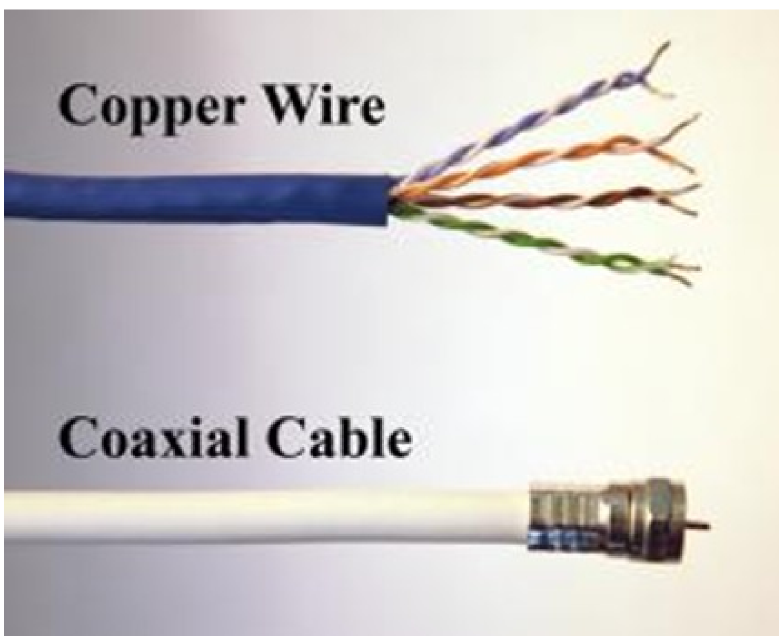
ODN Networks Evolution

The residential optical distribution network (ODN) is the final connection between a telecom operators' internet, cable, and telephone services and its customers. Over the past decade, and often out of the spotlight, ODNs have played a critical role in the widespread adoption and deployment of Passive Optical Networks, and development efforts have focused on reducing upfront costs rather than increasing functionality. Now however, there is a push by industry to introduce modern technology to the ODN in order to reduce operating expense and increase performance of access networks. This research note will provide an introduction to this topic.

ORIGINS OF THE TODAY'S ODN

For fifty years or more, the 'last mile' of telecom operators access networks consisted of twisted pairs of copper cables, one per household, bundled together in massive cables, in a tree and branch physical architecture. Cable operators used coaxial sheathed metallic cable in similar tree and branch arrangements. Early internet services were delivered, often painfully, over these now archaic technologies.

Figure 1 – 20th Century access network cabling technologies



Source: www.fairfaxcounty.gov/

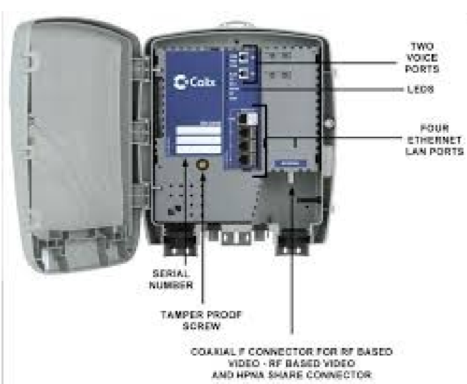
Starting early in the 21st century, deployment of Passive Optical Networks began in earnest, in support of ‘triple play’ service bundles, in which faster internet speeds, lower latency, and more video bandwidth were all key selling points. The first wave of deployment used BPON, followed by GPON/EPON, and we are now in the third generation of PON deployment with NG-PON2 and XGS-PON, offering 10 Gbps transmission speeds and 1G services.

Unlike earlier access networks, the ‘last mile’ of PON networks utilize point-to-multipoint optical fiber, with a single or pair of fibers originating at an Optical Line Terminal (OLT), terminating at a passive optical splitter located somewhere in the outside plant, with multiple fibers exiting the splitter and connecting to or near individual residences in a device called an Optical Networking Terminal (ONT) or Optical Networking Unit (ONU).

Figure 2 – Common PON network elements

OLTs by various equipment vendors

1x32 planar optical splitter (connectorized)



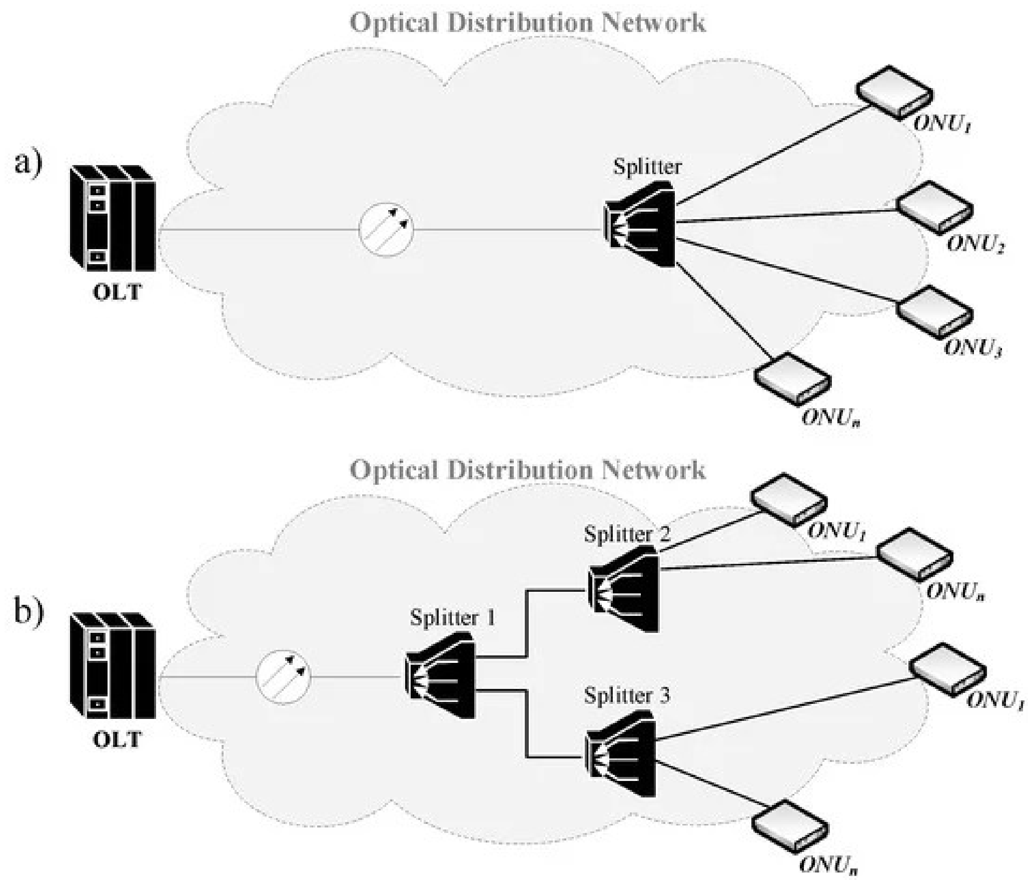
ONT for outdoor use

Typical ONU for indoor use

Source: various

The most common split ratios for GPON and EPON are 1:32 and 1:64, which can be implemented in single-stage (monolithic splitter) or two-stage (cascaded splitters) topologies. The fiber and splitter connecting an OLT with its subtending ONUs is called the Optical Distribution Network, or ODN.

Figure 3 – Schematic of Optical Distribution Networks



Source: Horvath et al, https://doi.org/10.3390/electronics9071081

ODN TECHNOLOGY EVOLUTION

There have been three generations of PON deployment already, and a fourth has begun (25G/50G PON), ODNs have remained basically the same – a combination of optical fiber and passive splitter. What has changed is the manner in which ODNs are built.

The first generation of ODNs (let's call them **ODN1**) were spliced together using highly skilled technicians and expensive fusion splicing machines which needed a controlled environment, usually a van, to keep dust and other contaminants away. While expensive and time consuming, this practice resulted in low-loss optical links which performed well.

Starting around 2015, a second generation of ODN (**ODN2**) started deployment, using various pre-connectorized components made available by several vendors, including Corning, CommScope, Huber+Suhner, Huawei, Fiberhome, and Furukawa. These products, architectures, and use cases are described in detail in ETSI TR 103 775, published in August of 2021. The ETSI technical paper also introduces the term 'QuickODN' to describe ODNs built with pre-connectorized components.

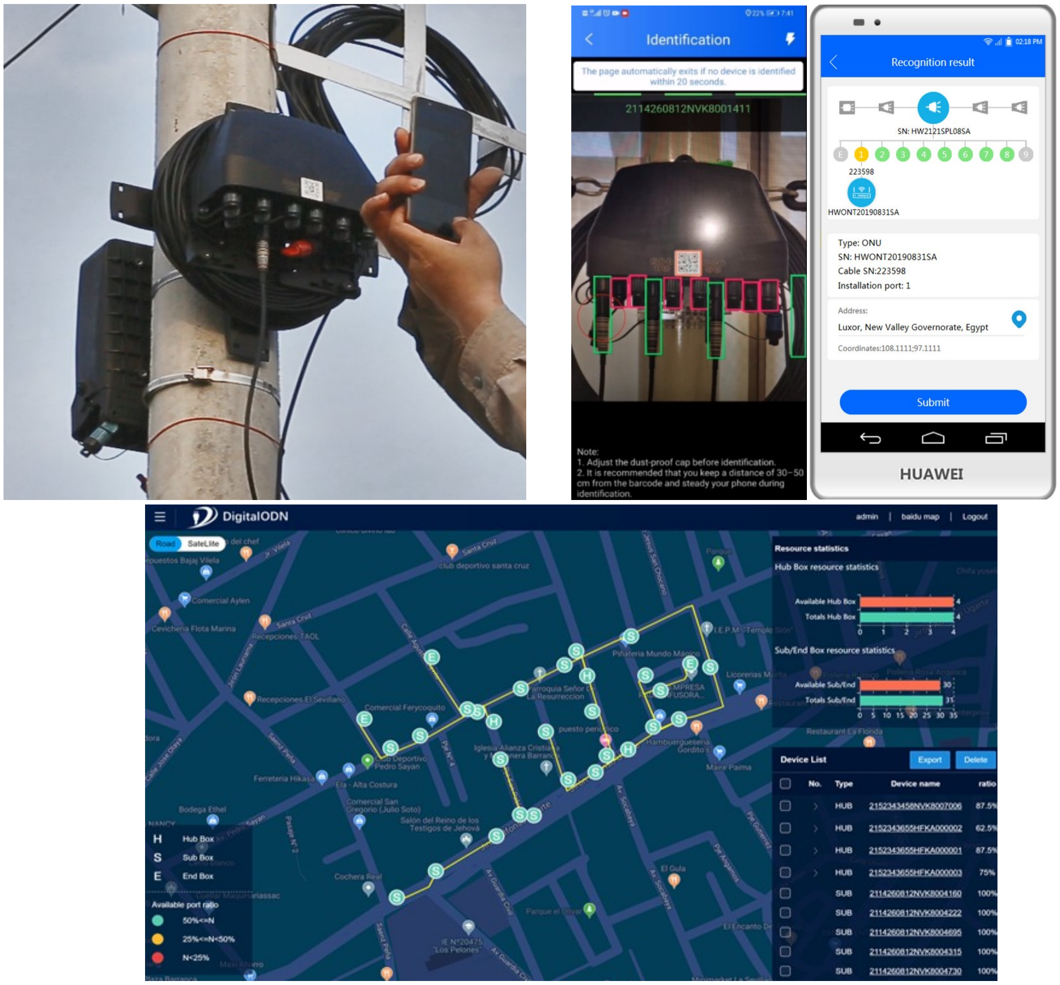
The main advantage of ODN2 is that no fiber splicing is required in the field, as all fusion splicing and subsequent testing is done in a vendor's factory setting. This means field installation can be done more quickly and less expensively, with more predictable results. Some products are even designed to allow subscribers to connect their homes to a FTTH Q-ODN junction box via a supplied pre-connectorized optical cable, without any involvement of the service provider.

Figure 4 – Pre-terminated optical cables and pre-connectorized products for QuickODN

Sources: Corning, Commscope, Alibaba, Huawei

Along with pre-connectorization, another major innovation in ODN2 is the use of digital labels (bar codes or QR codes) for each fiber and port that can be easily entered into a smart database creating a digitalized Optical Distribution Network. This 'Quick ODN' uses the unique identities of ODN passive elements to create intelligent management functions like automatic storage of optical fiber location information, automatic identification of optical fiber connections, optical fiber calibration information and a visual guide for onsite operations (Figure 5).

Figure 5 – Illustration of using QR codes to easily map access port locations



Source: Huawei

The advent of pre-connectorized and digitally labeled fiber, splitters, and fiber handling trays, cross-connects, and boxes greatly reduced deployment time and expense for operators, but did little to address operating expense. Today a third generation ODN (**ODN3**) is being developed which aims to address the operational expense of ODNs by introducing active, automated monitoring and intelligence.

ODN3: PON Network digitization and automation

Communications networks of all kinds are undergoing rapid transformation via the application of "digitization" and "automation", in the form of software defined networks (SDN), cloud-based networks (e.g. C-RAN), and the application of artificial intelligence (AI) to mundane tasks like service provisioning, performance monitoring and optimization, and fault identification and location. This topic is covering in detail in LightCounting's Network Transformation Report, scheduled for publication in June 2023.

Passive Optic Networks (PON) are no exception to the digitization and automation trend, as touched on in Part 1. Digitization and automation can provide numerous benefits to network operators, such as:

- Allowing operators to be more proactive with troubleshooting and preventative maintenance
- Reducing the number of customer calls to report service issues
- Reducing the number of truck rolls, reducing opex
- Improving results of service calls by equipping technicians with more accurate and detailed information
- Reducing risks during network maintenance, repair, and upgrade work
- Reducing IT opex via consolidating support tools and processes

However, PONs pose some unique challenges to digitization and automation:

1. PON customer-side equipment (ONUs and ONTs) must be extremely low cost. GPON BOSAs (Broadband optical sub-assemblies) used in indoor ONUs cost only a few dollars today.

2. PON optical transmissions pass through a 1xN optical power splitter, which complicates identification and monitoring of individual customer-side network elements.

Traditionally, the challenge of monitoring PON networks has been addressed through the use of OTDRs (optical time domain reflectometers). The basic principal is to send a high energy light pulse down a fiber, and monitor reflected light coming back. Breaks in the fiber integrity caused by connectors, splices, and damage will each cause reflections to return to the monitor, and the time of arrival is used to calculate distance from the source. A non-interfering wavelength is used, typically 1625nm for PON networks.

OTDRs work well on point-to-point fiber links, and can quickly determine the distance to a fiber break, and if combined with geo-mapping will provide a location for dispatching a service call. OTDR performance degrades with distance however and is sub-optimal for PON networks especially below the splitter. Faults there are located by process of elimination – an OLT alarm together with an OTDR showing no problems between OLT and splitter, indicates a problem between the splitter and the premises. This technique cannot tell which port on the splitter or which drop fiber the fault lies in, but narrows down the location to a handful of specific endpoints. Physical visits to multiple locations may still be required to identify the problem.

Due to cost, OTDRs are typically portable standalone equipment that are used when and where needed, and are not built into individual network elements. Instead, an ODN is characterized during construction and the ‘birth certificate’ report is maintained as a baseline reference in the event of issues later. Built-in OTDRs for OLTs have been proposed and considered by the PON vendors, but to date this idea has not been put into practice due the extra cost and some performance tradeoffs.

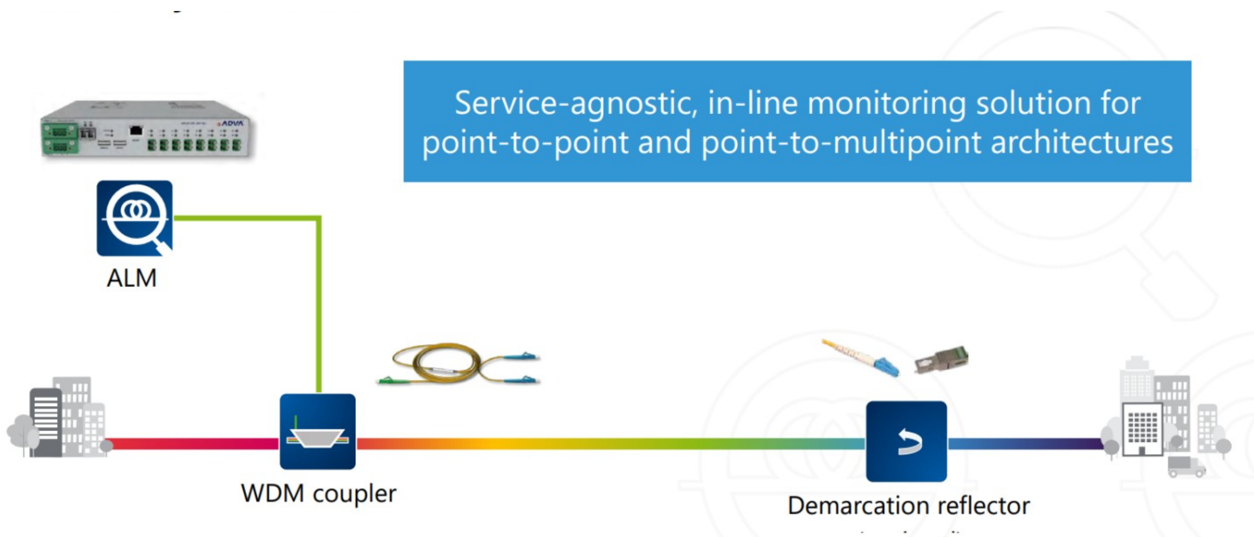
Various companies are addressing the PON monitoring challenge in different ways. Here's a look at solutions developed by several leading companies.

ADTRAN-ADVA

Although Adtran and ADVA have completed their merger, the ADVA brand and products survive. For PON network monitoring, ADVA recently upgraded its Advanced Link Monitoring (ALM) solution to support PON environments. Key features of this product are:

- Can monitor 16 or 64 fibers
- Active device is located at the upstream end of the link only; downstream end uses only a passive 'demarcation reflector'.
- Can verify fiber integrity and locate loss points
- Nominal reach is 160 km

Figure 7 – ADVAs Advanced Link Monitoring solution



Source: www.advaoptical.com

COMMSCOPE

CommScope has grown over the years from a simple purveyor of optical fiber cable to offering a broad range of passive and active optics, radio, and software products, in part via its $7.4 billion acquisition of long-time cable equipment maker Arris in 2019. The company now offers PON splitters, OLTs and ONUs aimed at the cable TV market, along with its mainstream HFC DOCSIS gear.

CommScope addresses PON digitization via its ServAssure NXT software suite, which consists of three parts:

- ServAssure® NXT— Analyze: Provides service performance trending, risk analysis, and troubleshooting, across HFC & PON networks
- ServAssure® NXT— Alarm Central: Provides automated identification and prioritization of existing and potential service impairments. Modules include Network Outage Management, Proactive Networking Monitoring, Fast Outage Detection, and Intelligent Spectrum Analyzer
- ServAssure® NXT— Insight: Provides tools for analysis and display of network performance data

NOKIA

Nokia is leading supplier of PON OLTs and ONUs to western service providers and offers several network monitoring solutions for PON networks.

Nokia's Access Management System (AMS) is the element management system (EMS) for the Intelligent Services Access Manager (ISAM). It provides tools for monitoring, troubleshooting, provisioning and upgrading broadband networks. Add-on modules include:

- Inventory Data Manager (IDM)
- Statistics and Data Collector (SDC)
- OSS Alarm Dispatcher (OAD)
- Access Provisioning Center (APC)

Nokia's Altiplano Access Controller is the key component of Nokia's Software Defined Access Network (SDAN) solution set. An Altiplano application called the Network Trend Analyzer (NTA) uses machine learning techniques to derive a trend of monitored KPIs using historical data for fundamental trend, random variance, seasonal, weekday and time of day behavior. This allows real-time detection of abnormal system temperature, optical attenuation, traffic, or CPU/memory/resource usage.

The NTA also allows for medium-term threat prediction and prediction of future issues, so anomalies can be reported before they actually occur. Examples could be a gradual increase in board temperature or degradation of UPS batteries, which could become problematic in the future, or increasing PON occupancy that could result in contention. This allows operators to address issues before they affect the customer's perceptions of service.

Traditional monitoring systems rely on rule-based analytics like Threshold Crossing Alerts and raise notifications when the KPI values cross a set threshold, which are set manually, defined network-wide, and only address with extreme conditions. Conservative thresholds result in missed detections, and too aggressive ones lead to false positives (wrong detections).

Nokia has also launched the Altiplano Application Marketplace, which makes available a catalog of operational tools developed by third parties as well as Nokia. One of the first apps available is the Nokia-designed Bandwidth Sharing Optimizer (BSO). This app uses high-frequency traffic telemetry data and unsupervised learning techniques like clustering and model fitting, to build a model for residential traffic. A set of AI/ML-based algorithms then predicts and improves the peak rate available to subscribers.

VIAVI

Viavi has long been a leading vendor of fiber optic test and measurement equipment like Optical Time Domain Reflectometers (OTDRs). It's not surprising therefore that the company offers products tailored for FTTx networks. Chief among them is the VIAVI Optical Network Management System (ONMSi) Remote Fiber Test System (RFTS), which can remotely detect and locate fiber faults quickly and accurately, and can improve security by quickly detecting intrusions.

Viavi also offers several different OTDRs designed specifically for PON networks:

- The SmartPocketV2 OLP-37XV2 is a wavelength selective PON power meter for performing downstream optical power level measurements on PON services
- The SmartPocket V2 OLP-39 is a TruePON tester that adds PON-ID analysis for both G and XGS-PON services.
- The SmartClass Fiber OLP-87 supports simultaneous upstream and downstream power measurement for PON network activation
- The SmartClass Fiber OLP-88 TruePON tester adds PON-ID analysis to verify correct OLT port and drop terminal connection.
- The Optimeter optical fiber meter performs selective PON downstream optical power measurements plus certification and troubleshooting of the last mile FTTx fiber link in less than a minute.

Viavi's TruePON PON-ID technology can be used to determine if a given subscriber ONU is connected to its assigned OLT port. Viavi recommends taking a bi-directional approach to PON fiber certification (testing at installation), meaning an OTDR trace is run both from the subscriber side and the OLT side. This optimizes results on both sides of the splitter.

ZTE

ZTE like Huawei is also evolving its ODN products. In October 2022 it announced a new product set called Light ODN which uses pre-connectorized splitters, distribution frames, drop cables, and other devices to enable zero splice, plug-and-play ODN installation, thereby greatly shortening the ODN deployment time.

Figure 7: ZTE's pre-connectorized ODN splitter product offering

Source: ZTE

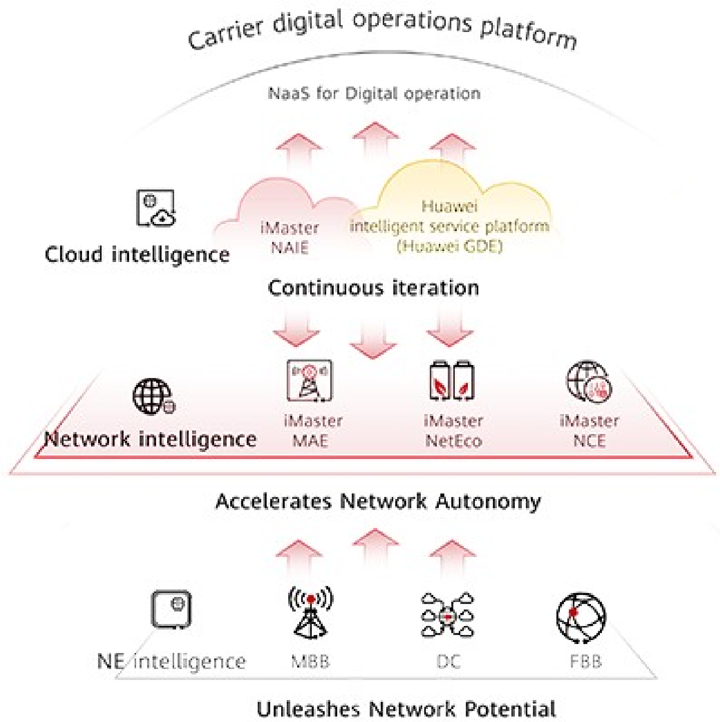
ZTE's Fiber Efficient Box (Feb) products contain combinations of power splitters which make the configuration and installation of cascaded ODNs easy and simple.

ZTE has also developed a feature it calls its Fiber Fingerprint Solution, that assigns unique QR codes and barcodes to the devices and cables at the fiber link node to ODN nodes and cables, which are then interpreted using intelligent image identification to look up information about the device or fiber in the management database. The system then transmits, manages, and verifies the data. The process is automated to avoid human error and to ensure efficient allocation of resources, in theory saving O&M costs for operators. The product was chosen by a panel of industry experts to receive a Lightwave Innovation Award in February 2023. The Light ODN and Feb products are ODN2 level improvements, while the degree of automation and use of AI in the Fiber Fingerprint solution seem more like ODN3.

HUAWEI

Huawei has coined the phrase "Autonomous Driving Network" (ADN) to describe its vision of an intelligent network capable of monitoring and optimizing itself with little to no human intervention. The three main elements or layers of Huawei's ADN are cloud intelligence, network intelligence, and network element (NE) intelligence as shown in Figure 8 below:

Figure 8: Conceptual view of Huawei's Autonomous Driving Network

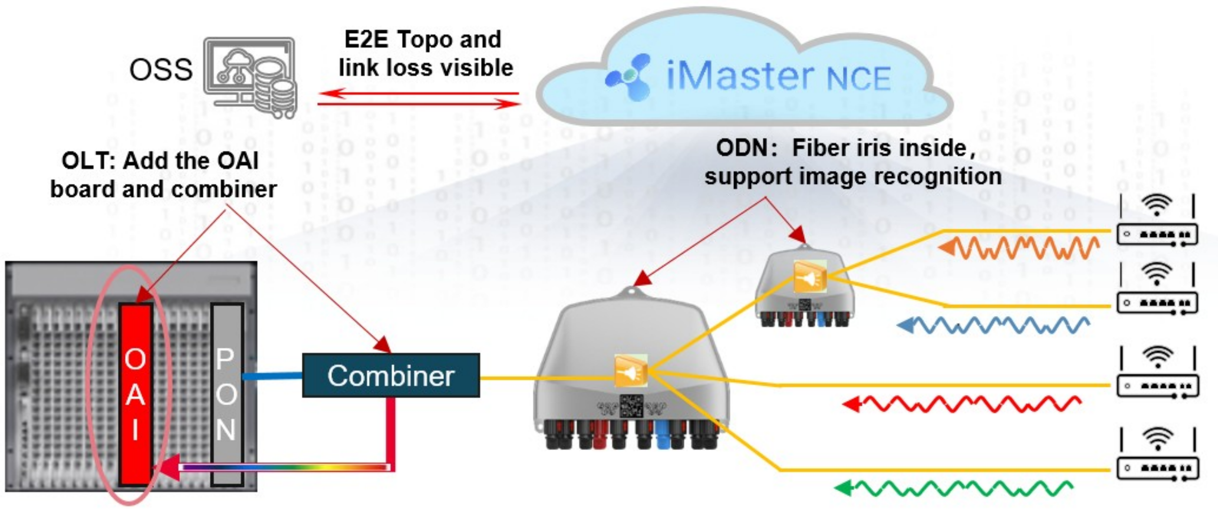


Source: Huawei

In relation to PON networks, using an optical monitoring system of some sort (based on reflections, introduced delay, or other), will allow an intelligent management system to automatically identify and locate impairments and failures down to the level of specific fibers and ports in an individual network element. This information is then provided to a centralized network operations center and to handheld devices in the hands of field technicians. Huawei calls this solution its "Digital Quick ODN" or DQ ODN for short, and it received a Lightwave Innovation Award in February 2023.

Huawei has developed technology it calls "Fiber Iris" to provide real-time monitoring information without adding to the cost of the consumer-side ONUs and ONTs.

Figure 6: Huawei's Fiber Iris Quick Digital ODN



Source: Huawei

The key to Huawei's Fiber Iris is the clever use of optical micro-structures in the 1xN splitter of the ODN to introduce unique differential phase changes in the upstream signal originating at each ONU or ONT. The combined optical signal arriving at the OLT is split via a filter and a small fraction is diverted to a highly sensitive receiver (located on what Huawei calls the OAI board) which can distinguish the phase changes from one another and thereby identify each ONU/ONT individually. No additional optics are required in the ONU or ONT, Each OAI board provide 16 monitoring ports, each ports can monitor 48 GPON ports in real time. Therefore, one OAI board can manage up to 768 GPON ports. Ultra-high integration greatly reduces the cost per user. The benefits of being able to 'see through' the 1xN splitter in the ODN are significant. Fiber breaks can be accurately located the fault point, the accuracy is less than 2m, and unused ports and full ports can be individually identified ahead of a service call. And service uptime/downtime can be monitored on the level of individual ONU/ONT as well. Of course there is some additional cost associated with the solution in the form of the non-standard, enhanced splitters, and the OAI board in each OLT and OSU (Combiner) This means operators will have to spend a little more in upfront cost in order to save on operating expense over the life of the network.

Is it all for naught? Is PON headed for the dustbin?

This paper has focused on PON ODNs, highlighting a lot of hard work done by vendors to make them simpler, easier, and less costly to manage. But what if all this investment will soon be obviated by the adoption of a newer technology? FWA – Fixed Wireless Access poses a serious alternative to traditional Fiber-to-the-Home networks.

FWA means using a wireless (mobile RAN) network to deliver broadband access between two fixed locations. In recent years, operators like Verizon have deployed FWA using 5G millimeter wave technology to deliver broadband access services in regions where they are not the incumbent wireline provider. It is far less expensive, and much faster, to deploy FWA than FTTx, and while there are tradeoffs in speed, reliability, and security, they are not significant enough to matter to most consumers.

For the full year 2022, Verizon reported net additions of 128,000 fixed broadband (its FiOS FTTx network) compared to additions of 783,000 FWA subscribers. While Verizon still has 8 times more fixed broadband subscribers than FWA, **FWA subscribers grew by more than 750% while fixed broadband subs grew just 1.9% compared to 2021**.

Continued adoption of 5G FWA, and the development of even higher performance 6G FWA, poses a challenge to the continued dominance of PON Fiber-to-the-Home networks for delivering consumer broadband access. Consumer electronics is rife with highly successful products than were eclipsed and fell into obsolescence quite rapidly – Walkmans, CD players, iPODs being some prime examples. The communications industry has its share of highly successful, widely distributed, and now – obsolete - technologies also. A few examples that come to mind are SONET/SDH, BPON, analog VHF video broadcasting, and “landline” telephones.

Wireless technology already holds a strong beachhead in the consumer residence via the nearly ubiquitous use of WiFi for in-home networks, and to a lesser extent, 4G LTE cellular data. It is not so far-fetched to think that FWA could push the radio/fiber boundary from the house or apartment to a point down the block or around the corner, to a fiber-fed fixed wireless access point. Rather than wrestling with all the issues associated with PON ODNs with their passive optical splits, operators may choose to simply walk away from them, and move to a different technology altogether.

Is this a “black swan” event, i.e. possible, but unlikely? Maybe, but stranger things have happened.