REFERENCE ARCHITECTURE

Service Providers
Smart and Connected Home

Meet escalating broadband demand with fiber optic communications

Intel offers a range of technology options for the service provider and on-premises equipment to enable fiber to the home

What You'll Find in This Document

This solution provides a starting point for creating fiber to the home (FTTH) technologies.

If you are responsible for:

- Investment decisions and business strategy...
  You'll learn how Intel® technologies can help you to deliver FTTH, so you can meet customer expectations for fast and high bandwidth internet connections.
- Figuring out how to implement FTTH...
  You'll learn about the architecture components and how they work together to create a cohesive business solution.

Executive Summary

Service providers are facing ever greater demand for broadband, as homes and businesses connect more devices, and increasingly consume data-hungry media services. Next generation speed tiers will require multiple gigabits per second (Gbps) of bandwidth capability and extremely low latency. Service providers are looking to Passive Optical Network (PON) technologies to deliver these gigabit services.

This document outlines the key architectural components of fiber to the home (FTTH) technologies, including the service provider's and the on-premises equipment. Intel offers a range of technology options for OEMs to choose from as they build these technologies end-to-end, including processors with dedicated communications and networking capabilities and Field Programmable Gate Arrays (FPGAs). This document will help OEMs to understand these options, and to make choices based on their own architecture preferences.

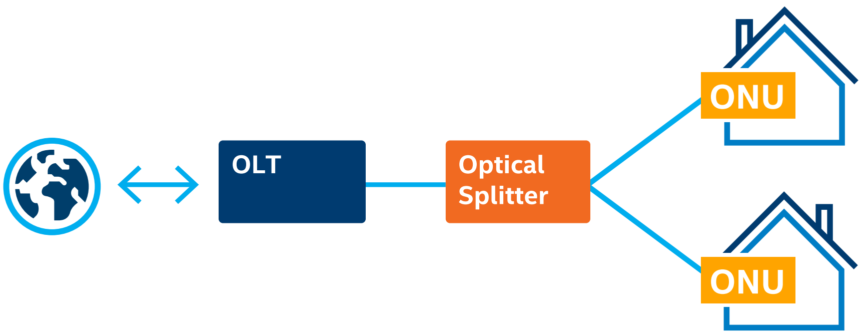

Figure 1. FTTH enables high speed communications over a shared fiber optic cable Intel provides a range of technology solutions for all the key points in the network.

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Introduction

As more and more devices become connected, and video and audio is consumed more than ever before, service providers could struggle to keep pace with rising broadband demand. Entertainment, the Internet of Things, peer-to-peer communications and real-time gaming will continue to drive demand, pushing it beyond a level that can be satisfied by phone lines or coaxial cable. Next generation speed tiers will require multiple Gbps of bandwidth capability and extremely low latency. This can only be achieved using fiber optics. Service providers are looking to Passive Optical Network (PON) technologies to deliver these gigabit services.

Passive Optical Networking (PON) enables a single optical fiber to be shared by many customers, so there is no need to install or manage separate fibers from each customer to the hub. Passive Optical Networking has three main components (see Figure 1):

- **The Optical Line Termination** (OLT) is installed in a service provider's hub or central office. It sits between the fiber network and a IP or Ethernet network, transporting and translating the data between the networks.
- **The Optical Network Unit** (ONU) is installed at the customer premises, either a residential home or business. It is sometimes called the Optical Network Termination (ONT).
- **The Optical Splitter** is used to divide the fiber, close to the customer premises. It is a passive optical device that does not require any power.

What is an OLT?

The OLT is the intermediary between the fiber optic network and the Ethernet or Internet Protocol (IP) network. It translates data protocols in both directions, and manages the incoming and outgoing signals on the fiber optic line. The OLT provides switching, routing, quality of service, security and other functionality to the traffic traversing the PON network.

The OLT fiber port architecture uses a line card, which is a printed circuit board designed to plug into the telecommunications network (see Figure 2). Each OLT typically has multiple line cards, which connect to a multi-gigabit per second back plane. Each line card has multiple fiber ports. The fiber ports each connect to a single fiber, but because the cable splits, each fiber typically serves 32 ONUs. It is also possible to have a single port OLT with a single line card.

The fiber ports use different optical wavelengths for upstream and downstream communications. A wavelength is a frequency of light that is sent along the fiber. To give a simple explanation, the OLT could send downstream traffic using a blue colored light and receive upstream traffic using a red colored light. The different wavelengths of light can pass through each other, so the fiber can be used in two directions at the same time. Depending on the standard used, multiple wavelengths can be sent in each direction, increasing the capacity of the cable. No more than 4 or 5 wavelengths are typically used in each direction, because the transmitters and receivers become prohibitively expensive for most applications as the required precision increases.

As Figure 2 shows, each fiber port connects to a single PON Physical (PHY) layer interface and PON Media Access Control (MAC) interface. These two components translate between the Time Division Multiple Access (TDMA) protocol of PON and the standard Ethernet or Internet Protocol (IP) packets, as traffic passes in both directions.

The line card connects to the optical network through an optical connector. The downstream and upstream optical wavelengths are split by the optical splitter, so the correct wavelength is routed to the receive diode.

The receive diode converts the signal from the optical domain to the electrical domain and sends the signals to the upstream PHY module. The PHY demodulates the signal and sends it to the MAC framer. The MAC framer converts the traffic to an Ethernet or IP packet and sends it to the network packet processor. Some of the upstream traffic is comprised of upstream and downstream time slot requests, such as a request to send upstream traffic to a web server and receive a web page as downstream traffic from it. All time slot requests go to the upstream scheduler. This module allocates time slots to the requesting PON devices.

The downstream traffic from the Ethernet/IP network goes into the downstream MAC framer. The framer maps Ethernet frames into time slots for the PON network. The framer sends those time slots to the downstream PHY, which converts the data into the electrical domain. The electrical PHY output is connected to a laser diode that transmits the signals as light.

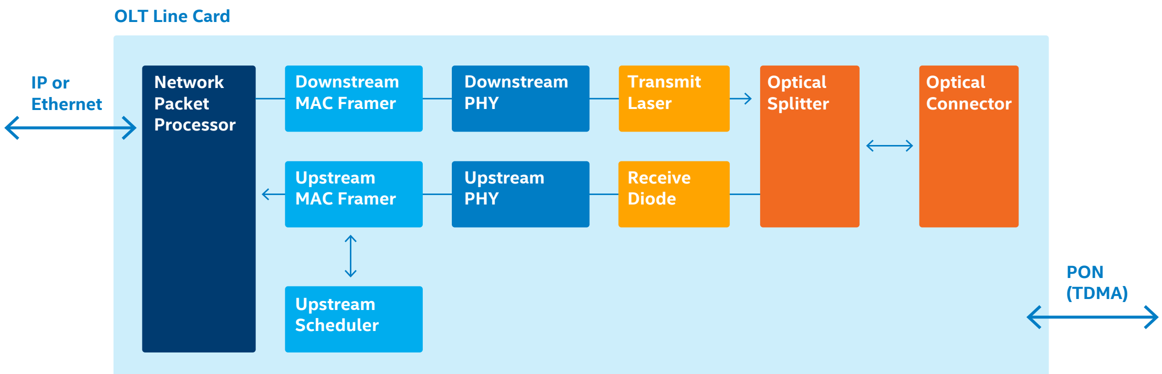

Figure 2. The OLT architecture for the PON shows how the Ethernet or IP traffic (on the left) is converted into the optical domain (on the right), and vice versa

What is an ONU/ONT?

The ONU or ONT is the network termination point for the customer premises. The ONU implements the PON MAC and PHY, to convert between the optical domain and Ethernet/IP, and then transfers standard Ethernet or IP traffic into and out of the customer premises Local Access Network (LAN). The ONU can be an integrated function in a service provider gateway or a standalone device.

Understanding the PON standards

There are many PON standards that are defined by different standards committees. The standards have similar specifications for the MAC and PHY layers, which govern how and when data is transmitted. The differences are typically in the optical wavelengths, bandwidth, and the number of ONUs supported by a single OLT port. Additionally, NG-PON2 has support for Dense Wavelength Division Multiplexing (DWDM),which enables more wavelengths to be used in each direction. NG-PON2 is still being modified, but GPON, XG-PON1, XG-PON2, XGS-PON, EPON and 10G EPON have been ratified as standards. Table 1 shows a comparison of the current PON specifications.

Standard	GPON	NG-PON2	10GPON (XG-PON1)	10GPON (XGS-PON)	10G EPON
Specification	ITU G.984.x	ITU-G.989.x	ITU G.987.x, G.988.x	ITU G.987.x, G.988.x	IEEE802.3av
Upstream Wavelength(s) (nm)	1310 (single wavelength)	1524-1544 (Between 4 and 8 wavelengths)	1270 (single wavelength)	1270 (single wavelength)	1270 (single wavelength)
Downstream	1490 (single wavelength)	1596-1602 (Between 4 and 8 wavelengths)	1577 (single wavelength)	1577 (single wavelength)	1577 (single wavelength)
Upstream/ Downstream bandwidth (Gbps)	1.25/2.5	2.5 to 10 per upstream and 10 per downstream	2.5/10	10/10	1/10 or 10/10 (depending on optics chosen)
Split Ratio	Max 128	Max 128	Max 128	Max 128	Max 32
Other Features	1550nm reserved for video overlay, but could be used for data	Dense Wavelength Division Multiplexing with Tunable ONT optical receiver, so it can be configured and updated for the wavelengths in use			

Table 1. The table shows an overview of the different standards specifications for PON services.

Solution Architecture

Intel provides end-to-end technologies to support the delivery of FTTH services.

Solution Overview and Benefits

For service providers developing OLT and ONU devices, Intel provides flexible technologies that are ready to support the new network, and ready for integration with the existing network. The range of technologies offered by Intel spans from the OLT in the head end or hub, to the ONU premises equipment.

There is a range of implementation options, including dedicated chipsets and field programmable gate arrays (FPGAs), so that service providers can select the approach that best fits their requirements. Intel's ONU solutions are integrated with the latest home networking technology, streamlining the creation and deployment of customer premises equipment.

Solution Architecture Details

Figure 1 shows the solution architecture for FTTH. Intel offers a range of technologies to help OEMs design and implement OLT and ONU equipment that best meets their individual requirements for power, cost, size and other considerations.

Field Programmable Gate Array (FPGA) devices from Intel can be used to create the line cards in the OLT. They offer freedom in design and integration with other OEM technologies, as well as the potential to update the devices in the field. A range of pre-built PON capabilities is available for integration into the FPGA design.

Intel also provides solutions that can be used to create the ONU, including technologies for an integrated home gateway device. Depending on the OEM's preferred architecture strategy, FPGAs can be used to reduce the number of chips and create more flexible hardware. Alternatively, dedicated Intel® PON Chipsets can be used for the PON MAC and PHY, which are used to convert between the PON and Ethernet/IP protocols.

The Intel® AnyWAN™ SoCs enable service providers to create innovative connected home solutions, and to connect to any wired or wireless technology.

Intel's solutions are all compatible with widely adopted open source software solutions, and are supported by Intel's own software stack.

Intel® Solutions for Optical Line Termination (OLT) Solution

Intel offers a number of Field Programmable Gate Array (FPGA) devices that can be used to create an OLT line card. FPGAs can be used for everything to the left of the transmit laser and receive diode in Figure 2. FPGAs provide abundant resources with high logical elements (LE) count and large on-chip memory capacity.

The Stratix® V FPGA, for example, has 14.1 Gbps integrated transceivers (PHY capabilities), with native PON burst mode to smooth latency when there is a spike in traffic. It provides a 10GBase-KR serial interface to the back plane, and high performance interfaces for the external memory used for packet switching and processing, and smoothing out traffic spikes. It also comes with a list of intellectual property cores (IP cores) from Intel and partners that provide off-the-shelf functionality for key OLT functions, such as Intel's 10G PON MAC IP core.

Figure 3 is a reference design for a 10Gbps OLT line card using the XG-PON1 standard.

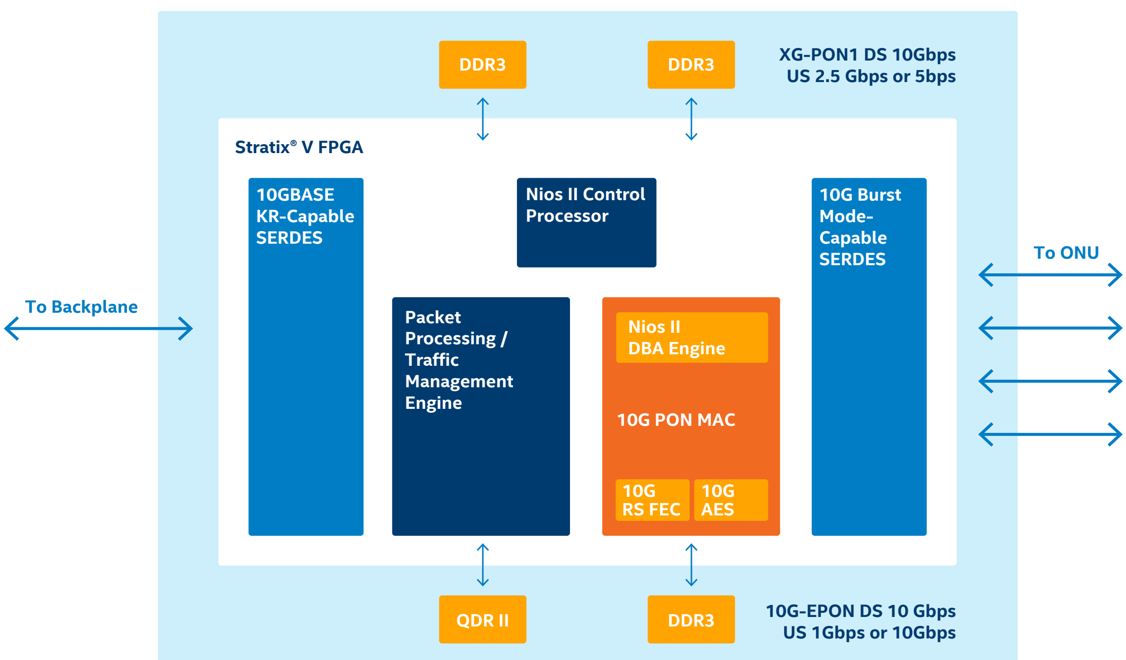

Figure 3. One-Chip Solution 10G PON OLT on a Stratix® FPGA

An OEM can use one FPGA or several to implement the line card, and can incorporate external PHY, MAC, packet processing and traffic management capabilities, and an external fabric interface chip. Using virtualization, it's possible for an Intel® Xeon® processor to be used to run the MAC capability in the cloud, and for the upstream and downstream PHY capability to be in an FPGA.

Intel® PON Chipsets

Intel provides a wide range of solutions, including SFU, SFP, FTTdp and HGU, for standalone ONU implementations, standalone home routers, and integrated ONU/home router solutions. Intel also provides purpose-built processors and chipsets and FPGAs that be used for 1Gbps to 10Gbps PON PHY chips, 1Gbps to 10Gbps PON MAC chips, WLAN MAC and PHY (802.11n, 802.11ac and 802.11ax), voice processors, and home router processors. All of these solutions can be combined to create the desired ONU platforms, with the technology choice governed by the business needs.

A SFU (Single Family Unit) for Ethernet to PON conversion ONU

A SFU (Single Family Unit) for Ethernet to PON conversion ONU converts downstream traffic from PON to Ethernet. The optical front end of the ONU can vary. An OEM can use embedded optics, or a Small Form factor Pluggable (SFP). The interface to the optics can vary as well. Some optics output a typical differential pair signal that drives directly into the PON PHY. Other optics connect to the PON MAC and PHY through a Media Independent Interface (MII) variant or Serial/Deserial (SERDES) interface. Some service providers also require voice ports on the ONUs.

The example in Figure 4 shows a generic ONU solution. Some parts (such as voice) might not apply to some use cases, depending on your business requirements. The diagram is a logical diagram and can support different PON standards on the front end and different voice and Ethernet standards on the back end.

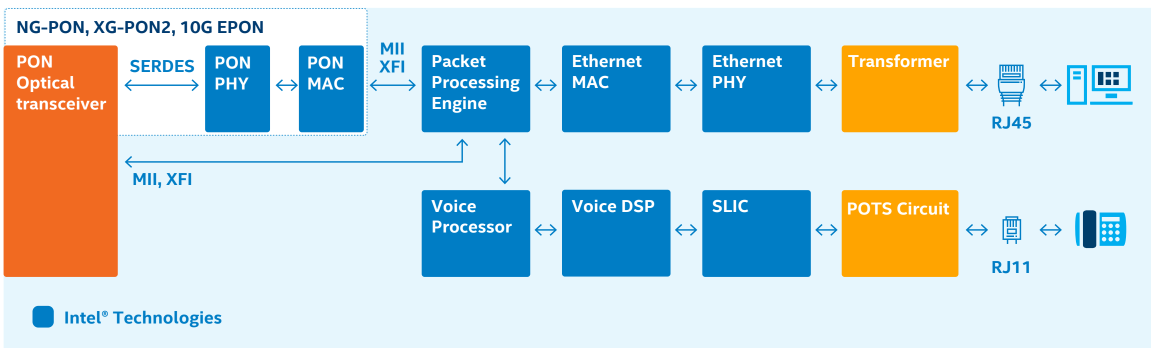

Figure 4. Generic PON ONU Architecture

An ONU has the same basic components. It starts with the connection to the PON network, using any of the standards available today. The optical transceiver contains the optical connector, optical splitter, transmit laser and receive diode. The transceiver is connected to the PON PHY chip, which is connected to the PON MAC chip. The MAC chip connects to a packet processing engine using a standard MII or XFI bus depending on the configuration. In some cases the chosen PON optics have integrated MAC and PHY capability and connect directly to the packet processing engine. The packet processing engine provides basic Ethernet switching and routing capability. The engine in some cases will provide Virtual LAN (VLAN), quality of service, tunneling capability and more. The packet processing engine connects to an Ethernet MAC via a standard MII bus. The Ethernet MAC connects to the Ethernet PHY. The PHY interfaces to the impedance matching transformer to ensure connection quality, and then on to an RJ45 Ethernet socket. In some cases an ONU may require multiple LAN Ethernet ports. In this case the Ethernet MAC would connect to a multiport Ethernet switch that would interface to multiple Ethernet PHYs. Upstream traffic passes through the same architecture in the opposite direction: starting at the Ethernet port, and passing through the Ethernet PHY and MAC, the packet processing engine, and the optical MAC and PHY, and optical transceiver.

The packet processing engine also connects to the voice circuit in some cases. The voice processor routes the voice packets to the voice DSP to be modulated into analog voice signals. It also runs the Session Initiation Procotol (SIP), which is responsible for call setup, data transfer, call operation and more. An example of this protocol support would be ITU H.323. The voice processor connects to the Voice Digital Signal Processing (Voice DSP) engine that converts the voice packets to analog voice or analog voice to digital. The voice DSP interfaces to the Subscriber Line Interface Circuit (SLIC). This circuit provides a complete analog telephone interface to typical phone consumer devices. The SLIC interfaces to some basic filtering circuits and then on to the RJ11 phone socket.

Intel® PON Chipset Solutions for the ONU

Intel® PON Chipset for 1 Gigabit per second (Gbps) solutions can be used to implement the PON MAC and PHY (see Figure 5). The PON Chipset product has the PON MAC and PHY embedded in it, and connects to an optical transceiver. On the LAN side, the Intel® PON Chipset connects to a typical Ethernet MAC and PHY.

The Intel® PON Chipset supports DDR RAM and SPI interfaces for SDRAM and flash memory to enable the ONU to handle bursts of traffic.

The Ethernet MAC/PHY capability can be implemented using an Intel® Ethernet controller. The Intel® Ethernet Converged Network Adapters X710/XL710 Family enables 1Gbps Ethernet, and the Intel® Ethernet Converged Network Adapters X550 Family enables 10Gbps Ethernet.

The Intel® Telephony Chipset for CPE provides the voice interface, connecting to a standard FXS analog phone port. Intel® DECT Chipsets can be used to provide the interface for DECT, the wireless digital standard for cordless home handsets.

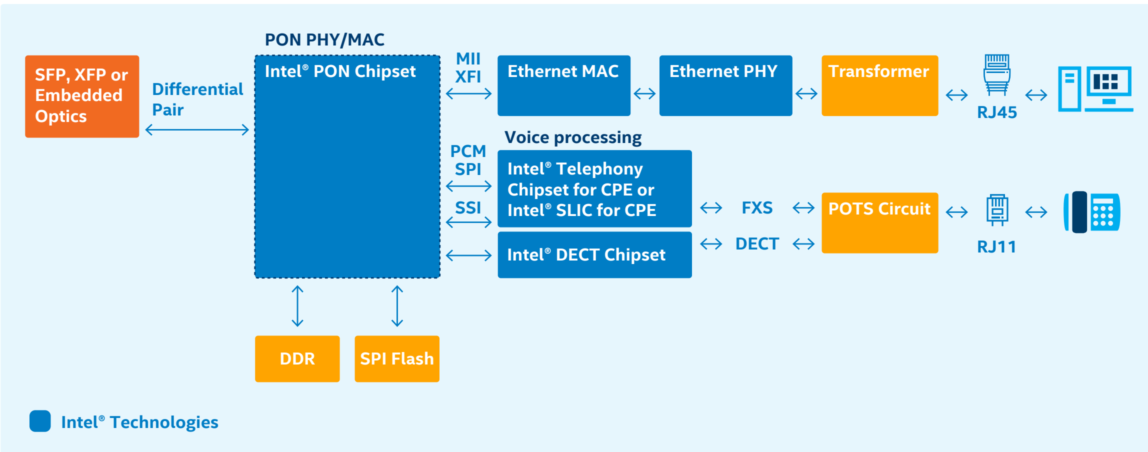

Figure 5. Intel®-based ONU Reference Architecture

Intel® FPGA Solutions for the ONU

Intel has a diverse FPGA product offering to implement the ONU. The FPGA reduces the number of chips in the ONU design and provides a level of hardware flexibility, because the FPGA can be more easily updated in the future than dedicated processors. Similar to the OLT offerings, the Intel IP cores can be used to create a single chip ONU solution. The Arria® 10 and Stratix® products incorporate SERDES transceivers for direct connection to the PON optical transceiver and include the PHY and MAC components for both the PON and Ethernet. Standard interface pins can be used to connect to the Ethernet and voice SLIC interface on the ONU. Figure 6 shows how to implement a reference architecture using FPGAs, which may prove useful for prototyping or certain unique applications.

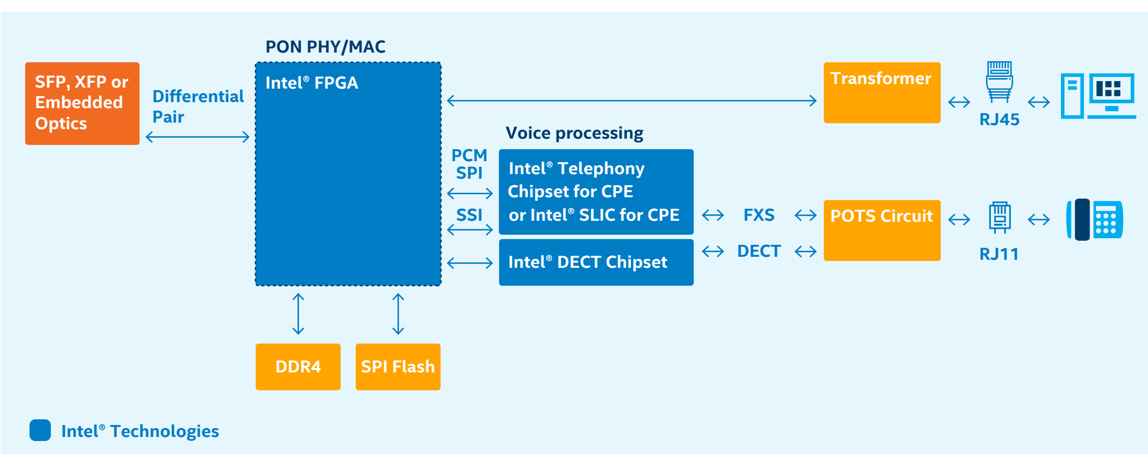

Figure 6. Intel® FPGA-based ONU Reference Architecture

Intel's Connected Home Solutions

While some operators will decide to provide the FTTH connectivity only as far as the home, others will add a home router, or converge the ONU and home router. Intel has the building blocks to support each of those decisions.

Intel has a range of technologies that can be used to create home routers. A home router is the central device of home networking in a commercial or residential environment. One side of the device connects to the Wide Access Network (WAN) and the other side to the Local Access Network (LAN) or customer network. A typical home router provides Ethernet and wireless connectivity to the Internet and services. The router supports multiple switched Ethernet interfaces, multiple Wi-Fi frequencies and SSIDs, Zigbee for IoT connectivity, other interfaces like Media over Coax Alliance (MoCA) and more. In a standalone home router, the WAN interface is connected to a modem provided by the service provider. This allows flexibility in the connection to the different WAN interfaces the service provider is supporting.

The home router reference architecture in Figure 7 shows a basic functional block diagram. There are different SKUs available to the developer depending on the WAN interface or bandwidth requirements. The WAN connectivity is provided by Intel Ethernet Controllers. The Intel Ethernet Converged Network Adapters X710/XL710 Family enables 1Gbps Ethernet MAC/PHY capability, and the Intel Ethernet Converged Network Adapters X550 Family enables 10Gbps Ethernet MAC/PHY capability. The Ethernet Controller connects to the Intel® AnyWAN™ SoC.

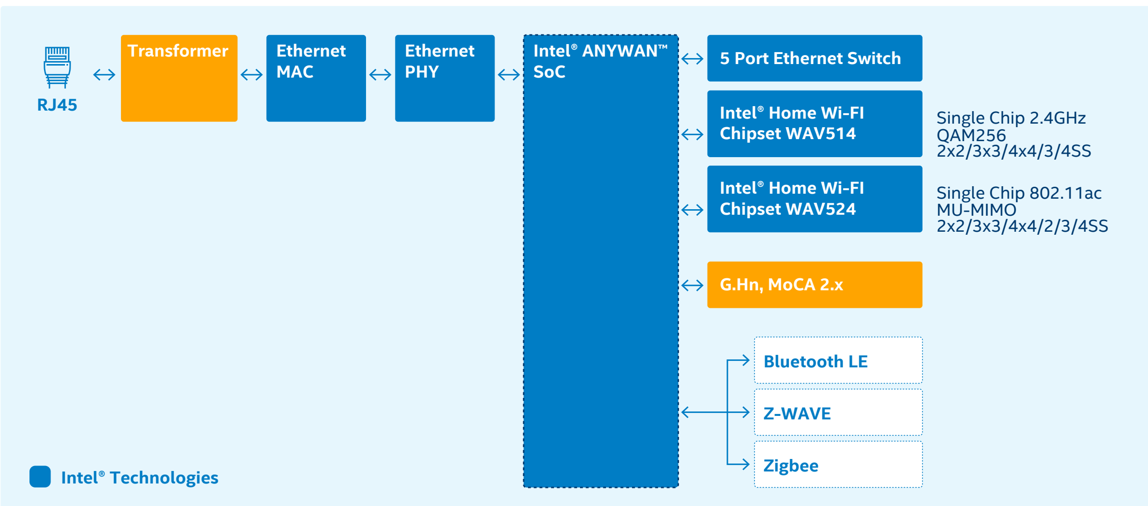

Figure 7. Intel®-based Home Router Reference Architecture

A developer can use the Intel AnyWAN™ SoC GRX350 or Intel AnyWAN™ SoC GRX550 for Gigabit applications.

The Intel AnyWAN™ SoC can be connected to Ethernet switches for providing multiple LAN-facing Ethernet interfaces. It can also be connected via the multiple PCI based networking solutions. Intel Home Wi-Fi Chipsets provide excellent performance for Wi-Fi connectivity in the home. Their integrated processing engine provides sustained bandwidth support for a high number of attached clients and advanced small packet performance over Wi-Fi.

To provide capability for the legacy 2.4GHz 802.11n and for the newer 5GHz 802.11ac Wi-Fi specifications, the interfaces for the Intel® Home Wi-Fi Chipsets WAV514 and WAV524 can be used. The drivers for the Intel® Home Wi-Fi Chipset WAV500 Series support the latest Wave 2 11ac specification, while also supporting intelligent band-steering and high packet-per-second processing—all with full CPU offloading. The Wi-Fi cards are certified by the FCC and European Telecommunications Standards Institute.

Home Gateway Unit (HGU) Solutions

The components of the ONU and home router solutions from Intel can be combined to make an integrated home gateway. There are a number of ways that the solutions can be used together.

The WAN interface can be supported by the Intel AnyWAN™ SoC. It includes integrated PON MAC and PHY capabilities, but also has a WAN port that can connect to an external MAC and PHY, depending on the requirements of the WAN interface. The Intel AnyWAN™ SoC can connect to a standard optical module via XFI or an optical module with integrated PON PHY and MAC-like SFP.

Intel® PON Chipset solutions can be used to provide 1Gbps PON MAC and PHY capabilities outside of the Intel AnyWAN™ SoC, including integrated in the MAC and PHY optics.

The Intel® AnyWAN™ SoC provides home routing and switching capability to the local access network (LAN) in the home. A 10G Base TX interface can be connected to the Intel AnyWAN™ SoC to enable full support for 10Gbps symmetric bandwidth within the premises. The same Wi-Fi interfaces in the home router reference architecture can be connected.

Figure 8 depicts an integrated PON MAC and PHY plus home router to form a HGU.

Other interfaces such as Zigbee, Z-Wave, Bluetooth LE, LTE, and MoCA can be connected to the onboard MII and PCI interfaces.

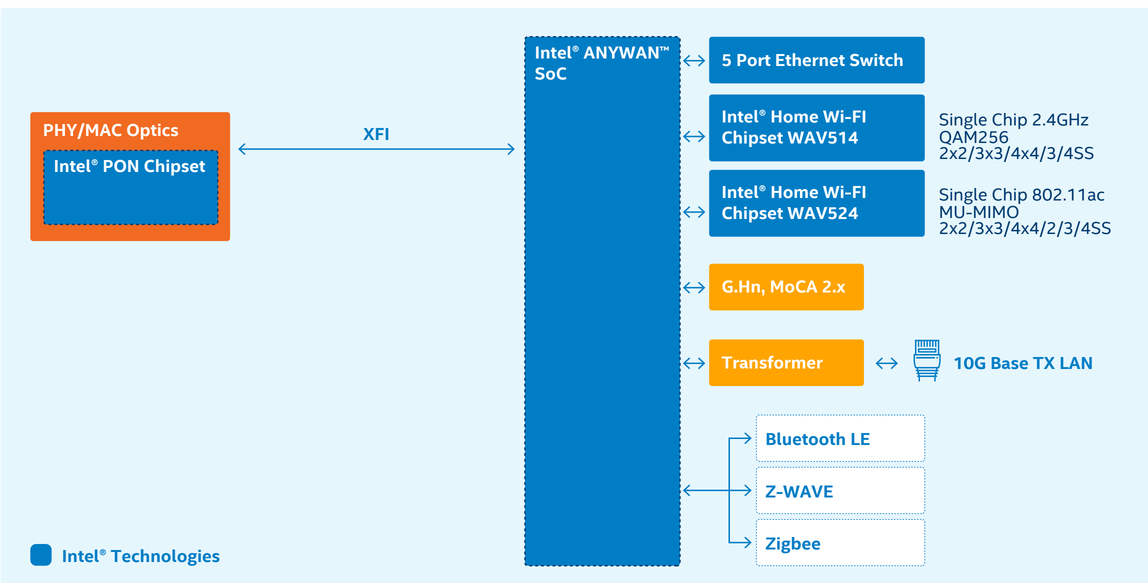

Figure 8. Integrated 10G PON ONU based on Intel® technologies

The PON software stack

The Intel® Universal Gateway Software can be used for non-cable applications and Intel also offers a software development kit that is compatible with RDK for use in cable applications.

The Intel Universal Gateway Software (UGW) Software provides a modular gateway software stack that addresses networking as well as a framework to adapt various carrier applications such as security, smart home and management.

Intel UGW Software is based on a Linux Kernel with a combination of OpenWrt open source modules and Intel-developed modules. The Functional API (FAPI) provides an API that allows developers to integrate their own software stacks or applications.

The FAPI approach provides seamless migration to other Intel UGW Software releases and hardware platforms.

RDK is a pre-integrated software bundle that provides a common framework for powering customer premises equipment. It represents an industry effort to standardize cable modem components for open source. The Intel UGW Software provides access to the RDK via the RDK defined SoC Hardware Abstraction layer. The Linux-based architecture provides an adaptation layer to the RDK-B OEM middleware. The RDK-B middleware implements the embedded gateway (eGW) functionality as well as all the operational control interfaces for the operator. Operator- and service-specific applications can be built above the RDK-B stack.

OEMs can also develop their own solutions or port other open source solutions if they are required.

Summary

PON serves millions of subscribers today. 10Gbps PON solutions will be used to increase the delivery of high bandwidth applications such as 4K video, virtual reality and faster gaming. Intel offers a range of technologies for service providers who want to build a converged network for their video, voice and data services. Those technologies include dedicated chipsets and FPGAs which can be used to build remote OLTs at the edge and technologies for the modem and home router/gateway in the customer premises.

Solutions Proven by Your Peers

These solutions are based on real-world experience gathered from customers who have successfully tested, piloted, and/or deployed these solutions in specific business use cases. Solution architects and technology experts for this solution reference architecture include:

- **Chris Cholas,** Gateway Solutions Architect, Service Provider Group, Intel Corp.
- **Lance Koenders,** Global Segment Director, Clients & Connected Home, Service Provider Group, Intel Corp.

Intel Solution Architects are technology experts who work with the world's largest and most successful companies to design business solutions that solve pressing business challenges.

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Solution Provided By: