Single-wavelength rates for 100G access

Already a significant optical access node rate, 25G capability on a single wavelength is the next step to 100G PON. To get there, Huawei's research into 4x10G TWDM PON has yielded a number of multi-wave layering solutions.

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Access rates are increasing across the globe to accommodate the ultra-broadband capacity needed by technologies like 4K and 8K UHD video, VR, smart homes, and IoT. More than 50 carriers across the planet are delivering Gigabit broadband, with some even providing 2 or 10 Gigabit services.

In China, the State Council's 2013 National Broadband Strategy set out a plan to deliver broadband access rates of up to 1 Gbps to homes in certain Chinese cities. In Europe and the US, governments are pushing national broadband development schemes.

Fast single wavelength for next-gen PON

Holding true from 1983 to 2014, Nielsen's Law of Internet Bandwidth projects an annual bandwidth growth of 50 percent for each high-end user, taking the figure up to 1.6 Gbps by 2020 – far beyond the reach of current

PON systems and 1x64 splitters.

Operators are already mass-deploying next-gen Gigabit PON (GPON) and Ethernet PON (EPON) networks, while XG-PON1 and 10G-EPON are being commercially deployed on a small scale.

As an evolution of GPON and XG-PON1, the NG-PON2 standard is part of the ITU-T GPON series. NG-PON2 architecture will be implemented with TWDM-PON to provide either four or eight wavelengths per fiber, with each delivering 10 Gbps to yield a total capacity of 40 Gbps or 80 Gbps.

The IEEE802.3 standard series lags behind ITU-T, with NG-EPON still in early days. Objectives for the standard were published in September 2015, with defined schemes including upstream and downstream single wavelength speeds of 25 Gbps (25G) and Nx25G, and major modulation formats like non-return-to-zero (NRZ), duobinary, and four-level pulse-amplitude modulation (PAM-4).

With various mature specifications offering 10 Gbps on a single wavelength, the industry is now searching for a 25G standard. PON architecture delivering 25G on a single wavelength will form the main solution for PON networks and home user access.

Solutions for governments and enterprises, which need faster networks, will include wavelength overlapping to deliver two and four wavelengths of 25G. ITU-T is expected to discuss project approval for the corresponding standard in Q1 2016.

The challenges

Due to the difficulty and cost of building infrastructure, operators prefer to stick with Optical Distribution Networks (ODN) after upgrading to next-gen PON networks. To do so, current ODNs must – at the very least – support an optical fiber range of 20 km and 1x32 splitters. However, the road ahead is bumpy: dispersion, power budgeting, and rate selection hinder high-speed single-wavelength PON.

Dispersion: Current PON networks, including EPON, 10G-EPON, GPON, XG-PON1 and NG-PON2, don't suffer from dispersion. At single wavelength rates of 10G and below, NRZ modulation is simple and inexpensive; but, at 25G or above, NRZ dispersion tolerance is too low for optical fiber spans of 20 km.

There are two possible solutions. The first, zero-dispersion O-band, isn't viable because O-band is occupied by EPON and GPON networks, and is hard to use due to coexisting generations of PON networks. The second, Electronic Dispersion Compensation (EDC), is more feasible thanks to its high-dispersion tolerance modulation formats and electrical equalization algorithms.

Limited power budget: Power budgeting will be a major headache for PON networks due to the high insertion loss in ODN splitters caused by point-to-multipoint architecture.

Two main types of detectors exist for boosting optical transmit power and receiver sensitivity: PIN diodes and avalanche photodiodes (APD).

PON networks mainly adopt APD optical receivers due to higher power budget requirements, but APD receiver sensitivity is strongly linked to signal rate. When this rises from 10 Gbps to 25 Gbps, receiver sensitivity decreases by 4 dB, reducing the power budget of system links unless compensatory measures are applied.

Currently, only a handful of providers offer 25G APD chips and ROSA package technology – a technology which is immature and expensive.

Going forward, there will be a need for cheaper 25G PON optical transceivers.

Rate selection: Single wavelength rates above 10G suffer from dispersion and limited power budgets, with higher rates raising the impact of dispersion on the system and reducing the power budget of the architecture.

Solutions come in the shape of 25G/single-wavelength systems, duobinary, PAM-4, and NRZ+DSP (Digital Signal Processing). Each of these multilevel modulation formats uses relatively simple encoding and decoding, and requires little from equipment. In 40G single-wavelength systems, however, the higher rates need more complex high-order modulation formats or DSP algorithms, placing an even greater strain on power budgets.

Current 10G-EPON power budget levels are insufficient for 40G/single-wavelength architecture, but maturity is on the horizon for 25G circuit technology, which includes laser drivers, trans-impedance amplifiers, and clock data recovery (CDR) circuits.

That's why Huawei is focusing on next-gen, high-speed 25G/single-wavelength technology, and using multi-wavelength overlapping to hit rates of 50G, 100G, and eventually 200G.

Three modulation schemes

NRZ modulation

The simplicity of the NRZ modulation format positions it well for use in EPON, 10G-EPON, GPON, XG-PON1, and NG-PON2 systems. At rates of 25G on a single wavelength, the dispersion tolerance of signals transmitted on the zero-dispersion O-band using NRZ is sufficient for the standard 20-km optical fiber range of PON systems. Using bands with positive dispersion like C-band or L-band results in inadequate dispersion tolerance. In that case, optical or electrical dispersion compensation methods are needed. Contenders include 25G electro-absorption modulated (EAM) lasers on the transmit side, and 25G APD receivers on the receive side. However, 25G optical components are expensive and dispersion tolerance is poor.

These downsides can be remedied by dispersion compensation through DSP algorithms on the receive side. Correctly optimized algorithms means that 10G optical components can replace 25G components on the receive side and compensate for signal distortion caused by insufficient bandwidth.

Duobinary modulation

Duobinary modules generate a three-level electrical signal, halve the spectrum, and give a dispersion tolerance value that's 2.5 times higher than NRZ. There are two kinds of duobinary with different eye patterns: electrical duobinary (EDB) and optical duobinary (ODB).

EDB is a conventional three-level modulation format that forms two eyes. ODB produces a three-level electrical duobinary signal that passes through an electro-optical phase modulator and modulates the two eyes in different phases, producing a similar eye pattern to NRZ. ODB modulation reduces dispersion by forming an inverted optical phase signal, boosting dispersion tolerance.

Two types of symmetrical 25G PON systems can be formed using EDB and ODB. The first type uses EDB modulation for upstream and downstream data. As Optical Network Units (ONU) in PONs are relatively expensive, 10G ONUs and 25G Optical Line Terminals (OLT) can be used at the transmit side to generate EDB upstream signals and carry out EDB modulation, respectively. A more complex algorithm on the cheaper OLT receive side can compensate for upstream signal distortion caused by device bandwidth limitations.

The second uses ODB modulation for downstream data, forming ODB signals at the OLT transmit side through phase modulation on the three-level signals generated by the Mach-Zehnder Modulator (MZM). Two-level signal judgment can be used on the ONU receive side, much like NRZ. This greatly simplifies receiver circuitry, reducing ONU costs. The upstream modulation solution is the same as the first type's, where 10G ONUs are used on the transmit side to generate three-level EDB signals.

PAM-4 modulation

PAM-4 combines two bits into one baud. It halves the baud rate, doubles frequency efficiency, and gives a dispersion tolerance value that's four times higher than NRZ 25G. PAM-4 modulation uses 12.5G externally modulated lasers (EML) and 12.5G linear drivers on the transmit side, and 12.5G APD linear optical receivers on the receive side. As most optical components are 10G, 10G optical components can replace the 12.5G EMLs and APDs, and electrical compensation algorithms compensate for bandwidth.

The PAM-4 solution enables digital-to-analogue converters (DAC) on the transmit side to generate four-level signals, which DAC decodes on the receive side.

NRZ, duobinary, or PAM-4?

Each of the high-speed single-wavelength solutions has advantages and disadvantages. NRZ modulation has a simple structure, but it needs DSP on the receive side for dispersion compensation and 25G optical components are costly.

The symmetrical EDB modulation scheme uses low-cost 10G receivers and optical transmitters on the ONU side, but 25G downstream receivers require EDB three-level decoding, driving up ONU costs. The 25G downstream ODB and 25G upstream EDB solution benefit from high downstream receiver sensitivity and simplicity; however, 25G optical devices need to be used on the receive side. Equally, the transmit side is more complex due to the phase modulator.

By halving the baud rate, PAM-4 decreases the bandwidth needed by optoelectronic equipment, but increases the required device linearity and yields less sensitivity than the other solutions. Transceiver chips are expensive and heavy power users, though the cost and complexity of PAM-4 transceivers is expected to fall drastically as major chip makers start to launch PAM-4 chips.

To meet PON systems' power budget requirements, all the solutions need expensive, power-hungry optical amplifiers that are hard to integrate. If not addressed, this issue will make high-speed single-wavelength PON unfeasible.

Each successive PON generation depends largely on industry-wide cooperation. At the moment, 25G optoelectronic equipment is maturing, and 25G chips are used in 25G EAM laser drivers, 25G MZMs, 25G CDR, and trans-impedance amplifiers. PIN-receiver-based 25G O-band lasers have been commercially used for a number of years, and component makers are focusing more on 25G APD receivers.

Advances in optical network technology and the development of high-speed optoelectronic chips will continue to drive up single-wave rates so single-wave high-speed PON systems can unlock the promise of ultra-speed broadband.