The future of PON

White paper

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Executive summary

Fiber is the driving force of broadband connectivity today. It is the biggest and fastest growing fixed access technology with the largest eco-system of players, which includes fixed and converged operators, governments, cities, utilities, enterprises, and infrastructure investors. Fiber broadband investment is attractive because it enables a premium customer experience, competitive advantage, the lowest operational costs (OPEX), and the lowest power consumption of any broadband technology. Over the years, fiber technologies have evolved towards more capacity, lower latency, network programmability and better resilience, enabling fiber to be the single digital infrastructure to converge all type of services (residential, enterprise, smart city, industry 4.0, and 5G transport) generating more revenues and more cost savings.

One of the greatest attributes of fiber is its unlimited bandwidth potential. As technology evolves, the same fiber networks will be able to increase capacity using the same fiber infrastructure, without the need to make updates in the most valuable part of the network: the fiber outside plant. The increase of capacity is possible by adding new wavelengths (colors of light), each wavelength carrying data traffic and even working on different transmission rates. New fiber technologies unlock the potential of fiber to be a single infrastructure that underpins the entire telecom eco-system and connects everything.

For over a decade, Gigabit PON (GPON) has been the primary fiber broadband technology worldwide. Today, it is being surpassed by XGS-PON (symmetrical 10G PON), which reuses the same outside plant (fiber cables, splitters and access nodes) to increase bitrates.

The first 25G PON deployments began in 2022 and a few operators, like Google Fiber and Hong Kong Broadband Network, have announced country-wide 25G PON deployments, not only for business users but also for residential services. Early demos and trials of 50G PON have already started, and even 100G speeds on fiber networks have been demonstrated. The evolution of PON technologies ensures that fiber will meet ever-growing bandwidth demand and that the fiber networks built out today will be used for decades to come.

This paper examines the PON fiber technologies beyond 10 Gb/s.

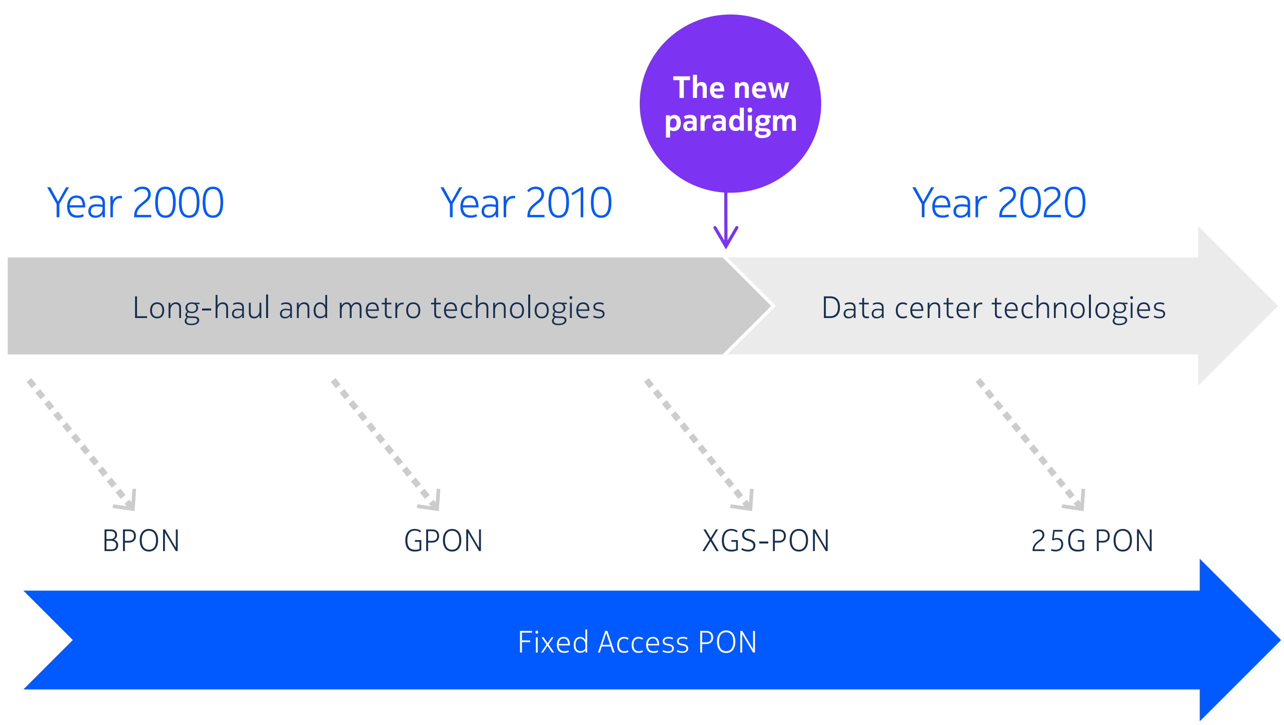
The history of PON and the new paradigm

The evolution of PON has been based on trickle-down technologies originally designed for other purposes. Up to 10G PON, the origins were long-haul optical technologies, which were then adopted by the metro market, driving component volumes and maturation until they reached a price point that became viable in massive-scale fixed access deployments. These technologies have had to be adapted for larger power budgets and the burst mode operation used in PON. Nevertheless, the trickle-down process has worked well, spawning EPON, GPON and 10G PON technologies.

The generations of PON beyond 10G will use a slightly different, but highly efficient path. They will be based on the world of data centers and, specifically, 100G Ethernet technologies with 25 Gb/s channels that are used for intra-data center connectivity. The increased demand for data center capacity, much of it on single-mode fiber, has begun to drive large volumes and reduced costs on 25G components. This is the mature ecosystem that the next generation of PON leverages, and 25 Gb/s will be the baseline for the next steps: 25G, 50G and 100G PON.

Is it possible to just plug these data center components into OLT and ONU transceivers? The answer is no. PON applications will require new wavelengths, a higher launch power from transmitters, and greater sensitivity in receivers. However, this is no different from the work that has been done for previous PON generations based on components from long-haul and metro transceivers.

Figure 1. PON evolution depends on the pre-existence of mature optical and electronic technologies. 25G PON leverages mature Data Center optical technologies.



25G PON: the straightforward evolution

For an access technology to be successful, a few significant requirements need to be fulfilled. The first is cost efficiency, which includes CAPEX and the cost of introduction, etc. In massive access networks deployments, where millions of endpoints need to be connected, cost-efficiency is key. (There are examples of technologies that have a very attractive value proposition but, because of complexity and a very high cost, they did not become widely adopted). Next, demand must be well-defined, with viable use cases in the near- and mid-term for the technology. 25G PON fulfils these conditions.

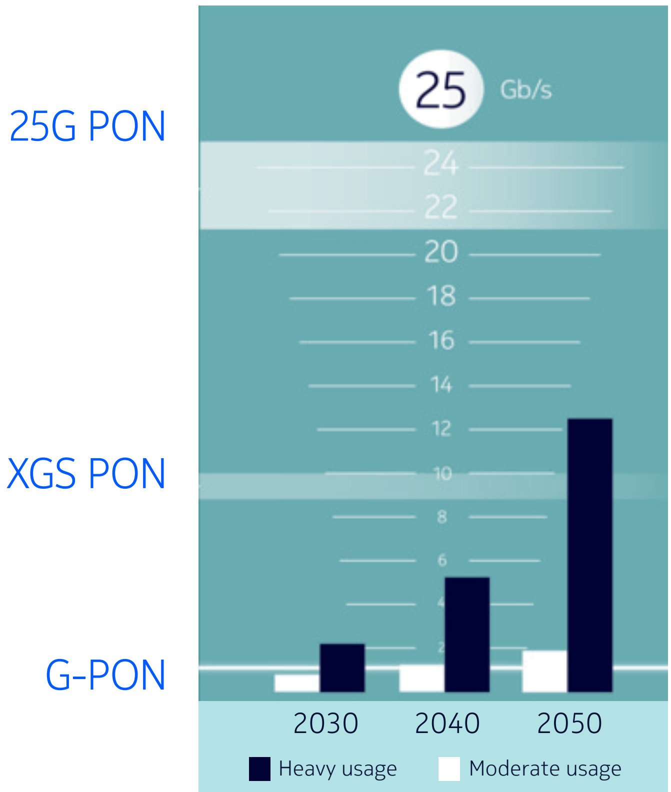
Cost efficiency. 25G will be the most cost-effective evolutionary step for the next decade. It leverages mature and massively deployed data center technologies. It is a simple technology which does not require advanced digital signal processing (DSP), amplifiers or tunable lasers. 25G PON is likely to be the last step in the evolution that will be a straight evolution from 10G PON: steps beyond 25G will be a technology leap and require advanced DSP and optical amplifiers, all of which will take years to mature.

Use cases. The massive capacity of 25G PON will enable unified services – connecting everyone and everything over a single high-performance network. Operators are already seeing the demand for speeds beyond 10G to:

- Offer market leading 10G residential services, enabling premium experiences and a new generation of internet services.
- Connect enterprises with true 10G (current marketplace) and >10G speeds for bandwidth-demanding, latency-sensitive applications, unlocking higher ARPU vs. residential services.
- Provide mobile transport (i.e., X-haul) for the high volume of traffic from densely deployed 5G antennas.
- Wholesale providers need big pipes to meet the demand of all their tenants and applications. 25G PON is ideally suited to network slicing, which can be used to maximize network utilization and differentiate quality of service (QoS) for each tenant or service.

Huge capacity. 25G PON is 10x faster than GPON and 2.5x faster than XGS-PON. The Ethernet market has found that a step increase in speed by a factor of 2-2.5x delivers the best commercial results. The 25G step has been adopted by IEEE (25G EPON), data centers, WDM, G.metro and 25GS-PON MSA. It is driven by concrete demand for enterprise services and 5G transport and will be able to meet residential demands when the time comes. To illustrate: today, 1 Gigabit is a product for premium connectivity in many markets, and 25G (when overheads are accounted for) is 20x faster. The Nokia bandwidth modelling tool projects that 25G PON will be sufficient for the consumer market at least until 2040.

Figure 2. Nokia's bandwidth forecast for the consumer market



Simple introduction. 25G PON can be introduced on the same passive and active assets. It is available on the same access nodes (OLT) and line cards that are deployed today for GPON and XGS-PON, so there is no need for new hardware. Co-existence is another major requirement for ensuring graceful migration. The 25G PON standard defines three options for 25G PON upstream wavelengths, ensuring co-existence with GPON, XGS-PON, or 50G PON.

Availability. The demand for true 10G speeds has started, providing operators with opportunities for competitive advantage and more revenues. Due to overheads, XGS-PON provides a maximum 8.5 Gb/s capacity for data transfer. Today, 25G PON is the only mature and field proven technology optimized for speeds up to 20 Gb/s. With 25G PON operators are able to react quickly when needed and protect their business.

25G PON implementation

The guiding principle of 25G PON is to deliver 2.5x more bandwidth at <2.5 higher cost. The strategy to lower the incremental cost is composed of the following elements:

- **O-band wavelengths**. Dispersion effects increase with higher bitrates. 25G PON downstream and upstream wavelengths need to be in the O-band to avoid large penalties or the need for dispersion compensation. The 25G-PON standard specifies 1358 nm wavelength in downstream and three options for upstream:
  - 1300 nm (subset of GPON) for co-existence with XGS-PON.
  - 1270 nm (same as XGS-PON) for co-existence with GPON.
  - 1286 nm to support triple co-existence of 25G PON, XGS-PON and GPON.

  This choice of wavelength plan ensures a smooth evolution path in any network.
- **Transmission**. While leveraging data center technologies, 25G PON does not require all the functionalities needed in data centers. Instead of higher-level, costly modulation schemes like PAM4, it can use simple non-return-to-zero (NRZ) transmission.
- **Optical amplification**. 25 Gb/s has about a 5 dB power penalty compared to 10 Gb/s. To achieve a 29 dB (PR30 EPON, N1 class ITU-T PON) loss budget, and to avoid the cost of optical amplification, those 5 dBs need to come from a combination of higher launch power, improved receiver sensitivity and stronger FEC. This will be possible, but with little margin to spare.

Higher Speed 50G PON

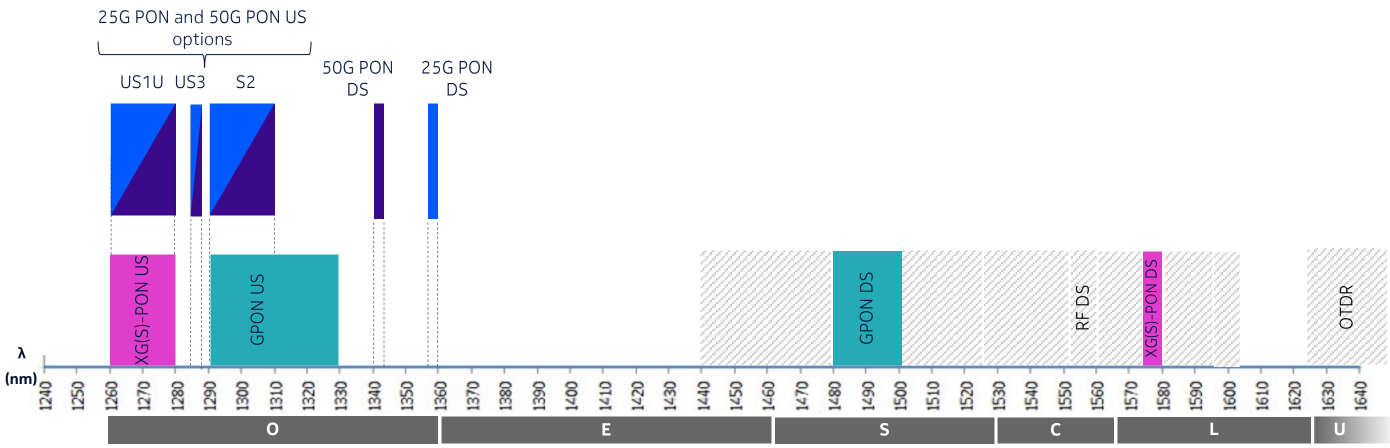
Services requiring speeds beyond 20 Gb/s will need 50G PON or 100G PON. The standardization work on 50G PON G.hsp (Higher Speed PON) is already under way and early trials of 50G PON have started, but the technology still needs time to mature and become cost effective for mass market deployments.

50G PON will require digital signal processing (DSP), which was not needed in previous PON technologies. This is because the higher data rates experience greater attenuation and dispersion effects, leading to weaker and more distorted signals at the receiver. While this adds to the cost of 50G PON, DSP will be implemented on SOC (system on chip), allowing mass volumes and commercial cost-efficiency to be reached by 2030. These techniques are established in the 50G G.hsp standardization project at ITU-T, to which Nokia is a leading contributor.

A few vendors, including Nokia, have trialed 50G PON and early solutions are available, but it does not mean that 50G will be deployable in volume soon. There is a need for further research work to optimize the technology. For example, there is no common view in the industry about the practicality of high loss budget (>29 dB) solutions.

50G PON will also leverage the O-band wavelength for upstream, enabling it to benefit from lower dispersion properties. The O-band is already crowded, as it is being used for GPON, XGS-PON and 25G PON upstream, so the standard has defined that 50G PON will use the same three upstream wavelength options as 25G PON. Multiple upstream options will enable future upgrade paths through triple-coexistence, and 50G PON can exist with: GPON and XGS-PON, GPON and 25G PON or XGS-PON and 25G PON.

Figure 3. PON wavelength bands



The futuristic 100G PON and beyond

The discussions about a 100G PON standard have started, and Nokia Bell Labs showed the industry's first 100 Gb/s demo on a single wavelength in a live PON network. The early prototype uses the same base technology that is needed for 50G PON using advanced DSP techniques that are not yet commercially available. The trial shows that, once there is a baseline ecosystem for 50G PON, the step to 100G PON will follow quickly.

To achieve this, Nokia Bell Labs broke the considered wisdom that IM/DD lasers could not move between on and off states any faster than they currently do. To deliver 100 Gb/s, we have used pioneering digital signal processing techniques and the world's first application of flexible rate transmission in a PON network.

Today's PON networks offer the same data rate to all optical network units (ONUs). However, this results in varying degrees of degradation due to the topology of the network, the length of the different fiber segments, and statistical variations. This works as long as the degradation is smaller than the so-called loss budget of the PON technology. Through data made available by Nokia operator partners about their networks, we know that the majority of ONUs experience losses that are significantly smaller than the loss budget and are therefore able to support a larger data rate (since a lower loss means a higher receive signal quality).

Introducing flexible rate transmission enables us to increase the data rate for the majority of ONUs and thereby supercharge the capacity of the entire PON system. Using flexible rate transmission also results in lower latency and cuts power consumption in half, two essential characteristics for massive-scale fiber broadband networks.

Because we remain with the trickle-down technology of data centers that are already developing higher performance IM/DD devices, computer simulations predict that we can achieve suitable cost-efficiencies by 2030.

An alternative path to 100G PON being explored uses a technology known as coherent PON. Rather than a single dimension to encode and transmit data, coherent PON uses three: amplitude (the same as IM/DD), phase, and polarization.

The phase of a light wave can be understood as exploiting the time dimension of the light wave, where additional information is encoded by slightly delaying or advancing the wave fronts of the signal. Exploiting the polarization of a light wave can be understood as sending two waves in parallel but oscillating in different spatial directions. This is similar to the waves you can create by swinging a rope up and down as well as side to side.

The key advantages of coherent PON are that the three dimensions effectively triple the capacity of the technology while the advanced receivers required improve sensitivity and precision.

However, there is – currently – a considerable downside: the complexity of using three dimensions adds significant cost. And given that coherent PON is not a trickle-down technology, it is uncertain when volume and maturity of components will make it a viable option for massive-scale broadband deployments.

Conclusion

The industry keeps pushing the boundaries of PON technology to make sure the investments in fiber networks made today will be usable for many years to come to meet the inevitable growth in demand for faster, more responsive, and immersive internet services.

There have always been, and will continue to be, various flavors of PON technology, and all of them have been deployed. Operators make a choice of technology for various reasons: cost, service focus, competition, business priorities, timing, or usually a combination of these factors. Different flavors of PON help operators to diversify their service offering and compete more effectively. There is no single market that drives a worldwide trend. No two markets are the same, no two operators are the same, and hence there is no one-size-fits-all fiber technology.

It is important for operators to have various technology options that will enable them to address their business needs.

The industry is already embracing 25G PON, as it is a straightforward evolution and the technology that is most optimized for speeds up to 20 Gb/s. For speeds beyond 20Gb/s, 50G PON is the obvious choice. Operators who don't anticipate upgrades in volume before 2030, can also consider 100G PON, which will be available by that times frame.

Nokia is leading the industry, with the first commercial 25G PON solution that has now been deployed in live networks. We are one of the main contributors to the ITU-T 50G PON standard, and we have demoed this technology in a live network. In early 2021, we demonstrated the industry's first 100G PON prototype, showing that there is a small incremental step from 50G to 100G.

These advances in technology will ensure the continued evolution of fiber networks and demonstrate the superiority of fiber to serve as a unified infrastructure to connect everything, everywhere.

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