STRATEGIC WHITE PAPER

Leveraging GPON for Mobile Backhaul Networks

Overcoming the challenges of mobile broadband adoption

As mobile operators deploy 3G networks, subscribers are increasingly accessing bandwidth-hungry services such as Internet access and streaming video with their smartphones. However, these services are straining the traditional voice-optimized TDM mobile backhaul network, which does not cost-effectively scale to handle exponentially increasing data traffic. In response, converged packet-based mobile backhaul solutions are being developed to help network operators meet the cost challenges of supporting 3G services while effectively preparing for future Long Term Evolution (LTE) networks. These solutions leverage the GPON triple play network, which is uniquely positioned for rapid and cost-effective relief of the mobile backhaul bandwidth problem. With GPON, expensive leased lines, whose costs scale linearly with bandwidth, can be capped and ultimately retired.

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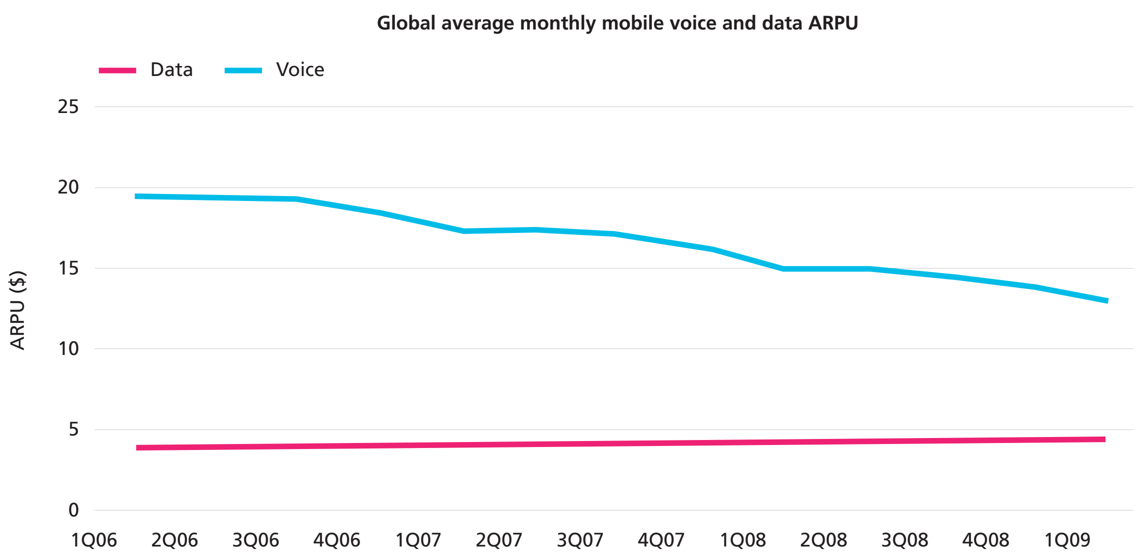
Mobile backhaul and the challenges faced by network operators

As the mobile voice communications market has saturated, it has become increasingly difficult for mobile service providers (MSPs) to grow revenues simply by expanding the size of their subscriber bases. Price competition has been the inevitable result for MSPs seeking to gain (or even just retain) voice services market share, resulting in declining mobile voice average revenue per user (ARPU).

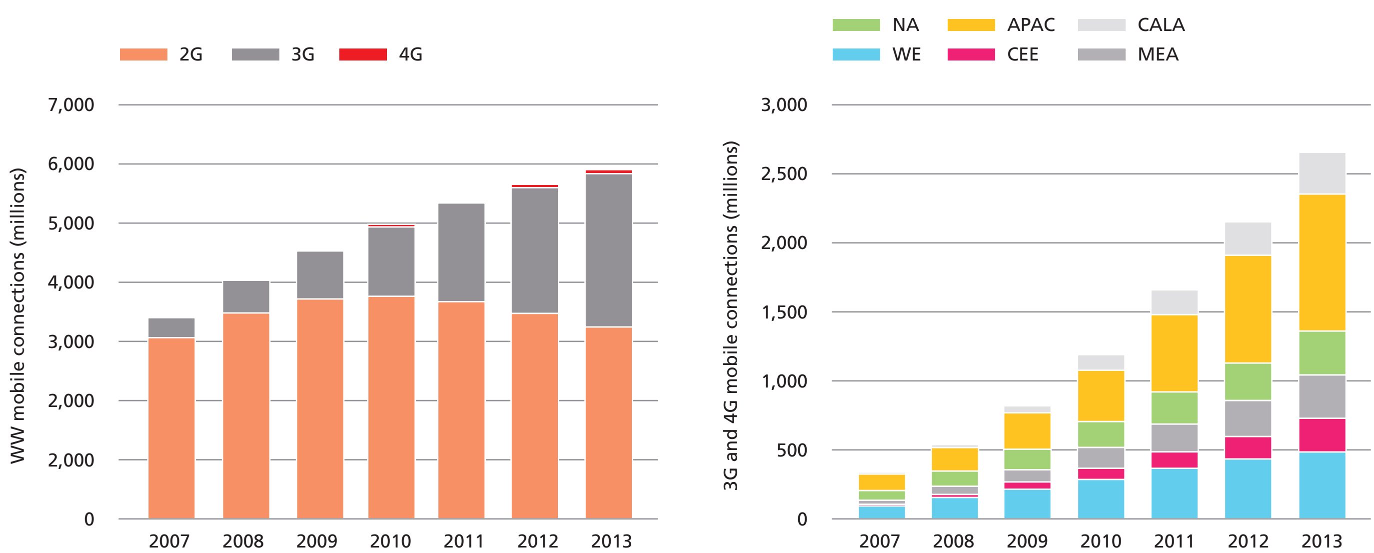
In response, MSPs launched new mobile data services to generate additional revenues, starting with the widespread success of short messaging, and mobile data services ARPU has been steadily increasing. Data now accounts for 25 percent of total ARPU, with the potential to offset declining voice revenues.

Figure 1. New mobile data services improve ARPU



Today, as MSPs deploy 3G networks, subscribers are now using their smartphones to access true broadband data services, such as Internet access and streaming video. High-bandwidth consumption is no longer limited to the home — and driven by the deployment of 3G and future 4G systems, fast growth is predicted for mobile broadband adoption. By 2013, 2.5 billion 3G and 4G mobile subscribers are forecasted, comprising almost half of all wireless connections.

Figure 2. Forecasted adoption of 3G/4G mobile broadband



Source: Alcatel-Lucent, 2Q09

In parallel, service evolution is driving bandwidth from 100 kb/s for GSM to more than 100 Mb/s for long-term evolution (LTE) networks[1]. Accordingly, both the number of mobile broadband subscribers and the bandwidth consumed per subscriber are growing exponentially — forcing MSPs to face the simultaneous challenge of exploding traffic and overall declining ARPU.

The Alcatel-Lucent Mobile Evolution Transport Architecture

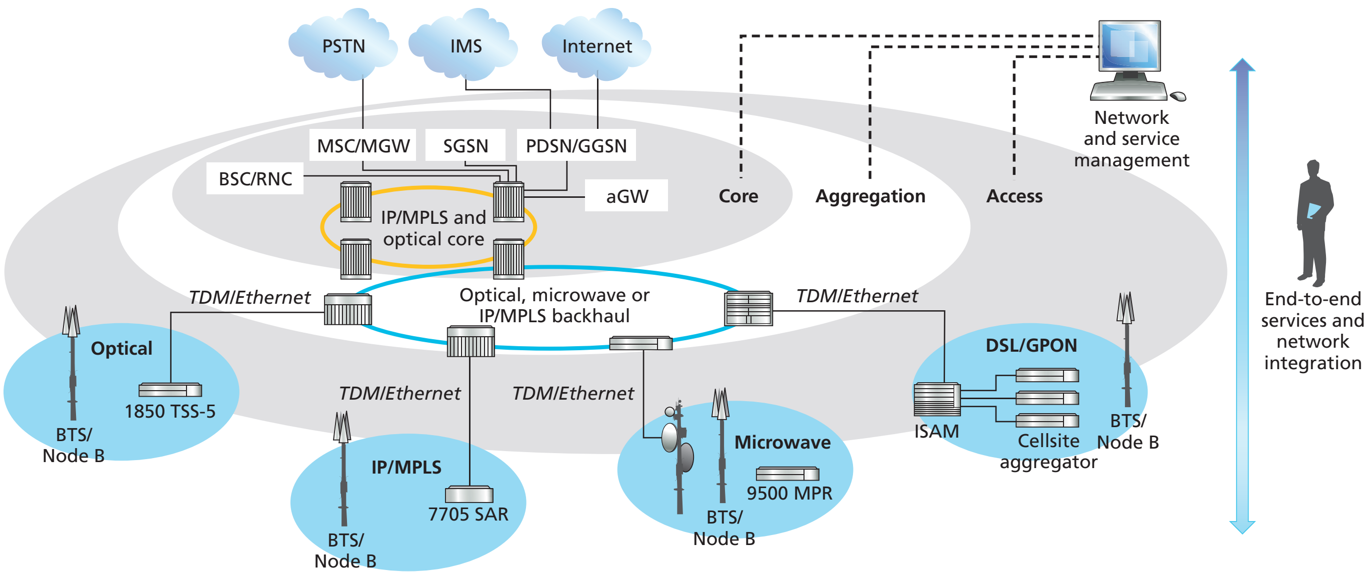
In the mobile network, cell site base stations[2] are connected to their network controllers[3] by the mobile backhaul (MBH) network. Traditionally, this is a TDM network optimized for voice — but this type of network does not cost-effectively scale to support the growth of mobile data traffic. Consequently, it is critical that operators adopt an affordable backhaul solution that does scale and provide end-to-end packet-based transport.

Anticipating this need, Alcatel-Lucent has developed the Mobile Evolution Transport Architecture (META): a broad family of converged packet-based mobile backhaul solutions that allow network operators to meet the challenges associated with supporting a 3G network while preparing for the future adoption of LTE.

Looking specifically at the last-mile access portion of the MBH network, about half of all cell sites today are backhauled by microwave, with the other half by wireline systems. In the case of wireline access, E1/T1 leased lines are typically used — but these are expensive and their costs scale linearly with bandwidth, making them particularly unsuited to meet the bandwidth demands of mobile broadband. One strategy for a packet-based wireline access network is to leverage GPON residential broadband deployments for mobile backhaul. Put into effect, expensive leased lines can then be capped and ultimately retired.

[1] While LTE is the primary 4G technology (and will be addressed specifically in this paper), WiMAX is also in scope.
[2] Base station refers collectively to all mobility elements at a cell site (BTS, NodeB, eNB, etc.).
[3] Network controller (NC) refers collectively to all mobility elements at a MTSO site (BSC, RNC, aGW, MME/S-GW, etc.).

Figure 3. Alcatel-Lucent Mobile Evolution Transport Architecture (META)



Why GPON makes sense for mobile backhaul

Service providers are pushing fiber closer to the home to support advanced business and residential services, with the most capable networks being those where fiber is deployed all the way to the subscriber's premises. These fiber-to-the-home (FTTH), fiber-to-the-building (FTTB) and fiber-to-the-business optical access networks predominantly use passive optical network (PON) technology,[4] with the two most common being Ethernet PON (EPON, standardized by the IEEE) and Gigabit PON (GPON, standardized by the ITU-T).

EPON preceded GPON and was deployed extensively for FTTH in Japan in the early 2000s, and is now the more common PON technology in Asia. However, looking forward, GPON is expected to overtake EPON in China, Asia's largest market[5].

In North America and in Europe, GPON has already been widely preferred to the virtual exclusion of EPON due to GPON's superior bandwidth, quality of service (QoS) capabilities and greater suitability for triple play service bundles. These same capabilities also make GPON more fitting for backhauling mobile voice, video and data services. Therefore, it is only natural to ask the question: Can (and should) GPON optical access networks be leveraged for mobile backhaul?

First, more than microwave and copper, fiber is the ultimate backhaul medium from both a bandwidth and reliability perspective. Optical fiber systems currently serve core, aggregation and last-mile access networks — of these fiber-based systems, PON has the potential to be the most cost-effective for last-mile mobile backhaul, having already hit the cost points for residential broadband. Existing GPON optical line terminals (OLTs) are low-cost broadband aggregation platforms that minimize port consumption in switches and routers. In addition, GPON as it is deployed today is already

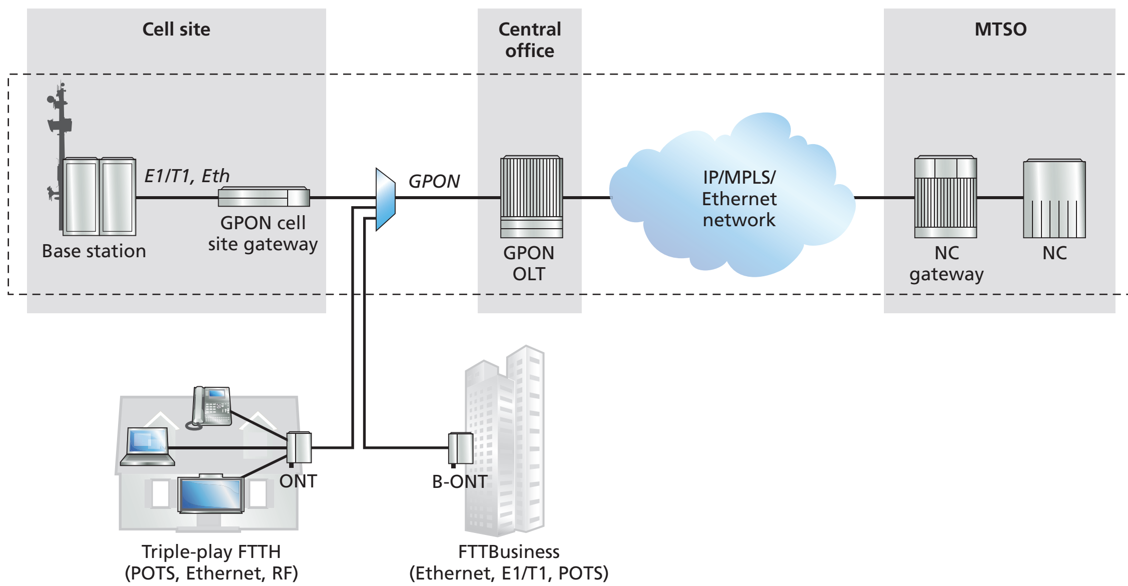
[4] Broadband access employing point-to-point fiber is an equally valid technical approach, but most operators have concluded that PON is more cost-effective due to the absence of outside plant electronics and the distributed multiplexing of a point-to-multipoint topology that reduces the amount of fiber and the number of optical interfaces.

[5] All major Chinese operators are moving from EPON to GPON, but at different speeds. China Telecom has been the strongest proponent of EPON to date; however, their CTO predicts GPON will be put into massive use starting in 2010 and will supersede EPON in terms of market share in 2012.

cost-optimized for asymmetric bandwidth consumption. The most salient question, however, is whether it is possible to leverage a GPON residential network for mobile backhaul in a way that would increase its return on investment and reduce operational costs (see Figure 4).

The answer to this question depends on whether GPON can meet the requirements for 3G/LTE backhaul. If it can meet these requirements, then GPON could be uniquely positioned for rapid and cost-effective relief of legacy mobile backhaul bandwidth bottlenecks.

Figure 4. GPON mobile backhaul transport architecture



Meeting the requirements for 3G/LTE mobile backhaul

If it is to be implemented as a cost-effective solution for the bandwidth bottlenecks experienced in existing MBH networks, it is imperative that GPON meets the following six key requirements:

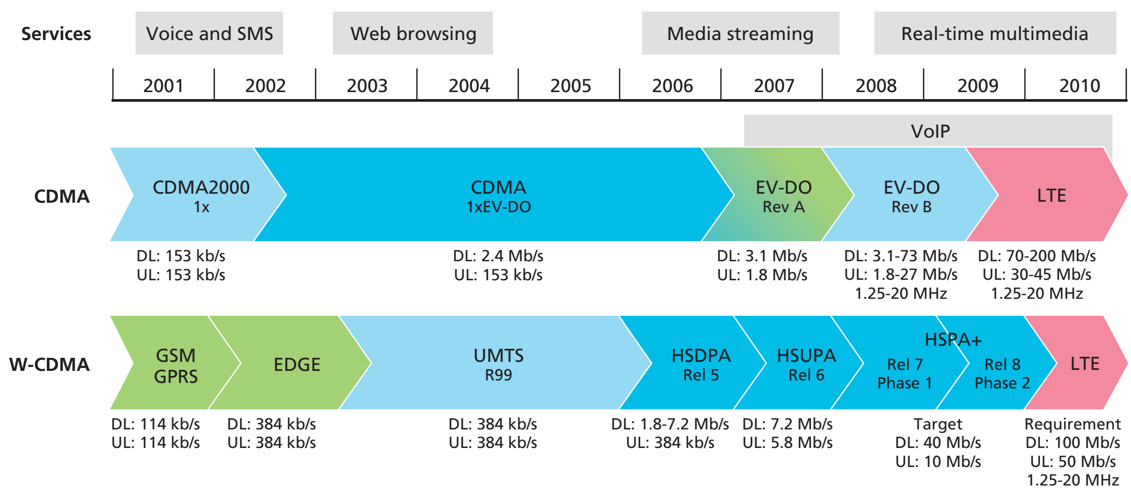
- *Bandwidth:* The capability to support mobile broadband services as wireless networks evolve to full LTE.
- *QoS:* The capability to support services that are sensitive to delay and jitter.
- *Converged packet transport:* The capability to transport and manage TDM-based and packet-based services on a single Ethernet (or packet) network.
- *Demarcation:* The capability to monitor end points of the backhaul network in support of service level agreement (SLA) enforcement, policing and fault isolation.
- *Base station synchronization:* The capability to provide the synchronization required by radio access networks.
- *Hardening:* Optional support for redundancy and environmental hardening.

Meeting the needs of residential triple play goes a long way toward satisfying the requirements for bandwidth, QoS and convergence. In addition, supporting business services is synergistic with the mobile backhaul requirements for convergence, demarcation, synchronization, redundancy and hardening. The fact that GPON has already been deployed to triple play and small business customers makes it a good candidate for mobile backhaul — further optimizations could make it an even better choice.

Bandwidth: Mobile broadband services driving geometric growth

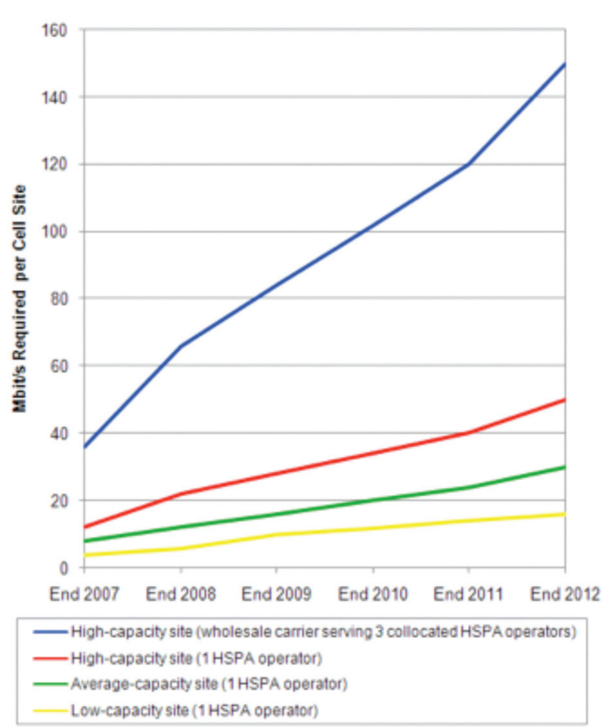
The introduction of new mobile data services over 3G and evolving to LTE will lead to maximum bandwidths of 100 to 200 Mb/s per base station.

Figure 5. Increasing bandwidth needs for new mobile data services



In actual practice, the bandwidth will be less, and the migration to full LTE capability will take some time. On the other hand, a wholesale backhaul provider may need to backhaul traffic from multiple operators sharing the same site. These factors are considered in the backhaul bandwidth forecast in Figure 6.

Figure 6. Backhaul capacity requirements at the cell site[6]



[6] This chart shows a forecast for backhaul capacity requirements, specifically at 3G W-CDMA/HSPA cell sites with a roadmap to HSPA Evolution and LTE. Source: P. Donegan, "Ethernet Backhaul Quarterly Market Tracker", Heavy Reading, March 2009.

These bandwidths can be managed easily in deployed GPON networks that support 2.5 Gb/s downstream and 1.25 Gb/s upstream. GPON bandwidth is shared by all subscribers connected to the same PON (usually a maximum of 32), although in practice take-rates much lower than 100 percent usually lead to less sharing. Video drives bandwidth needs; and even assuming a high video service take-rate and a worst-case scenario where every residential subscriber is simultaneously streaming multiple and unique high-definition video channels at about 10 Mb/s each, a rough calculation shows that about half (or more) of the downstream bandwidth is still available for multiple LTE base stations on the same PON. In the case where GPON is being considered exclusively for MBH, it is clear that 10 to 30 LTE base stations could be accommodated on a single PON.

In the unlikely event that GPON bandwidth becomes scarce, the well-known PON engineering technique of reducing the fiber split can decrease sharing and free up bandwidth for high-bandwidth users and base stations. In the future, next-generation 10G PON interfaces will provide an even fatter pipe on the same fiber network via a wavelength overlay. Consequently, from a bandwidth perspective, GPON represents a strategic long-term solution for 3G to LTE migration.

QoS: Requirements driven by voice services

Like its fixed-line counterparts, real-time mobile services such as voice, video and gaming require proper network engineering to ensure end-user satisfaction. Voice and gaming applications drive the strictest requirements on end-to-end delay — about 200 ms for voice and 50 ms for gaming. How these delays are apportioned across the various network elements and segments is varied, but typical delay requirements cited for mobile backhaul networks are 15 ms one-way delay for 3G, decreasing to 10 ms for LTE.

Voice and streaming video are sensitive to jitter, with a typical delay requirement of 5 ms. Traditional TDM networks guarantee low delay and jitter, while packet networks may add unacceptable levels of delay and jitter if not properly managed. In comparison, GPON triple-play networks — already deployed to provide these same services over fixed lines — have been proven to have the robust QoS engineering features required to transport real-time services.

Converged packet transport: A platform supporting both E1/T1 and packet

The GPON element at the cell site that interfaces to the base station is the cell site gateway. Basic cell site gateway functionality includes termination of the GPON link on the network side and presenting physical interfaces to the base station. At this time, the majority of cell site interfaces are E1/T1, with the availability of native Ethernet interfaces continuing to grow over time. Therefore, to realize the CAPEX and OPEX savings that can come from the deployment and operation of a single converged MBH network, the cell site gateway must present to the base station:

- E1/T1 interfaces with a circuit emulation services (CES) interworking function for packet transport
- Native Ethernet interfaces

In the case of CES, it is advantageous to support both unstructured and structured transport. Structured CES allows for the concentration of E1/T1 lines so that fewer expensive TDM interfaces need to be presented by the NC gateway to the NC. Similarly, native processing of ATM IMA (inverse multiplexing over ATM) or multilink PPP (ML-PPP) by the cell site gateway allows for statistical multiplexing and lower transport costs.

Demarcation: Enhancing operators' SLAs

More sophisticated cell site gateways will also provide a manageable demarcation between the MBH network and the base station equipment. This demarcation is particularly useful for the wholesale scenario, where different operators own the two different facilities and mobile backhaul performance is governed by an SLA. It is also relevant when both facilities are owned by the same operator but managed by different departments. In either case, demarcation can support SLA enforcement, policing and fault isolation.

The demarcation, at both the base station and NC ends of the MBH network, is implemented with manageable end-to-end pseudowires. Depending on the architecture of the metro aggregation network, standardized pseudowires can be implemented at the Ethernet, MPLS or IP layers. The link and service layer operations, administration and maintenance (OAM) feature suite associated with the pseudowires will allow for detection and isolation of faults.

Base station synchronization: Requirements driven by radio access network

There are two types of base station synchronization relevant to radio access networks: frequency synchronization and time-of-day (ToD) synchronization.

Frequency Synchronization

Cell site equipment requires an accurate clock to set its RF frequencies in support of call hand-offs. All cellular radio systems require frequency synchronization of ±50 ppb[7]. The questions are: must the GPON MBH network provide this frequency synchronization, and if so, how is it achieved?

There are two instances when base station synchronization is provided by another source, not by the GPON MBH network: the base station is synchronized by GPS (common in North America), and the data off-load scenario. In the latter case, the GPON MBH network is only backhauling data traffic, complementing a legacy leased line that backhauls voice traffic and is already providing frequency synchronization. (This is an interim step in the evolution to a single converged packet-based MBH network.)

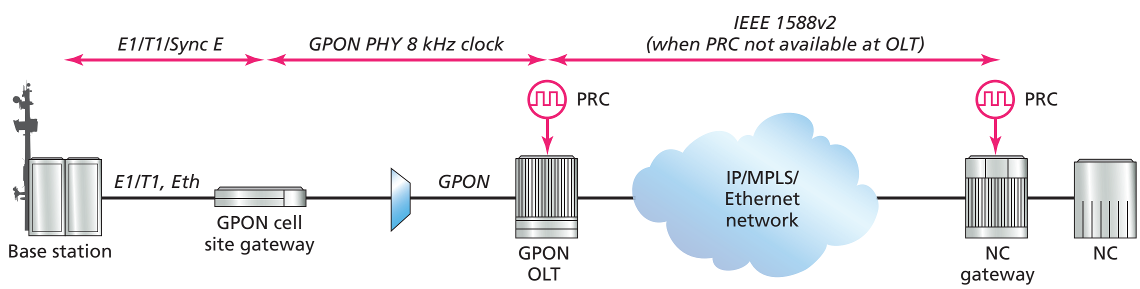
The GPON MBH network must provide frequency synchronization when there is no GPS (typical outside of North America) and when the legacy leased line network providing the synchronization has been decommissioned (which is, at any rate, one of the goals of deploying a converged packet backhaul network).

Unlike TDM networks, traditional packet networks do not transparently transport frequency synchronization. However, ITU-T G.984.3 (the standard that specifies the GPON transmission convergence (GTC) layer), defines the transport of an 8 kHz clock via 125 µs framing from the GPON OLT at the central office to the GPON ONT (with the cell site gateway). This physical layer clock provides a reliable, deterministic frequency synchronization like a TDM network. The cell site gateway can then slave an E1/T1 or Ethernet interface to the GTC clock, thereby providing the required synchronization to the base station.

Of course the GPON OLT needs have access to the primary reference clock (PRC) in the first place — this is typically done via a BITS interface or, if not available, via the IEEE 1588v2 Precision Time Protocol (PTP) at the packet layer.

[7] This is the requirement for the air interface. It translates to delivery of a local clock reference meeting at least the "traffic interface" jitter/wander requirements of ITU-T G.823 (for E1) or G.824 (for T1), or (in the absence of a sufficiently stable local clock) the more stringent "synchronization interface" requirements of G.823/G.824. A synchronization reference meeting this condition will enable most base stations, via filtering, to meet the ±50 ppb frequency stability requirement of the base station local clock.

Figure 7. GPON mobile backhaul end-to-end synchronization architecture



Alternatively, an IEEE 1588v2 PTP slave can be utilized at the cell site gateway for frequency synchronization. However packet-layer synchronization techniques are sensitive to the impairments of packet transmission (e.g. traffic congestion), and are therefore not preferred wherever an adequate physical layer clock, like the GTC clock, is available.

Time of Day Synchronization

With few exceptions, frequency-division duplex (FDD) radio systems require only the frequency synchronization discussed above. However, time-division duplex (TDD) radio systems also require ToD synchronization for accurate framing of timeslots. Typical requirements are 1 to 2.5 µs, with ToD being delivered by either a GPS subsystem on the base station equipment or by the IEEE 1588v2 PTP (which is capable of supplying both frequency and ToD synchronization) over-the-top of the backhaul network.

Hardening: A cost-effective way to improve availability

The MSP's service availability targets may lead, in some cases, to the addition of redundancy at key points in the network. In a GPON network, the largest failure group size occurs on the network side of the optical splitter, where all traffic is combined onto a single feeder fiber. The GPON standard describes a "Type B" redundancy scheme, whereby a second diversely-routed feeder fiber connects the optical splitter to a second GPON port at the OLT. This is a relatively low-cost approach that significantly improves availability.

Hardening at the cell site gateway can also be considered (e.g., redundant power feeds). Also, many cell sites will not have controlled environments and therefore temperature hardening will often be a requirement.

Conquering the mobile backhaul challenge

As mobile broadband data services consume exponentially increasing bandwidth, the CAPEX and OPEX of legacy voice-optimized TDM backhaul networks will scale linearly with that bandwidth. These surging costs are at the heart of the mobile backhaul challenge that is currently faced by operators evolving to 3G and LTE networks. In order to tackle this problem and remain competitive, a new packet-based backhaul approach is required to make these mobile broadband services profitable.

Given the cost advantages of leveraging GPON access networks to solve this problem, as well as GPON's ability to satisfy the various technical requirements placed on the mobile backhaul network, it can be concluded that GPON networks (which are already deployed to support high-bandwidth real-time residential and business services) can indeed overcome the mobile backhaul challenge — not only for the 3G networks of today, but tomorrow's LTE networks as well.

For network operators already deploying GPON, there is a strategic platform in place today that can be leveraged to provide a rapid and cost-effective solution. For other operators contemplating deep fiber access networks for residential and business services, the fact that GPON can also help solve the mobile backhaul problem is just one more factor to consider in its favor.

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