white paper

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High-speed technologies for mobile backhaul

Microwave links have been the obvious mobile backhauling choice for many operators, and microwave solutions are likely to remain very important. New, high-speed link technologies in the form of microwave with more than 1Gbps capacity, plus fiber and bonded DSL, are recommended in an all-IP radio access network (RAN) over a carrier Ethernet network optimized for data traffic.

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Contents

1 Executive summary

We have now seen the initial success of 3G and HSPA network deployments and the first wave of worldwide mobile broadband adoption. Not only is network capacity increasing rapidly, but there has been an encouraging rapid rise in data traffic. Getting the combined offer right, with attractive flat rates for end users, plus high-impact marketing, good service coverage and high throughput, has resulted in a tremendous uptake of services, with an associated increase in data traffic. As capacity increases dramatically, operators need to find the right commercial and technical approach to their backhaul to manage the challenges of convergence, flexibility and cost-effectiveness.

Microwave links have been the obvious mobile backhauling choice for many operators, and microwave solutions are likely to remain very important components of future mobile backhaul solutions. These solutions are also being enhanced to meet the requirements of full-scale HSPA and LTE network deployments and service take-up.

Packet-based microwave equipment can today provide the capacity needed for Gigabit Ethernet transport utilizing high-order modulation, a combination of multiple radios, and channel sharing with interference cancellation. New spectrum allocations can also be exploited for high-capacity transport. In the near future millimeter-wave radios for point-to-point (P2P) applications will be able to further increase the capacity of each microwave radio to more than 1Gbps. These radios are based on E-band (71-76GHz and/or 81-86GHz) technology, and are capable of facilitating a hop distance ranging typically from 1km to 8km, depending on availability performance and data-rate requirements.

Optical access technologies are able to handle very high demand for bandwidth. Together with new and emerging solutions for bonded Digital Subscriber Line (DSL) links, they will make it possible to adapt mobile backhaul networks to varying demand levels using the existing infrastructure. P2P fiber-optic connections will provide a future-proof solution for mobile backhaul. If there is an existing Gigabit Capable Passive Optical Network (GPON) close to the RBS, it will allow operators to allocate bandwidth to individual subscribers (or base stations).

Second-generation very-high-speed digital subscriber line (VDSL2) in combination with bonding and vectoring can increase the capacity of DSL links. This aggregation of multiple lines creates a high-speed virtual pipe. For example, with five VDSL2 lines running at 100Mbps, the supported data rate would be 0.5Gbps over a distance of 500m. These new, highly efficient link technologies are best for an all-IP RAN over a carrier Ethernet network optimized for data traffic.

Packet transport infrastructure can be deployed and maintained at a lower total cost of ownership (TCO) than legacy TDM transport infrastructure. Packet transport infrastructures (MPLS and carrier Ethernet) also provide scalable capacity without granularity limitations, and in addition support efficient aggregation, statistical multiplexing and native multicasting. These factors help to reduce the transport cost per bit and improve transport functionality. Over-provisioning will also cost less due to the availability of inexpensive IP/Ethernet equipment. Both of these factors are in fact essential for meeting future service demand.

2 Mobile backhaul in the Full Service Broadband architecture

The Ericsson White Paper [“Full Service Broadband Architecture”] described how, after years of talk about fixed-mobile convergence (FMC) and next-generation networks (NGNs), technology is now ready to help fixed and mobile operators make a major leap forward in their Full Service Broadband offerings. Operators have an opportunity to deploy an open, standards-based architecture that offers a cost-effective, evolutionary route to new fixed and mobile Full Service Broadband opportunities.

Mobile backhaul is defined in the context of the metro network. The metro network is a key part of the Full Service Broadband architecture, transporting traffic between access and service nodes and also providing transport connectivity. The metro network can be optimized for all geographical areas, from dense urban to sparse rural. The metro network in a mobile-only scenario is also commonly referred to as a mobile backhaul network, which is the term used in this document.

In this paper we use the following terms to detail the mobile backhaul architecture (Figure 1):

- ***LRAN:*** Low Radio Access Network, which is the cell site access part of the mobile backhaul network that typically uses multiple physical link technologies (microwave, copper and fiber). The availability of any of these access media in the LRAN often significantly influences the choice of backhaul technologies. This paper focuses on high-capacity technologies for use in LRAN.

- ***HRAN:*** High Radio Access Network, which collects, aggregates and concentrates traffic from the LRAN into the core network.

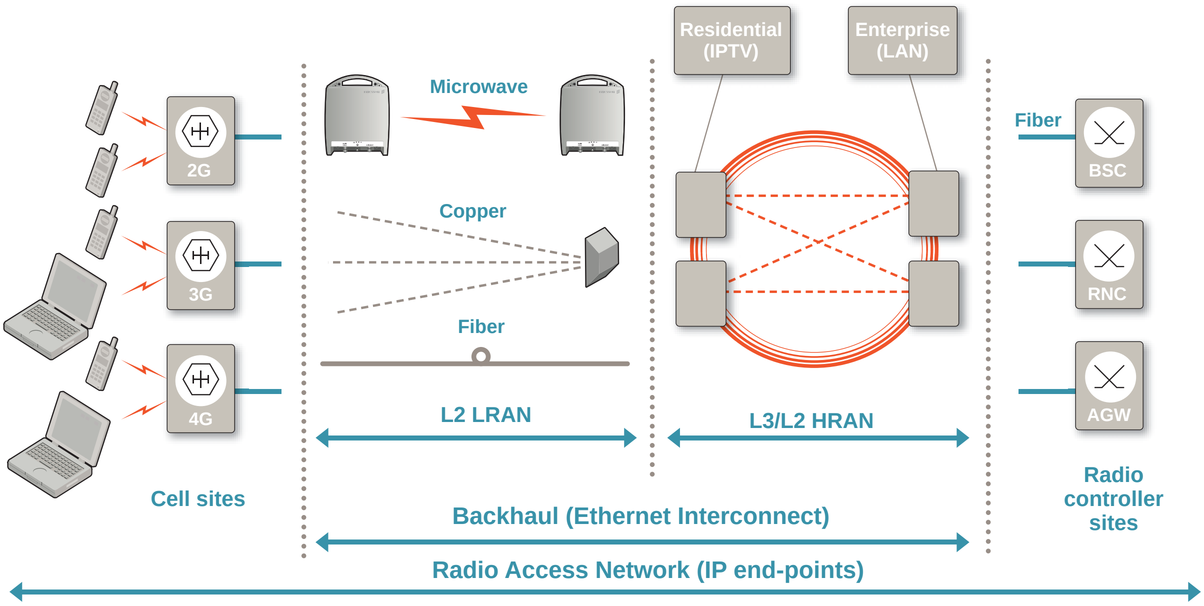


Figure 1) LRAN and HRAN in the backhaul architecture

3 Drivers and challenges

The continued success of mobile broadband calls for efficient evolution paths on both the RAN architecture and mobile backhaul network architecture. The three key challenges that were identified in Ericsson's "Full Service Broadband Metro Architecture" whitepaper also need to be addressed by any mobile broadband backhaul solution. They are as follows:

- ***The cost challenge*** – a network with low TCO when migrating to higher broadband capacities. The dramatically increased data traffic requires the mobile broadband backhaul networks to handle the challenge of capacity and cost. Therefore, consideration of these two main parameters becomes the key decision-making criterion for planning backhaul networks. The efficient use of existing infrastructure, in combination with a migration towards IP/Ethernet architecture and the right level of network automation, plus effective operation, administration and maintenance (OAM) tools will decrease the TCO.

- ***The convergence challenge*** – a single network to deliver all services. The term "converged network" is normally used for a common network used for fixed and mobile services. Such a network is typically characterized by a multitude of access types and services, resulting in a wide spectrum of requirements in terms of network characteristics. A backhaul network could be a part of such a converged network that delivers all services to both fixed and mobile users. Also a network dedicated to all forms of mobile access and services will have to meet a similar range of requirements when it is to be evolved to simultaneously carry the traffic of 2G, 3G and beyond. Mobile-only operators often benefit from building their own backhauling networks utilizing microwave and P2P fiber links, while converged operators can add microwave radio, fiber and DSL to their existing networks for fixed services, to support the backhauling of mobile services.

- ***The flexibility challenge*** – a network optimized for every situation. A mobile broadband backhaul solution should be able to accommodate different types of existing physical infrastructures as well as different business models. Depending on their business model, mobile operators can either build their transport networks or lease the necessary capacity from a transport operator. A combination of the two is also possible, where an operator leases link resources to their cell sites where leased lines are available, and builds its own links where they are not. Flexibility also means scalability, to ensure future-proof capacity.

Introducing mobile broadband with HSPA that will be further enhanced later by LTE networks results in a large increase in traffic. The downlink peak rate for a 20MHz 2x2 MIMO LTE cell can be up to 170Mbps for a single user.

The high level of traffic calls for a substantial upgrade of backhaul technologies. This new data traffic needs to be transported through the backhaul network, in just the same way as voice has needed to be. High-speed links must be used between the RBS and the first node in the network, and IP/Ethernet architecture must be used in the RAN core and transport networks. This will reduce costs while also making it possible to handle the increase in traffic.

4 Access network technologies

4.1 Present infrastructure

Copper wire, optical fiber or microwave links can all provide the physical connection to the base station in the LRAN. However, there are numerous factors for operators to consider when determining which of these to use. These factors include: maximum capacity; maximum distance; capital expenditure (capex) and operational expenditure (opex); existing infrastructure; ease of deployment; and competition issues. In fact, different types of backhaul transport technologies are and will be used in different parts of the world.

- In North America, the majority of backhaul lines are copper or fiber because there was very little wireless spectrum available for microwave links when the existing mobile networks were being built. For example, one major operator uses 50 percent fiber, 15 percent microwave links and 35 percent leased copper lines.
- In Europe, the majority of backhaul lines are microwave links because leased line (E1) links were provided by monopoly post, telephone and telegraph operators (PTTs) at a high cost in many countries, and wireless spectrum was available at the time.
- In Asia, microwave link is also the dominant backhaul technology, albeit with a smaller share of the total market. Asia also has extensive fiber deployments, and many of the biggest Asian mobile operators have both mobile and fixed operations.

4.2 Microwave radio solutions for mobile backhaul

4.2.1 Meeting the cost/capacity challenge

Microwave often provides the lowest TCO in cases where no infrastructure is present at the base station site, and it scales effectively in capacity. As a result of the low TCO, it also increases the addressable market for profitable deployment of mobile networks. From a revenue and early mover advantage perspective, the possibility for quick deployments is attractive. The result is that today, approximately 60 percent of all mobile base stations are connected by microwave links for further transport over fiber links. With the evolution to mobile broadband, operators are increasingly investing in self-owned microwave networks to control their costs.

The capacity requirements for HSPA evolution and LTE backhauling are met in microwave links in two ways: through increased spectrum efficiency; and through products using new frequency bands. Spectrum is a scarce resource, and in certain cases, it is an opex driver.

The latest microwave technology provides higher transport efficiency and throughput in the available spectrum, and packet operation avoids the limitations imposed by PDH and SDH multiplexing hierarchies. Higher (doubled) capacity in existing spectrum is achieved by co-channel dual polarization support in the microwave link – that is, two carriers in the same frequency channel with cross-polarization interference cancellation (XPIC). Even higher capacities can be achieved by using multiple frequency channels. The result is that Gbps microwave radio links are available in the market already today.

Increased spectrum efficiency can also be achieved by utilizing higher-order modulation schemes, but this is at the expense of system gain. The reduced system gain can be compensated for by larger antennas (at a higher cost). To get around this, the approach of higher-order modulation in combination with adaptive modulation can be adopted, leveraging the QoS differentiation of the traffic to deliver higher availability for high-priority traffic and lower availability for best-effort traffic.

Figure 2 illustrates how link capacity can be increased from 40 to 160Mbps by increasing the modulation order from 4 to 128QAM. With adaptive modulation the radio links can be dimensioned to give an availability performance of 99.999 percent for the 40Mbps for high-priority traffic. The remaining capacity for best-effort traffic has a reduced availability performance of 99.95 percent. In short, this achieves 120Mbps "extra" traffic not otherwise achieved 99.95 percent of the time.

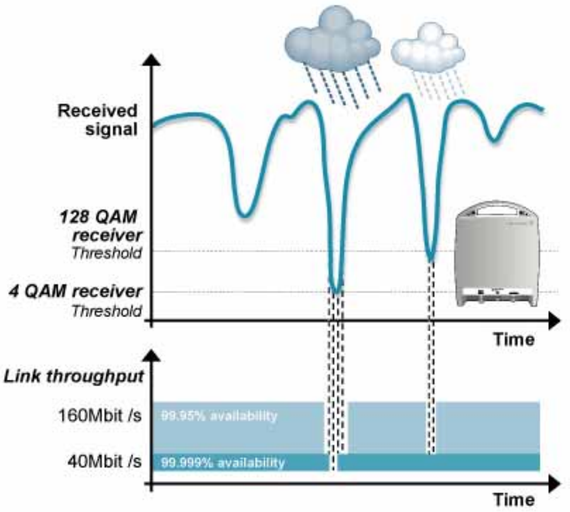


Figure 2: Link capacity as a function of modulation scheme

Another approach to delivering increased capacity over microwave links is to utilize new spectrum allocations such as the E-band.

Ericsson has built a demonstrator E-band P2P link system that supports data transport of at least 1Gbps over a distance of 1km. The demonstrator is an all-outdoor unit with an optical fiber data interface and complies with the Gigabit Ethernet (GE) standard.

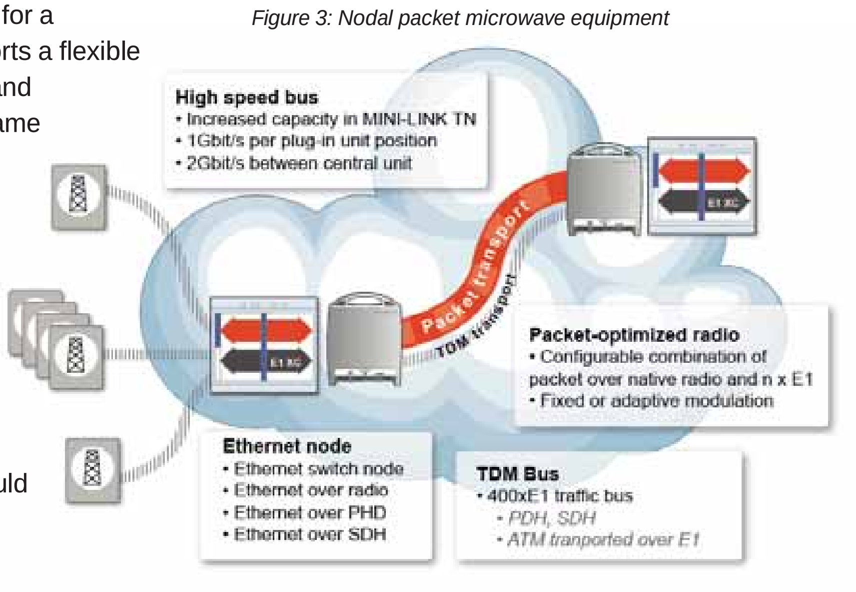
4.2.2 Meeting the convergence and smooth evolution challenge

Most operators will deploy a mobile broadband network that operates in parallel with their legacy base stations. This makes the convergence challenge equally relevant for mobile operators and for operators with fixed or combined fixed and mobile networks. Although legacy base stations can be migrated to IP RAN and IP/Ethernet interfaces, not all sites will be upgraded at once and the GSM and WCDMA base stations will continue to run on TDM in many cases. This results in the need for a microwave solution that supports a flexible transport of TDM (ATM/TDM) and IP/Ethernet in parallel, in the same node, over the same radio link, in any mix. This will enable the operator to seamlessly evolve its network according to its strategies and service take-up, and not be restricted by vendor-specific technical limitations.

For mobile-only operators the convergence challenge could be recognized in the evolution from 2G to 3G and beyond, in combining high-capacity leased lines with their own backhaul networks utilizing microwave.

The shift to IP/Ethernet transport is most efficiently handled by hybrid TDM and Ethernet support in the microwave link, so that transport capacity is seamlessly divided between TDM and Ethernet traffic. Figure 3 below shows an example of such microwave equipment.

Figure 3: Nodal packet microwave equipment



4.2.3 Meeting the flexibility challenge

Flexibility in the transport network is required every time the network reach is extended or bandwidth increases. Also service flexibility, and flexibility according to local conditions must be supported in the sense that rural areas are different from urban areas, and therefore have different requirements. In addition to the challenge of handling multiple baseband interfaces, the challenges of traffic aggregation and of optimizing topologies for traffic growth need to be met in the evolution of mobile broadband backhauling.

Typical GSM transport networks have been based on long chains of interconnecting BTS sites all the way up to the BSC. The backhauling network was planned ad hoc to match the radio access network deployment, and the links were fundamentally engineered as independent P2P links.

The capacity increase per RBS site from one or two E1s to tens of megabits for mobile broadband backhaul, has led to a transformation of microwave network topology (see Figure 4). The shift from typical chain networks to star-based configurations has led to the development of microwave nodal concepts (see Figure 3) with advanced integrated traffic handling, efficiently supporting a high number of microwave links. The impact of a capacity increase can be reduced by support for aggregation in the microwave nodes. By integrating microwave nodes with TDM and ATM cross-connectivity, and Ethernet switching, as well as fiber optic interfaces, TCO for the site can be greatly reduced. The benefits of these nodal solutions really come into play when migrating to HSPA and LTE networks.

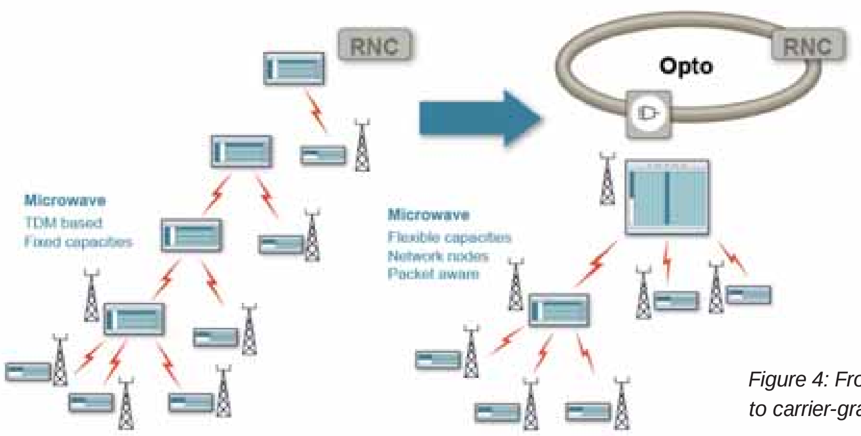


Figure 4: From carrier-grade TDM to carrier-grade Ethernet

4.3 DSL solutions for mobile broadband backhaul

4.3.1 Meeting the cost/capacity challenge

In locations with access to copper, DSL technology can be a solution for delivering cost-efficient capacity for mobile backhaul. The DSL technology currently used for mobile backhaul is high-bit-rate DSL (HDSL), second-generation HDSL (HDSL2) or Single-pair High-bit-rate Digital Subscriber Line (SHDSL). HDSL can be used either at the T1 rate (1.544Mbps) or the E1 rate (2Mbps) using two copper pairs, whereas SHDSL can have a bit rate of up to 2.3Mbps on a single pair.

With the use of enhanced spectra (Enhanced SHDSL), speeds of up to 5.7Mbps are possible for up to 800m on 0.4mm copper cable. The use of ADSL2+ (a further development of ADSL) for mobile backhaul is still not common, although this technology could provide up to 28Mbps. A significant reason for this is that ADSL2+ has been seen principally as a technology for asymmetric residential usage, combining broadband access with POTS or ISDN access.

A large number of E1/T1 lines use copper pairs (also called "loops" when connected to subscribers). These loops could be used more efficiently by replacing their SHDSL modems with VDSL2 modems, provided copper loops are short enough, which would suit HSDPA traffic well.

Over short loop lengths, the performance of a VDSL2 system is limited by its self-Far End Crosstalk (FEXT) noise. It is possible to reduce crosstalk down to the level of the background noise. In the upstream direction, the receive modems are co-located in the central office (CO), or at the remote DSLAM in Fiber To The Node (FTTN) applications. This permits the use of crosstalk cancellation technologies, vectoring, or Dynamic Spectrum Management Level 3 (DSM3) as it is also called. The theoretical result of using crosstalk cancellation is illustrated in Figure 5, which shows the simulated rate reach performance of a VDSL2 system using ITU-T G.993.2 PSD B7-10 (30MHz PSD) with crosstalk and without crosstalk and just background noise, respectively.

Vectoring can be combined with bonding:

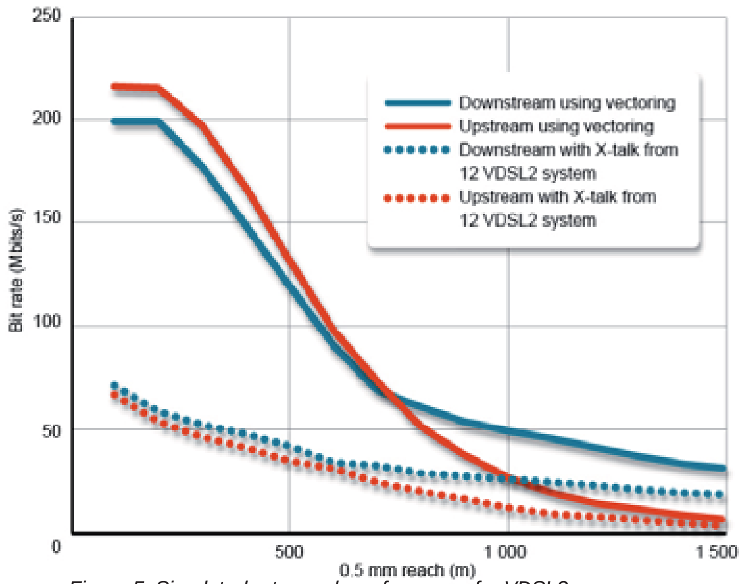


Figure 5: Simulated rate reach performance for VDSL2 with 997E30 band plan and 12 VDSL lines

the technique of combining pairs in a copper cable into bonding groups where the total data rate of the bonding group is the sum of its individuals' data rates. This aggregation of multiple lines creates a high-speed virtual pipe. As an example, with five VDSL2 lines running at 100Mbps, the supported data rate would be 0.5Gbps.

4.3.2 Meeting the convergence and smooth evolution challenge

For operators with access to copper, there are two main evolution paths for upgrading the existing copper infrastructure towards higher capacity. In a typical copper-centric Fiber To The Cabinet (FTTCab) deployment scenario, outside cabinets equipped with VDSL2 access multiplexers (IPDSLAMs) are installed in the vicinity of the users to bridge the very-last mile by re-using the copper infrastructure. In this way, the capex costs for the cabinet and VDSL2 equipment are traded off against the cost of drawing the fiber all the way to the customer's premises, which can be very expensive in urban scenarios. The fiber-centric alternatives are discussed in section 4.4.

4.3.3 Meeting the flexibility challenge

VDSL2 technology is flexible and can provide different combinations of bit rates in the downstream and upstream directions, depending on the band plans and profiles used. Theoretically, using VDSL2 profile 30a (providing 30MHz bandwidth), a symmetrical bit rate of 100Mbps for up to 500m is possible, provided that only background noise is present. By combining pairs with bonding as described in ITU-T G.998.2 (Ethernet bonding for Multipair DSL), it is possible to configure a high-bit-rate pipe suitable for HSPA and LTE backhaul. Data rates of 400-500Mbps could be achieved by bonding five VDSL2 lines if each line could provide around 100Mbps. However, the presence of crosstalk between the members in a VDSL2 bonding group, combined with the crosstalk from other VDSL2 systems sharing the same binder, could lower the bit rate significantly.

If the RBS has a coax connection to the aggregation network another alternative can be to use VDSL2 over coax.

4.4 Fiber backhaul solutions

Several physical-media-dependent functions, as specified by the Institute of Electrical and Electronic Engineers (IEEE), are available on the market for deploying P2P active Ethernet and passive point-to-multipoint (P2MP) EPON. These technologies can be deployed in Fiber To The Home (FTTH) or Fiber To The Building (FTTB) scenarios. GPON, as specified by the ITU-T, is an alternative P2MP solution.

4.4.1 Meeting the cost/capacity challenge

With the increasing availability of fiber, it becomes an important solution for mobile backhaul services, and once deployed it offers virtually unlimited possibilities for cost-effective capacity upgrades. While P2MP-PON technologies are still costly due to low volume deployment, P2P fiber components used in the access domain are mature, with high production volumes from other application areas. In terms of capex, both systems are almost equal for active components, since the savings from the use of PON resulting from the sharing of physical resources (expensive but shared OLT optics and trunk fiber) are balanced out by the inexpensive optical transceivers available for P2P Ethernet.

Because PON-like systems feed 32 or even 64 users via a single transceiver and trunk fiber on the network side, the fiber count at aggregation points such as COs is small compared to that of P2P architectures, reducing capex and opex as a result of less stringent building and fiber management requirements. Since PON-like systems have a more hierarchical structure than Ethernet networks (which are flat, comprising equally qualified switches), OAM is inherently easier, which has a positive impact on opex. While P2P fiber is expected to be the main choice for backhaul applications, PON is an alternative mostly when it exists in the vicinity, built for fixed BB access.

4.4.2 Meeting the flexibility challenge

P2P fiber gives operators an important transport alternative that helps to solve the flexibility challenge, in particular in urban areas. It is an attractive fiber backhaul solution due to its simplicity, cost-effectiveness and widespread use. Active Ethernet is available in both 100Mbps and 1Gbps versions, and allows for cost-effective capacity upgrading to meet the future bandwidth requirements of mobile backhaul. In many cases, it is possible to mount P2P fiber interface modules directly on the RBS equipment. Thus, no additional boxes are needed for fiber backhaul. P2P fiber solutions will have full flexibility for future capacity upgrades.

5 Deployment scenarios for mobile backhaul

There will not be one best solution for the high-capacity connections needed between the RBS and the first aggregation node in the network. Different solutions will be used depending on the existing infrastructure, the operator's business situation, the type of end users (business or residential) and the services and distances the end users require, for example. Converged incumbent operators that have both wireline and wireless access will be able to optimize their networks to be used for both types of customers, and more easily implement new technologies. There are great potential savings in capex if investments in fiber infrastructure can be used (shared) by mobile, residential and corporate business users.

Mobile operators will need to negotiate with fixed operators in order to get access to leased lines, or build their own transport infrastructure using mainly microwave links and/or optical fiber. Another alternative that is attracting more and more attention is site and RAN sharing at different levels, where a number of operators can then split the capex and opex for the backhaul network. The operators could use the same site to install their own equipment using a shared tower with common antennas. They could also share the Node B and even the complete backhaul network. The shared network can be run by a joint venture or by a separate "tower operator". A tower operator could manage several mobile operators separated on VLANs, or they could be set apart by different wavelengths in a WDM GPON.

To illustrate different strategies for the implementation, two cases will be presented and discussed here: one rural/suburban, and one in a densely populated urban area.

5.1 Rural/suburban areas

The present backhaul solution in rural areas is dominated by E1/T1 over microwave or copper. With SHDSL, quite long distances can be covered since repeaters can be used. The principal options for implementing a backhaul solution that can handle future bandwidth needs will be to upgrade the capacity of microwave links, depending on the distance; to use single links or a chain of links; or in certain cases, to install optical fiber in the form of P2P links or GPON (only when already available in the vicinity). High-capacity bonded DSL links will not be an option in this case, since they have a useable distance of only 500–1000m, and VDSL does not permit the use of repeaters.

5.2 Urban areas

The majority of sites in urban areas worldwide will be connected using microwave radio links. However, in certain countries and cities, high-speed fiber and copper is widely available for backhaul.

A case study of the backhaul network for WCDMA and GSM in one of Sweden's biggest cities shows that 30 percent of the RBS sites already have fiber access that is not currently being used for mobile backhaul; and that the distance between the RBS and the closest fiber access point will decrease substantially within five years. Therefore, typical backhaul solutions for urban areas will be either fiber direct to the base station; or a fiber-deep solution where the fiber is terminated in cabinets close to the RBS, and single or bonded VDSL2 lines are used for the last few hundred meters. Fiber-deep solutions are already being driven by ongoing VDSL2 deployment for residential and business users.

6 All-IP over Ethernet transport

The architecture for Ethernet service backhaul consists of IP-capable RAN nodes with native Ethernet interfaces to the transport network. The transport network provides a Layer 2 (L2) or Layer 3 (L3) VPN service, which the RAN nodes perceive as Ethernet or IP layer connectivity. The transport network services are implemented over Ethernet or MPLS networks, or a combination of these. The solution is compatible with FSB architecture that provides a consistent, multi-layer User to Network Interface (UNI) connecting end users to next-generation service delivery platforms by combining fixed and mobile access technologies. The Full Service Broadband architecture enables users to authenticate and reach all their services anywhere, using any device connected to a mobile or a fixed access network, thus providing them with a transparent service experience. The backhaul part of the mobile access network constitutes a key component of the FSB architecture.

Ethernet is commonly deployed in broadband access networks, and is a proven technology that is also generally seen as the foundation of converged fixed and mobile access network infrastructure. MPLS, which was originally deployed mainly in core networks, is now also being installed in aggregation networks as IP Edge functionality becomes more widespread. MPLS provides better multiprotocol support (is protocol-agnostic) and has standardized interworking capabilities with other networks. MPLS is also a mature technology for handling multiple instances of L2 VPN and L3 VPN services. Both transport network options, MPLS and Ethernet, are able to provide connectivity for radio networks. Some operators may choose recent connection-oriented variants that are being standardized, such as MPLS-TP or PBB-TE. This makes all-IP over Ethernet an attractive, future-proof choice for mobile operators.

Packet transport infrastructure can be deployed and maintained at a lower TCO than legacy TDM transport infrastructure. Packet transport provides scalable capacity without granularity limitations and supports efficient aggregation, statistical multiplexing and multicasting. These factors help to achieve a reduced transport cost per bit and provide transport functionality that can meet future service demand.

6.1 All-IP RAN service aspects

Regardless of the type of packet service used, there are four key service aspects for transport from the RAN’s point of view: synchronization, security, QoS and service OAM.

6.1.1 Synchronization

Network synchronization is a key consideration in the design of telecommunications networks in order to meet performance and availability requirements.

In next-generation packet networks there are a number of alternative ways to distribute the reference timing signals. End-to-end packet methods are independent of the underlying transport layer, and a complete solution using these methods is likely to be more cost-effective than others, and is the only option for many established networks.

Synchronization over IP (SoIP), a refined NTP-based algorithm that has been optimized for distributing (radio) timing, is one example of an end-to-end packet-based timing-regeneration technology that is very stable over time and will thus decrease the opex.

Synchronous Ethernet is a technology

that can provide accurate frequency synchronization, but one which relies on dedicated hardware in the transport layer. It is not suitable for carrying timing across operator boundaries or across multiple technologies.

For applications requiring accurate time and phase synchronization such as LTE TDD and multicast/broadcast single frequency networks (MBSFNs), the use of GPS is still the most reliable and preferred solution.

6.1.2 Security

Security is more inherently important in the lower levels of the network. Multilayered security is both a key feature and a challenge of IP transport. One recommendation is to designate separate site security zones and to assign protection according to the assessed risk. To reduce the risk of intrusion, access from one zone to another can be restricted by fire-walling traversing traffic. RAN traffic may transit public or semi-public transport networks. In this case, RAN traffic is controlled and encapsulated in an IPSec VPN. The IPSec protocol suite offers different levels of security for IP communication by providing authentication, integrity and/or confidentiality. IPSec can be used to interface a non-trusted network or shared network to protect non-encrypted payload from other radio systems. If necessary, MPLS-based VPNs can provide additional levels of security and traffic separation. Security gateways are deployed at BSC, RNC, and RBS sites.

6.1.3 QoS

For networks that carry diverse traffic types and do not have unlimited capacity, the implementation of QoS differentiation is strongly recommended. Different types of traffic can be marked using either Differentiated Services (DiffServ) code points or Ethernet priority bits. DiffServ maps each traffic class to standardized per-hop behavior including delay, bit rate and drop probability. On the other hand, Ethernet priority bits leave the treatment of each traffic category up to the individual transport network implementation. It is therefore imperative that the transport network provider and the mobile operator agree on a set of well-defined SLA parameters concerning packet drop rates, delay and delay variation. With video driving the need for mobile broadband networks, it becomes imperative that backhaul networks offer low frame loss rates coupled with QoS differentiation. The ability to support three to four classes of service will be sufficient in most cases.

6.1.4 Service OAM

Mobile operators will clearly want to be able to monitor their packet-based services for faults, continuity and performance. With packet-based transport in the RAN, operators will be particularly interested in having the tools necessary to monitor the status of their packet-based services so that they can tweak service parameters for better performance and localize where faults have occurred (in their network domain or in the service provider's domain, for example). IEEE 802.1ag Connectivity Fault Management (ITU-T Y.1731) and the Metro Ethernet Forum (MEF) specify a framework for Ethernet OAM that can be applied to verify service connectivity between sites, locate faults and gather statistics on service performance. These capabilities will be vital during the transition period to packet-enabled radio systems, and will offer mobile operators the security of knowing that they have up-to-date information about the current status of their services. They will also serve to assist mobile operators in learning more about, and understanding, the capabilities and limitations of their new services.

Mobile operators will also be interested in checking the performance of their services by employing Ethernet service performance monitoring mechanisms. The mobile operator may choose to use these mechanisms continuously, or to monitor a service periodically. Continuous monitoring introduces some level of traffic overhead on the service, but offers the capability to identify trends in a service quickly and thus be able to initiate appropriate counteraction to assure end-user quality of experience (QoE). Alternatively, periodic or on-demand monitoring uses fewer network resources and may be initiated as a reactive measure to alerts from the radio system or customer complaints.

Three fundamental OAM messages are defined by IEEE 802.1ag that the ITU-T has extended for performance monitoring. These are continuity check message (CCM), linktrace and loopback.

In combination, Ethernet OAM connectivity fault management and performance monitoring provide mobile operators with a complete set of tools for verifying SLA fulfillment and identifying and localizing connectivity faults and failures. This will prove to be an important capability during the transition to packet-based mobile backhaul networks, and valuable for facilitating management as mobile networks grow in size and capacity.

7 Conclusions

This document has presented and discussed various technologies that will be able to handle the demand for HSPA and LTE backhauling. The main conclusion is that backhauling must not be a capacity bottleneck that will delay the introduction or decrease the capabilities of future mobile networks. The choice of backhaul strategy should be a key issue for operators. IP/Ethernet in combination with high-capacity microwave, fiber, or high-capacity VDSL2 links will substantially decrease the cost per transported bit. The following are some of the key conclusions divided into the three main types of challenges:

Cost challenges:

- The need for increased capacity and decreased cost per transported bit drives packet-based mobile backhaul capacity boosts over microwave, copper and fiber. The general trend in the backhaul link technology arena is increasing use of fiber and high-speed microwave solutions. Microwave volumes are expected to increase significantly in coming years while remaining stable in terms of the percentage share of deployments and total revenues.
- Microwave-based solutions enable low TCO and high capacity. Leased-line scenarios become less attractive in some markets as backhaul traffic increases and more advanced services are deployed. Microwave and P2P fiber deployments by operators investing in their own networks will enable improved monitoring and more flexibility in timing investment decisions to secure additional capacity.
- In a fiber-deep deployment scenario re-using the copper, outdoor cabinets equipped with VDSL2 access multiplexers are installed in the vicinity of the RBS with fiber connections leading towards the aggregation network. High-capacity bonded VDSL2 links can be used if there are multiple existing copper connections to the RBS site.

Convergence challenges:

- A standardized approach to mobile backhaul based on carrier Ethernet creates a common platform for communication between mobile operators and leased-line service providers.
- The shift to IP/Ethernet transport is most efficiently handled by avoiding circuit emulation solutions and employing native IP interfaces in base stations to the greatest possible extent. Hybrid TDM and Ethernet support in microwave nodes ensures seamless and efficient transport of TDM and IP traffic should native IP interfaces not be available from the base station vendor.

Flexibility challenges:

- Microwave node concepts and scalable capacity are now available to support the topology flexibility needed in the mobile backhaul architecture.
- P2P fiber and VDSL2 support flexible capacity upgrades once the base stations are connected.
- The best solution for synchronization is end-to-end packet-based timing-regeneration such as SoIP, which is a refined NTP-based algorithm that has been optimized for distributing (radio) timing.

8 Glossary

ADSL	Asynchronous Digital Subscriber Line
ADSL2+	A development of ADSL that doubles the number of downstream bits
AGW	Access gateway
ATM	Asynchronous Transfer Mode
BB	Broadband
BSC	Border Session Controller
BTS	Base transciever station
Capex	Capital expenditure
CCM	Continuity check message
CO	Central office
DiffServ	Differentiated Services
DSL	Digital Subscriber Line
DSLAM	Digital Subscriber Line Access Multiplexer
DSM3	Dynamic Spectrum Management Level 3
E1	The European equivalent of the North American T1 (see T1 below)
EPON	Ethernet PON
FEXT	Far End Crosstalk
FMC	Fixed-mobile convergence
FTTB	Fiber To The Building
FTTCab	Fiber To The Cabinet
FTTH	Fiber To The Home
FTTN	Fiber To The Node
GE	Gigabit Ethernet
GPON	Gigabit Capable Passive Optical Network
GPS	Global Positioning System
GSM	Global system for mobile communications
HDSL	High-bit-rate digital subscriber line
HDSL2	Second-generation high-bit-rate digital subscriber line
HRAN	High RAN
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access. Part of the 3rd Generation Partnership Project (3GPP) WCDMA standard
IEEE	Institute of Electrical and Electronic Engineers
IP	Internet Protocol
IPDSLAM	Internet Protocol Digital Subscriber Line Access Multiplexer
IPSec	Internet Protocol Security
ISDN	Integrated Services Digital Network

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ITU-T	International Telecommunication Union Telecommunication Standardization Sector
L2 VPN	Layer 2 Virtual Private Network
L3 VPN	Layer 3 Virtual Private Network
LAN	Local Area Network
LRAN	Low RAN
LTE (3G)	Long Term Evolution (3rd generation)
MBSFN	Multicast/broadcast single frequency network
MEF	Metro Ethernet Forum
MIMO	Multiple Input Multiple Output
MPLS	Multi Protocol Label Switching
MPLS-TP	MPLS Transport Profile
NGN	Next-generation network
NTP	Network Time Protocol
OAM	Operation, administration and maintenance
OLT	Optical Line Termination (device)
Opex	Operational expenditure
P2P	Point-to-point
P2MP	Point-to-multipoint
PBB-TE	Provider Backbone Bridges – Traffic Engineering
PDH	Plesiochronous Digital Hierarchy
PON	Passive Optical Network
POTS	Plain old telephone service
PSD	Power Spectral Density
PTT	Post, telephone and telegraph operator
QAM	Quadrature amplitude modulation
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio access network
RBS	Radio base station
RNC	Radio Network Controller
SDH	Synchronous Digital Hierarchy
SHDSL	Single-pair High-bit-rate Digital Subscriber Line
SLA	Service Level Agreement
SoIP	Synchronization over IP
TCO	Total cost of ownership
TDD	Time Division Duplex
TDM	Time Division Multiplexing

T1	Trunk Level 1, a digital transmission link
UNI	User to Network Interface
VDSL	Very-high-speed digital subscriber line
VDSL2	Second-generation VDSL
VLAN	Virtual LAN (Local Area Network)
VPN	Virtual Private Network
WCDMA	Wideband Code Division Multiple Access
WDM	Wavelength Division Multiplexing
XPIC	Cross-polarization interference cancellation

9 References

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