High-speed mobile backhaul demonstrators

The transition to new mobile technologies calls for an increase in backhaul capacity. The initial rollout of LTE will require a capacity of 100–150Mbps. Future releases will increase this requirement to gigabits per second all the way to the cell site.

With increasing demand for high-capacity mobile data services and a simultaneous decline in revenue per bit, network operators face the challenge of providing high traffic capacity while reducing overall network costs. At the same time, profitable migration needs the availability of high-capacity backhaul solutions. This article presents two high-speed technology demonstrators: one for microwave, a single-carrier GbE microwave link; and one for copper, a 500Mbps vectorized VDSL2 link.

The mobile backhaul network provides connectivity between the radio base station (RBS) site and the switch site at the edge of a transport network. Ericsson divides the backhaul architecture into two distinct parts (Figure 1) with separate requirements:

- the low radio access network (LRAIN) and the high radio access network (HRAN).
- The HRAN typically aggregates traffic from several LRAN networks using an existing fiber or microwave network, such as a metro network. The LRAN, which is frequently microwave-based, provides the last mile of connectivity for the RBS sites.
- The LRAN typically aggregates traffic from 10 to 100 RBS sites and feeds it into the HRAN. Owing to the large number of cell base station sites in the LRAN and the dynamic changes in the network, the LRAN must be cost-effective, simple, upgradeable, flexible, and able to provide peak capacity. Globally, LRANs use multiple physical link technologies (microwave, copper, and fiber), depending on operator strategy and availability at the site. Microwave usually provides the lowest total cost of ownership when no other infrastructure is available at the cell site, and it is today the dominating LRAN backhaul technology. However, both fiber and copper serve as common first-mile backhaul solutions in many parts of the world.

Why we need high-capacity backhaul

Mobile broadband has been a huge success thanks to the launch of flat-rate high-speed packet access (HSPA) services, which triggered a sharply rising demand for mobile data services. It is anticipated that this trend will continue with the rollout of HSPA Evolution and 3GPP Long Term Evolution (LTE), which reduce the cost per transported bit.

Historically, the transition to new mobile technologies has resulted in the need for a fourfold to fivefold increase in backhaul capacity. With the rollout of LTE, this translates into an LRAN backhaul capacity of 100–150Mbps. And future releases of LTE will increase the requirement for backhaul capacity to gigabits per second (Gbps) all the way to the cell site.

Fiber access is the obvious first choice of technology for any high-speed link. The capacities of point-to-point or gigabit passive optical network (GPON) links exceed any LTE backhaul requirement so far. However, microwave and copper also provide technologies for reaching Gbps capacity.

High-capacity microwave links

The conventional spectrum for microwave backhaul offers frequency bands between 6GHz and 38GHz. Each band is split into several narrow-frequency channels to ensure that the available spectrum is used most efficiently. The widest channel offers approximately 50MHz of bandwidth. Using advanced modulation formats, these bands support up to 500Mbps on a single carrier. Polarization multiplexing and multiple-input/multiple-output (MIMO) techniques may further increase spectral efficiency. Likewise, adding
channels (spectra) multiplies the capacity.

Ericsson’s MINI-LINK node solutions already offer gigabit Ethernet (GbE) capacity using multiple channels and polarization multiplexing. For LTE backhaul, 14MHz and 28MHz channels with a more advanced modulation format are enough to manage the capacities in last-mile applications. For aggregated links, 28MHz channels and above will be used.

The newly available 71–76GHz and 81–86GHz frequency bands, also referred to as the E-band, allow 10GHz bandwidth and thus the ability to support Gbps capacity using simple modulation formats on a single carrier. Radios on these frequency bands are suitable for fiber extensions within a fixed HRAN backhaul.

High-capacity DSL links
The dominant digital subscriber line (DSL) technologies used for the mobile backhaul are high-bit-rate DSL (HDSL), enhanced high-bit-rate DSL (HDSL2) and, to some extent, single-pair HDSL (SHDSL) (Figure 2, top).

Fiber-to-the-curb (FTTC) deployment brings the DSL access multiplexer (DSLAM) closer to the end user and makes it possible to provide even higher bit rates. Enhanced very-high-speed DSL (VDSL2) technology is optimized for FTTC scenarios (Figure 2, bottom). Indeed, on short loops, VDSL2 technology can provide up to 100Mbps transmission upstream and downstream.

VDSL2 can also provide the bit rate required for the LTE backhaul and might be used as a high-capacity DSL backhaul link. Rates well above 100Mbps can be achieved for VDSL2 by combining a cross-talk cancellation technique called “vectoring” and line bonding.

High-capacity backhaul microwave demonstrator
In 2008, Ericsson Research developed a technology demonstrator to evaluate the characteristics of a 70/80GHz radio with Gbps capacity.

70/80GHz frequency band
The 70/80GHz band was opened for commercial use in 2003 in the US and in 2006 in Europe. A novel light-licensing model was introduced in the US in 2008.
dB/km versus frequency and rain intensity.

The green curve shows attenuation from oxygen; the blue curve shows attenuation from water vapor. Snow and fog have marginal impact on the path attenuation.

A common quality grade for mobile operators is 99.999 percent availability (the “five 9s”). As a consequence, where installed, a 70/80GHz link must tolerate a rain intensity that happens on average only 5 minutes per year. In most parts of the world, this corresponds to a rain intensity of 50mm or more per hour.

Figure 3 (right) shows the maximum hop length for different rain intensities versus system gain in decibels. Here, system gain is defined as the sum of the transmitted output power and antenna gains (Tx and Rx) minus the receiver threshold, which is defined as the minimum received power for a bit error rate of less than 10-12.

The maximum hop length is defined as the distance for which the received power is equal to the receiver threshold value. Assuming realistic system gains for commercial backhaul radios of 160–200dB, it can be seen that the 70/80GHz radio technology is best suited for less than 3km in most parts of the world. The ITU-R has collected precipitation statistics from around the world, and models are available for calculating the distribution of rain intensities.

Ericsson 70/80GHz microwave radio mounted on test site.
world. This is an optimum distance for urban and suburban settings. In rural areas, conventional frequency bands using channel aggregation or polarization multiplexing provide a more efficient solution.

Gbps microwave demonstrator overview
The microwave demonstrator is an outdoor radio with an optical GbE interface (Figure 4). The radio supports full-duplex GbE traffic (1.25Gbps) and has a latency of less than 1µs. It is mounted in a MINI-LINK case with standard power supply and monitor port for alignment. Power consumption is 40W. The demonstrator is implemented in frequency-division duplex (FDD) mode, transmitting on the high band (81–86GHz) and receiving on the low band (71–76GHz) or vice versa. Due to the wide available bandwidth (2x5GHz), it uses a sloppy but simple modulation format—differential binary phase shift keying (DPSK).

The maximum transmitted output power is 18dBm and the receiver threshold power is -58dBm. Each radio unit is equipped with a 39cm antenna, providing an antenna gain of 43dBi. This results in a system gain of 162dB. From Figure 3 (bottom) we can see that the demonstrator supports roughly 1.5km hop lengths in heavy rain (50mm/h). Increasing the transmitted output power a few decibels has only limited impact on the maximum hop length. A larger antenna providing 10dB extra gain would extend the hop length roughly 50 percent.

Figure 5 shows maximum hop lengths in Europe for the 70/80GHz radio assuming 99.999 percent availability. The calculations are conservative in the sense that they assume

- that the rain cell covers the full hop; and
- a bit-error rate (BER) of less than 10^-12.

In September 2008, an outdoor test site was set up over a 1km hop in Gothenburg, Sweden. Rain intensity, drop size, fog, and snowfall were monitored and logged at one-minute intervals by a local weather station. Figure 6 shows the monitored received power and rain intensity from March to August 2009. As expected from the ITU-R recommendations mentioned above, snow had limited impact and rain had a major impact on path attenuation.

On March 23, 2009, a heavy snowfall (intensity of more than 30mm/h) was measured at the site. On this occasion the received power dropped a few tenths of a dB. The link experienced two outage events during unusually intense rainfall in July. The heaviest monitored rainfall was 132 mm/h on the morning of July 12, 2009. The measured path attenuation at that time increased by 31.6dB (the expected attenuation at 132 mm/h rain was 35.6dB). The measured path attenuation agrees well with the expected attenuation calculated from the measured rain intensity. The deviation between expected and monitored attenuation is caused by the variation of rain intensity over the hop.

Link availability, which was measured from September 2008 to August 2009, was 99.9992% (4 minutes). This is slightly worse than the statistically expected 99.9998% (45 seconds) calculated from the ITU-R recommendations.

High-capacity backhaul DSL demonstrator
During 2008, Ericsson developed a demonstrator for evaluating the potential to attain 500Mbps on VDSL2 by comb...
referred to as Dynamic Spectrum Management Level 3) reduces or cancels self-FEXT. By knowing the transmitted symbols from the disturbing lines and the crosstalk coupling gains between the pairs, it is possible to pre-distort (pre-code) the transmitted signal in downstream transmission in such a way that crosstalk is eliminated on the channel. Different pre-coder structures can be used.

Vectoring for VDSL2 can be applied in both upstream and downstream directions. The performance improvement comes from joint signal processing: in the downstream direction, transmissions are coordinated; in the upstream direction, reception is coordinated.

There is an ongoing effort in ITU-T SG15/Q4 to standardize self-FEXT cancelation for VDSL2 transceivers for downstream and upstream transmission.

Bonding is a technology for creating multiple bit streams. The new bit streams may then be transmitted over multiple DSL lines and reassembled into the original bit stream at the receiver. The DSL lines are combined into a bonding group whose total rate is the sum of the individual line rates.

In the operation of the bonding mechanism, the Ethernet frame is first divided into fragments, where fragment size...
can be between 64 and 512 bytes. Each fragment is given a sequence number so the receiver can assemble the fragments in the correct order. The fastest-to-
slowest net data rate ratio between bonded lines should be at most 4:1.

**Demonstrator overview**

The high-capacity backhaul DSL demonstrator consists of a VDSL2 DSLAM vectoring prototype that implements self-FEXT cancellation by pre-coding for six lines. It also implements Ethernet bonding over DSL according to ITU-T G.998.2. A six-line bonding VDSL2 customer premises equipment (CPE) prototype replaced the standard CPE. The system was connected to AWG24 twisted-copper cable. Performance was verified with an Ethernet traffic generator/analyser (Figure 8).

**Measurements**

All measurements used VDSL2 Profile 17a; the PSD mask was B8-I1. Table 1 shows the results achieved over 500m using six lines of 0.5mm (AWG24) copper cable.

**Figure 9** shows the performance and gains of vectoring. The solid blue curve indicates single-user performance (the rate without any crosstalk) when only one line is active in the system. The red curve indicates a drop in performance when all six lines are active and vectoring is not used. The green curve shows performance when all six lines are active and vectoring is used. Note that these results are close to single-user performance. The dotted blue curve shows the attainable bit rate, which is the theoretical rate according to the measured signal-to-noise ratio at the receiver.

**Figure 10** shows the rate/reach performance when six-line bonding is used. In this case, the six-line bonding CPE prototype was used instead of six separate CPEs.

Delay and delay variation (jitter) are important parameters in the mobile backhaul. The requirements for jitter are crucial for correct synchronization. The delay determines the quality of service and should be kept to a minimum for voice services, as an example. The requirement for average latency (one-way) and real-time traffic is less than 5ms; for best-effort data the limit is less than 10ms.

The measured delays were 3.30ms (downstream) and 3.94ms (upstream).

The maximum jitter requirement is less than 10ms, and the measured values were 0.51ms (downstream) and 0.93ms (upstream).

The results from the measurements show that the allowed jitter and delay requirements can be met with good margin.

**Summary and future perspectives**

A successful transition to new mobile technology generations will require low-cost, high-capacity backhaul 

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**TABLE 1**

<table>
<thead>
<tr>
<th>Measured results of the DSL demonstrator</th>
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<tbody>
<tr>
<td>100Mbps per line (=130Mbps attainable)</td>
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<tr>
<td>70 percent bit rate improvement compared with the legacy VDSL2 system</td>
</tr>
<tr>
<td>540Mbps bonding rate over 6 vectored lines (&lt;1 percent bonding overhead)</td>
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**FIGURE 9** Measured rate and reach for the VDSL2 vectoring system.

**FIGURE 10** Measured rate and reach for VDSL2 with both vectoring and bonding.
Providing high traffic capacity while reducing network costs

Where fiber is available, the recommended choice is optical access. Where there is no fiber infrastructure, microwave and copper can be used.

As a complement to existing multi-carrier Gbps microwave solutions in traditional frequency bands, the 70/80GHz band provides sufficient bandwidth to enable single-carrier Gbps microwave links. This ensures that microwave will remain a viable backhaul solution. Applications for radios on these bands currently include urban and suburban HRAN fiber-extension solutions that cover hop lengths of up to 3km.

Ericsson has presented a VDSL2 demonstrator with vectoring technology and line bonding. Measurements show that it is possible to attain bit rates of 500Mbps over copper loops longer than 500m. Vectoring is an efficient crosstalk cancellation technology that boosts the per-line performance in a binder.

In a fiber-deep deployment scenario, outdoor cabinets equipped with VDSL2 access multiplexers are installed in the vicinity of the RBS site with fiber connections leading to the aggregation network. High-capacity bonded VDSL2 links can be used if there are multiple copper connections to the RBS site. Point-to-point fiber (GPON) and VDSL2 support flexible capacity upgrades once the base stations are connected.

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Jonas Hansryd

holds a Ph.D. in high-speed optical communication from Chalmers University of Technology, Sweden. After finishing his doctorate in 2001, he joined CENIX Inc., now Cyoptics, in Allentown, PA, USA, for two years, developing 10Gbps and 40Gbps optical transponders. He also spent one year as a postdoctoral fellow at Cornell University, Ithaca, NY, USA, working with advanced optical modulation formats. Returning to Sweden, he spent four years developing link layer network applications that target the automotive industry before joining Ericsson Research in 2008. At Ericsson he primarily works with high-capacity microwave solutions.

Per-Erik Eriksson

joined Ericsson in 1989 to work with ISDN design. Today, his focus is on xDSL at Ericsson Research where he is involved in high-speed DSL research. He is also involved in DSL standardization, representing Ericsson in ITU-T and ETSI. Per-Erik holds an M.Sc. in electronic engineering from the Royal Institute of Technology, Stockholm.