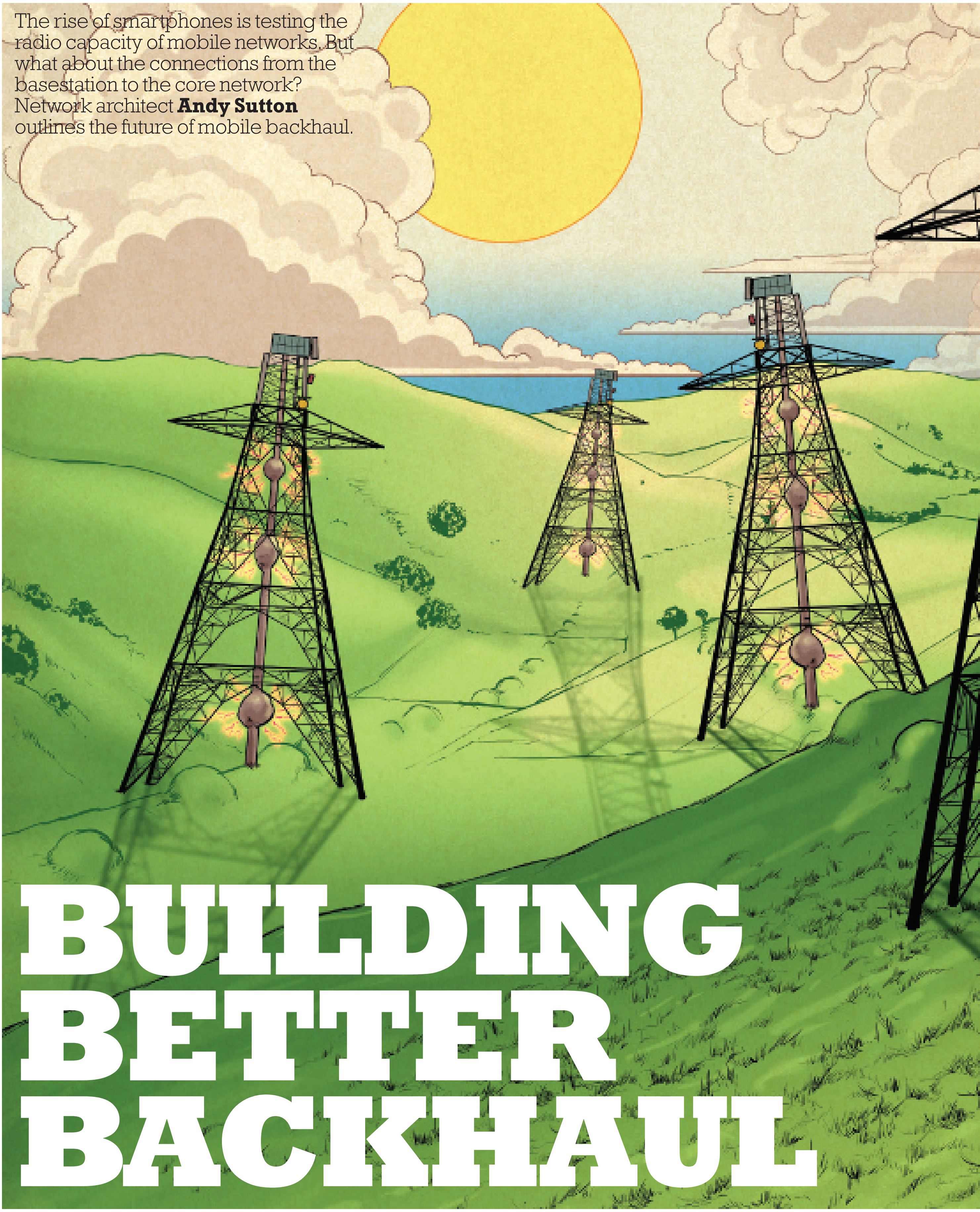


The rise of smartphones is testing the radio capacity of mobile networks. But what about the connections from the basestation to the core network? Network architect **Andy Sutton** outlines the future of mobile backhaul.

BUILDING BETTER BACKHAUL

ANDY SUTTON, ANGUS CAMERON/NB ILLUSTRATION, ODI ILLUSTRATION

CELLULAR NETWORKS have always relied on connections between each basestation and a mobile telephone exchange or switching centre (MTX/MSC) to 'backhaul' phonecalls and mobile data to the rest of the network. Backhaul has for years been taken for granted by all but a relatively small group of technicians and engineers who manage, maintain, and develop the time-division-multiplexing (TDM) systems that provide this vital connectivity.

However, the rise of dongles, smartphones and tablets means this is changing. Kristin Rinne, senior vice president for architecture and planning at AT&T, told a panel session at this year's Mobile World Congress that her company had experienced a 3,000 per cent growth in data traffic on its network in the three years since it started offering the iPhone.

Although much of the industry's focus in the face of this onslaught has been on optimising the radio link between each device and its basestation, once the data has

reached the mast the backhaul connections are also in danger of congestion.

How we got here

The UK's first cellular technology, TACS, was an analogue system that used a digital backhaul connection. These 2.048Mbit/s (often referred to as 2Mbit/s) TDM connections, known as E1 circuits, carried up to 30 calls from the cell site to the MTX. Voice traffic was coded into 64kbit/s timeslots, which were then mapped into the 2Mbit/s frame of the E1 circuit. The benefit of using E1 circuits for mobile backhaul was that the same approach was used in the public switched telephone network (PSTN), simplifying the integration of fixed and mobile telephony.

As cellular networks have evolved the definition of mobile backhaul has blurred, but it is usually taken to mean the link between a basestation (in GSM parlance, the base transceiver station; in UMTS, the NodeB), and its associated network controller (in GSM parlance, the basestation controller; in UMTS, the radio network controller). This definition breaks down with next-generation mobile systems such as LTE, which don't use a network controller, but the principle is the same.

It's also worth noting that, although mobile backhaul is often depicted as a direct connection between a basestation and a network controller, the physical connection is likely to be made up of a number of links connected at nodes known as transmission high sites, transport nodes and aggregation nodes.

Cellular evolution

TACS was followed by the introduction of digital cellular technology based on GSM, which adopted a new voice-coding technique that resulted in 16kbit/s, rather than 64kbit/s, voice channels. GSM also introduced signalling requirements for call set-up, mobility and basestation operation and management. This increased the number of calls each traditional E1 frame could carry, but changed how mobile calls were organised within the frame, making it different from the way that calls were organised within their frames on the PSTN. At least, though, the way that E1 frames from either source were carried on the transmission network remained the same.

GSM, like TACS before it, was mainly designed to carry voice calls. The first implementation of data on GSM used a circuit-switched approach, until the advent of the general packet radio service (GPRS) in the late 1990s. GPRS added packet switching, based on the Internet protocol (IP), to GSM; this began the evolution to mass-market data services and the mobile Internet. From a backhaul perspective, GPRS added new considerations, although the external structure of the E1 frame remained stable.

The third generation of cellular technology was also designed as a voice telephony network, but with much greater consideration for handling data services. The UMTS standard has both a circuit-switched element, mainly for voice, and a packet-switched element that builds upon the technology and infrastructure deployed for GPRS. UMTS provides much higher data rates than GPRS, even though GPRS was eventually updated with a new modulation and coding scheme. Initial UMTS implementations offered downlink data-rates of 64, 128 or 384kbit/s and uplink data-rates of up to 64kbit/s.

Faster data

UMTS also introduced an updated codec for voice services, and, significantly for the backhaul infrastructure, asynchronous transfer mode (ATM). ATM moves away from carrying voice traffic in fixed timeslots within E1 frames, in favour of a more data-friendly allocation of backhaul capacity on the basis of need. ATM (and therefore UMTS) still uses the established E1 frame but links multiple E1 connections to support higher bit-rate connections, for example linking four 2Mbit/s E1 links into an 8Mbit/s logical path. A new network element, known as an ATM cross-connect or switch, was introduced to enable this aggregation and optimisation of ATM links.

Mobile technology continues to evolve and it wasn't long before the concept of mobile broadband came along. 3GPP (The 3rd Generation Partnership project, the international organisation responsible for mobile network specifications) anticipated the growth of mobile data and released a series of specifications for high-speed data services, starting with high-speed downlink packet access (HSDPA) in 2002. An enhanced uplink followed and the combination of the two enhancements is now known as high-speed packet access (HSPA) – or mobile broadband.

HSPA offered peak theoretical downlink date rates of 14.4Mbit/s and peak uplink rates of 5.76Mbit/s. Although few users are likely to experience these rates in practice, it's easy to see that backhaul systems based on multiple 2Mbit/s circuits are soon going to be overwhelmed in the face of this level of traffic.

The growth of mobile data has driven standards further, so that faster variants of HSDPA have been defined and introduced. A new cellular technology has been standardised by 3GPP, and is now known as LTE (for long term evolution). LTE promises peak data rates in the downlink of more than 100Mbit/s, an enhanced uplink and better cell-edge performance than HSPA.

Another driver of increased traffic on backhaul connections is infrastructure sharing. Operators already share cell sites and towers, but increasingly they want to share the radio access network and its backhaul connections to cut costs. With such sharing, modern cell sites may support multiple cellular radio technologies (such as GSM and UMTS), and therefore multiple basestations, for each operator, as well as multiple operators, all trying to get their traffic back to their networks over a shared backhaul link.

So, what does all this mean for mobile backhaul?

Traffic density and distribution

It's worth pausing here to take a look at the UK cellular network, which covers most of the UK land mass, although GSM coverage currently exceeds that of 3G. Most of the >

> 'Moving to packet-based backhaul is a big step for the mobile industry'

< UK cell sites don't carry that much traffic, although many urban sites carry a much greater burden. This means that the next generation of mobile backhaul must work well and be cost effective for widely varying amounts of traffic.

Rising traffic, coupled with the proliferation of IP and packet- and frame-based technologies has led to an evolution in mobile backhaul.

The 2Mbit/s E1 links of old are being replaced with Ethernet connections, while the ATM transport layer from UMTS is being replaced with IP. In certain cases even 2G GSM networks are being upgraded to using an IP-based transport-network layer.

To understand this evolution we need to divide the backhaul network into several layers. Starting at the bottom, the physical interconnection may be done on copper wires, fibre-optic cable or even a microwave link. The optical fibre options range from point-to-point fibre to PON systems, and the microwave radio systems may be point-to-point or point-to-multipoint.

Next up the stack, the protocol used for the mobile backhaul transmission layer, which moves the data packets between network nodes, is evolving from the E1 frames discussed earlier to Ethernet. This was designed as a local area network (LAN) technology, so how can it be used across a wide-area cellular network? The answer is thanks to the work of the Metro Ethernet Forum (MEF), which has led the definition of Carrier Ethernet. This provides a framework for Ethernet to become the dominant transmission technology for both mobile backhaul and fixed networks.

To enable Carrier Ethernet to fulfil this role it needs to be able to carry each of the three transport-network layer protocols used in mobile networks – TDM, as still widely used in GSM networks, and ATM or IP for UMTS. There are various standard ways to do this, the most common being to tunnel the transport-network layer traffic over Carrier Ethernet in a 'pseudo-wire' (also known as PWE3 and defined by the IETF in RFC3985). These tunnelling techniques are used for TDM and ATM, and are also an option for carrying IP.

Ethernet interfaces run at either 10/100Mbit/s or 10/100/1000Mbit/s and automatically sense the line rate of connected interfaces. Although a physical link such as a microwave radio system might have multiple Gigabit Ethernet interfaces, the actual capacity of the link is likely to be much lower than the sum of the physical interfaces. The bandwidth of Ethernet backhaul services may also be limited because the physical interface may have one or more corresponding logical interfaces, known as virtual LANs, whose bandwidths are also less than that of the physical interface.

Mobile network traffic varies considerably, from voice and real-time data services to interactive gaming and mobile TV. The various traffic types place varying requirements on the backhaul network and so offer an opportunity for traffic engineering. This traffic engineering results in a high probability of a statistical multiplexing gain when several access circuits are connected through one point, since each link will carry different mixes of traffic.

This means the network is used more efficiently, so long as the design has correctly accounted for the type of traffic being carried and the total capacity requirement. This means that the sum of the backhaul from an aggregation node to the core site will be less than the sum of the individual access circuits.

This is one of the key advantages of using Carrier Ethernet. As a packet (strictly, a frame-based) technology, one can apply quality of service, differentiate and aggregate traffic from multiple links onto one connection and separate traffic logically within a single physical interface.

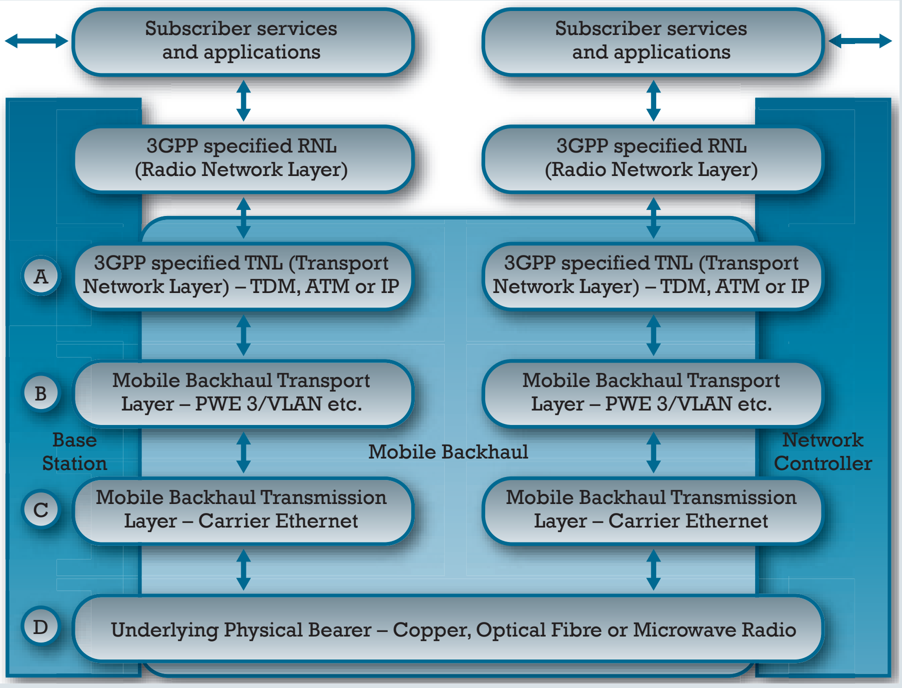
In sync

Radio networks need a stable RF transmission signal to function well. This is especially true for cellular networks, both for regulatory reasons, to ensure basestations only transmit within their authorised frequency bands, and for mobility reasons, to support seamless handover between cell sites. This is particularly important as the mobile device will have to lock on to a new cell prior to a handover, so the frequency at which the new cell is transmitting must be accurate.

For historical reasons, the 2Mbit/s E1 frame has an inherent frequency

NETWORK

A MATTER OF PROTOCOL



There are multiple protocol layers within a mobile backhaul network, which work together to guide a subscriber service, such as a phone-call, over the radio access network and backhaul connection. The diagram shows a subscriber service running between a basestation and a network controller, being carried over the radio network layer and then down into the transport network layer (TNL), marked as level A, of the backhaul connection.

A: The TNL resides within the basestation and network controller and is based on TDM, ATM or IP technology. The choice of technology is important because it directly affects what happens at the next level.

B: The mobile-backhaul transport layer provides logical encapsulation and/or framing of the TNL protocol. This ensures the traffic can be carried over the Carrier Ethernet technology used at level C. Certain Ethernet functions may exist at this layer; mechanisms such as pseudo-wire encapsulation are also options.

C: Carrier Ethernet is becoming the backhaul technology of choice, and has five key attributes: standardised services; scalability; reliability; quality of service; and service management.

Carrier Ethernet is a cost-effective and scalable way to meet future backhaul demand. Interface rates start at 100Mbit/s rather than at 2Mbit/s for TDM E1s, so it offers greater bandwidth, and Ethernet ports ship in high volume and so have cost benefits.

Carrier Ethernet equipment is widely available at 1Gbit/s and 10Gbit/s, with 40Gbit/s and 100Gbit/s options available for early adopters.

D: This physical layer - copper, optical fibre or microwave radio - provides the circuit connections and protects them using line coding and error detection and correction. The physical layer may have intermediate points of interconnect, but this does not affect the higher layers of the protocol stack.

synchronisation signal, traceable to a primary reference clock, which ensures that a highly accurate and stable clock signal is available to discipline the basestation oscillator and so ensure RF stability.

Replacing the E1 signal with Carrier Ethernet means finding an alternative synchronisation signal. Several approaches are available or in development, including using a local telecoms-grade GPS receiver; an evolution of Ethernet known as Synchronous Ethernet, which adds a physical-layer synchronous signal to achieve much the same as the E1 frame; a packet-layer solution known as IEEE 1588-2008; and a variant of the network timing protocol known as NTPv4.

The introduction of LTE and true fourth-generation mobile network services, known as LTE-Advanced, will mean ever higher peak data-rates, higher user data-rates and a significant improvement in overall cell capacity to support advanced data and multi-media applications. To ensure the industry moves smoothly towards using Carrier Ethernet for its backhaul, a number of industry initiatives are underway within organisations such as the Broadband Forum, the Metro Ethernet Forum and the Next Generation Mobile Networks Alliance.


Basestations are becoming more complex and costly as operators add support for new standards

Moving to packet-based backhaul is a big step for the mobile industry. The introduction of Carrier Ethernet for mobile backhaul will deliver greater capacity at lower cost, and so enable the continuing evolution of mobile broadband services accessible on laptops, tablets and smartphones. *

Andy Sutton CEng, FIET is Principal Network Architect at Everything Everywhere

Links

References and further information

DSL backhaul paper: http://bit.ly/DSL-backhaul
MEF Homepage: http://metroethernetforum.org
RFC3985: http://www.ietf.org/rfc/rfc3985.txt
IP/MPLS 20.0.0: http://bit.ly/ip-mpls
MEF22: http://bit.ly/ET-MEF22
NGMN Alliance Optimised backhaul requirements: http://bit.ly/NGMN-backhaul