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Working Together: the Synergies of Fibre and Wireless Networks

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Deployment & Operations Committee**

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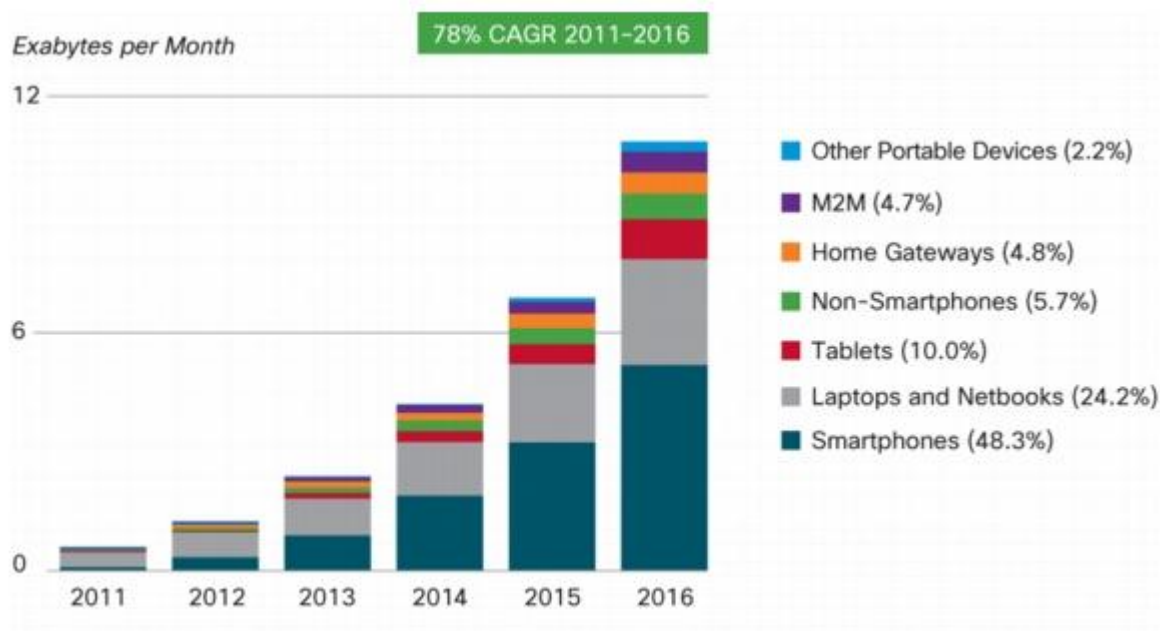
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Overview

This paper considers optical fibre as an enabler for wireless systems, ensuring they can deliver the necessary data rates to meet the anticipated growth in data consumption by mobile devices. The benefits of fibre for wireline access networks are well documented; fibre provides significantly better performance for broadband services than copper networks still used widely today. However, wireless technologies are improving in terms of performance; they also look to address a different challenge to wireline networks, that of delivering mobile data and voice requirements. As wireless and wireline technologies converge and the dividing lines become less clear, the common denominator will be optical fibre. Whether considering fibre-to-the-x (FTTx), WiMAX or LTE, future access networks will include fibre as an essential part of the network infrastructure.

Figure 1: Cisco's Visual Networking Index predicts that mobile data traffic will grow at a compound annual growth rate of 78% between 2011 and 2016.



Source: Cisco, Visual Networking Index (2012)

IP traffic growth puts pressure on mobile networks

Global Internet Protocol (IP) traffic is soaring as consumers and businesses embrace bandwidth-hungry services such as video streaming, gaming and cloud-based software. This increase in data traffic is enabled by the deployment of faster broadband networks, both fixed and mobile.

Mobile data usage is projected to grow three times faster than IP traffic from fixed lines. According to Cisco's Visual Networking Index, mobile data traffic worldwide will increase 18-fold in the period 2011—2016. The demand for video content is expected to be a significant driver for this growth. The increase in the number and sophistication of mobile devices, such as smartphones, tablets and dongles, is also driving mobile data growth. Indeed, laptops with dongles generate 450 times more data traffic than handsets.

Operators' networks are already being pushed to the limits by mobile data usage. One way that operators can reduce the pressure on network capacity is to encourage their customers to offload mobile data traffic onto existing wireline access networks using Wi-Fi or femtocells. As a large proportion of mobile data traffic is being consumed in the subscriber's home or workplace, this approach is compelling for operators. The use of complementary network technologies for delivering mobile network data has created a new market sector. Roughly one third of mobile data traffic was offloaded in 2011, according to Cisco.

The increasing demand for data capacity in mobile networks raises interesting questions: can or should fibre and wireless coexist, or are they ultimately competing technologies?

Wireless technologies explained

Communication through the air essentially fulfils one of two functions. Fixed wireless access provides an extension or replacement for wireline access networks; while mobile networks are designed to meet the communications needs of people on the move. Different technologies have been developed around these different user scenarios.

Local area networks (LANs) provide connectivity to a local group of computers and other electronic devices. Wireless LANs were developed to serve places where it was difficult or expensive to install LAN cabling. The technology has been standardised by the IEEE Standards Association under IEEE 802.11, but is better known by its brand name Wi-Fi.

In order to offer a "Wi-Fi like" user experience on a larger geographical scale such as a city or campus, new wireless standards were needed. Described by the IEEE 802.16 standards, wireless metropolitan area networks (MANs) have been commercialised under the name WiMAX.

Mobile or cellular networks provide connectivity over a wide area and allow users to move seamlessly between different locations on the same network or even between different networks (roaming). Originally designed to carry voice services, mobile technology was later adapted to support data transfer, and the latest generation of mobile network standards, known as Long Term Evolution (LTE), have been designed from the ground up to support data transmission.

Mobile network technology can also be configured to provide fixed wireless access. Operating from a fixed location results in a clearer signal and eases constraints on battery life and form factor, which improves overall network performance.

Let's look at the technologies in a little more detail.

Wi-Fi

Wi-Fi is one of the most popular wireless communications technologies in use today, primarily because it is easy to install, easy to use and inexpensive.

The technology enables electronic devices, such as computers and printers, to exchange data over a LAN using radio waves instead of wires. The wireless connection does the same job as an Ethernet cable running from a computer to a router or switch. The router allows the computers connected to the LAN to communicate with the wide area network (WAN).

Many devices now come with built-in Wi-Fi connectivity, e.g. personal computers, smartphones, tablets, games consoles or connected TVs, which enables them to connect to a network resource such as the internet via a wireless access point or "hotspot".

Wi-Fi has become extremely popular in the home environment, enabling connectivity in any room without installing cables. Nomadic use of Wi-Fi, in coffee houses and other high street locations, is also expanding rapidly. Some towns and city centres provide blanket Wi-Fi coverage.

A wireless access point can transmit or receive data over a distance ranging from several metres (if, for instance, there are thick walls in the way) to many kilometres, given no obstacles and a powerful enough signal. In practice, since Wi-Fi uses mainly unlicensed spectrum, signal power is usually limited to prevent interference between different users. However, special point-to-point configurations can reach many kilometres.

The maximum reach and capacity of the Wi-Fi system are determined by the version of the IEEE 802.11 standard being used, as well as any specific options implemented by the hardware manufacturer. IEEE 802.11-1997 was the original wireless networking standard, but 802.11b was the first to be widely accepted, followed by 802.11g, and 802.11n.

Released in 1999, 802.11b used the original 2.4GHz frequency band with a reach of 30 metres and maximum speeds of 11 Mbps, which was comparable to broadband speeds at the time.

To keep up with the increases in broadband speeds, a new version, 802.11g, was released in 2003. This increased the data rate to 54 Mbps using a more efficient coding scheme, while staying on the 2.4 GHz frequency.

With the 802.11n amendment in 2009, things got more complex. This added the ability to operate with wider frequency channels in both the 2.4 and 5 GHz frequency bands, and the use of multiple antennae. Multiple input, multiple output (MIMO) techniques enable multiple users to connect to a single Wi-Fi access point by assigning each user to a single antenna. 802.11n has a maximum data rate of 150 Mbps per antenna (using a 40 MHz channel), with up to four antennae supported.

At present, the IEEE is finishing up work on 802.11ac, which promises speeds of up to 867 Mbps per antenna (using a 160 MHz channel), and increases the number of antenna supported up to eight, for a theoretical maximum total capacity of 6.93 Gbps. Early products appearing on the market ahead of the standard's completion offer a configuration that supports up to 1.3 Gbps.

WiMAX

WiMAX (an acronym for Worldwide Interoperability for Microwave Access) is an IP-based wireless technology that provides wireless MANs as an alternative to DSL and cable networks. It is based on the IEEE 802.16 family of standards, also called WirelessMAN.

In parallel with IEEE standardization efforts, the WiMAX Forum promotes adoption by establishing a brand for the technology and encouraging interoperability through a certification programme.

WiMAX provides similar performance to 802.11/Wi-Fi networks, but with the coverage and quality of service of cellular networks. It can provide broadband wireless access up to 50 km for fixed connections and about one third of that distance for mobile users.

The issue of interference with other networks is lessened through the technical approach. WiMAX operates on both licensed and unlicensed frequencies, with licensed frequencies providing a regulated environment that is suitable for wireless carriers.

Like Wi-Fi, WiMAX standards have evolved through several technology generations. While the early focus of WiMAX was on providing wireless access to a fixed location, there was a later push from the industry to provide mobile WiMAX services as well. Hence the resulting standard, approved in 2005 and described in 802.16e, is known as Release 1.

Mobile WiMAX Release 2.0, approved in 2011 and described in 802.16m, is also known as WirelessMAN-Advanced. It offers significantly faster download and upload speeds than the previous technology generation with peak download rates of up to 365 Mbps for mobile users and in excess of 1 Gbps for fixed connections (achieved by bonding more spectrum bands).

Like Wi-Fi, the actual speed supported by WiMAX equipment will depend on various technical choices, such as the number of antenna and the amount of spectrum available.

WiMAX 2 has also been officially approved as a "True 4G" mobile technology by the International Telecommunications Union (ITU). The ITU has described – in the International Mobile Telecommunications Advanced (IMT-Advanced) set of specifications – what it believes represents a true generational shift in mobile technology compared to previous third-generation (3G) systems. The requirements include the ability to provide sustained data rates of 100 Mbps for mobile connections and 1 Gbps for fixed connections.

Thus while it originated from the same stable as Wi-Fi, WiMAX currently bears more resemblance to LTE in terms of its capabilities. WiMAX and LTE are often said to be competitive, but they also appear to be converging. In future versions, the WiMAX standard is expected to provide a framework that can support multiple air interfaces including both 802.16 and the time-division duplex (TDD) flavour of the LTE standard.

Mobile Communication

A mobile or cellular network, as the name suggests, is a radio network made up of a number of radio cells each served by at least one fixed-location transceiver known as a base station. These cells cover different geographic areas to provide radio coverage over a much wider area than the area of any single cell. Portable transceivers (mobile phones or other devices) can be used in any one cell and moved through more than one cell during transmission.

Mobile networks use licensed spectrum. Mobile network operators must purchase spectrum “property” giving them the exclusive rights to transmit in a particular spectrum band, typically at auction, and often at considerable cost.

When a mobile device is turned on, it registers with the mobile network, using unique identifiers; it can then be alerted when there is an incoming call. The device constantly “listens” for the strongest signal being received from the surrounding base stations and switches between sites to maintain the signal as the user moves around the network, hence maintaining the call.

Table 2: Four generations of mobile network technology

| Generation | Requirements | Comments |
|------------|---|---|
| 1G | Analogue technology | Deployment started in 1979 |
| 2G | Digital technology No official requirements | First digital systems, deployed from the 1990s onwards. SMS and low-rate data introduced. Primary technologies include GSM in most countries and IS-95 (cdmaOne) in the US and South Korea. |
| 3G | Defined by IMT-2000 , 3G services must deliver 144 kbps in a moving vehicle, 384 kbps at walking speeds and 2 Mbps indoors. | Primary technologies include UMTS/HSPA (the evolutionary path from GSM) and CMDA-2000 EV-DO (the upgrade from cdmaOne). |
| 4G | Defined by IMT-Advanced , 4G services should provide sustained data rates of 100 Mbps for mobile connections and 1 Gbps for fixed connections. | LTE is usually marketed as 4G. “True 4G” technologies that are officially recognised by the ITU include LTE-Advanced (Rel. 10 onwards) and WiMAX 2. |

Source, Rysavy Research and FTTH Council Europe.

The technology used in the radio interface has changed considerably over the years. The first generation (1G) of mobile systems, based on analogue technology, only carried voice calls.

When second generation (2G) systems arrived, they replaced analogue networks with digital. The most widely deployed 2G technology is Global System for Mobile Communications (GSM). It is a circuit-switched technology; ideal for the delivery of voice but with limitations for carrying data.

In 2000 the introduction of General Packet Radio Service (GPRS) added packet functionality, and kick started the delivery of the Internet on mobile handsets with speeds up to 56 kbps. Further improvements to GSM were made with the introduction of Enhanced Data rates for GSM Evolution (EDGE), which increased peak data speeds to a maximum of 236.8 kbps.

In 1998 the 3rd Generation Partnership Project (3GPP), a collaborative effort between standards development organizations and industry, was formed to drive future development of mobile technologies based on GSM. The result was the Universal Mobile Telecommunications Systems (UMTS) family of third generation (3G) standards, which uses the GSM core network, but has a new air interface standard based on Wideband Code Division Multiple Access (W-CDMA).

When UMTS was released, it not only provided more reliable and faster data rates of up to 384 kbps, but was based upon an improved platform that allowed concurrent use of voice and data. Evolutionary upgrades to UMTS have resulted in higher data rates, with speeds of up to 14.4 Mbps initially supported by High Speed Packet Access (HSPA). Maximum theoretical data rates increase to 42 Mbps when Evolved HSPA (HSPA+) is implemented in the network.

In parallel to the development of GSM technologies, mobile operators in other parts of the world have pursued different approaches. In North America and South Korea some carriers chose IS-95 or cdmaOne, which evolved into CDMA-2000 and then CMDA Evolution-Data Optimized (EV-DO). Time Division Synchronous Code Division Multiple Access (TD-SCDMA) is a radio interface developed for UMTS mobile telecommunications networks in China.

The Long Term Evolution (LTE) family of standards created by 3GPP is intended to provide a common upgrade path for the various standards around the world, and it is said that this convergence of technologies inspired the name. LTE is a revolutionary upgrade requiring a new radio interface together with core network improvements.

LTE (Release 8 and 9) has a theoretical bit rate capacity of up to 300 Mbps in the downlink and 75 Mbps in the uplink in a 20 MHz channel when the highest class of equipment is used (4x4 MIMO antennae). However, LTE handsets on the market today generally support a maximum data rate of 100 Mbps in the downlink and 50 Mbps in the uplink.

LTE Advanced (Release 10 and 11) brings the mobile network standards development process up to the present day. LTE Advanced meets the ITU's highly demanding requirements for "True 4G" as defined by IMT-Advanced – providing sustained data rates of 100 Mbps for mobile connections and 1 Gbps for fixed connections. It's worth noting, however, this would require up to five 20 MHz carriers, which is impractical for most operators as they don't hold enough spectrum.

Wireless speeds in the real world

As we saw in the previous section, wireless technologies are continually improving and today they are theoretically capable of speeds that rival and sometimes even exceed those achievable in fixed access networks, even fibre to the home (FTTH).

Figure 3: Theoretical maximum speeds for various wireless technologies *

| Standard | Peak downlink rate (Mbps) | Peak uplink bit rate (Mbps) |
|-------------------------------|---------------------------|-----------------------------|
| GSM EDGE Evolution | 1.89 * | 0.947 * |
| CDMA Ev-DO Rev B. | 4.9 | 1.8 |
| Wi-Fi 802.11b | 11 | 11 |
| UMTS/W-CDMA (3G) HSPA | 7.2, 14.4 * | 5.7 |
| UMTS/W-CDMA (3G) HSPA+ | 21.6, 28, 42 * | 11.5, 11.5, 22 * |
| Wi-Fi 802.11g | 54 | 54 |
| WiMAX 802.16e | 46 * | 4 * |
| Wi-Fi 802.11n | 288, 600 * | 288, 600 * |
| LTE (3GPP Rel 8.) | 300 * | 75 * |
| WiMAX 2 | 365 * | 376 * |
| LTE-Advanced (3GPP Rel. 10) | 1200 * | 568 * |
| Wi-Fi: 802.11ac | 1730 * | 1730 * |

*Depending on standards version and/or equipment configuration

Source: Wireless Gigabit Alliance and FTTH Council Europe

However, the theoretical speeds of wireless networks are never achieved in practice. There are a number of reasons for this:

Technical design: The highest data rates can only be achieved when the highest specification equipment is used, both on the user's equipment and at the access point or base station connected to the network. Wireless is equipment will always fall back to the lowest common denominator; both the network and the user's equipment must be capable of supporting the speed. Furthermore, for MIMO approaches to be viable the antennae have to be positioned at least half a

wavelength ($\lambda/2$) apart. At 2 GHz half a wavelength corresponds to 7.5 cm. At least in small handsets such an antenna distance is hard to achieve.

Protocol overhead: The theoretical maximum speed includes a significant overhead from network protocol data that wireless connections must exchange for security and reliability purposes. The useful data exchanged will always occur at lower data rates. Wi-Fi overheads in particular can occupy a significant portion of transmissions, especially in situations where there are multiple overlapping networks, such as an apartment block.

Range adjustment: Wireless networks can support their maximum speed or their maximum range but not both at the same time. The wireless signal becomes weaker as it gets further away from the transmitter. If the wireless signal between two connected wireless devices is not strong enough, the wireless protocol reduces its transmission speed, using a more robust but slower protocol in order to maintain the connection. Once set, the new lower value becomes the new maximum speed for that connection.

Interference: Fast moving vehicles, solid walls and buildings, and bad weather can hinder the transmission of wireless signals in the outdoor environment. The reduced signal strength will reduce system performance, as the wireless system lowers the transmission speed in order to maintain the connection.

Multiple users: Wireless is fundamentally a shared medium (through the air). The total bandwidth available from a single access point or base station must be shared among multiple users and as a consequence yields lower speeds in practice. In busy areas such as a city centre or football stadium, network capacity can easily be swamped by the sheer number of users unless the operator installs more mobile transmitters to cope with the exceptional demand.

In spite of their limitations, wireless networks have become an essential part of modern communications. They have revolutionised the way we can use computers and mobile devices, both in the home and office, and when we are out and about.

However, we believe that wireless networks should be promoted mainly for their strengths – the ability to provide Internet connectivity on the move – rather than as a direct substitute for fixed access networks.

These comments also assume that fast networks are available, which may not always be the case. The fastest mobile networks have limited geographic coverage. LTE networks have mainly been deployed in selected major cities; even though deployment started 10 years ago, the roll out of 3G networks has yet to reach many rural areas.

In some countries LTE deployment has been slow to get underway because suitable spectrum has to be allocated first. Spectrum is a scarce resource (a single optical fibre has more capacity than the entire radio spectrum), and national regulators often have to clear regions of the spectrum in order to make way for new technologies and services.

The challenge of mobile backhaul

A wireless network is only wireless at its edges.

Backhaul refers to the action of transporting communications traffic from a distributed node, such as a Wi-Fi access point or mobile base station, to a more centralized node. In the mobile space, backhaul corresponds to the portion of the network between base stations and the nearest point of aggregation, typically a radio network controller.

As mobile data rates increase, it requires a corresponding increase in mobile backhaul capacity. As seen in the table below, a cell site carrying only GSM voice would require a typical bandwidth of about 1.3 Mbps. Bandwidth requirements for a cell site based on the 2.75G EDGE architecture would increase to about 6 Mbps, 3G requires about 21 Mbps, and LTE would necessitate as much as 80 Mbps. If a mobile operator has more spectrum at its disposal, or makes use of MIMO antennae to increase capacity, then backhaul requirements would increase further.

Traditionally, base stations were linked to their core networks with T1/E1 leased lines (the North American T1 rate is equivalent to 1.544 Mbps and the European E1 rate to 2.048 Mbps). For many years, when an operator needed more capacity it simply provisioned more leased lines. With LTE this approach will no longer be sufficient.

Table 4: Mobile backhaul capacity requirements

| | Voice spectrum (MHz) | Data spectrum (MHz) | Voice spectral efficiency (bit/s/Hz) | Data spectral efficiency (bit/s/Hz) | # sectors | Traffic eng % peak | Total bandwidth (Mbps) | # T1s |
|-----------|----------------------|---------------------|--------------------------------------|-------------------------------------|-----------|--------------------|------------------------|-------|
| GSM 2G | 1.2 | - | 0.52 | - | 3 | 70 % | 1.3 | 1 |
| GSM /EDGE | 1.2 | 2.3 | 0.52 | 1 | 3 | 70 % | 6.1 | 4 |
| HDSPA 3G | - | 5 | - | 2 | 3 | 70 % | 21 | 14 |
| LTE 4G | - | 5 | - | 3.8 | 3 | 70 % | 39.9 | n/a |
| LTE 4G | - | 10 | - | 3.8 | 3 | 70 % | 79.8 | n/a |

Source: Fujitsu, 4G Impacts of Mobile Backhaul

Mobile network operators are already under financial pressure. Over the last 10 years, they have invested heavily in 3G network deployment. It is natural that they will be looking to minimize any additional investments as they deploy LTE networks to meet the escalating demand for mobile bandwidth. Therefore mobile operators will look to exploit existing infrastructure where possible.

The lowest cost option would be to use their own installed connections but, as we have seen, the dramatic increase in backhaul requirements generated by LTE makes such a policy unviable.

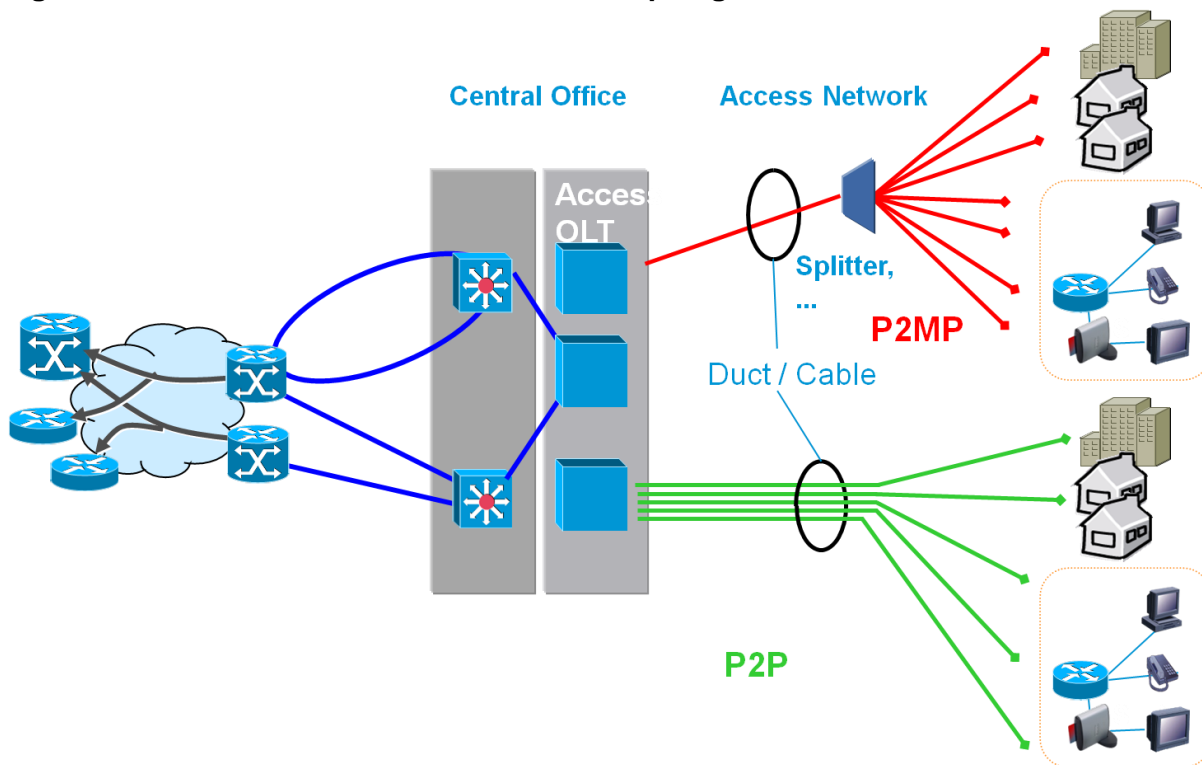
Some operators are already using optical fibre to connect mobile base stations. Where a new connection is required, it makes sense to install optical fibre. Optical fibre has virtually unlimited capacity, and can support future upgrades without requiring new cables.

Optical fibre networks employ one of two basic architectures: point-to-point (P2P) systems or point-to-multi-point (P2MP) systems usually referred to as passive optical networks (PONs).

P2P networks are usually Ethernet-based networks with 100 Mbps or 1 Gbps of bi-directional capacity.

There are a number of different PON standards. The primary choice around the world is Gigabit Passive Optical Network (GPON) offering 2.488 Gbps of downstream bandwidth, and 1.244 Gbps of upstream bandwidth. A 10-Gbps upgrade to GPON, called XG-PON1 is also available, delivering 10 Gbps of downstream bandwidth and 2.488 Gbps of upstream bandwidth over the same configuration. Future standards will take the capacity of these systems to 40 Gbps.

Figure 5: Access network architectures and topologies.



Source: FTTH Council Europe.

Optical fibre also supports Radio over Fiber (RoF) technology, which enables the use of small, low-cost base stations in cellular systems. RoF systems are now being used extensively for enhanced cellular coverage inside buildings such as office blocks, shopping malls and airport terminals.

In RoF systems, wireless signals are transported in optical form between the central station and the base station before being radiated through the air. Light is directly modulated by a radio signal and then transmitted over the optical fibre. (Although radio transmission over fibre can be used for other purposes, such as in cable television networks, the term RoF is usually applied when this technique is applied to wireless access.)

The RoF architecture uses a radio frequency (RF) signal with a high frequency (usually greater than 10 GHz), which is imposed on a light wave. In this way, wireless signals can be optically distributed to base stations directly at high frequencies and converted from the optical to electrical domain at the base stations before being amplified and radiated by an antenna. No frequency up/down conversion is required at the various base stations, resulting in simple and cost-effective implementation at the base stations.

RoF is fundamentally an analogue transmission system because it distributes the radio waveform, directly at the radio carrier frequency, from a central unit to a radio access point. RoF supports wideband signals like UMTS and WiMAX. (Note that although this transmission system is analogue, the radio signals are still digital.)

The role of Wi-Fi in this new world

Up to now, we have been discussing mobile communications and in particular the growth of the mobile network; so what is the role of Wi-Fi in this new world?

It is clear that Wi-Fi has a significant role to play, especially in buildings where it is used to distribute residential and business broadband signals around the home or office.

Studies on mobile data usage show that a large number of people use their phones at home. Therefore, the industry has been developing software that allows the user to swap from mobile networks to Wi-Fi in a seamless manner, allowing the consumer to benefit from the low cost data usage, whilst also reducing the load on the mobile network.

The other in-building benefit is to the user, who effectively has mobile access within the range of the building, rather than being restricted by fixed cabling systems. As more and more devices, such as smartphones and tablets, only have wireless interfaces, the option to connect directly to a wireline network isn't available and hence wireless becomes the only choice.

Mobile operators can also extend in-building coverage with femtocells – tiny base stations that can communicate with a mobile device over a range of up to 10 metres, with the home broadband network providing backhaul. A hybrid device combining both Wi-Fi and femtocell technologies gives the best of both worlds.

Wi-Fi is also becoming more popular outside of the building, in particular in areas where there is high demand for mobile services. Wireless networks are appearing in many of the major cities, offering users the opportunity to drop from their mobile networks for cheaper and faster download capability.

Other areas that are seeing the benefits of Wi-Fi are rural locations where the cost of building a FTTH/FTTB network can be prohibitive; whereas Wi-Fi equipment is cheap and relatively easy to install.

However, as with any mobile communications network, Wi-Fi networks still need to backhaul the data to the primary or core network, and therefore the problem of providing adequate backhaul capacity still applies.

The capacity of Wi-Fi networks will soon be diluted if copper-based telephone networks are used to deliver the backhaul. A typical example of this would be a city-based coffee house offering free internet service, where the Wi-Fi network provides 54 Mbps, but the broadband connection in the building only connects at 24 Mbps (downstream).

Wi-Fi networks will also require optical fibre-based backhaul to keep up with the growth in consumer demand for data.

Conclusions

Mobile service providers are seeing an upsurge of data traffic across their networks by users who increasingly expect ready access to online services that consume large amounts of data without being limited to a fixed location. Improved availability of mobile broadband services, combined with the proliferation of dual-mode 3G and Wi-Fi smartphones, affordably priced data plans, and new online services, has stimulated the growth in data traffic from wireless users.

Mobile broadband networks have evolved over time but they have now reached saturation point, requiring a major overhaul to make them robust enough to withstand future demand. It is a dilemma; having invested so heavily in the past, mobile network operators have little impetus to go through another round of heavy capital investment and yet, the existing infrastructure will struggle to meet demand.

The answer lies in network upgrades and exploiting fibre infrastructure for wireless backhaul, which can provide the very high bandwidth capacity necessary to meet ongoing growth, making it an ideal medium for a robust and future proof network.

Obvious synergies exist in the build-out of fibre-based access networks for wireline access and wireless backhaul. A case in point is the Swedish city of Stockholm, which already supports two LTE mobile operators and has a third on the way, believed to be a direct result of the citywide availability of optical fibre.

In our view, wireless should be considered as a complementary technology to fibre, rather than a competing technology; with the following considerations:

- Wireless networks in all their forms should be promoted for their strengths – nomadic computing and networking with limited requirements for services and bit rates – rather than as direct substitutes for highly demanding residential and business connections. Legacy wireless networks will struggle to cope with the demands of large data transmission, especially when there are multiple users sharing the network.
- An exception to this general rule is services in very sparsely populated areas, where the deployment of new wireline networks may not be commercially viable. In these areas, coverage with wireless access networks can be provided comparatively quickly and at relatively low cost, at least for a transient period.
- When combined with wireless networks, wired services can provide alternative backhaul capabilities to meet the increase in mobile data demand.

The question for mobile network operators is how can they provide a service that satisfies the market demand for bandwidth, whilst maximising the return on investment? In answering this question, we have in fact come full circle; to provide a mobile service that offers the highest bandwidth for backhaul, a fibre infrastructure is required.

If the fibre infrastructure already exists, then it makes sense to utilise it to minimise capital expenditure. If it is a new build, then deploying a fibre infrastructure will be capital intensive, so it needs to be done in a way that minimises costs. There is a persuasive argument for sharing capital spending by deploying FTTH for fixed broadband access and mobile backhaul at the same time.

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