Future Networks

Mobile Backhaul: An Overview

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1. Introduction

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Mobile backhaul refers to the transport network that connects the core network and the RAN (Radio Access Network) of the mobile network. Recently, the introduction of small cells has given rise to the concept of fronthaul, which is a transport network that connects the macrocell to the small cells. Whilst mobile backhaul and fronthaul are different concept, the term mobile backhaul is generally used to encompass both concepts. Furthermore, innovations to reduce demand on mobile backhaul sometimes involve architectural changes in the antenna (also referred to as radio unit in 4G) and the controller (also referred to as digital unit in 4G). Therefore, the components labelled in red in the figure below will be covered for backhaul demand case studies within the GSMA Future Networks Network Economics.

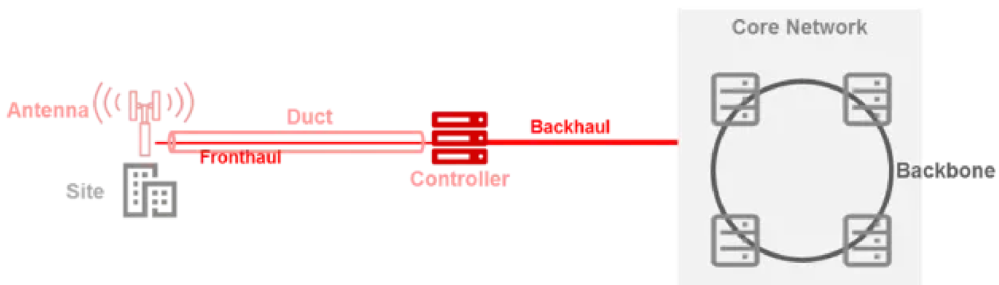

Figure 1. Mobile network and the scope of mobile backhaul

Success of LTE and Growing Importance of Mobile Backhaul

Wireless and fixed-line backhaul infrastructure is an essential component of the mobile telecommunications network. Mobile networks are ubiquitous and support a mix of voice, video, text and data traffic originating from and terminating to mobile devices. All of this traffic must be conveyed between the mobile cellular base stations and the core network. The success of 4G Long-Term Evolution (LTE) has placed even greater challenges on mobile operators as they strive for more network capacity, latency reduction, and the need to deliver an enhanced user experience. Notwithstanding the success of LTE (as of May 2019, there were 729 LTE operators in more than 221 countries), there are also a number of new challenges on the horizon that will impact on the MNO's backhaul network infrastructure.

In the era of 5G, where a network will be densified and more stringent requirement will be imposed, mobile backhaul will become even more important. Given the limitations governed by laws of physics, the mobile backhaul will add much more pressure on mobile operators' cost. Whilst mobile operators will be able to unlock new business opportunities with 5G, the costs need to be optimised for the operators to sustainably reap the benefits of 5G. These are described in more detail in the next section.

2. Challenges in Mobile Backhaul

There are a number of market trends that result in new challenges and requirements that must be met by the backhaul infrastructure of MNO networks.

Evolution of LTE

There are a number of technical innovations occurring on LTE, which is known as LTE-Advanced Pro or 4.5G which enable enhancements such as improved peak bandwidth and greater energy efficiency for IoT connections. The peak bandwidth of 4.5G is around 1Gbps which is 8-10x higher than standard LTE, and will enable (inter alia) support of video traffic at 4K resolution to mobile devices.

Emergence of 5G

By the end of 2018, there have already been some 5G deployments for FWA (Fixed Wireless Access) but the first mainstream 5G mobile services are expected to commence in 2020. In early 2018, there were 113 operators in 56 countries doing 5G trials and it is anticipated that by 2024, 50 countries will have in-service 5G networks. The 5G network will comprise both NR (New Radio) as well as a new 5G Core Network (5GC). The advent of NR offers a leap in bandwidth speeds in comparison to 4G via the utilisation of higher frequency spectrum. There will be 3 separate 5G bands initially, namely Sub-1 GHz, 1-6 GHz and above 6GHz. It is expected spectrum bands above 24GHz will be agreed upon at the WRC in 2019, which includes 26GHz and 40GHz bands. The higher frequencies enable wider channel bandwidths at the access but also result in smaller cell sizes. Both have implications for backhaul.

5G Network Slicing

5G Network Slicing. One of the key features of the 5G Network is the concept of "network slicing" whereby the physical network infrastructure can be partitioned into bespoke logical networks ("slices") in the RAN and 5G core which are targeted to the needs of a specific application or use case. Slicing will also impact on the backhaul network and will also facilitate sharing of infrastructure to optimise cost (for more information on infrastructure sharing, see

here

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Subscriber Growth

At the end of 2017, subscriber numbers stood at over 8.1 billion with an annual growth rate of 5.4% year on year. It is estimated that by 2025, the number of subscriptions will be 9.8 billion. In terms of different RAN technologies, LTE subscriptions were at 2.86 billion in 2017 (35.2% of the overall total) and will be at 4.24 billion (43.3% of the overall total) by 2025 whilst 5G subscriptions will be around 850 million by 2025. Furthermore, IoT devices (LTE-M and NB-IOT) will grow from 376 million to 4.2 billion in the 2017-25 timeframe. Therefore, backhaul strategy/evolution must cope with both an increase in subscriptions as well as a large number of those subscriptions being “high bandwidth” users.

Mobile data traffic growth

The increasing subscriber total plus increased access bandwidth usage of those subscribers results in mobile data traffic increasing at a rate of 28.9% CAGR to reach over 1300 Exabytes [1300 x 10^{18} bytes] by 2025. By 2025, 4G and 5G subscribers will represent 55% of subscriptions but will generate 91% of the traffic. There will also be a marked shift in the type of traffic being carried with video streaming increasing from 81 Exabytes (which is just under 50% of total traffic) to 910 Exabytes (which is 70% of total mobile traffic). Per-user traffic per month is expected to grow from 1.7 GBytes to 11.3 GBytes between 2017 and 2025. In some markets (e.g. Korea and Japan), it is noted that some smartphone users were already generating 12GBytes per month in 2017.

Stringent latency requirements

Both 5G mission-critical applications and increased video streaming will result in more stringent end-end latency requirements and impact on the backhaul latency budget. For example, an end-end latency cap of 10ms implies a latency across the backhaul that is <1ms – which means that only fibre optic and microwave links will be able to support such low latency requirements. If higher latency backhaul links are deployed (e.g. satellite links), then such backhaul would only carry 2G/3G and non-latency sensitive LTE services.

Network densification

The increased demand for mobile broadband results in the number of macrocell sites being estimated to grow globally from 11.1 million to 14.1 million. The new macrocells include both 4G and 5G technologies. This results in extra traffic to backhaul as well as additional challenges due to the smaller cell size for 5G NR.

Furthermore, the growth of LTE traffic resulted in MNOs being increasingly reliant on small cell site deployments. Small cells will be even more essential for 5G. Small cells can be deployed outdoors or indoors and include low power microcells, femtocells and picocells. They can be deployed on private or public infrastructure in the urban environment (e.g. rooftops, street poles etc.). In the period 2017-25, the number of small cells is expected to increase globally from 0.71 million to 4.3 million. From a backhaul point of view, there is a need to be able to carry traffic from many more cell sites in a scalable, efficient and economic manner.

3. Technology Choices for Mobile Backhaul

There are a number of technical solutions used by Mobile operators for backhaul, including both wireline and wireless solutions.

Copper-line

Copper-based backhaul was the primary backhaul technology for 2G/3G. At the heart of copper-based backhaul is the T1/E1 protocol, which supported 1.5 Mbps to 2 Mbps. This bandwidth can be boosted by using DSL over the copper pair as well as so-called copper-bonding (i.e. multiple copper pairs are bonded together). For example, having up to 12 bonded pairs can provide over 150 Mbps downlink capacity over 1.5 km. Nevertheless, copper lines do not scale easily to provide adequate bandwidth at a distance above a few hundred meters to support LTE broadband usage and 5G traffic scenarios will prove particularly challenging for mobile service providers. In bonded configurations, as monthly costs increase linearly with bandwidth requirements. Therefore, as bandwidth requirements become more onerous, copper-based backhaul has become an infrequently used solution and operators are increasingly preferring fibre-optic where available (e.g.. in city centres). For all that, DSL is still an option for mobile backhaul for indoor small cells, in-building HetNets, and public venue small cell networks.

Fibre-Optic

This technology is the mainstay wired backhaul in MNO networks and second overall only to microwave backhaul. Even though fibre has significant inherent bandwidth carrying capability, several additional techniques can be used to offset any bandwidth constraints and essentially rendering the fibre assets future-proof. These techniques include Wavelength Division Multiplexing (WDM) technology which enables multiple optical signals to be conveyed in parallel by carrying each signal on a different wavelength or colour of light. WDM can be divided into Coarse WDM (CDWM) or Dense WDM (DWDM). CWDM provides 8 channels using 8 wavelengths, while DWDM uses close channel spacing to deliver even more throughput per fibre. Modern systems can handle up to 160 signals, each with a bandwidth of 10 Gbps for a total theoretical capacity of 1.6 Tbps per fibre. The traffic generated by LTE has accelerated the demand for Fiber to the Tower (FTTT) and has required Mobile Network Operators (MNOs) to upgrade many aspects of their backhaul networks to fibre-based Carrier Ethernet. The main limitations of fibre are the cost and logistics of deploying fibre (ducts etc.), although the cost of fibre has been decreasing over the last few years (e.g. it now costs circa $70K/km whereas 5 years ago it cost circa $100K/km). Nonetheless, it can still take several months to provision a cell site with fibre optic backhaul. Fibre backhaul was used for 26% of global macrocell backhaul links in 2017, growing to just under 40% by 2025. Fibre will also be the main choice

Wireless backhaul (microwave)

Despite fibre being the preferred choice for MNOs for 4G/5G backhaul, microwave backhaul is the most used technology due to a combination of its capability and relative ease of deployment (i.e. no need for trenches/ducting) making it a low-cost option that can be deployed in a matter of days. Most MNOs rely heavily rely on microwave backhaul solutions in the 7 GHz to 40 GHz bands, in addition to higher microwave bands such as V-band (60 GHz) and the E-band (70/80 GHz). Backhaul links using the V-band or the E-band are well suited to supporting 5G due to their 10 Gbps to 25 Gbps data throughput capabilities. Microwave can be used in LOS or NLOS mode which makes it ideal to be used in a chain, mesh or ring topologies to enable resilience and/or reach. The main drawback is that microwave backhaul requires a licence, apart from the V-band that is unlicensed and to a lesser extent the E-band which is lightly licenced. It is also possible to combine a low-frequency microwave band with a high-frequency microwave band to achieve high capacity over long distances with enhanced availability.

LOS vs. NLOS

Historically, most wireless backhaul links have been LOS (Line of Sight) due to the high frequencies being used, as well as the narrow beam widths used. However, over the past 10 years, NLOS (Non-Line of Sight) has become a viable solution that should prove particularly advantageous with a large number of clusters of small cells that MNOs are expected to deploy over the next few years.

LOS backhaul has the advantage of using a highly directed beam with little fading or multi-path dispersion and enables efficient use of spectrum as multiple transceivers can be located within a few feet of each other and use the same frequency to transmit different data streams. On the other hand, it may be difficult to always have an unobstructed path in certain scenarios (e.g. trees, buildings in the way) and the transceiver pair need precise alignment. In the latter case, this can be impacted by "pole tilt" where the alignment is spoiled by movement caused by the wind and a particular concern for small cells. The pole tilt issue gets worse as frequencies increase due to the beam narrowing. For large numbers of small cells (e.g. in a metropolitan hot spot), the cost of backhaul can increase quickly if a number of links are daisy chained together.

NLOS backhaul is much more "plug and play" and so take less time with less skilled labour to set up. NLOS backhaul OFDM technology (Orthogonal Frequency Division Multiplexing) to relay information back to a central base station. NLOS backhaul needs only to be within a range of the receiver unit with OFDM providing a level of tolerance to multi-path fading not possible with LOS. There is a limit to how many small cells can be blanketed by a single NLOS backhaul to ensure each cell has a given QoS as all of the bandwidth is shared between the multiple base stations covered by the central unit. This bandwidth sharing is a disadvantage in that there is an upper limit on the bandwidth available to each base station and calculations need to be re-done if further base stations are added. Frequency planning also needed to avoid interference as the NLOS frequency ranges can also be used for access.

Satellite backhaul

Satellite Backhaul is a niche solution for MNOs and used in fringe areas (e.g. remote rural areas) and sometimes as an emergency/temporary measure (e.g. a disaster area or in place of a microwave link whilst waiting for licence approval). This backhaul is used in developing markets and as a complementary role in developed markets. The technology can deliver 150Mbps/10Mbps (downlink/.uplink). However, latency is a challenge as there a round trip delay of circa 500-600ms for a geostationary satellite. LEO (Low Earth Orbit) satellites have tried to address the latency issue (i.e. using a much lower orbit of 1500km versus 36000km and resulting in a one way trip of circa 50ms). However, LEO satellites are not geostationary and thus there is sometimes a need to route traffic via multiple satellites. LEO satellites are also relatively immature technology. Fees are also usage based on satellite links and means that such links need to be monitored and controlled.

WiFi backhaul

There is marginal (<1%) use of this technology for macrocell backhaul in some emerging markets. The unlicensed nature of the technology combined with the growing interference from increasing public and private WLANs plus poor transmission ranges severely limits its deployment.

Market share and trends

In terms of market share and trends, wireless backhaul (microwave) in the traditional (7-40GHz) range was responsible for nearly 57% of macrocell backhaul links in 2017, diminishing to 45% of macro-cell links by 2025. Microwave links in the 41-100GHz will double from 3.2% to 6.1% in the same period. The shorter range of the latter (<3km) is offset by their increased data throughput and thus make it a suitable technology in urban areas. For small cells, traditional microwave was used for 35.2% of links in 2017 diminishing to 21% in 2025, whilst microwave links in the 41-100 GHz range will grow from 10.4% to 13.1% in the same period.

Fibre based backhaul was responsible for 25.6% of macrocell links in 2017, rising to 39.6% by 2025. Fibre is the market leader for small cell backhaul with 43.2% of the market on 2017, rising to 56.1% in 2025. DSL based backhaul was used for 3.6% of macrocell backhaul in 2017 and this share is expected to decline over the next few years. Satellite comprised 1.9% of backhaul links in 2017 and this will diminish to 1.4% in 2025 (although the overall number will increase), reflecting its niche/complimentary role. These trends are summarized in the figure below.

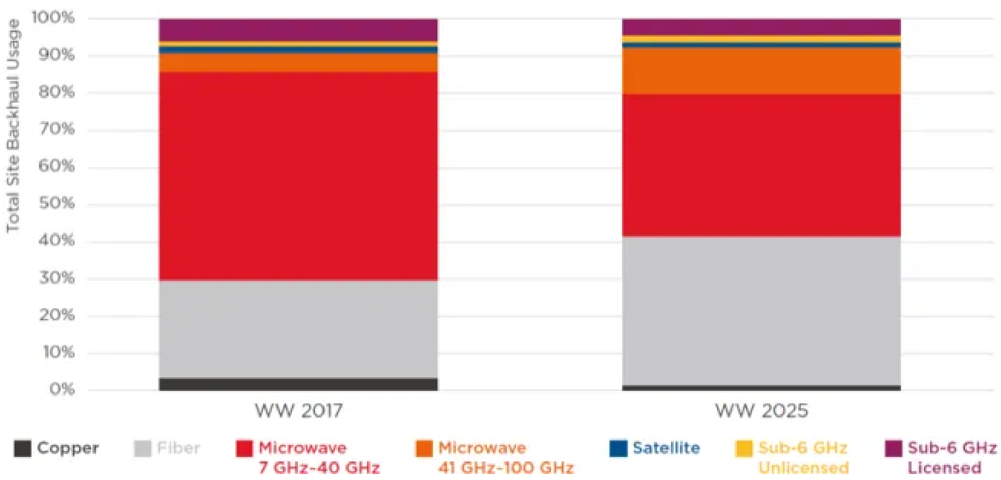

Figure 2. Backhaul technology trend and forecast (Source: ABI Research)

Cost comparison of selected technologies for mobile backhaul

While fibre promises the best performance among the technologies considered, economics can be challenging for the mobile operator to deploy. As shown in the figure below, the economics of fibre depends on how much civil engineering work is required (i.e. duct reuse or 100% trenching) along with the effect of regulation. For most sub-urban scenarios (other than 90% duct reuse), achieving 1Gbps with microwave is more economic while fibre is more economic for urban scenarios except for the case of own build with 100% trenching. The comparison also indicates that sharing of backhaul infrastructure (i.e. leasing or duct reuse) can lead to better economics (for more information on infrastructure sharing, see

here

). It can be deduced that wireless solutions can be used to reduce the cost of mobile backhaul as it reduces necessary civil engineering work.

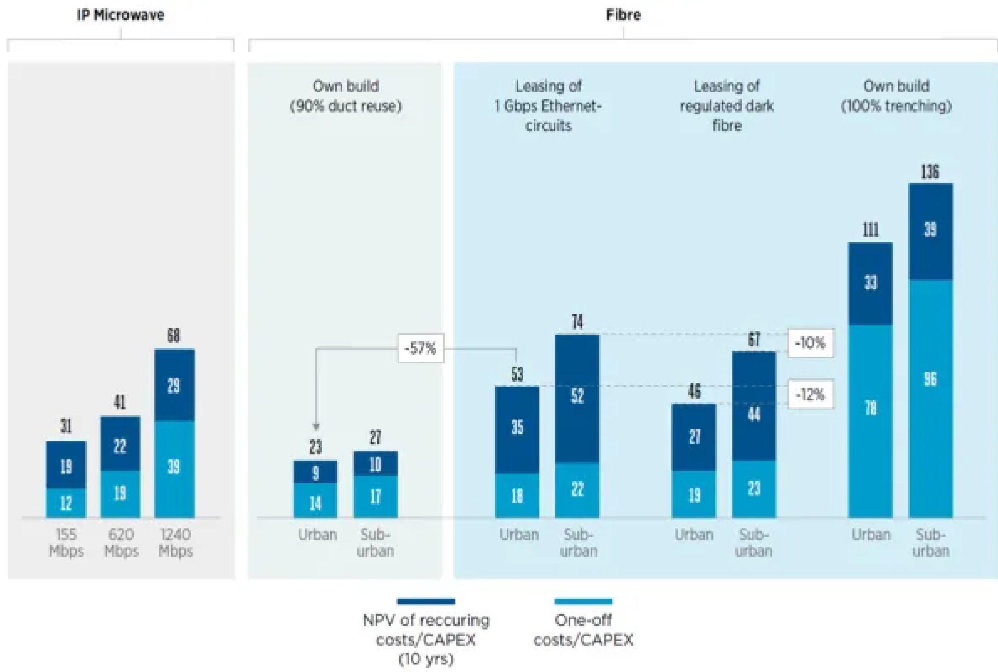

Figure 3. Backhaul economics per site: Fibre vs. IP microwave (Source: OFCOM, BT Openreach, Bernstein)

Deployment scenarios are complex and diverse and mobile operators will need a mixture of wired and wireless solutions to provide the optimum solution for a given deployment scenario.

4. Alternative Architectures for Mobile Backhaul Optimisation

MEC (Multi-access edge computing)

MEC (Multi-access edge computing) is where computing and intelligence capabilities that were mostly centralized in the core network are provided at the edge of the access network. MEC enables high bandwidth and ultra-low latency access to cloud computing/IT services at the edge to be accessed by applications developers and content providers.

MEC, while incurring a cost to implement core functions at the edge, can provide opportunities to optimise backhaul demand via caching and/or local breakout. Caching reduces the load on mobile backhaul and enhances the customer experience by storing frequently accessed contents in the edge network. Customers can access the contents at a lower latency (with less distance for signal to travel) and backhaul demand is reduced as there is no need to reach further to the external network to obtain the contents. Local breakout also enables the mobile backhaul to be optimised as the contents do not need to travel to the core network and then to the internet. The caveat with local breakout is that the transport network to connect the edge to the internet needs to be in place and therefore won't optimise cost in certain scenarios.

Cloud RAN

Cloud RAN is where some layers of radio access network are centralized to an edge site rather than at the cell site, which allows some (or all) of the processing capabilities to be focused at the edge site reducing the complexities at the cell site. This architecture is suitable in the small cell era, where only a little space and cost constraint is affordable at the cell site. While the architecture may not be suitable for traditional macrocell base stations as they would need to process significant load of signal transmitted from/received by various radio elements, heterogeneous networks with many small cells would benefit from this architecture.

As shown in the figure below, Cloud RAN in its two forms (low-level and high-level splits) significantly reduces complexities and capabilities at the cell site to be concentrated in the edge site. The low-level split is where only the physical layer is processed at the edge site while all the electronics are concentrated in the edge site. This architecture allows easy installation and very low complexity at the cell site but comes at a higher fronthaul cost as baseband signals would need to be transferred. On the other hand, high-level split brings relatively less fronthaul cost but comes with more complexity at the cell site than low-level split.

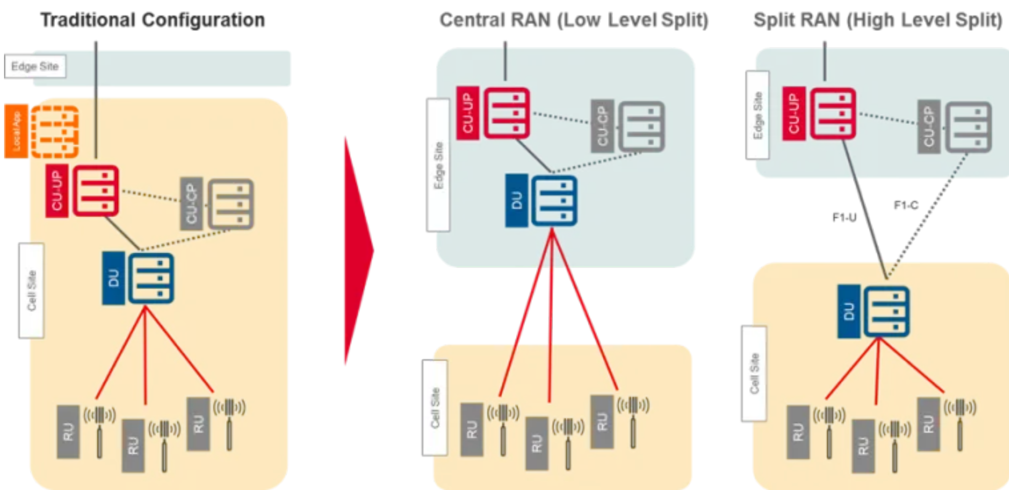

Figure 4. Cloud RAN Architecture

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