Fixed Wireless Access handbook

Extracted version

New edition

ericsson.com/fwa

Discover what´s new in FWA Handbook 2019

New case studies

European suburb

The countryside

The business park

FWA market potential
example – analysis of nationwide US

Expanded CPE evolution section

Customer-centric analytics

In this 2019 edition of the Fixed Wireless Access Handbook, you will find new and updated areas where you will gain deeper insights and knowledge.

Chapters 1-3 have been updated with insights reflecting new Ericsson-internal research and dialogue with customers and analysts since the first edition. A new page introduces the small/medium enterprise (SME) opportunity for FWA. We manifest the 3GPP operators' ideal position for FWA through reuse of both assets and 3GPP ecosystem economies-of-scale. A description of the FWA first-mover advantages and how those interplay with fiber competition is added. We elaborate on the need for a surgical approach to selecting neighborhoods for FWA deployment and give an example of the estimated addressable market in the US.
And we publish insights about how FWA data consumption is likely to grow rapidly at first until approaching levels and limited growth rates of full 'IPTV' homes.

Chapter 5 has been expanded to include material on the importance of customer-centric insights. Analytics using real-time correlated data can be used to provide an end-to-end view on the customer level, to better understand and pro-actively improve user experience. This is useful for FWA, and also for understanding of how MBB and FWA services affect each other in a mixed deployment scenario. We cover both general reasoning and the corresponding Ericsson product offering in this area.

Chapter 6 takes a closer look at the CPE evolution. In particular, we expand on the types of 5G NR CPE that are expected on the market by late 2019 and early 2020, which will offer households and enterprises sustained speeds and throughput that fully compete with fiber.The potential and trade-offs for consumer-installed CPE are also discussed, as is the important topic of customization versus generic best-of-breed CPE and key choices that operators need to make.

Chapter 8 has been updated with three new case studies, aiming to broaden the understanding of which FWA opportunities exist and make them concrete. All cases, both previous and new, are expanded with business cases sensitivity analysis, to widen the applicability of the cases to fit many different operator situations around the world.

- **European Suburb:** Addressing high-end 'wireless fiber' experience in a dense suburb, with ARPU level and spectrum situation applicable to Europe as well as to many other markets. By reusing macro assets and adding midband TDD spectrum, high market share and data consumption can be offered, with the base case showing 18 month pay-back time of the investment, and long-term evolution secured by mmWave spectrum.

- **The Countryside:** A 'build-with-precision' case, showing that FWA also addresses very sparse rural areas where fiber will certainly not reach. High speed and moderate data consumption needs are addressed by utilizing macro assets and undeployed FDD spectrum, and later by adding midband TDD spectrum. The base case shows payback in less than one year.

- **The Business Park:** A case which shows the potential of addressing SMEs, where data rates and consumption patterns differ from that of households, with more emphasis on the uplink. High 'wireless fiber' data rates and consumption offerings can be offered by utilizing macro assets and undeployed FDD spectrum, and by adding TDD midband spectrum. The long-term evolution is handled by adding mmWave spectrum. The base case shows a payback time of 19 months.

Our ambition with the new additions is to give new and previous readers deeper insights into the FWA market as it gains momentum.

Happy reading!

Table of Contents

This document is an extract from the Fixed Wireless Access handbook.

The complete version covers 10 chapters and 192 pages.

Please contact your local Ericsson representative for information about the complete version.

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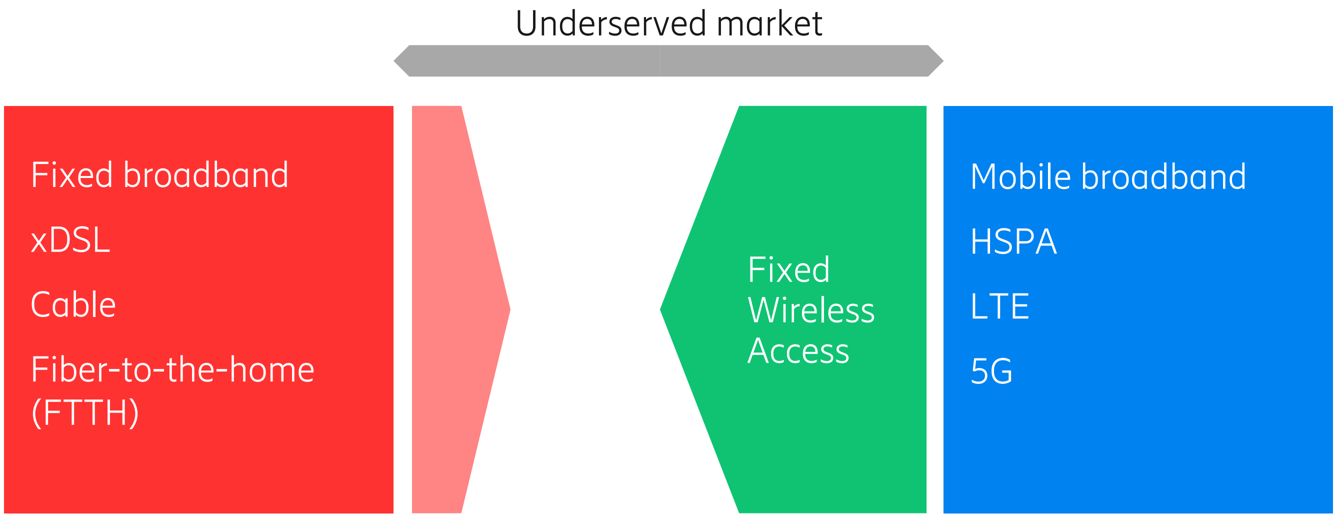
1. FWA market opportunity

Broadband market



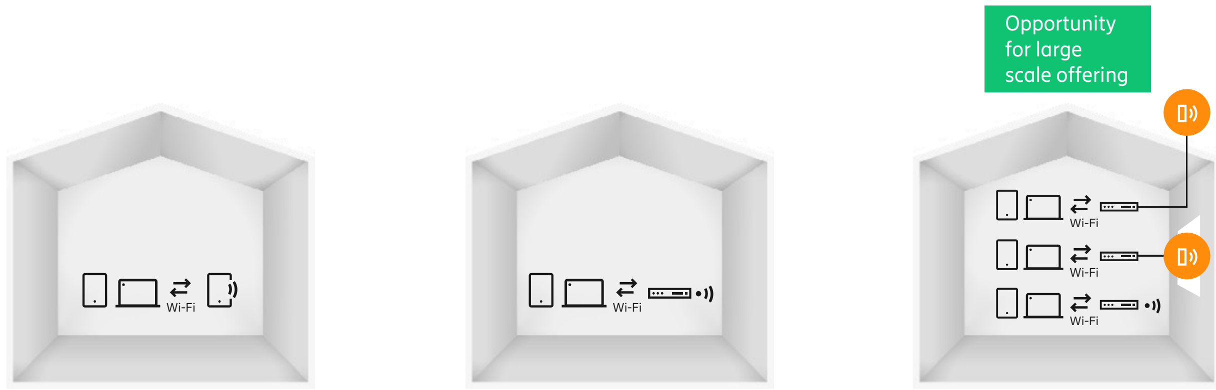
Global demand for broadband connections from both households and Small and Medium-sized Enterprise (SMEs) has been strong for several years.

Essentially, the broadband market can be divided into fixed and mobile. From a global subscription perspective, the mobile broadband market is substantially larger than the fixed broadband market: approximately 6 billion mobile broadband versus 1.1 billion fixed broadband subscriptions at end of 2018 (Ericsson 2019). It is worth noting that the number of fixed broadband users is at least three times the number of fixed broadband connections due to shared subscriptions in households, enterprises and public access spots.

Globally, the fixed broadband market is still growing and, according to the ITU (2018), fixed broadband subscriptions have increased by eight percent annually over the past five years. The majority of this growth comes from China. Furthermore, this growth is expected to slow down as existing technologies struggle to reach a growing number of households economically. The mobile broadband market has enjoyed higher growth; increasing on average by more than 20 percent annually over the past five years (Ericsson, 2019).

Despite the growth in both fixed and mobile broadband, there is a large underserved household market. This market can, to a very large extent, be served cost-efficiently with FWA, when it is built on the huge installed base and global reach of mobile technologies such as LTE and 5G New Radio (NR).

Our definition of Fixed Wireless Access



Tethering
Mobile Broadband

Standard MBB pricing, device logistics and management

Includes tethering to Wi-Fi only devices.

Best effort
Fixed Wireless Access

Nomadic indoor device (CPE) with MBB-like device handling.

May involve special price plan.

Guaranteed QoS
Fixed Wireless Access

1. Managed device (CPE), indoor or outdoor.
2. Special fixed-inspired price plan.
3. Subscription tied to known location.

To put FWA properly in context, it is important to distinguish between a few different cases of wireless service delivery to households.

Tethering - Mobile broadband
In this case, one or more mobile phones are used to communicate to and from the household. This also includes tethering to Wi-Fi only devices. Mobile broadband implies standard mobile operator pricing schemes, and standard ways of handling retail, provisioning, fault handling, and so on.

Best effort – Fixed Wireless Access
Here, the household has obtained an indoor wireless router, with wide-area wireless (such as 3GPP) capabilities to and from the household, and Wi-Fi (or LAN cabling) used within the house, between the router and other local devices.

The device and subscription are normally nomadic in nature, meaning the family can take the router elsewhere, and as long as the subscription is valid, the device will continue to work. The subscription normally reuses MBB paradigms, possibly with higher data allowances to cater for the whole household's needs.

Device handling is inherited from MBB, in terms of retail setup, provisioning and fault management. It is like a mobile phone without a screen.

Despite the nomadic character of this case, we include it in the definition of FWA, since, from the household perspective, it resembles fixed broadband. We add the label 'best-effort' since it is a challenge to provide very high grade guaranteed offerings when customer premises equipment (CPE) is nomadic and the subscription terms need to be valid everywhere.

Guaranteed Quality of Service – Opportunity for large scale offering
This case is where we believe the industry needs to focus more, and is one of the reasons for writing this handbook.

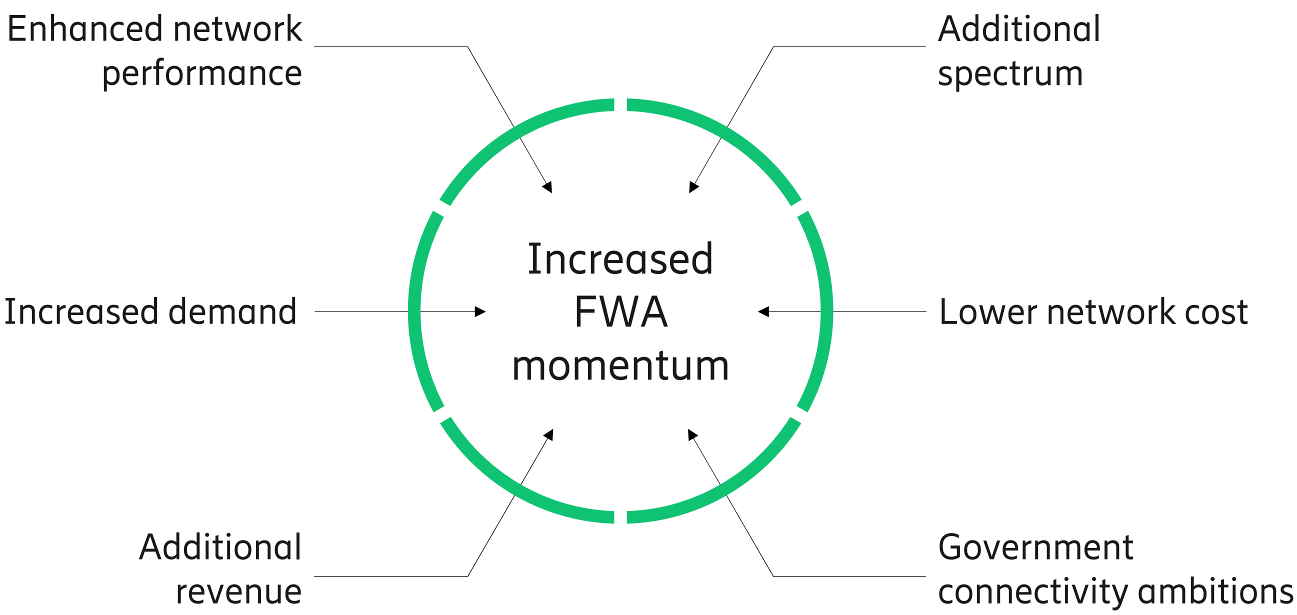
Here, the household is provisioned with a wide-area wireless-capable (such as 3GPP) device. This could be outdoor-mounted on a roof or wall, or an indoor unit, either fully integrated like a standard router, or with a more advanced antenna arrangement to improve performance. It is normally managed according to the fixed broadband paradigm, enabling remote configuration and fault management from a customer service center over standard protocols.

The price plan is specially designed for the service, typically inheriting the focus on sold data rate, from fixed broadband offerings. In terms of pricing positioning, Guaranteed QoS offerings typically can have higher ARPU than Best-effort offerings given the superior performance, with pricing levels similar to fixed broadband offerings available in the market.

Finally, the subscription agreements are typically only valid in the subscribed location, either inherently though the fixed-mounted CPEs, or logically so that if the CPE is moved, the unit does not work or the subscription is modified.

We will focus on this case in this handbook, since this is what requires extra insights and actions to capture its opportunities, while being aware that FWA best-effort offerings do exist in many mobile operator networks today.

Drivers and momentum



FWA is by no means a new phenomenon. Those who have had a not so successful experience of deploying FWA, based on WiMAX or earlier technologies, may ask themselves, why now? What is different this time?

There are six main reasons FWA is gaining momentum in the industry.

Network performance keeps improving, making FWA increasingly competitive and good enough for various use cases, including extensive video streaming. In addition, new spectrum in several bands is being made available globally.

The upcoming WRC-19 will also include identification of bands above 6 GHz that will help meet even greater capacity demands (ITU, WRC-15).

At the same time, the network cost (cost per delivered bit) keeps dropping, enabling a viable operator business case for FWA, and making it affordable to households for services such as TV/video streaming. As an example, a site fully evolved with 4G and 5G capacity will deliver mobile data 10 times more cost-efficiently than a basic 4G site today (Ericsson, 2018). However, many of the cost-efficiency steps can already be achieved through the LTE-A evolution.

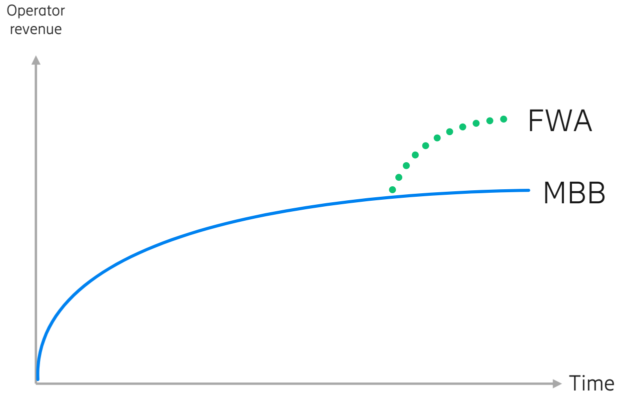
The growing global popularity of the Internet and video streaming has led to increasing demand for high-performance broadband services. This demand cannot be meet with legacy xDSL or cable.

In addition, many operators are struggling to find revenue growth. FWA is seen as a good opportunity for additional revenue streams.

Governments are also fueling connectivity and broadband roll-outs through various programs and subsidies, as there is a clear link between increased broadband penetration and economic growth (Ericsson and Imperial College London, 2017).

These six factors combined are generating increased industry momentum behind FWA.

Operator opportunities for additional revenues targeting residential household spending



Upsell opportunities

Telephony
- Voice services

Bundles
- MBB Quad-play
- Music, e.g. Spotify etc.

Entertainment and video on-demand
- Netflix
- HBO
- Amazon Prime
- Hulu etc.

Smart home services
- e-health
- e-climate
- e-security
- e-education

Over the past seven years, total global mobile operator service revenues, in constant currency, have been flattish (GSMA and Strategy Analytics, 2019). As a result, many operators are struggling to find top-line growth. FWA is seen as an exciting new opportunity to increase revenues.

For mobile-only operators, household broadband is in many cases an unaddressed market. By targeting this market with FWA, these operators can tap into a considerable pool of residential spending.

For converged operators, FWA also offers a new revenue opportunity in areas and segments that are not cost-efficiently addressed or reached by their existing fixed broadband offerings. FWA is also of interest to converged operators trying to close down existing POTS/xDSL services, which are getting increasingly outdated and costly to maintain. By replacing their POTS/xDSL service with FWA, built on existing mobile infrastructure, converged operators can find significant cost savings and efficiencies, strengthening the business case for FWA.

The additional revenue streams that can be targeted are highly dependent on the operator strategy being pursued. For instance, many operators act as a triple-play Internet Service Provider (ISP), selling Internet connectivity, fixed telephony and IPTV. Those who do not already offer IPTV can use FWA to open up new IPTV revenue streams. All of these offerings can also be bundled with mobile services, including MBB, as a quad-play offering.

Interest in connected homes is growing fast and they include home security, energy and utility management, online shopping and health and wellness, to mention a few. There are also upselling opportunities through offering add-on video-on-demand services, such as Netflix. It is worth noting that such services are only revenue generating if they are bundled into service packages, as they can be bought separately (over-the-top, OTT) by households.

In addition, there are opportunities to offer new services in areas such as e-health, e-security, and e-education.

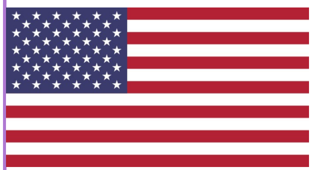
Which new services are offered will vary according to the operator's current position. For example, a converged operator may already have a number of offerings on the fixed side that can be easily extended into an FWA offering; while a mobile-only operator may be very selective about which services they want to offer.

In summary, connecting a home with FWA opens up a number of possible revenue streams beyond pure connectivity.

Examples of government connectivity initiatives

USA

Connect America fund

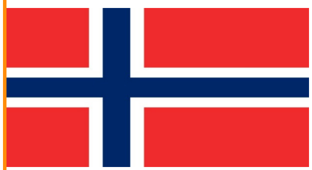


Europe

Connecting Europe broadband fund

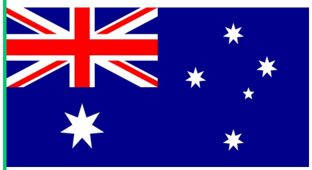
Norway

Haga model



Australia

National broadband network



As mentioned earlier, governments are fueling connectivity and broadband roll-outs through various programs and subsidies, as there is a clear link between increased broadband penetration and economic growth (Ericsson and Imperial College London, 2017).

There are a number of such initiatives globally, and these are increasingly technology agnostic. There are four examples that involve FWA.

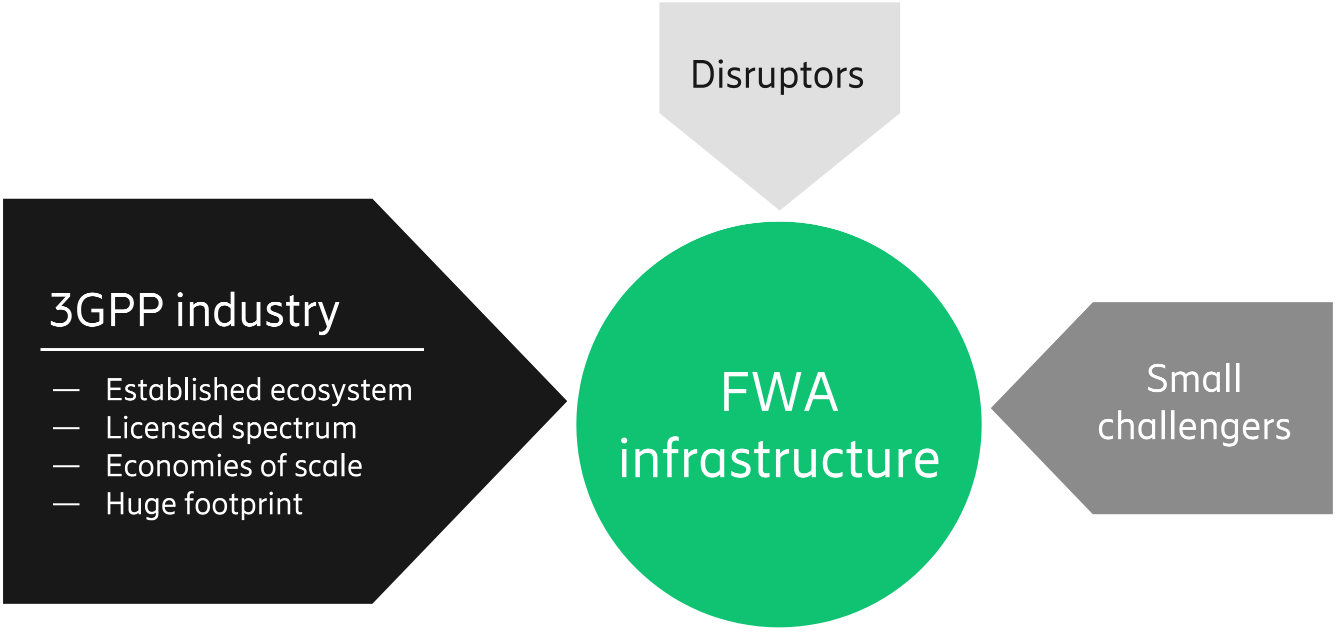
In the USA, the Connect America Fund (CAF) has the ambition to expand the benefits of high-speed Internet to millions of consumers in every part of the country. The ambition is to not only drive economic growth in rural America, but to expand the online marketplace nationwide, creating jobs and business opportunities across the country (Federal Communication Commission, 2017). As an example, during 2018, The Connect America Fund Phase II (Phase II) conducted an auction to give support to certain eligible areas across the United States. In this Auction103 bidders won USD 1.49 billion over 10 years to provide fixed broadband and voice services to over 700,000 locations in 45 states (Federal Communication Commission, 2018).

In Europe, a similar initiative offers a fund to unlock investments of EUR 1–1.7 billion in broadband deployment in underserved areas, where high-capacity networks are not yet deployed. The fund aims to have invested in 20 countries by 2021 (European Commission and the European Investment Bank, 2016).

Norway has an interesting model – the Haga model – involving municipality-driven collaboration in rural areas where purely market-driven broadband build-out is not feasible. Passive site infrastructure is funded, owned and managed by the municipality. Different stakeholders can then contribute different assets – such as land-owners providing site access – and co-funding is granted from the Government (NKO 2018). This approach has increased broadband coverage in Norway. The Swedish regulator has also discussed a model based on these principles (PTS, 2014).

Another approach has been adopted in Australia, where state-owned nbn is building a fast, wholesale local access broadband network to connect the nation and bridge the digital divide. nbn's key objective is to ensure all Australians have access to fast broadband as soon as possible, at affordable prices, at the lowest cost (nbn, 2019). It is worth noting that nbn is technology-agnostic and uses the technology that is most appropriate for the household or area – including fiber, FWA and satellite, among others.

Competitive FWA infrastructure landscape



The vast new opportunities opened up by FWA are attracting three main types of vendor, each aiming to address and supply equipment to operators.

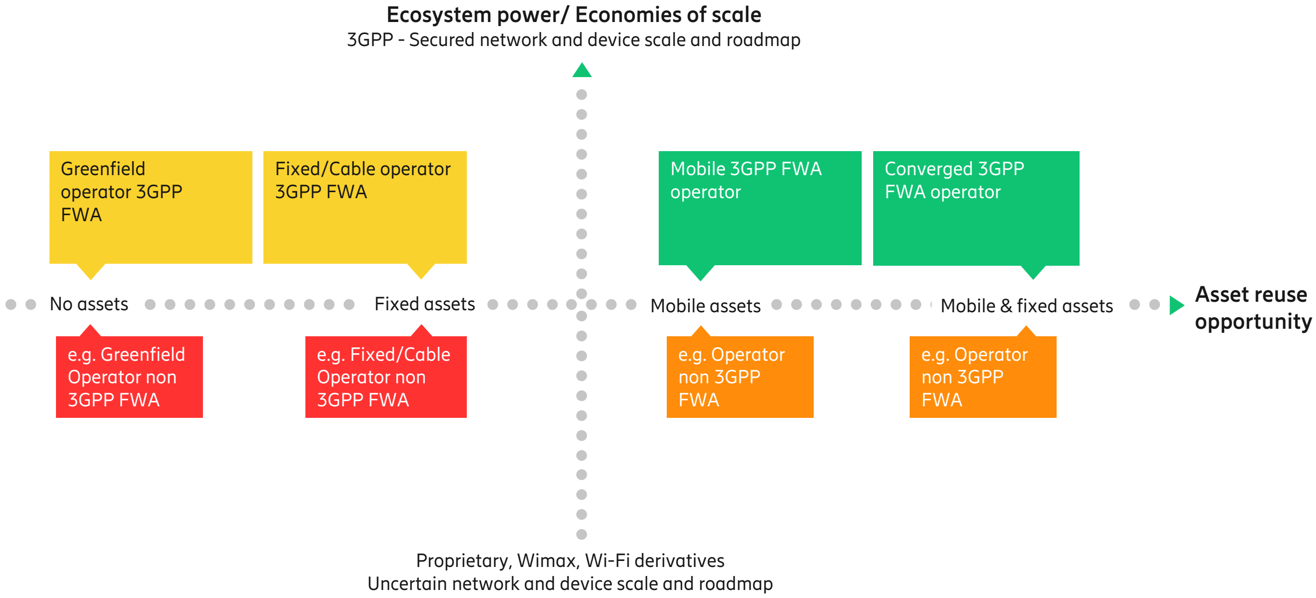
There are a handful of disruptive connectivity initiatives. For example, Google's Project Loon promises to create a network of balloons, floating on the edge of space, to extend Internet connectivity to people in rural and remote areas worldwide (Google, 2018).

There is also a group of 'small challengers', which are providing proprietary FWA solutions. These include start-ups as well as more established vendors (many with a history of offering WiMAX or proprietary solutions based on IEEE 802.11). Such vendors offer single-frequency-band products in both licensed and unlicensed spectrum, ranging from 3.5 GHz to up to 60 GHz. The 3.5 GHz band was the main spectrum band for WiMAX deployments, but this band will now be used for 3GPP deployments instead. The established proprietary IEEE 802.11-based vendors are targeting many smaller operators, which cannot afford licensed spectrum and need to use the unlicensed 5 GHz band. There are also a few commercial proprietary IEEE 802.11-based solutions emerging for the unlicensed 60 GHz band.

Unlicensed spectrum, such as that in the 5 GHz and 60 GHz bands, is particularly useful when combined with licensed spectrum. The 5 GHz band is already supported by 3GPP and the support for the 60 GHz band is expected in 3GPP Release 18.

By far the largest vendor group is the 3GPP industry, offering evolution to 5G with FWA as one of the main use cases. Given the enormous established ecosystem of 3GPP, vast number of frequency bands, the focus on high-quality spectrum and the corresponding performance and capacity, economies of scale, and huge footprint, this is the group which will provide FWA on a massive scale globally.

Ecosystem power and reusable network assets drive FWA operator competitiveness



To be competitive, FWA operators need to be able to offer data at very low production cost per bit, both in the short term and into the future. The two dominant factors influencing this are:

- the ability to reuse assets from existing operations
- having a future-proof ecosystem with scale and cost-efficiency

The potential of reusing existing assets is illustrated for a variety of operator types along the horizontal axis in the illustration above. A greenfield operator, deploying a new network for the sole purpose of offering FWA, has no assets to reuse – it has to finance all network deployments and the establishment of business processes and systems, as well as the creation of brand recognition and sales channels, for example.

An incumbent fixed broadband operator is in a different but better starting point: most existing network assets, other than the access, can be reused, as can existing business processes and know-how. The wireless access part is new, which is still a major investment.

An incumbent 3GPP mobile operator is in a much more advantageous starting position, since it can reuse the entire mobile network, and much of its business processes as well.

Finally, a converged operator is in a sweet-spot, being able to reuse both mobile and fixed network components, as well as business processes from selling fixed broadband (provided that the operator really combines assets in a converged way and collaborates across the company).

The ecosystem power and scale aspect is shown along the vertical axis in the illustration.

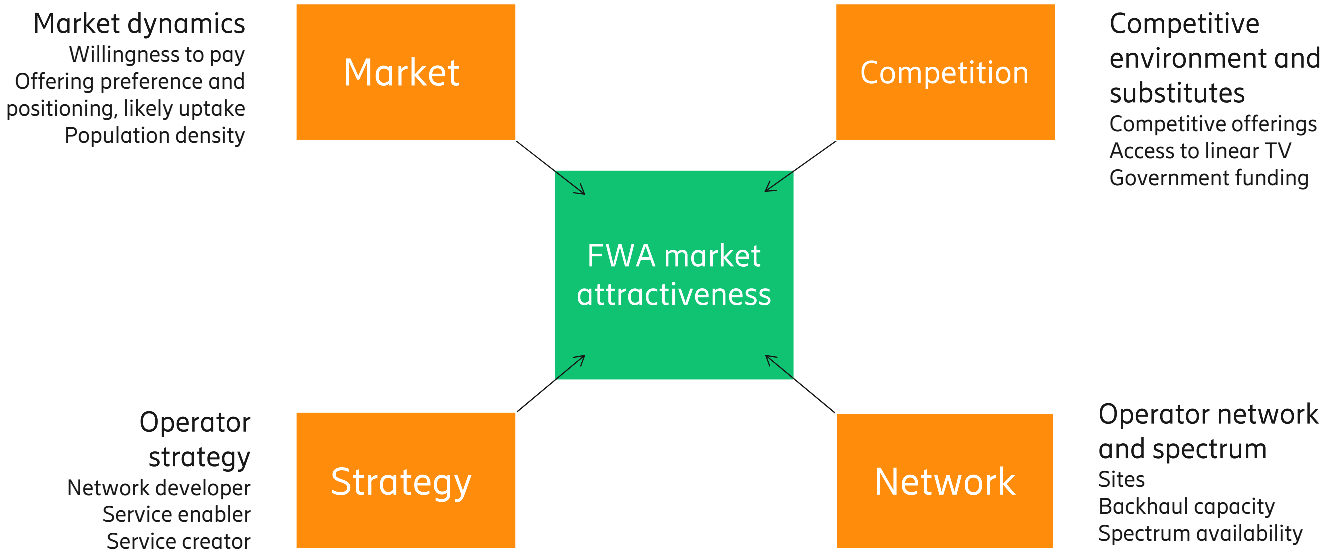
At the bottom of the axis, we see local, proprietary technologies. These are often Wi-Fi derivates using unlicensed spectrum. Such customized solutions can often give impression of cost-efficiency, since the equipment is purpose-built without any feature beyond the needs of FWA. However, evolution of such solutions over time is very challenging. A good example is WiMAX, which, despite major initial traction among FWA operators and big incentives from authorities in terms of spectrum, for example, has ultimately failed because of a poor ecosystem.

By contrast, the 3GPP ecosystem benefits from the vast MBB and smartphone market size, both in terms of network equipment and device chipsets. The cost is driven down by economies of scale, and the availability of FWA CPE with attractive functionality evolution is secured.

For example, consider a mobile operator (upper right quadrant) wishing to complement its MBB offering with FWA. Choosing to offer FWA based on 4G LTE and 5G NR offers major potential to reuse assets (including spectrum, and RAN and core network equipment), and helps the operator maintain its position in the upper part of the graph, enjoying the benefits of the 3GPP ecosystem. By choosing a non-3GPP technology, the operator would have limited potential for asset reuse and a weaker equipment ecosystem, resulting in a shift down and left in the graph over time to a much less beneficial position.

In summary, 3GPP mobile and converged operators are in an excellent position to address the FWA market. Depending on the local competition, fixed and even greenfield operators also have a chance to get their piece of the market, assuming they decide to take advantage of the 3GPP ecosystem.

Drivers influencing FWA market



There are a number of drivers influencing the attractiveness of the FWA market. These may be divided into four main categories, as illustrated in the picture. It is worth assessing these drivers at a national, regional or local level (such as a small city or a suburban area) to gain a better understanding of how successful and profitable an FWA rollout would be in that specific area. It makes sense to 'cherry-pick' and find the most profitable geographical 'sweet spot' areas in which to make first deployments.

Let's take a closer look at each of the four main FWA success factors.

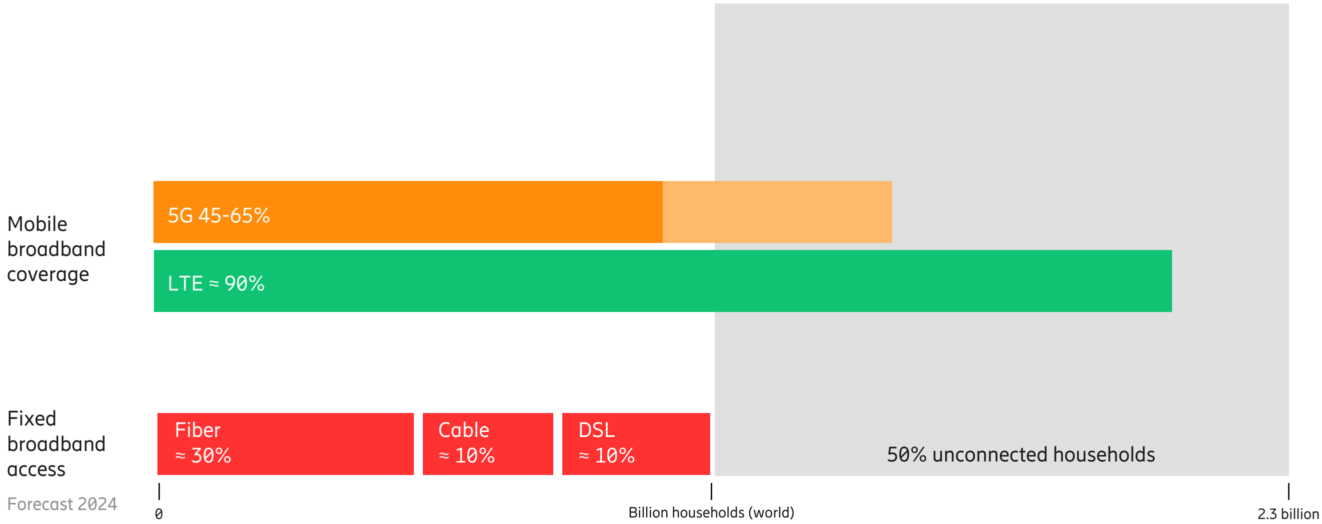
Operator strategy
Independent of operator strategy, FWA offers an opportunity to increase topline revenue. The exact market positioning and nature of the offering depend on the operator's overall strategic ambitions. For instance, an operator pursuing a 'network developer' strategy may decide to focus on earning money profitably on the pure connectivity part of FWA. While an operator pursuing a 'service creator' strategy may want to launch innovative smart home services in addition to the connectivity part.

Market dynamics
It pays to get a better understanding of the market being evaluated for an FWA rollout. This process involves assessing consumers' willingness to pay and the types of service offerings they are likely to want. Further key factors in determining the market potential are population density and likely uptake.

Competitive environment and substitutes
It is also important to assess the competitive environment. The first step is to determine the availability of other fixed broadband alternatives, such as fiber, xDSL and cable. In addition, other mobile operators' capabilities and likelihood of offering competitive FWA services need to be evaluated. The availability of government funding for the specific area should also be assessed.

Operator network and spectrum situation
The condition of the network in the targeted FWA area needs to be assessed, as it is an important factor in the ease and cost of FWA rollout. Key considerations are: site and current installed hardware and software, backhaul capacity, spectrum availability and current system load.

Broadband households by 2024



There are approximately 2.3 billion households worldwide. The chart above shows a forecast of how household broadband coverage will be provided by a variety of technologies by 2024.

Approximately half of all households are forecast to have a fixed copper or fiber broadband connection in 2024. In many markets, it's not economically viable to build out such fixed broadband infrastructure much further. Based on ITU data, we estimate the addressable market to be more than one billion households, with either no or poor fixed broadband connectivity. This opens up an opportunity for FWA deployments.

3GPP technologies are forecast to have huge population and household coverage by 2024. For instance, LTE is forecast to reach around 90 percent population and household coverage. As with previous mobile technology roll-outs, 5G is expected to be deployed first in dense urban areas to support enhanced mobile broadband (eMBB) services and, by 2024, up to 65 percent of the world's population is expected to be covered by the technology. The difference with 5G roll-out, compared with previous generations, is that it is largely driven by use cases with a wide range of requirements. During 2018, the first initial commercial 5G launches that took place, mainly in North America, were for FWA.

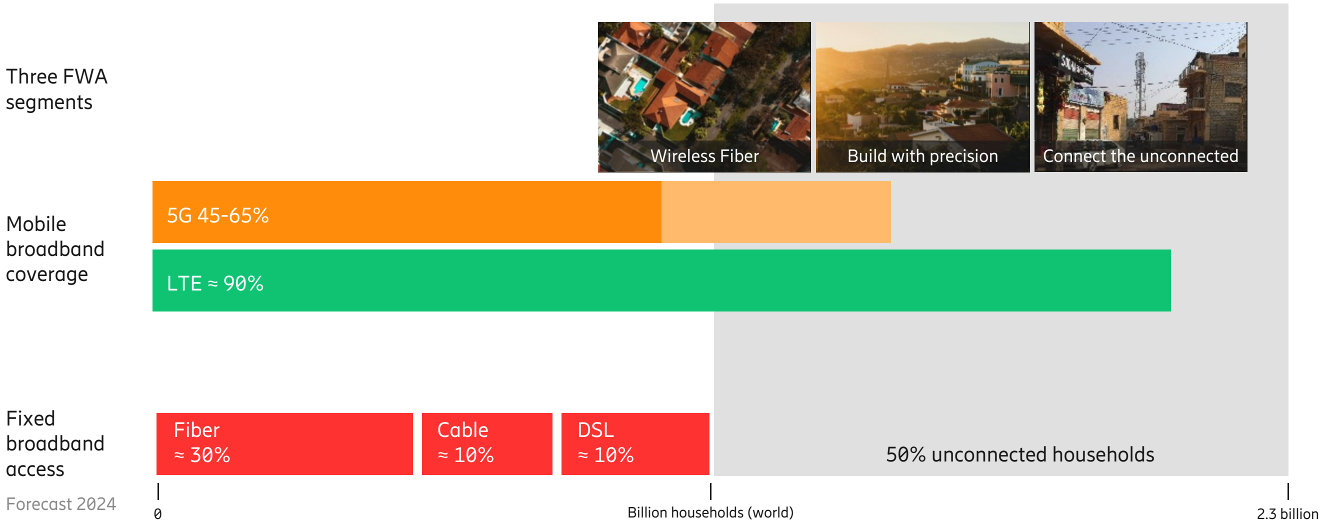
The huge potential household coverage creates a great opportunity for mobile operators to deliver FWA services on top of their existing MBB offerings.

Many operators already offer FWA services, across a range of emerging and developed markets and solution types (with indoor or outdoor CPE, for example), but very few explicitly report subscriptions and uptake. AT&T has publicly announced a commitment to offer high-speed Internet to more than 1.1 million hard-to-reach locations by the end of 2020 as part of the participation in a Federal Communications Commission (FCC) program. By the end of 2018, AT&T stated that it was on track to cover 60 percent of that commitment, offering a high-speed Internet connection to 660,000 homes and small businesses, in 18 states and across 1,000 counties. Through this effort, the operator stated that it has brought new opportunities, information, education and entertainment to areas where a high-quality Internet connection wasn't available (AT&T, 2018). Telefonica reports 0.9 million FWA subscribers in Mexico, Argentina and Peru (Telefonica, 2019).

There is wide variation in external forecasts of FWA market uptake. There are also multiple definitions of FWA (for example, 5G-only and 4G/5G), with different uptake rates, as very few operators report FWA subscriptions separately.

Industry analyst, Analysis Mason estimates a global addressable FWA market of 290 million subscriptions by 2023 (Analysis Mason, 2019).

Three FWA segments



We have divided the FWA market opportunities into three distinct segments, each with different characteristics mainly based on the offering, availability of fixed access and the corresponding average revenue per user (ARPU) which can be expected from customers.

The first segment is 'Wireless Fiber'. Here, there is competition with fixed broadband, driving a need for higher-rate offerings and capacity. The ambition is to provide fiber-like speeds and handle the household's TV needs with a corresponding high ability to pay. Typical sold data rates are 100-1,000+ Mbps and ARPU levels of USD 50–100.

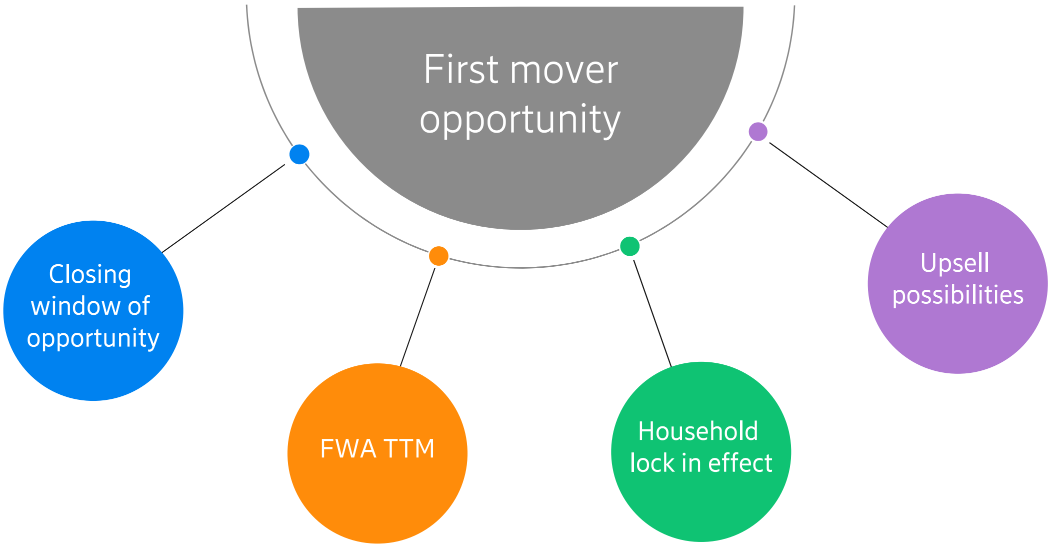
The second segment is 'Build with Precision'. Here, there may be some availability of xDSL. However, there is a limited business case to provide fixed broadband alternatives. The need is for high data rate and capacity and a willingness to pay. Typical sold data rates are 50–200 Mbps and ARPU levels are around USD 20–60.

The third segment is 'Connect the Unconnected'. This segment is characterized by virtually non-existent fixed broadband alternatives, and mobile broadband using smartphones is the dominant way of accessing the Internet. ARPU levels are limited and user expectations of access speed are relatively low. Typical sold data rates are 10–100 Mbps and ARPU levels are around USD 10–20.

It is worth noting that for 'Connect the Unconnected' and 'Build with Precision' segments, we assume that linear TV needs are satisfied by other means, such as terrestrial or satellite TV. For the 'Wireless Fiber' segment, some offerings may include a full IP-TV offering, implying dramatically higher data consumption.

These three segments will be used throughout this handbook to distinguish the offerings and technical solutions tailored to them.

First mover advantage



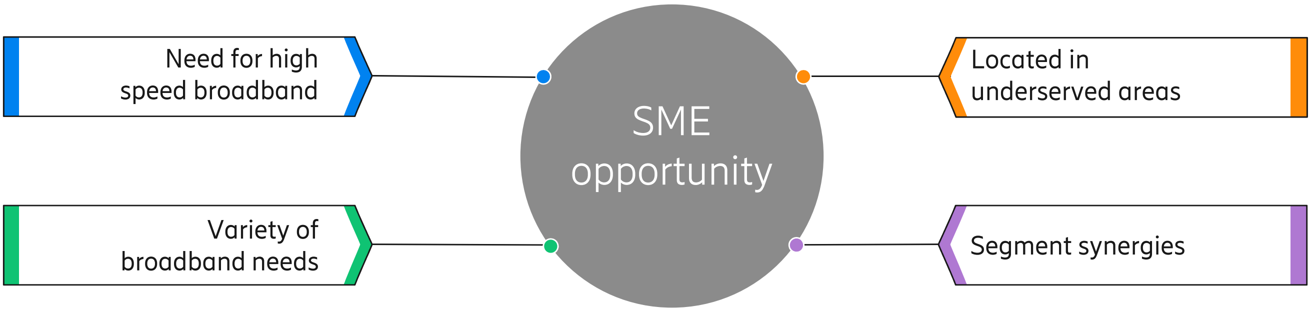
Substantial academic research has found that 'first movers' – firms that enter a market early – tend to exhibit higher business performance than firms that enter the market at a later stage. The degree of improved performance varies according to several factors and across industries. Studies within the telecommunication industry tend to support the theory of first-mover advantage, showing that they enjoy higher market share and operational financial results than later entrants (Jakopin and Klein, 2012).

For FWA, there are four main areas contributing to first-mover advantage:

- **Closing window of opportunity** – as has been mentioned previously, the FWA and broadband opportunity needs to be assessed at a local level. However, the opportunity window is closing as fiber build-out are targeting the most profitable household areas. In addition, there are also CSPs with proprietary wireless technologies addressing these areas. The reverse situation is also true: when FWA is deployed in an area, it is very hard to develop a sustainable business case for fiber, as it tends to need a high sign-up level among households in a given area to be profitable.
- **FWA time-to-market (TTM)** – in view of the closing window of opportunity, FWA CSPs have a competitive advantage as it is typically around four times faster to deploy FWA than fixed broadband alternatives. For example, fiber deployment has the challenge of obtaining permits for trenching, meaning much slower time to market than FWA, which is built on top of existing MBB infrastructure. In addition, FWA is much more capital-efficient and, according to Fierce Wireless, FWA providers can enter rural and urban markets at about one-tenth of the cost of laying physical fiber (Fierce Wireless, 2018).
- **Household lock-in effect** – once CSPs sign up households to broadband subscriptions there tends to be a 'lock-in' effect. In some cases, there are long-term contracts which contribute to this. Experience shows that for FWA household broadband subscriptions – with CPE installations as well as bundling with MBB, fixed telephony and entertainment, for example – tend to increase this lock-in effect.
- **Upselling possibilities** – building on the household lock-in effect, connecting a home with FWA opens up several potential revenue streams beyond pure connectivity, including bundles with MBB and Smart home services.

To summarize, FWA offers a business opportunity that needs to be addressed by CSPs, as there are many indications of a strong first-mover advantage.

Small & Medium Enterprises – opportunity to address a large underserved market



Beyond consumers, there is an opportunity for FWA to address enterprises, in particular the small and medium enterprise (SME) segment. With growing digitalization, there is a growing need for connectivity and high-speed broadband for enterprises. Enterprises today, including main offices and branch offices, require connectivity due to growing importance of electronic payment and ecommerce, cloud services and enterprise resource planning (ERP) applications. Moreover, companies are increasing the number of connected devices (e.g. IoT, surveillance cameras) and inventory management.

In order to give an understanding of the size of this opportunity, Jio reported that they estimate that in India alone there are 5,000 large enterprises, 1.4 million small and medium businesses, and 51 million registered micro and small enterprises, out of these micro and small enterprises hardly 1 million have wireline connectivity. They are also arguing that this lack of broadband connectivity is a huge obstacle impeding economic growth in India (Jio, 2019).

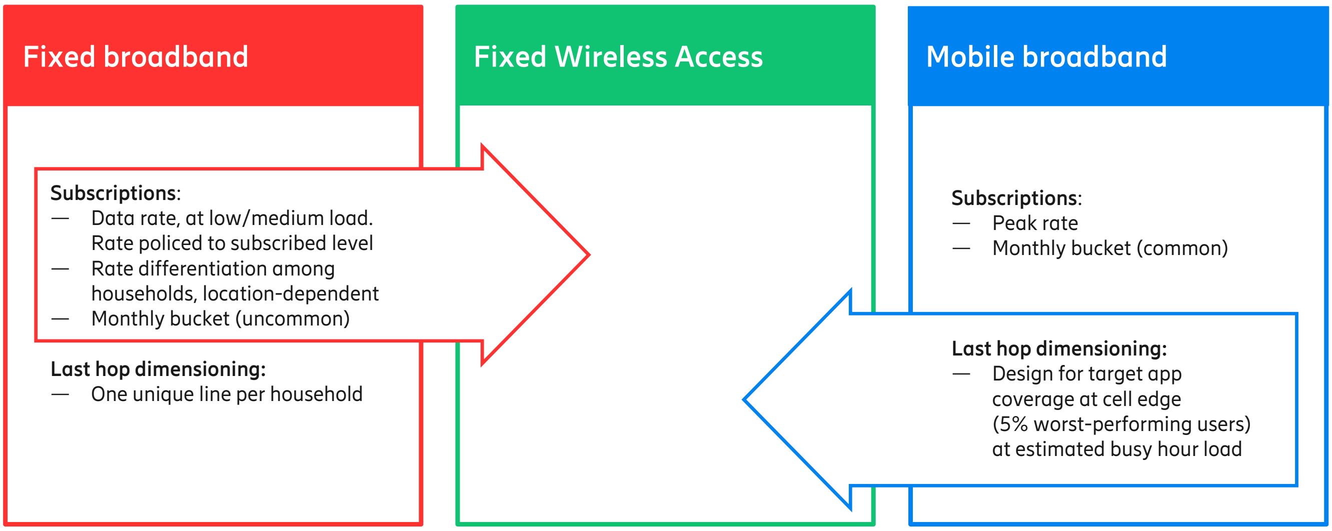
Many SMEs are located in underserved areas with low speeds, lack of broadband alternatives or no connectivity whatsoever. These locations could include SME and SoHo (Small Office and Home Office) in suburban areas or in the city outskirts (e.g., warehouses). In addition, some SMEs are located in buildings and business parks that lack in-building cabling to reach their facilities. In other cases, small enterprises are serviced with dedicated microwave point-to-point access which could be cost-wise more suitable for larger or IT intensive enterprises and take time to install.

In general, SME has a higher purchasing power compared to consumer. Offering FWA both for consumers and for SMEs in the same area may give synergy effects: SME usage patterns differ from consumer as most of the usage is during the day compared to evenings and weekends for consumers. In addition, the SME traffic is more balanced with regards to downlink and uplink. The busy hour network capacity can thus be kept lower than the sum of the needs of the two segments. SME can be a sizable market, in particular for emerging markets where SMEs are a significant part of the country's economy.

In order to address SMEs, operators need to carefully understand the market opportunity being addressed, as SME can have even higher requirements compared to consumers. Main parameters to drive SME broadband needs include:

- Type of business ranging from retail to IT intensive services (e.g. developers)
- Number of employees
- Degree of cloudification of the SME's IT infrastructure: servers, computers etc.

FWA paradigms are influenced by both fixed and mobile broadband



Fixed and mobile broadband paradigms are different, both in terms of subscription offerings and dimensioning.

Subscriptions
Fixed broadband subscriptions tend to focus on maximum data rates, achieved under normal circumstances, that is, at low to medium load. The user traffic is often shaped to not exceed the sold data rate. Additional monetization usually takes the form of upgrade packages with increased data rates. Monthly usage buckets are seldom advertised as a part of the subscription, although there are often rules against over-consumption in the contract details.

Hence, for fixed broadband, the sold data rate is the normal value that household subscribers relate to.

By contrast, for mobile broadband, peak rates are sometimes used for marketing, and normally the network transmits the maximum rate that the mobile device can handle. Monthly data buckets dominate the subscription paradigm, and additional monetization is achieved through upgrades to larger data buckets, all the way to 'unlimited' data.

Hence, for mobile broadband, monthly data buckets are the normal subscription value that mobile subscribers relate to.

This difference needs to be understood by both consumers and operators (fixed and mobile). Our view is that fixed broadband subscription paradigms will be inherited for FWA, rather than mobile broadband ones. Households should buy on the basis of data rate and not be concerned about consumption in terms of data buckets.

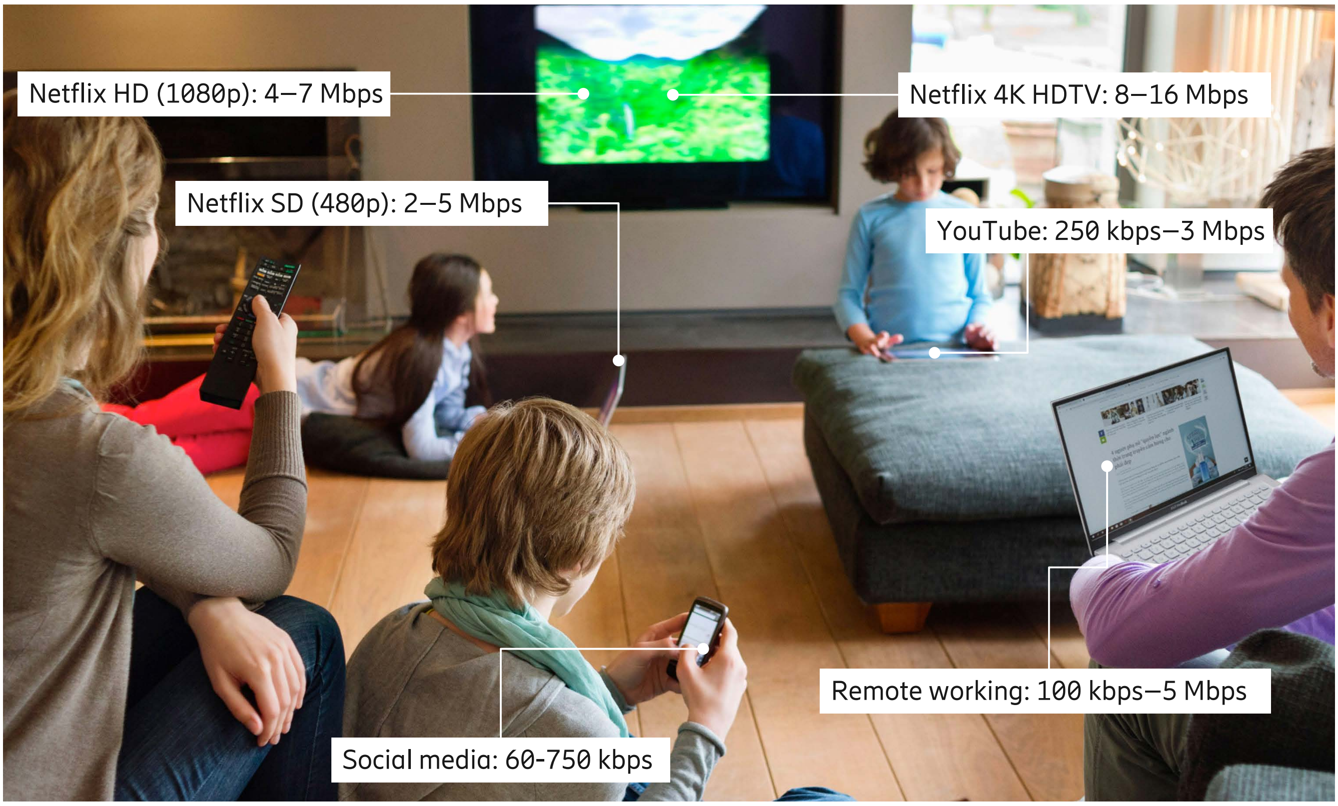
Last hop dimensioning
For dimensioning, the last hop is wireless, so all the characteristics of a wireless network will apply. Unlike fiber, but similar to DSL loop length, there will be varying connection quality to different households. And, unlike fixed broadband overall, the last hop is radio and so shared, which means that quality will degrade with load.

All these characteristics will have to be taken into account when dimensioning an FWA network, and since we promote the use of sharing assets with mobile broadband (when available), it needs to be brought into the operator's general RAN dimensioning exercise.

Note that for fixed, FWA and mobile broadband alike, there is transport aggregation above the last hop, which is dimensioned according to standard principles and can also contribute to a varying user experience.

In essence, FWA will reuse subscription paradigms from fixed broadband, while for dimensioning, due to the radio properties of the last hop to households, FWA will use modified dimensioning methods and terms from the mobile broadband paradigm.

How data rates relate to video – the dominating use of broadband



Household broadband is dominated by video usage. Different video applications use a range of resolutions and frame rates, leading to different requirements on data rate. The illustration shows some examples of required data rate for different applications.

Data rate
The data rate requirement depends on the quality of the video, which in turn depends on the resolution, frame rate and encoding quality. Modern video servers have content coded in multiple qualities, and end-to-end protocols switch between these, depending on the data rate perceived by the receiving client.

In the illustration, the Netflix numbers are based on the new encoding standard of HEVC in the 4K format and the less efficient H.264 encoding in the other formats (How-to Geek, 2018). Netflix and other vendors will introduce HEVC into all formats step-by-step, increasing the encoding efficiency by 25 percent (Apple, 2018).

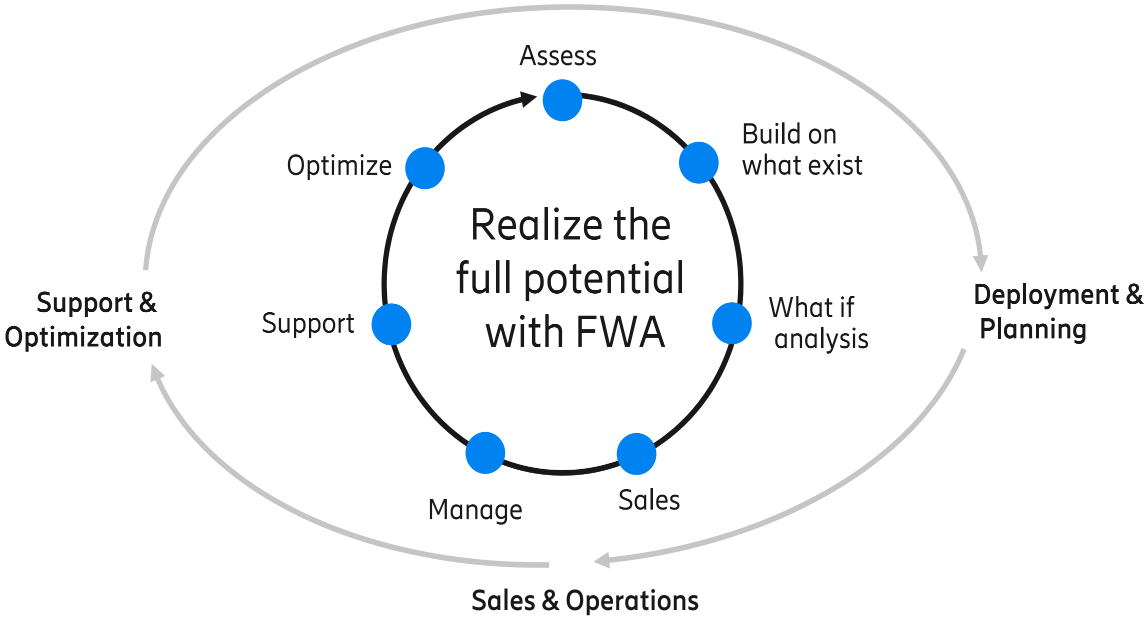
Video providers work with rather big device buffers to avoid quality degradation when network conditions vary. For example, Netflix typically strives to build up a 90-second buffer. Video providers, with YouTube leading the way, can rather accurately predict how each consumer will continue watching the shows once started, which means that significant buffers (up to one hour) of 'good' data could be built up using free capacity, if the operator provides such an option (see Smart Subscription later in this chapter). This relieves the dimensioning requirements, since a longer time interval than the actual peak can be considered.

Delay
The absolute delay of starting the play out is not very strict: one or a few seconds is acceptable. However, to be able to quickly get up to speed (say 10 Mbps) with TCP after possible link interruptions, a quite low delay is still desirable.

Direction
All the above requirements are for downlink. We regard the FWA household case as extremely downlink-dominated, as video streaming is the dominant service. The uplink must still support the application signaling to get the video started, and a relatively high rate of TCP acknowledgments, as well as reasonable experience for uploads and uplink webcam-type streaming.

For SMEs, the traffic patterns are different, less video-centric and less dominated by the downlink direction.

Enhance key FWA processes using expert insights



To realize the full potential of FWA, adequate initial planning is not enough. Critical decisions need to be made throughout each main lifecycle step:

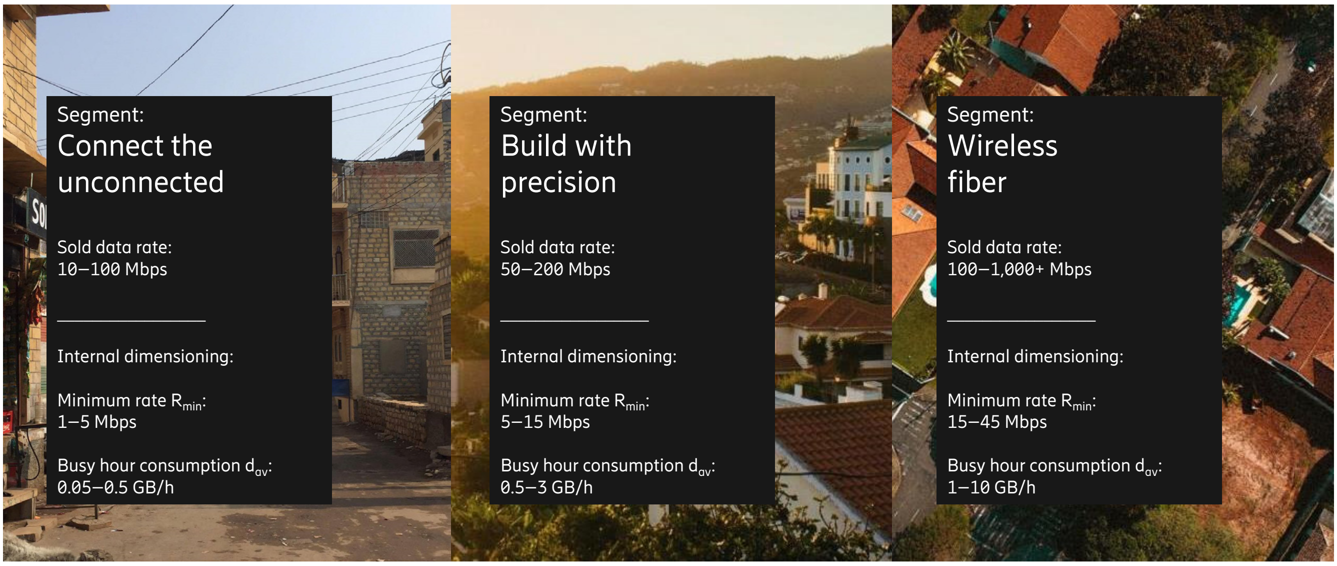
- Deployment & Planning
- Sales & Operations
- Support & Optimization

Customer analytics insights on an individual or FWA household level will simplify decision-making, improve customer experience and optimize return on investment. Examples of where information is needed to support decisions across each lifecycle step include:

- **Assess:** FWA performance with peak-hour dimensioning insights per location and per CPE to estimate minimum number of households to serve per location while maintaining service levels
- **Sales:** adjust the sales strategy to introduce targeted FWA offerings to a specific area where market penetration is low or availability of competing broadband offerings is high
- **Build on what exists:** to estimate the minimum number of households to serve per location while maintaining service levels
- **What-if analysis:** planning and prediction around service levels expected per household or cell/sector of interest
- **Manage:** monitor experience before and after an FWA upgrade, or when adding mid-band 5G NR to existing sites
- **Support:** prepare Customer Care with insights per user and relevant KPIs to respond to calls faster and more accurately
- **Optimize:** investigate and optimize user experience inside the building to guarantee specific QoS levels

2. FWA solution

Typical sold data rates and network dimensioning for three segments



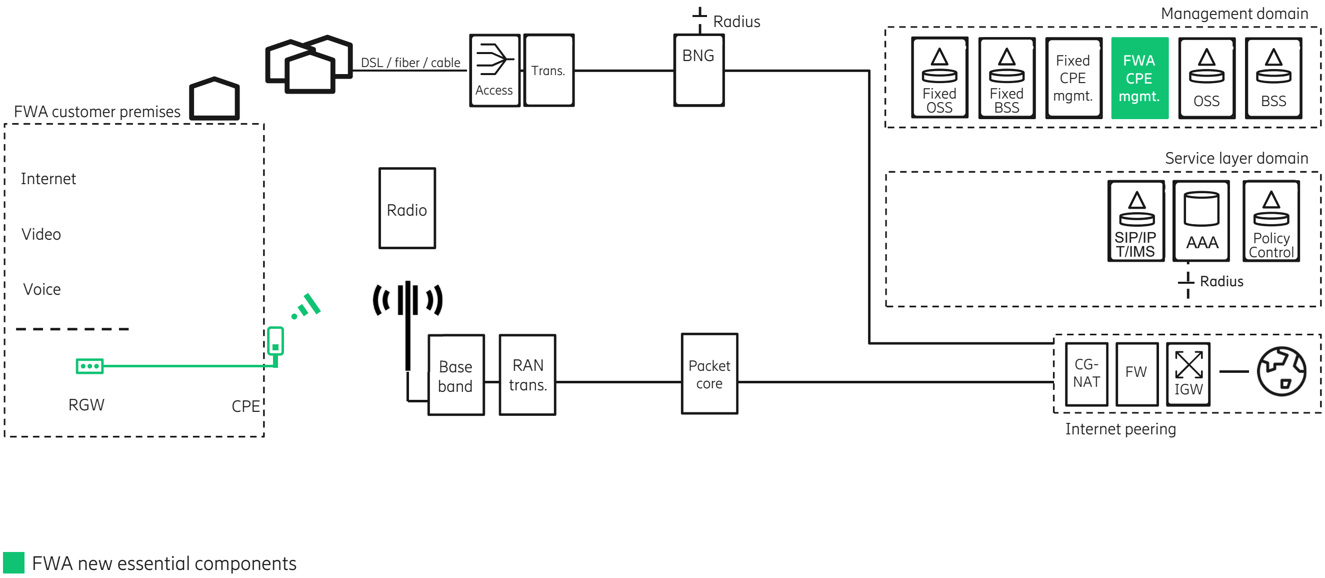
Our three defined segments are partly characterized by the range of the sold data rates offered. Examples of typical sold data rates for the three different segments are:

- **'Connect the unconnected'** – 10–100 Mbps
- **'Build with precision'** – 50–200 Mbps
- **'Wireless fiber'** – 100-1,000+ Mbps

Using the defined terminology for the operator-internal network dimensioning, we can also define indicative value ranges per segment for the minimum data rate R_{min}: 1–5 Mbps, 5–15 Mbps, and 15–45 Mbps, respectively. These correspond to different numbers of simultaneous video streams, and combinations of streams, for SDTV, HDTV and 4KHDTV resolutions.

Similarly, we can define indicative value ranges for the average busy-hour consumption per household d_{av}: 0.05–0.5 GB/h, 0.5–3 GB/h, and 1–10 GB/h, respectively. Note that for 'Connect the unconnected' and 'Build with precision' segments, it is assumed that linear TV needs are satisfied by other means (terrestrial or satellite TV). For the 'Wireless fiber' segment, some offerings may include a full IP-TV offering, which is the reason for the high end of the value range. Offerings to enterprises will typically also need to be dimensioned for high minimum rate R_{min} and for a higher fraction of traffic in the uplink, and such offerings are often considered part of the 'Wireless fiber' segment.

FWA for a converged operator



In a converged network operator – where both mobile and fixed access are offered by the same company – the degree of actual convergence of organizations and network components (such as BSS systems, network management and core networks) can vary widely, from very limited to moderate. Most converged operators have a clear strategy to converge more of their organizations and networks to realize synergy and cost benefits.

This means that, when combining their existing assets, converged operators will already have most of the knowledge, processes and network components needed to offer an FWA service. This puts these operators in an excellent position and represents a clear advantage over greenfield stand-alone FWA providers.

Radio Access Network (RAN) including RAN transport
The 3GPP RAN (including RAN transport), with its high-capability 4G LTE access, already exists, implying that equipment and processes to operate the network are already in place – from radio, via baseband and RAN transport and their management systems, to the site infrastructure and other related equipment. Adding FWA capability to these merely involves adding capacity and coverage in a well-defined and geographically selective way, while observing the FWA traffic model and its differences from mobile broadband when dimensioning the network. Smart slicing of the RAN capabilities helps in allocating suitable resources between mobile broadband and FWA.

Core network (CN)
The 3GPP core network is already deployed, with its ability to handle high numbers of flows and high volumes of traffic. When adding FWA, operators should ensure that core network handling of the data is suitably 'low touch', in order not to drive unnecessary cost. It is also worth considering a number of functional additions that will be valuable for FWA, including new ways of regulating bandwidth or data rates, flexible charging support, and limiting the use of FWA to a local geographical area.

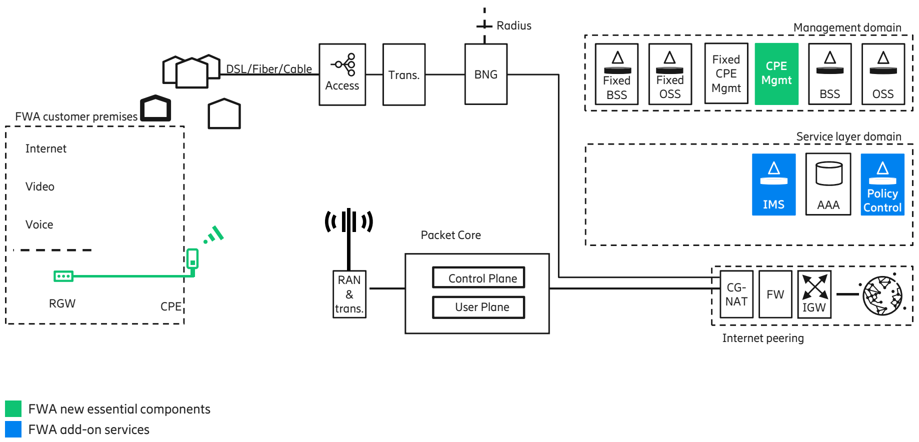
It is also worth operators considering reusing some components of the fixed access core network. This typically involves functions on the Internet side of the Broadband Network Gateway (BNG), such as Network Address Translation (NAT), firewall and caching.

Service layer domain
In the service layer domain, policy control is often already deployed, and helps to set policies for the core network functions listed above. In addition, when the FWA service includes a fixed telephony offering, the existing IMS/VoLTE system can act as the backend voice telephony server for that service too. Operators can also reuse an existing fixed VoIP service solution, different from IMS, for the new FWA offering if desired.

Management domain
Network management is already deployed to handle existing cellular and fixed services, and can be reused for FWA. Operators may consider additional management tools to optimize their understanding of network performance in the FWA-launched areas, and for detailed analysis of customer behavior and generated traffic. In the BSS field, operators will need to add the desired charging schemes for FWA. Depending on the degree of convergence between the operator's mobile and fixed BSS systems, the operator can choose whether to reuse mobile or fixed BSS systems and principles for FWA.

CPE and CPE management
New FWA CPE is needed, from simple indoor nomadic devices to fixed outdoor-installed units, and provisioned through standard device retail or new methods. A new CPE management system is likely to be needed to manage CPE in the fixed broadband sense – enabling the operator to log in to the devices, configure them and check status remotely. Converged operators have the choice of reusing the fixed access CPE management system or deploying a separate one for FWA. Both CPE and CPE management systems are separate network entities with generally quite limited integration with cellular networks, meaning that the operator can acquire best-of-breed products and expect them to work using standard protocols.

Core architecture for converged operators



Key functions

- Voice telephony
- End-to-end QoS
- Bandwidth control
- Flexible charging
- Location-awareness
- Flexible IP addressing
- CPE management
- OSS/BSS

The core network for FWA is a subset of what typically is used for MBB. As a starting point, converged operators can leverage their existing packet core to deliver FWA to new customers. From the fixed side, operators can reuse network elements on the Internet side of the Broadband Network Gateway (BNG), such as Carrier Grade Network Address Translation (CG-NAT) and caching. There is a large amount of optional functionality in the core that is useful for FWA. For example, Service Awareness in the gateway can be used to detect what services are used in the network, enabling actions like prioritization of voice. By adding Policy Control, polices can become more dynamic and individualized.

The Control Plane (CP) in 4G / 5G Non-Stand Alone (NSA) consists of Mobility Management Entity (MME) and Gateway-Control Plane (GW-C), while in 5G Stand-Alone (SA) it consists of Core Access and Mobility Management Function (AMF) and Session Management Function (SMF). The User Plane (UP) in 4G / 5G NSA consists of a Gateway- User Plane (GW-U), while in 5G SA it consists of a User Plane Function (UPF).

To simplify management and setting of network parameters, we recommend running FWA on a separate Access Point Name (APN). This enables general policies for FWA to be set for all FWA users, and statistics for FWA and mobile broadband to be collected separately. Operators might also consider having a separate Serving and PDN Gateway (S/P-GW) for easier dimensioning and management. The APN can be preconfigured in the CPE or provisioned in the HSS. In HSS it is also possible to set parameters such as Service Profile Identifier (SPID) used for RAN slicing (as described in the Radio Network Aspects chapter) for FWA subscribers. The FWA APN needs to be configured in the gateway with appropriate polices and parameter settings. If separate FWA gateways are used, for example because distribution is needed, steering to the right gateway should be configured in MME / AMF.

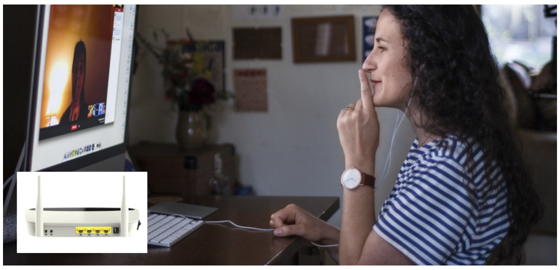
Proper dimensioning of the FWA core taking into account the existing mobile broadband offering and anticipated traffic volume is essential to ensure smooth operations and minimum cross-service impact.

While only a standard packet core is required for FWA, there are a number of additional core key functions which are useful for offering FWA services:

- **Voice Telephony** – voice service can be offered using an IMS-based telephony application with corresponding CPE support
- **End-to-end QoS** – a voice telephony session can be prioritized in the transport and radio transmission networks by activating functions in radio, transport and core
- **Bandwidth control** – the throughput allocated to a user or service can be managed by a number of different mechanisms in the core
- **Flexible charging** – both flat-rate and bucket-based charging schemes can be supported
- **Location awareness** – users' location can be determined and appropriate actions taken if subscribers move outside their home zone
- **Flexible IP addressing** – both dynamic IP address allocation (common in mobile broadband) and static IP addresses (common in fixed broadband) are supported
- **CPE management** – the new kind of CPE used in FWA will need a management system conforming to standards used in fixed broadband
- **OSS/BSS** – existing network monitoring and provisioning procedures need to be augmented to support FWA

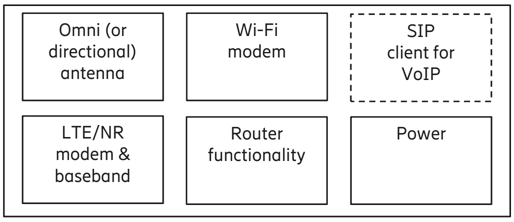
These are further elaborated in the next few pages.

Different types of CPE



Indoor CPE

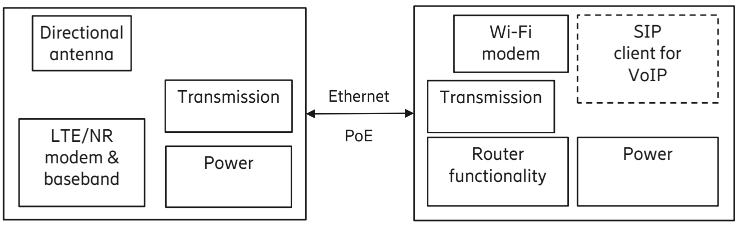
Combined LTE/NR modem including residential gateway



Outdoor CPE

Outdoor LTE/NR modem

Separate indoor residential gateway



Customer Premises Equipment (CPE) is a vital part of an FWA solution, as it terminates the 4G LTE and 5G NR air interfaces. This means it has a direct impact on end-user service and quality, as well as the operator cost for providing FWA services. There are two types of CPE: outdoor and indoor. From a performance perspective, an outdoor unit is always preferable unless the home is close to the serving radio base station.

Outdoor CPE typically contains a directional antenna and all the necessary functions to terminate the air interface protocols. It is connected via Ethernet to an indoor Residential Gateway (RGW), which connects end-user devices over Wi-Fi or via Ethernet. The outdoor unit itself is powered via Power-over-Ethernet, so only one cable is needed. There are different varieties of outdoor CPE: some designed for rooftop installation and others for wall mounting. One advantage of outdoor CPE is that it can be used with any Wi-Fi router, whether an operator-provisioned and managed RGW, or an off-the-shelf Wi-Fi router.

As well as terminating 4G LTE and 5G NR, indoor CPE also contains the necessary RGW functionality – making it a one-box solution which is easy to install and connect to the network. However, indoor CPE has significantly lower antenna gain which makes it less suitable in FWA deployments where many households are served. Additional receiver branches (4Rx) can be added to compensate for the lower antenna gain, normally with an omni antenna. Another side-effect of integrated LTE-NR/Wi-Fi units is that LTE and NR evolve in line with 3GPP standardization, while Wi-Fi evolves in line with IEEE standards, meaning that the unit may never meet the latest of both standards.

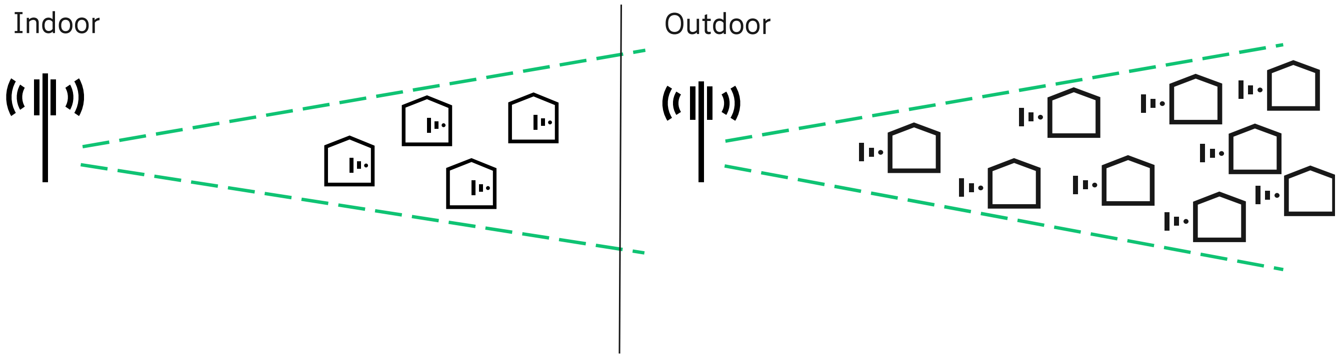
There are also hybrid solutions coming to market which can be installed on a favorable window either inside or outside. Window placement may be of particular interest for urban 5G NR services, where Inter Site Distance (ISD) is small but it is still essential to minimize wall, window and deep indoor attenuation losses. For outdoor window placements, a Wi-Fi unit may also be included, so that RF and power go through the window from an indoor support module, even though securing the required Wi-Fi coverage may be a challenge.

While indoor CPE units are widely available today and sold to end-users in operators' retail stores, outdoor CPE units are normally owned, controlled and managed by the operator, with continuous management and supervision of performance done via TR-069/TR-143 (see the description of CPE management). The outdoor CPE functions as a network termination point, where quality of service is measured and secured. With an indoor device there is always a higher uncertainty of the positioning and the corresponding radio link quality, as well as the risk that it gets moved or obstructed somehow.

If the operator wants to offer voice services, the indoor CPE or the stand-alone RGW should contain a SIP client that is compatible with IMS VoIP telephony, so that an RJ-11 device can be connected (see the description of voice support).

The type of CPE that makes best sense for an FWA deployment depends on many factors, including ISD, topology, offered service levels and number of households connected.

CPE performance difference



Outdoor CPE will improve spectrum efficiency, and allow 2–3 times as many served households with comparable service levels.

Alternatively, 2–3 times as much spectrum is needed for indoor CPE.

The biggest difference between outdoor and indoor CPE versions is the ability to achieve promised service levels, especially during busy hours. An indoor CPE device is comparable with a smartphone user in terms of the radio resources required, or slightly worse as it's always located indoors. By contrast, an outdoor CPE device has the advantage of a 15–25 dB better signal quality, which equates to lower Mbps production cost, higher speeds and better coverage – which is especially valuable further out in the cell in mid-band and mmWave deployments.

An outdoor CPE provides the best performance as it has an in-built directional antenna (for example, 10–14 dBi at 3.5 GHz) and is installed with a predictable radio link quality to the selected Radio Base Station. The typical antenna configuration has two Rx antennas, but devices with four Rx antennas are also available. More Rx antennas can be useful in urban environments, as multiple signal paths are available to the device. However, the transmission mode for a single CPE is still only rank-2 as the modem is expected to be installed with good line-of-sight or near line-of-sight.

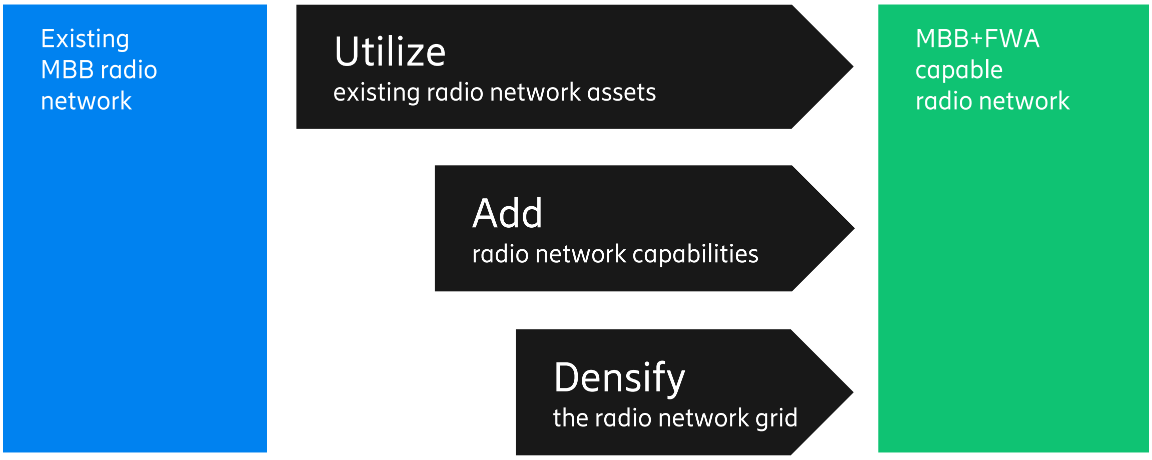
A correctly installed outdoor CPE is directed to the best serving cell, leading to a lower link budget path loss and improving the utilization of mid-band and mmWave TDD spectrum. The large gain in signal quality is a result of the 10–15 dB difference in antenna gain and the avoidance of another 10–15 dB in wall/window attenuation losses suffered by indoor devices. Another contributor to signal attenuation in indoor devices is the deep indoor loss, as the device is likely to be placed in a hidden location, perhaps to provide optimal Wi-Fi coverage, contributing another 5 dB in path loss.

Whereas indoor CPE is comparable to a smartphone in terms of spectrum efficiency, outdoor CPE is typically two to three times more efficient. Put another way, for the same data consumption, around two to three times as many households can be served or, alternatively, two to three times as much spectrum would be needed to serve indoor-only FWA households. A final advantage of outdoor CPE is that the relative performance difference between the best, median and worst users is significantly lower, which makes FWA commercial agreements easier.

End-users may detect that they receive fairly good coverage and acceptable speed with an indoor device, but this can change very fast once a specific cell gets loaded with more users. In an unloaded cell, any user can get many radio resources (PRBs) allocated, and achieve acceptable speeds whatever the radio link quality and the fact that only QPSK modulation may be possible, for example. In a loaded busy hour scenario, significantly fewer resources get scheduled and only the devices able to handle higher modulations (such as 64- and 256-QAM) can achieve acceptable speeds.

The modulation and channel coding scheme are determined by the devices' continuous Channel Quality Indicator (CQI) feedback in the uplink. A lower CQI indicator will make it very 'expensive' for the radio network to stream higher data rates, for example for video and TV with a lower modulation level.

FWA toolbox



An existing mobile radio network, normally designed for voice and mobile broadband, is an excellent base for offering an FWA service. Depending on the radio network starting point and the operator's ambitions for FWA, there is a toolbox available to make the network capable of handling a combination of voice, mobile broadband and FWA in combination.

This document describes these tools under three main categories:

- **Utilize** the existing radio network assets
- **Add** radio network capabilities, and
- **Densify** the radio network grid

A well planned mix of these tools should be deployed to meet the particular needs of each local situation.

Utilize existing radio network assets
The ability to utilize existing radio network assets is a fundamental advantage that sets mobile operators apart from start-ups or greenfield competition in the FWA market. However, the advantage is only fully realized if all relevant RAN assets are efficiently combined for voice, MBB and FWA. If the operator chooses to not utilize existing assets built for voice and MBB, the financial case for FWA becomes more difficult, which reduces the number of economically viable local areas for FWA. It also levels the playing field with stand-alone FWA providers and so opens up unnecessary competition.

Radio network assets to utilize include:

- Existing radio sites – a very important asset, both when sites are operator-owned and when rental agreements and processes exist with tower company-owned sites. The 'tool' of utilizing existing sites is not used by itself, but in combination with other actions to make those more cost-efficient.
- Spare load in deployed spectrum and associated deployed radio, baseband and transport network equipment, which is quite common in FWA target areas. A very efficient tool, since it ca be realized without new CAPEX.
- Acquired but undeployed spectrum – a situation common in FWA target areas, making radio deployment in new bands possible without the cost of acquiring new spectrum.

Add radio network capabilities
In a mobile broadband RAN, radio capabilities are continually added to handle more traffic, more customers and higher app coverage. To handle FWA as an additional service, some of these additions may have to be made sooner, to achieve a combined network with sufficient capabilities. Again, the opportunity to add capabilities and co-finance these from MBB and FWA together is an important advantage for an existing mobile operator.

Radio network capabilities to add include:

- Add spectrum – upcoming wide spectrum bands in 3–6 GHz and mmWave open up potential for high data rates and capacity, benefiting both MBB and FWA.
- Add higher-order modulation, MIMO and beamforming – offering the potential to squeeze out the most from each spectrum band.
- Add FWA-tailored software features – important capabilities to handle FWA in its own right, and to provide adequate quality to MBB and FWA in shared deployments.
- Add additional sectors on existing sites.
- Add 5G NR access – designed for low latency and for wide spectrum bands, creating an excellent overall network together with LTE.

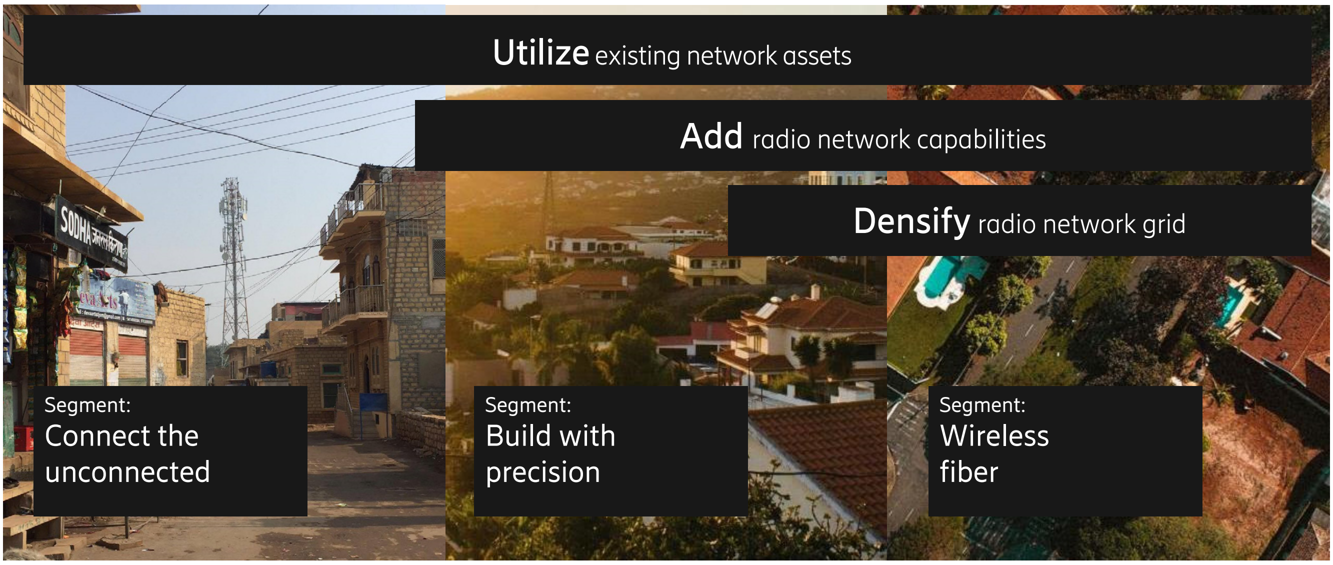
Densify the radio network grid
Densification of the radio network grid is an established way of increasing area capacity. In FWA target areas, and when the 'utilize' and 'add' tools have been used to their full potential, densification can offer further gains. Normally in such areas, there needs to be action taken to enhance MBB so, again, the MBB and FWA upgrade needs should be considered together and should co-finance densification of the network.

Options for densifying the radio network grid include:

- Macro site densification – this is an opportunistic approach: where new macro sites can be found, such opportunities can be taken.
- Small cell site densification on poles – can be needed if the macro grid is sparse and the operator's ambition level is high.

As described, these tools are also used to improve MBB, and since we advocate sharing resources and assets between MBB and FWA, all the actions taken will benefit both services simultaneously. This means that both decisions and financing of the actions can be taken jointly, considering both MBB evolution and FWA.

Choose FWA tools depending on segment



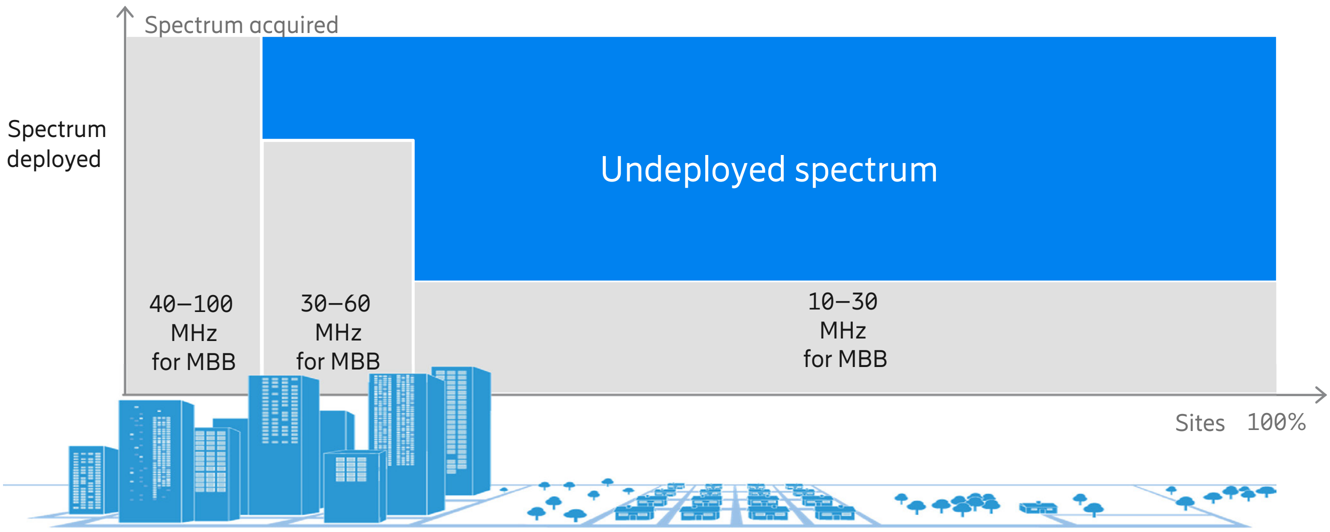
The choice of tools used depends on the network starting point and the operator's ambition level for the FWA offering; it is highly correlated with the segments we use to describe the FWA markets.

'Utilize existing network assets' is always applicable, across all segments.

'Add radio network capabilities' is mostly applicable in 'Build with precision' and 'Wireless fiber' segments, where ambitions are higher and there is competition with fixed broadband, driving the need for higher-rate offerings and capacity.

'Densify the radio network grid' is mainly applicable when absolutely needed, typically only for the 'Wireless fiber' segment, as it drives cost which need to be matched by a corresponding ARPU level.

Utilize acquired but undeployed spectrum



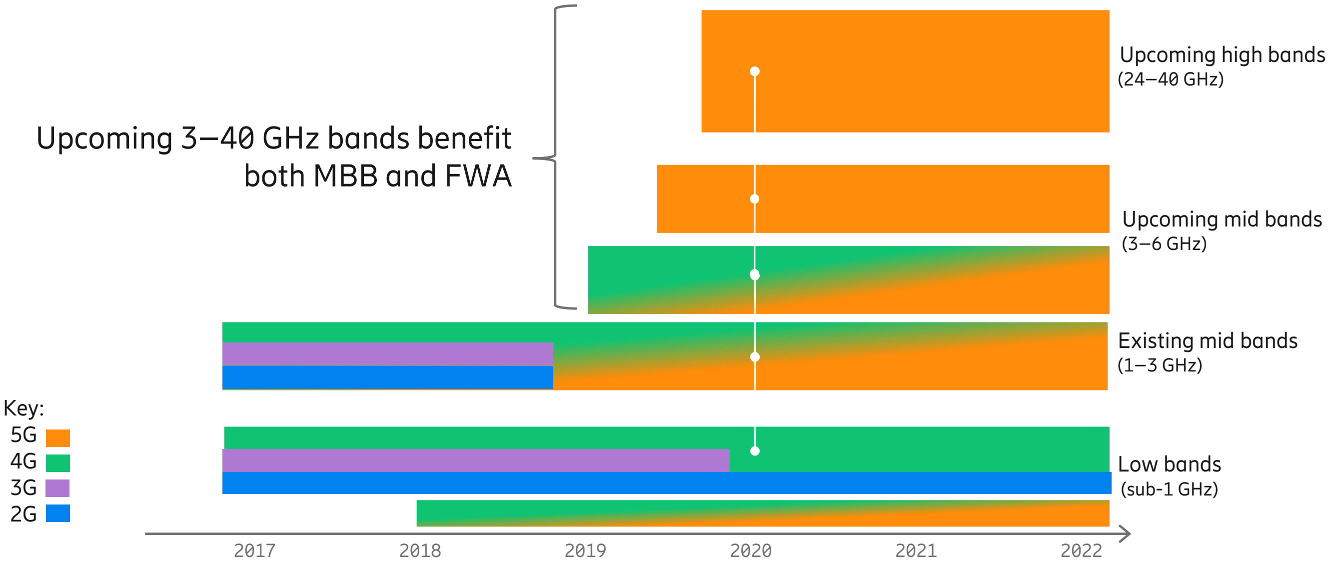
Spectrum is normally auctioned and acquired nationwide or over large areas or markets, including urban, suburban and rural areas. The full capacity is often only needed in urban areas for MBB.

The spectrum already acquired in auctions, but still undeployed in suburban and rural areas, is a great asset for which large investment are already made. For example, the US AWS-3 spectrum auction in 2015 raised close to USD 45 billion (FCC, 2015).

The geographical fit for FWA is excellent, since FWA targeted areas are often suburban and rural, where unused spectrum is most prevalent.

Utilizing undeployed bands and adding radios for them is a natural next step to cater for FWA, if utilizing previously deployed bands is not sufficient to meet FWA ambitions. Baseband and RAN transport equipment can be reused from the existing deployment, but a new dimensioning exercise is needed (see specific case studies).

Add new spectrum bands and radios



New spectrum with large bandwidths is becoming available in increasing quantities. This includes mid-band TDD spectrum in the 3.5–4.5 GHz range, 20–100 MHz per operator, and high bands in the mmWave range, notably 28 and 39 GHz, 400–800 MHz per operator.

Such broad bands can carry large amounts of traffic. This is one of the reasons the FWA opportunity has come to the fore recently.

All these bands are important for enhanced MBB and can also benefit FWA – as long as operators view their spectrum assets as one common pool, and deploy carrier aggregation between LTE carriers, and dual connectivity with NR (which we strongly recommend as a general rule).

The US case of CBRS (3.5 GHz) deserves a special mention, since it is a shared frequency with an incumbent military system. While not strictly always available in all cells throughout the country, it is believed that this band will be important for the US market in the coming years.

Add 5G NR capabilities

	Solutions	Benefits
New Bands	Beamforming Demand-adaptive cell technology Multi-X connectivity	Increased data rates: 20/10 Gbps DL/UL Extended usage of high bands Increased cell edge performance: 2–3-fold
Enhancements	Ultra-lean design Multi-user MIMO Dynamic TDD	Increased spectral efficiency: 3-fold Energy efficiency: 5–100-fold Reduced cost per bit: up to 10-fold
New services	Multi-service optimized radio Low latency Forward compatibility	Increased capacity: one million connections per square kilometer Ultra reliable communications: 'five-nines' Sub-millisecond latencies

5G NR access is standardized in 3GPP and provides a range of important benefits.

The technology solutions can be divided into three sub-categories; new bands, enhancements and new services.

New bands
New bands are needed to make larger chunks of spectrum available to operators. The bands used for mobile communication today are simply not wide enough to support tomorrow's traffic needs. To get access to wide bands, one has to go to higher frequencies, which comes with some challenges. The link budget in higher bands is much more challenging, as a result of increased free-space path loss and increased additional loss from diffractions and penetration. To make the high frequency bands usable, some new and improved technical solutions are needed:

- **Beamforming** – the ability to focus the transmitted energy in narrow 'beams'. Focusing the energy in the desired direction can compensate, at least partly, for the worsened link budget. Also, focusing the energy in the wanted direction instead of 'broadcasting' across the entire cell reduces interference
- **Demand-adaptive cell technology** – system and traffic control channels can be transmitted on sites and resources optimized for coverage and robustness. The is the option to turn on booster cells for user traffic if mobiles enter the coverage area
- **Multi-X connectivity** – transmission from multiple sites and RATs to enable the use of higher-frequency bands. Cell edge users can more than double their data rates by being simultaneously connected to LTE and NR.

Benefits of these include:

- Increased data rates – 20/10 Gbps DL/UL
- Extended use of high bands
- More than double the cell edge performance from multi-X

Enhancements
General enhancements can be made to improve spectral and energy efficiency, as well as reduce cost per bit:

- **Ultra lean design** – this involves minimizing network transmissions not directly related to user data delivery; for example, removing always-on reference signals (transmissions carry their own reference signals), and implementing on-demand system information and long periodicity of sync signals. This results in reduced interference and therefore increased capacity and data rates as well as increased energy-efficiency
- **Multi-user MIMO** – this involves using the narrow beams created by beamforming to transmit and receive data to and from multiple terminals using the same time and frequency resources; the terminals will only be separated in space. The higher the number of narrow beams, the higher the potential gains, since more terminals can be separated in the spatial domain
- **Dynamic TDD** – this involves dynamically controlling transmission direction based on instantaneous load, leading to a gain in object transfer delay (lower delay, leading to higher experienced end-user data rate)

Benefits of these include:

- Increased spectral efficiency – 3 x IMT-A transmission point (TRP), including MU-MIMO gains
- Increased energy performance – 100 x unloaded, 5 x loaded
- Reduced cost per bit – 10 x reduction

New services
Several improvements can be made to allow for new services that have new requirements, such as massive IoT and mission-critical IoT:

- **Multi-service optimized radio** – the flexibility to adapt various radio/RAN characteristics to the specific needs or capabilities of a certain service or device, and multiplex these on a common radio/RAN resource. Advanced scheduling mechanisms bridge the required characteristics of a slice, and high resource optimization
- **Low latency** – there are several improvements that can reduce latency:
  - Short scheduling units – short regular slots (for example, 125 ms at 60 kHz subcarrier spacing) and mini-slots (arbitrary starting point and length within a slot)
  - Fast retransmissions, for example by frontloading reference and control signals to enable rapid data demodulation and decoding
  - Uplink grant-free transmission to give fast access to the channel
- **Forward compatibility** – the option to extend the radio access technology with new capabilities and new technology components, while retaining support for legacy devices. Some design examples include minimizing always-on signaling, keeping transmissions together and avoiding static/strict timing relations.

Benefits of these include:

- Increased capacity – 1,000,000 connections per km^2
- Ultra-reliable communications – 99.999 percent
- Sub-millisecond latencies – <1 ms RTT
- Ready for future killer apps – 5G relevant for 10-plus years, despite technology acceleration

All numbers mentioned are based on the IMT-2020 requirements, and we believe that product performance may be able to exceed these numbers in many areas.

Densify with micro on poles

Densification using outdoor small cells is an option when utilization of existing assets and adding radio capabilities are not sufficient to meet FWA ambitions, and no macro densification is possible. This is a high-investment action, due to the relatively limited coverage area per site and the consequential high transport and site cost per household covered. It is a powerful tool, but should be used very selectively.

First, it is worth noting that microcells on poles are already deployed in various ways across different markets. A large variety of equipment is already installed on lighting and utility poles, and not just cellular equipment. The images on the left show such installations in North America. Often, there are permits to load the poles with considerable equipment weight and size, so it is not always the case that weight and size limitations limit the installation of normal microcells on poles. Of course, local regulations vary, and it is possible to find areas where the use of existing poles is virtually impossible, and others where the use of poles is perfectly viable for today's microcells and associated equipment.

Since the cost of acquiring the site and deploying its transport is high per area covered, the strategy must be to aim for maximum possible use of the site. Therefore, as many frequency bands as possible should be deployed, including both LTE and NR, and especially those used in smartphones, to also get an instant MBB benefit from the new site.

The availability of utility poles is heavily dependent on the use of overhead power lines. These tend to be common in parts of the Americas, and are a good asset when searching for FWA deployment target areas.

There is a need for good and easily deployable RAN equipment on such poles – both when using legacy poles, and when exchanging the light pole infrastructure with new poles ready-equipped with RAN equipment. The images above show some examples of efficiently deployable RAN solutions.

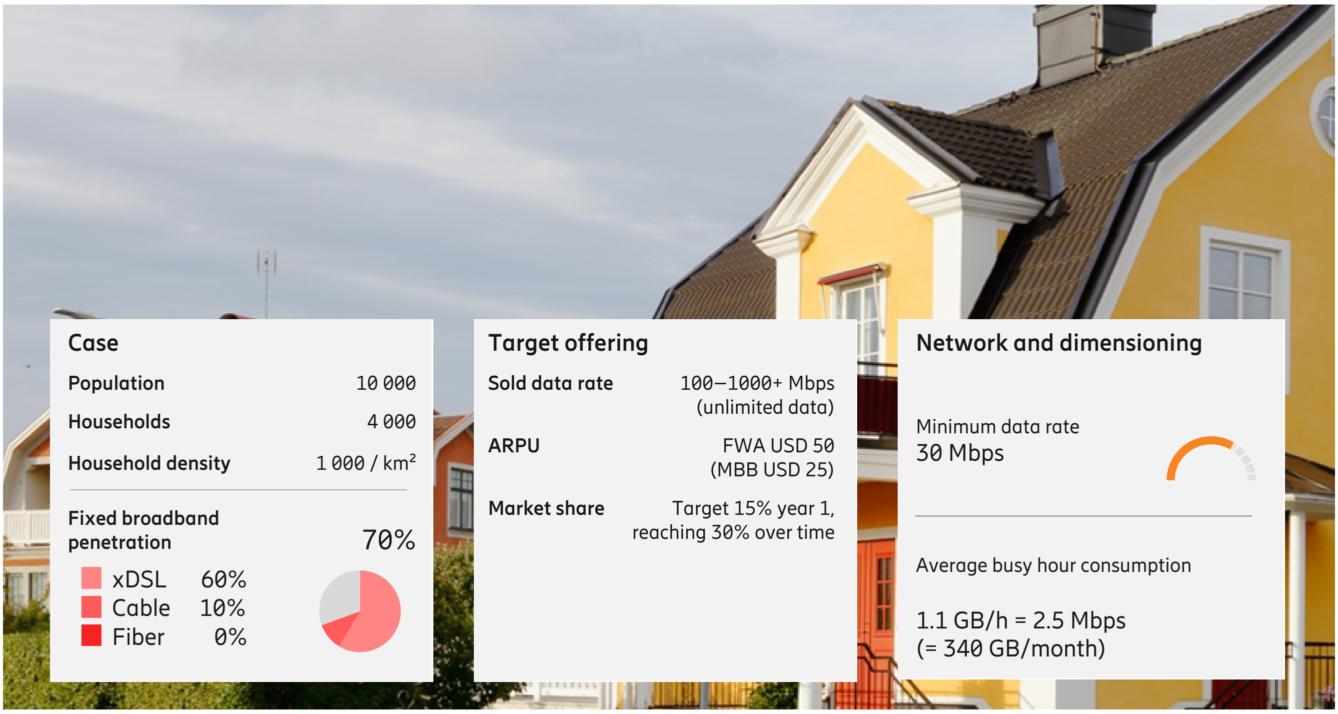
Site acquisition is another key factor: unlike macro sites, small cell sites must be acquired in bulk, for the process and administration cost to be viable. For example, site access can be obtained to all poles in a certain neighborhood or all bus stops in a certain area. However, this should not be confused with the density at which base stations are actually deployed at FWA launch. As we will examine in the transport section, providing transport connectivity to a pole site is a substantial cost item, so while the site acquisition needs to be done in bulk, the actual deployment has to be done selectively, with almost surgical precision to minimize transport deployment cost. Undeployed pole permits can be saved for further densification at a later date, if possible.

Finally, in some situations, strand mounting may be a cost-efficient deployment variant, although for that case, weight and size of equipment really matter more, and tend to drive a higher site density. This, in turn, increases overall transport cost and other cost items that scale with the number of sites.


ERICSSON
PHILIPS

3. Tailored network solutions for different segments

Case: The European suburb



'The European suburb' represents a market within our 'Wireless fiber' FWA segment, characterized by relatively mature LTE MBB, decent fixed broadband offerings (mostly ADSL), but with no general fiber infrastructure deployed in the targeted areas.

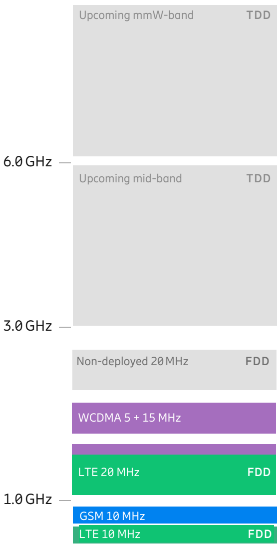
In the case study we assume a population density of 2,400 people per km^2 and, with an average of 2.2 people per household, that means 1,000 households per km^2.

Typical ARPU for MBB is around USD 25, and we expect to be able to charge USD 50 for a dedicated household FWA Internet service with a sold rate of 100–1,000+ Mbps and 'unlimited' data (with limitations against excessive consumption in the contract, as with fixed broadband services).

The operator uses the following as the basis for dimensioning the system:

- The network should be designed to be able to connect at least 30 percent of households with a target of 15 percent for the first year
- The households' TV needs are assumed to be served by the FWA service, via an IPTV bundle
- For video streaming support, households should, when needed, experience at least a minimum data rate (R_{min}) of 30 Mbps even during busy hours. This corresponds to two 4K HDTV video streams, or a combination of multiple SDTV and HDTV streams (see the chapter 'Household data rates and data consumption').
- Based on the operator's experience from similar FWA areas, the average household's consumption during busy hours is 1.1 GB/h, corresponding to an average data flow of 2.5 Mbps during busy hours (With the assumption of 10 percent of data being consumed during a busy hour, this would correspond to 340 GB per month).

Network starting point



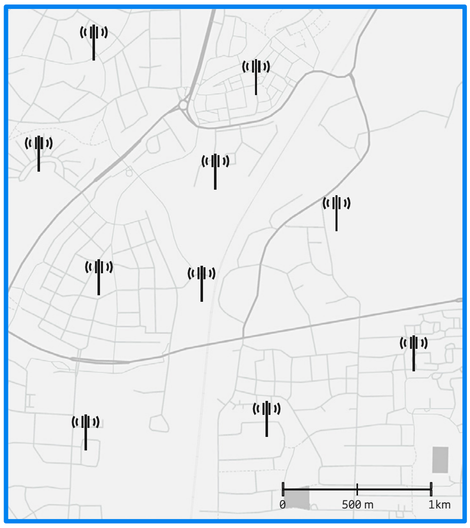
Three-sector macro, inter-site distance 1 km, height 20m

30 MHz (20+10) FDD LTE deployed to handle LTE smartphone traffic

WCDMA and GSM to handle legacy UE

LTE capacity utilization around 40% to handle MBB

Optical backhaul transport



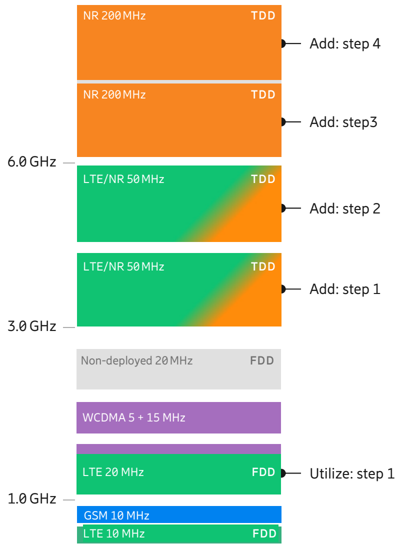
The starting point for this case is a network dimensioned for MBB capacity. There is a grid of macro sites with three-sector antennas and an average ISD of about 1 km, which means an average of 870 households per site. The operator has access to six FDD bands: three bands below 1 GHz (typically 700–900 MHz), and three bands in the 1–3 GHz range (typically 1,800, 2,100 and 2,600 MHz), but all bands are not deployed as the population density is lower than in urban environments.

Most of the smartphones are LTE-capable, and there is also GSM and WCDMA coverage to handle simpler phones. A typical macro site has one LTE carrier on 800 MHz and one on 1800 MHz as well as a WCDMA carrier in the 2,100 MHz band, and a GSM carrier in the 900 MHz band. The 2,600 MHz band is not deployed in this area.

Using the LTE smartphone forecast for Western and Central Europe for the end of 2019 from the Ericsson Mobility Report (Ericsson, November 2018), high-level analysis shows that the deployed LTE capacity is less than 50 percent utilized, given the LTE smartphone subscriber density in the area. This means that there is some spare radio capacity that can be utilized by FWA as well as to handle the expected growth of MBB traffic.

The macro sites are backhauled using fiber-optics and the transport is dimensioned to provide the LTE peak rate achievable using the deployed spectrum in one sector per site (around 225 Mbps with 30 MHz and 64QAM) – meaning it is sufficient for current MBB with some spare capacity.

Overall solution



Utilize existing macro sites, baseband and transport
Utilize available spare capacity on deployed sub-3 GHz bands for LTE

Utilize acquired but undeployed 20 MHz FDD band for LTE

Add LTE/NR in TDD midband (e.g. 3.5 GHz)

Add NR in TDD mmWave band (e.g. 28 GHz)

Add baseband and transport capacity

Use all LTE carriers above 1 GHz for MBB and FWA
– **Add** QoS/slice separation

Outdoor CPE focus to maximize performance
– Indoor CPE as complement

Here is an overview of the solution for introducing FWA services for this case.

Utilize
We recommend utilizing the existing sites, radios and baseband deployed to provide MBB, and sharing these resources with MBB users. Current deployments have spare capacity both in LTE carriers and in baseband units. To reduce requirements on the CPE, and reduce complexity, we have not anticipated support for bands under 1 GHz, even though we recommend also using such bands if supported by the CPE.

Carrier aggregation improves peak speeds as well as coverage for both MBB and FWA services.

Due to the ambition to provide 'fiber-like services', it will not be sufficient for the first step only to utilize the un-deployed 2,600 MHz FDD band. Instead, a 50 MHz TDD allocation in 3.4–3.8 GHz band is used (see below). (If the new capacity deployment is instead primarily driven by MBB, it may be desirable to use the 2,600 MHz band as well for MBB and FWA traffic, particularly if a large proportion of smartphones do not support the 3.4 – 3.8 MHz band. This could be delayed until steps 2, 3 or 4 need to be taken, but this variant has been left out of our analysis for simplicity.)

Add
As a part of the first step, a new 50 MHz TDD allocation in the 3.4–3.8 GHz band is added, either with 4G LTE or 5G NR. New 8 Tx/Rx radios and baseband are added for the new band.

In step 2, a second 50 MHz TDD allocation in the 3.4–3.8 GHz band is added. As spectrum allocation varies from country to country, we have anticipated that the band for step 2 is non-contiguous with that of step 1. We therefore have, conservatively, included new radios for step 2.

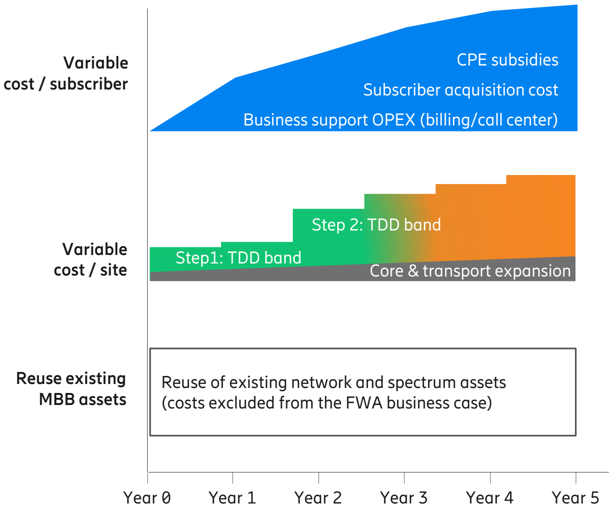
If even higher capacity is needed in the future, mmWave band can be added. In this case study, we have added 200 MHz TDD bands in steps 3 and 4. Massive MIMO radios and baseband are added in step 3, and these are capable of handling both step 3 and step 4.

Again, due to the differences in spectrum regulations, some operators might take step 3 before step 2.

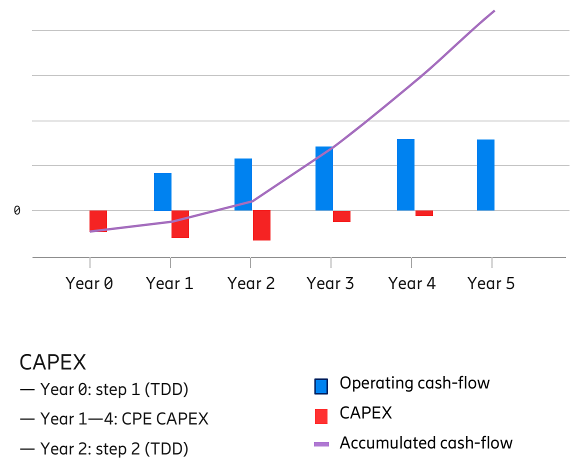
In all steps, baseband and transport capacity needs to be revisited and potentially upgraded to handle higher peak rates.

Business case financial results

Cumulative OPEX and CAPEX – low upfront investment



Cash-flow base case – payback in 18 months



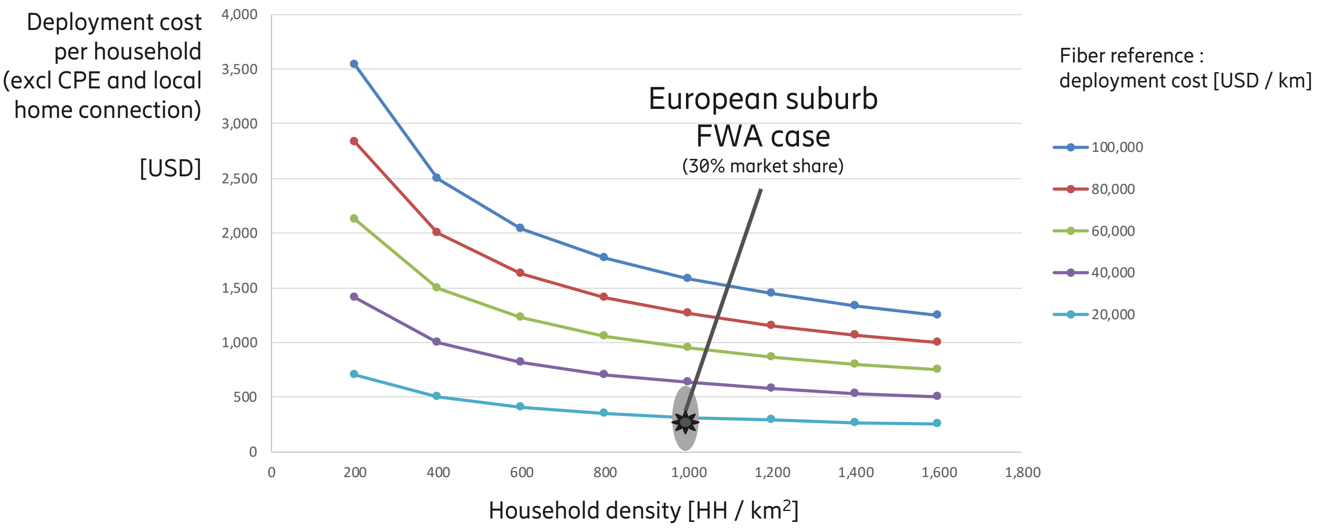
OPEX and CAPEX investments over time
FWA investments (OPEX and CAPEX) are very scalable, varying with subscriber uptake and number of site deployments. This is an important advantage over fixed broadband and fiber, where the investment profile is characterized by large upfront investments, before subscriber uptake is known. Moreover, FWA reuses existing MBB assets, including site infrastructure and spectrum assets.

Incremental FWA OPEX includes power consumption, backhaul transmission, core and network support, as well as subscriber acquisition costs and incremental business operation costs. The incremental CAPEX includes network systems and indoor CPE (fully subsidized in this case). Network CAPEX includes radio and baseband hardware, software and installation services, as well as a cost allocation of 10 percent of the radio CAPEX to allow for incremental transmission and core costs.

The left side of the illustration shows cumulative OPEX and CAPEX divided into variable cost per subscriber and variable cost per site for each of the first five years. The variable cost per subscriber grows with the new subscriber uptake, reaching 30 percent market share at year 4. The site-related variable costs, both CAPEX and OPEX, where step 1 radio, baseband and other site equipment is taken for year 0 and year 1 onwards, also include RAN OPEX. Step 2 is taken at year 2, ahead of the capacity needs expected for year 3.

Cash-flow – payback in 18 months
The estimated revenues are based on a monthly ARPU of USD 50, growing with subscriber uptake over time. The operating cash-flow (dark blue) in the cash-flow graph is represented by the difference between annual revenues and FWA operational costs. Annual CAPEX is related to CPE costs (distributed over years 1 to 4) and network CAPEX, where network investments take place at year 0 (step 1) and year 2 (step 2). The accumulated cash-flow curve indicates break-even in about 18 months from launch, resulting in an attractive business case.

Network deployment cost of European suburb FWA case compared with typical fiber cost range



Fiber deployment costs
Here, we compare deployment costs for the European suburb FWA case with fiber deployment costs. The fiber deployment costs are estimated using a simplified regular suburb model, with single-resident houses in a rectangular grid, evenly distributed along the streets. The diagram plots the deployment cost per household passed by fiber as a function of the household density. Each of the curves depicts a fiber cost per distance (km) of between USD 20,000 to 100,000 per kilometer, which is a common range in developed regions such as Europe. These differences in cost for fiber deployment relate to the type of terrain (sand, rock, etc.), the permits needed and the deployment type (for example, aerial or underground). It should be noted that the curves are plotted for all fiber-passed households (that is, 100 percent market share), so the real cost per connected household would be higher.

Comparison of fiber deployment versus FWA
The European suburb FWA case assumes a household density of 1,000 households per square kilometer, and an ambition to address 30 percent of the market. As our business case concludes, the deployment cost of the FWA solution is below USD 500 per connected household. We have marked this point in the diagram above, to show that the FWA network deployment cost for this particular case is lower than that of fiber, even when the fiber deployment cost is as low as USD 20,000 per km.

It is worth highlighting a few points about this comparison.

- The comparison excludes both the cost of the CPE and the local installation to and within the household (that is, the fiber from the curb to the house in the fiber case, and the cabling from an outdoor CPE in the FWA case). CPE and local installation costs are assumed to be within the same range, in the order of USD 400–1,000 for both FWA and fiber installations.
- The comparison excludes OPEX, which is typically higher for FWA than for fiber. This means that over longer time periods, fiber could be a more sustainable investment despite its higher deployment cost.
- As mentioned above, the fiber deployment is designed to handle 100 percent market share and total cost is distributed across all households in the area. However, in practice, the market share of connected households is often much lower. For example, if the fiber-connected household market share is 30 percent, the cost per connected household would be 3.3 times higher than in the graphs above. This highlights the high upfront investment characteristics and associated business risk of fiber deployment.
- A further advantage of FWA over fiber is its anticipated shorter time to market.

4. Abbreviations and references

3GPP	3rd Generation Partnership Program
ADSL	Asynchronous Digital Subscriber Line
APN	Access Point Name
ARPU	Average Revenue per User (per month if not stated otherwise)
AWS	Advanced Wireless Services
BNG	Broadband Network Gateway
BSS	Base Station (Sub)system
BSS	Business Support Systems'
CAPEX	Capital Expenses
CAT	Category
CAT-n	Category n
CG-NAT	Carrier-Grade Network Address Translation
CPE	Customer Premises Equipment
DL	Downlink
DSL	Digital Subscriber Line
EPC	Evolved Packet Core
EPG	Evolved Packet Gateway
FDD	Frequency Division Duplex
FWA	Fixed Wireless Access
GB	Gigabyte
GHz	Giga Hertz
GSM	Global System for Mobile Communications
GW	Gateway
HAG	Hybrid Access Gateway
HDTV	High Definition TV
HSPA	High Speed Packet Access
HSS	Home Subscriber Server
IEEE	Institute of Electrical and Electronics Engineers
IMS	Internet Protocol Multimedia Subsystem
IMT	International Mobile Telecommunications Specification
IMT-A	IMT-Advanced Standard
IP	Internet Protocol
IPTV	IP Television
ISP	In-service performance
ITU	International Telecommunication Network
LAN	Local Area Network
LTE	Long Term Evolution
LTE-A	LTE advanced
MBB	Mobile Broadband
MHz	Mega Hertz
MIMO	Multiple Input Multiple Output
MU-MIMO	Multi User MIMO
NPV	Net Present Value
NR	New Radio
OPEX	Operational Expenses
OSS	Operations Support System
PCRF	Policy and Charging Role Function
PDN	Packet Data Network
POTS	Plain Old Telephony Service
RAN	Radio Access Network
RAT	Radio Access Technology
RGW	Radio Gateway
RJ11	Registered Jack 11
SDTV	Standard Definition TV
SGSN-MME	Serving GPRS Support Node - Mobility Management Entity
SIP	Session Initiation Protocol
SLA	Service-Level Agreement
SME	Small and Medium-sized Enterprise
SPID	Service Profile Identifier
TCP	Transport Control Protocol
TDD	Time Division Duplex
TR-n	Technical Report n (Broadband Forum)
TRP	Transmission Point
TV	Television
UL	Uplink
USD	US dollars
WCDMA	Wideband Code Division Multiple Access
VoLTE	Voice over LTE
VRAN	Virtual RAN
WRC-15	World Radio Conference 2015
WRC-19	World Radio Conference 2019
xDSL	arbitrary Digital Subscriber Line, e.g. ADSL

1. FWA market opportunity
Ericsson, 2019

ITU, 2018

Ericsson Mobility Report November 2018, Ericsson, 2018

ITU-R conferences wrc 2015, ITU, WRC-15

Mobile broadband boosts the economy,
Ericsson and Imperial College London, 2017

GSMA and Strategy Analytics, 2019

Connect America Fund,
Federal Communication Commission, 2017

Connecting Europe Broadband Fund, European Commission and the European investment bank, 2016

Nasjonal kommunikasjonmyndighet, 2018

Samarbeidsprosjekter med kommune i Norge om mobilutbygging, Telenor, 2013

Förutsättningar för samhällsmaster, PTS, 2014

nbn, 2019

Project Loon, Google, 2018

AT&T, 2018

Telefonica, 2019

Analysis Mason, 2019

Jakopin and Klein, 2012

Fierce Wireless, 2018

Jio, 2019

2. FWA solutionData rates, data consumption and subscriptions
How much data does Netflix use?, How-to Geek, 2018.

General Authoring requirement, Video, Apple, 2018

Auction 97: Advanced Wireless Services (AWS-3),
Federal Communication Commission, 2015

3. Tailored network solutions for different segments
Ericsson Mobility Report November 2018, Ericsson, 2018

EN/LZT 2/28701-FGD 101 449 Uen Rev D