GTI White Paper

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Global TD-LTE Initiative

4G Wireless Broadband Industry

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Executive Summary / Introduction

Global internet consumption is growing at an ever increasing pace. More people and more devices connect to the internet every day. According to Cisco's VNI forecast, in 2020 there will be:

- 4.1 billion total Internet users (52% of population), up from 3.0 billion (40% of population) in 2015.
- 26.3 billion networked devices, up from 16.3 billion in 2015.
- 3.4 networked devices per capita, up from 2.2 per capita in 2015.
- 44% of all networked devices will be mobile-connected in 2020.

This growth will be driven by availability, affordability and desirability of broadband services and devices.

New, innovative applications and high quality content are published on the internet on a daily basis. This increases desirability and stimulates demand.

To connect over a billion new subscribers in only a few years, large scale fixed and wireless network deployments will be required.

1. Terminology

Term	Description
CPE	Customer Premise Equipment
ARPU	average revenue per user
CA	carrier aggregation
D-MIMO	Distributed Multiple Input/Multiple Output
DSL	digital subscriber line
E2E	end to end
FTTx	Fiber to the x. Generic term for any broadband network architecture using optical fiber to provide all or part of the local loop used for last mile telecommunications.
FBB	Fixed Broadband, signifying wired connection
FDD	Frequency Division Duplex
GTI	Global TD-LTE Initiative
HBB	Home Broadband
LDC	Least Developed Country
MBB	Mobile Broadband
MIMO	Multiple Input/Multiple Output
MSO	Multi-service Operators
RRU	Remote Radio Unit
TDD	Time Division Duplex
WBB	Wireless Broadband
WTTx	Wireless to the x. For the purposes of this paper, the term WTTx can be used interchangeably with 4G (and beyond) WBB.
xDSL	Refers collectively to all types of digital subscriber lines, the two main categories being ADSL and SDSL

2. Assumptions and Scope

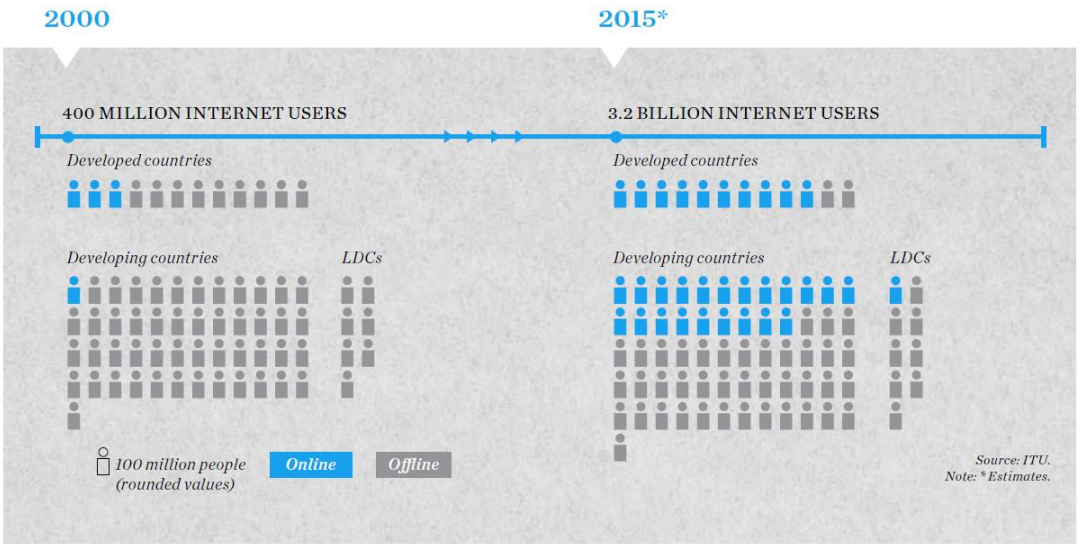
This whitepaper provides an overview of the wireless broadband industry and trends and the specific advantages over fixed broadband in reaching underserved populations. Highlighted are the key benefits and several key use cases illustrating the market potential of 4G TDD spectrum for wireless broadband use.

3. Industry Background / Regional Market Status

3.1. Value Proposition of Wireless Broadband (WBB)

3.1.1. Challenge of the Digital Divide

According to *The State of Broadband 2015* jointly released by the International Telecommunications Union (ITU) and United Nations Educational, Scientific and Cultural Organization (UNESCO), affordable and effective broadband connectivity is a vital enabler of economic growth. As such, it is an essential component of the UN's sustainable development plan. The following figure compares the internet user numbers in 2000 and 2015, as provided by the ITU. It is clear that the internet penetration rate has greatly improved in developing countries.



These numbers are encouraging, but they raise pipe transmission concerns in the information and communications industry. As the internet mushrooms in popularity, people around the

globe are categorized into netizens and non-netizens, and netizens are further classified into broadband netizens and non-broadband netizens.

In the home broadband (HBB) field, an obvious digital divide is being created due to the gap between the rich and poor. Considering the impact of gender, age, occupation, and other factors on internet penetration, promoting HBB for women, the elderly, children, and people not working has more social significance in narrowing the digital divide for the entire society.

Unfortunately, due to the limitations of country/region, educational level, occupation, age, gender, and income, people have access to vastly different amounts of information transmission resources. This fundamentally affects the common development and progress of mankind.

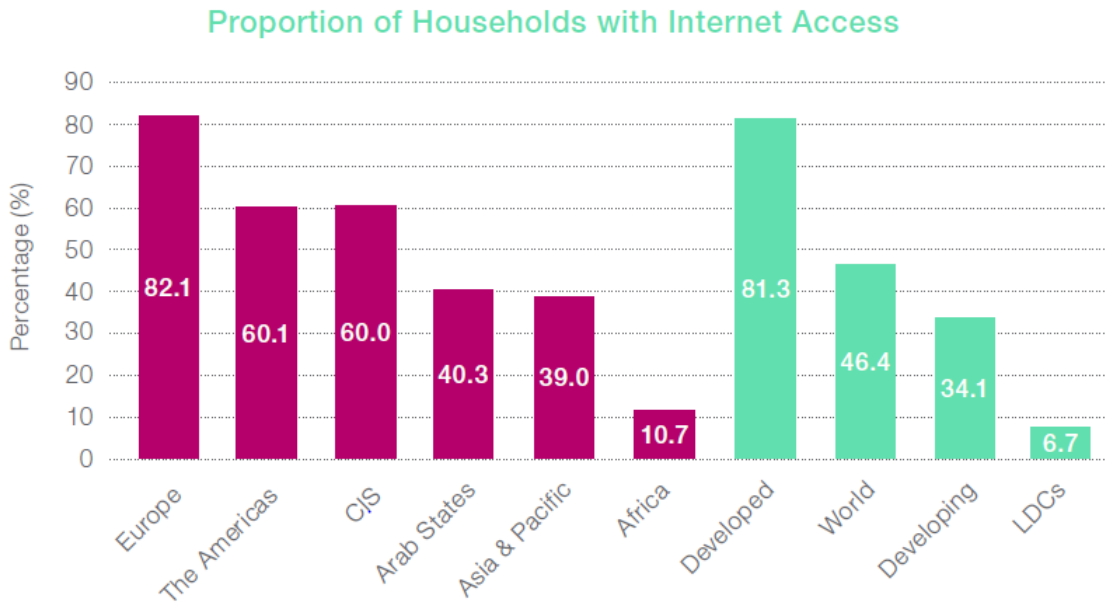


Figure 1: Proportion of Households with Internet Access

As figure 1 above shows, developing and underdeveloped countries have an HBB penetration rate of 40.8%, where approximately 800 million households have no HBB access. Developed countries possess an HBB penetration rate of 81.3%, where approximately 100 million households still have no broadband access.

3.1.2. New Digital Divide

The concept of digital divide is not limited to people's lack of internet access. Households with broadband access still face challenges in the new digital divide. With social development and

technological progress, more and more content is delivered through broadband. As a result, the strength and speed of people's broadband become critical. The following figures illustrate vast differences in broadband access between different countries, different areas in a country, and different people due to inequalities between countries and regions.

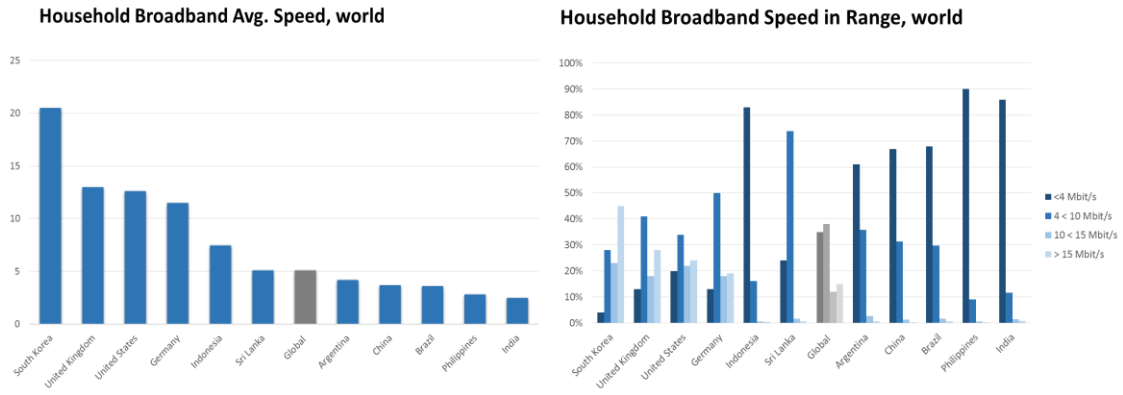


Figure 2: Household Broadband Speed

3.1.3. WBB Helps Bridge the Digital Divide

There are 4.2 billion people worldwide not yet connected to the internet. A key concern is how to give them affordable and effective access to the internet. This is particularly challenging considering basic broadband services cannot meet the requirements of the 3 billion people already connected to the internet. Broadband penetration unquestionably promotes the economic development of a country or region. So how do we quickly implement broadband acceleration? More and more countries have developed national internet and broadband development plans to do just that. We believe that WBB with its unique value can help them address these challenges.

3.1.4. 4G WBB Definition and Evolution

4G WBB mainly serves households and small and medium-sized enterprises whose major service demands are broadband internet access and video. For the purposes of this paper, 4G WBB can be defined as a wireless broadband access solution based on LTE and evolution technologies with performance comparable to wired broadband access. According to service requirements and wired broadband performance, WBB is further divided into three phases from the perspective of evolution:

Phase 1: The single-user rate is less than 10 Mbit/s. Basic internet services and 360P to 720P videos are accessible.

Phase 2: The single-user rate is greater than 10 Mbit/s and less than 50 Mbit/s. 1080P to 2K HD videos are accessible.

Phase 3: The single-user rate is greater than 50 Mbit/s. 4K HD videos are accessible.

As people's requirements for full connection are increasing and wireless broadband capabilities are improving, WBB entering vertical industries has become an inevitable trend. Through the Home Broadband gateway, WBB will be first applied in the smart household field, including video surveillance and smart household apparatus control.

3.2. **Comparing FBB & MBB**

Mobile broadband (MBB) has gone through a golden decade, when the mobile subscription has increased by tens to hundreds fold worldwide, mainly driven by fast technology innovation and a very strong ecosystem.

Unlike the rapid growth and wide penetration of mobile connections globally, fixed broadband (FBB) is progressing very slowly, and the gap between them continues to widen. For FBB, 3.9 billion people are still offline, and many of them are living in developing countries and rural areas. In Least Developed Countries (LDCs), only around one in seven people are online.

According to the data from the ITU, FBB development has stagnated behind MBB in the past years, and the overall penetration rate of MBB has long surpassed FBB and continues to lead ahead.

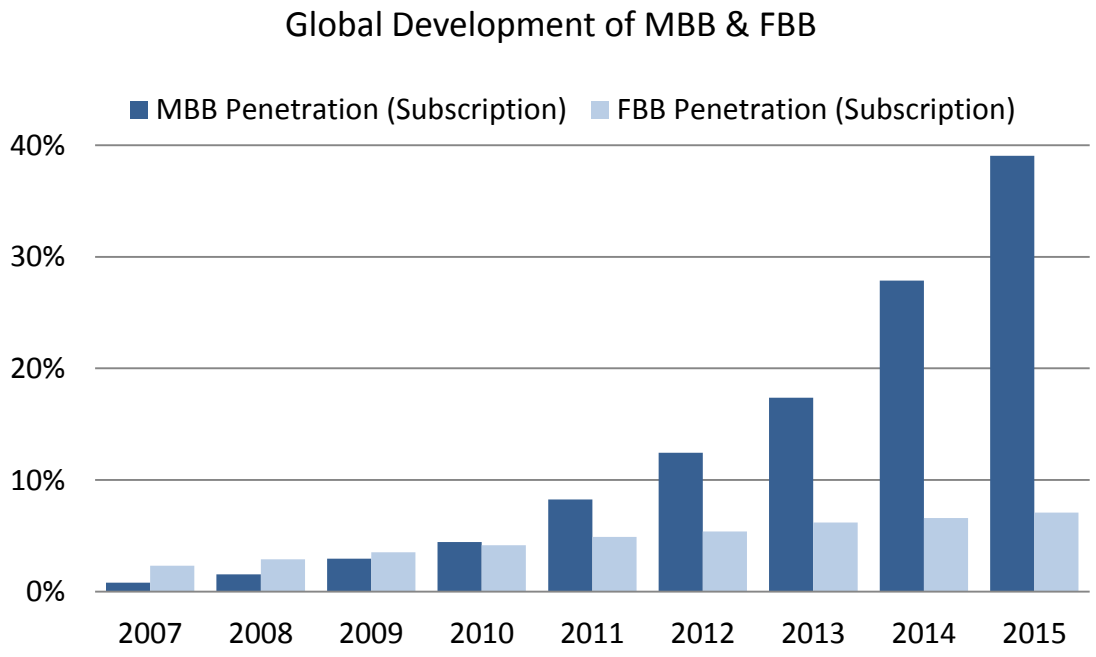


Figure 3: Global Development of MBB & FBB[2]

Two main factors lead to the slow progress of FBB. One is the shift of data traffic from PC to handsets, which is mainly due to the surging prosperity and prevailing popularity of smartphones. The other factor, which is critical from a technical perspective, is the roll out of conventional FBB networks, including FTTx and xDSL. These technologies face tough challenges mostly due to the high cost, when it comes to large scale deployment.

3.3. Regional Market Status

When it comes to FBB itself, another critical issue remains to be solved, and that is the remarkably uneven development of FBB not only at a global level, but also between urban and rural areas. This is another significant difference between FBB and MBB deployment.

According to Ovum Knowledge Centre, the 2016 world average broadband household penetration rate has reached to 42.66%, but the distribution of connected users is unevenly distributed from one place to another, leaving a large population and households still unable to access the internet and benefit from the digital prosperity and economy benefits.

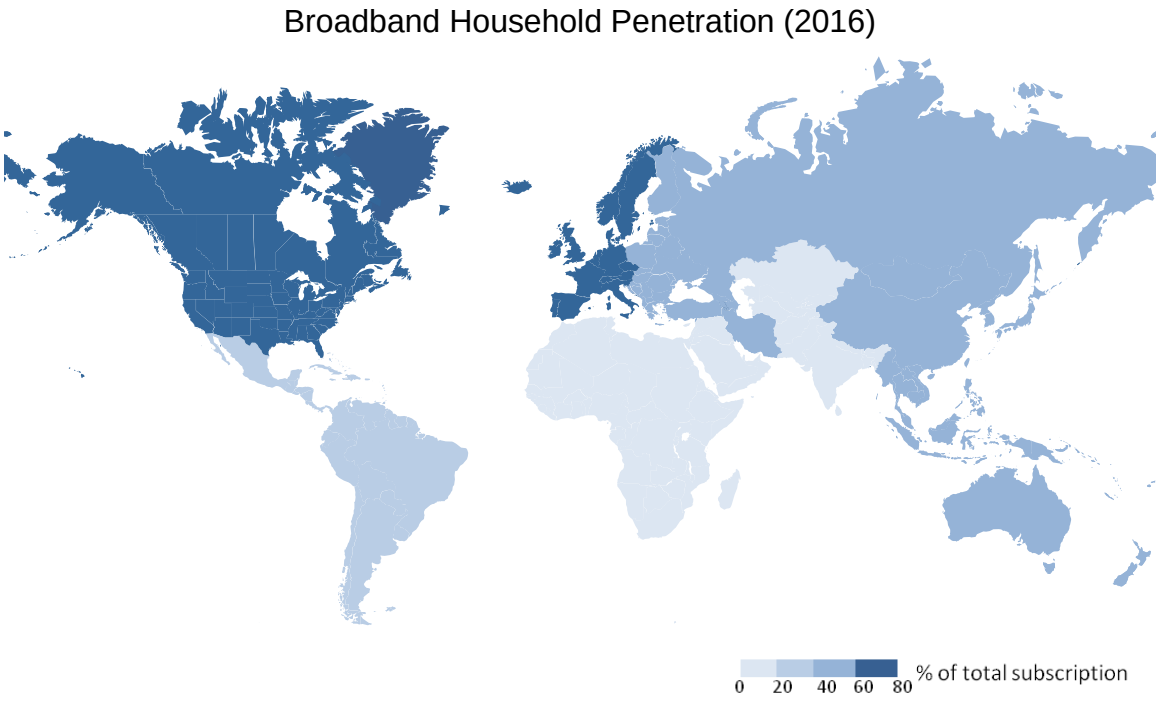


Figure 4: Broadband Household Penetration[3]

Africa and South Asia are the main two regions where the majority of households and businesses are not connected. Using South Asia as an example, this region holds a population of more than 1.8 billion. However, the penetration rate of FBB in most of the countries is even less than 10

percent, much lower than world average. Low economic development and private ownership of land are prohibiting broadband service from reaching more people.

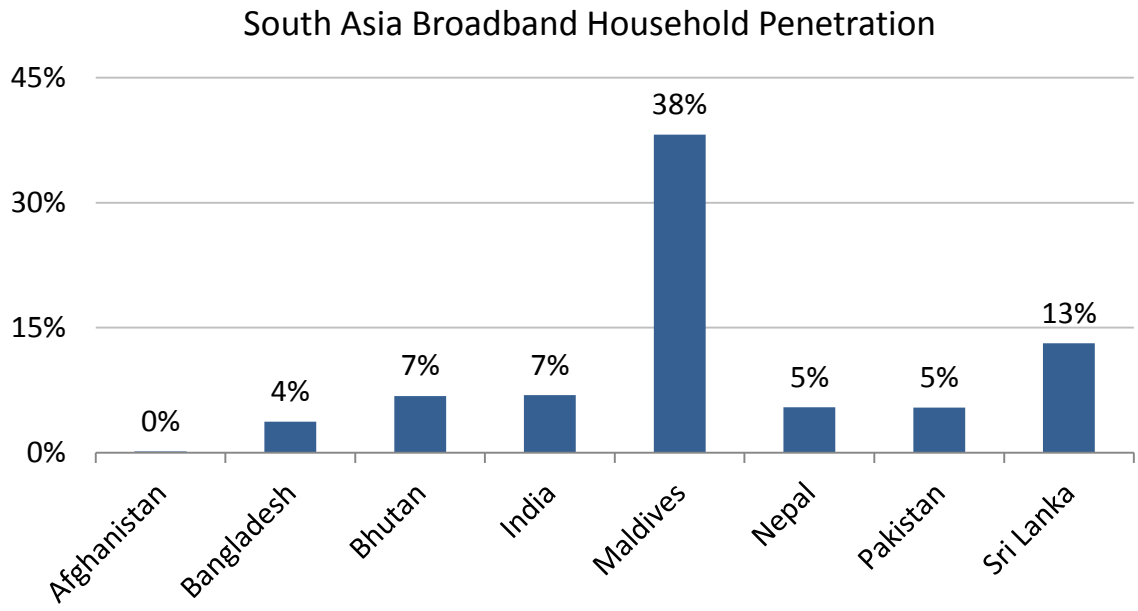


Figure 5: South Asia Broadband Household Penetration[4]

This represents a huge market potential to the telecommunication industry. The key lies in an alternative solution that provides people affordable connections with an experience matching incumbent technologies. WBB is poised to provide that solution. In addition, the difficulties in rolling out fixed lines should be dealt with properly.

4. Key Trends

With the rapid development of the digital economy, the family is increasingly becoming the centre of digital life. The need for universal connectivity means that alternatives to the wired network are more in demand than ever. How to provide sustainable and innovative home broadband service with affordability and efficiency is very important question.

4.1. WBB advantages compared with FBB

Compared with FBB, WBB will be the preferred connectivity solution. There are obvious benefits to wireless connectivity: rapid deployment, fast speed, quick return on investment and low cost to deploy compared to FBB. When it comes to South Asia, it's notable that WBB has already played a significant role for data connection. This delivers a promising future for WBB in the markets, especially in emerging economies.

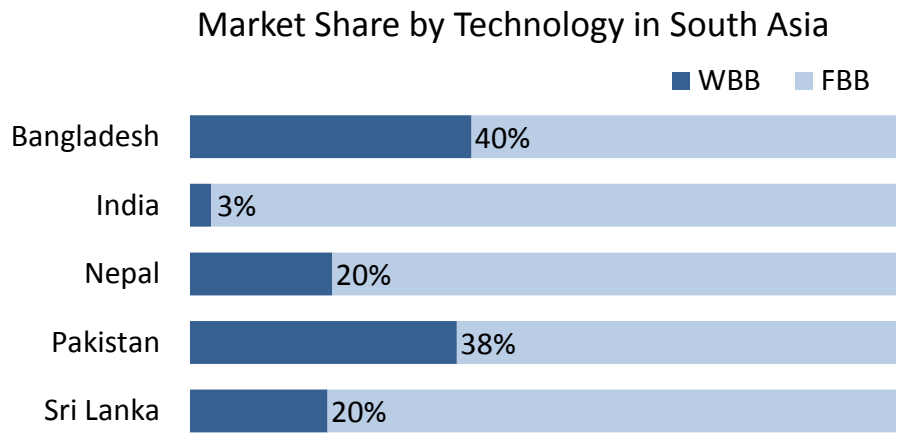


Figure 6: Market Share by Technology in South Asia[4]

4.2. 4G WBB advantages compared with other WBB technology

WBB is a group of several wireless technologies, serving the same purpose, including HSPA, WiMAX, LTE and others. WBB has long been proven to be a favourable approach to deliver broadband connections, where there is no FBB or it's more difficult and costly to be deployed. When it narrows down to a specific access technology, some of WBB technologies lack sufficient industry support. A typical example is WiMAX, which was massively taken for broadband services several years ago. WiMAX operators proved the concept of WBB by a remarkable business success, but lacked sustained support from the industry. That is why WiMAX operators migrating to TD-LTE has become a major trend in recent years. The transition path from WiMAX to TD-LTE is relatively straightforward. The same spectrum band can be used and infrastructure equipment upgrades are possible. Compared with other wireless broadband technologies, LTE has some advantages. First, LTE offers continuous experience enhancements. Increases in the efficient use of spectrum will continue to be achieved with lower-cost products. These innovations include more efficient coding, modulation, MIMO, interference cancellation, and spectrum harvesting using frequency aggregation. Second, LTE industry support is more mature and sustaining. LTE has been proved to be the most successful wireless standard in history.

4.3. 4G WBB enables fiber-like experience

All network users will continue to need high-speed throughput. Emerging multimedia venues, including social applications, virtual reality and e-commerce, require more bandwidth than ever before. High-quality video content and virtual reality will only accelerate this trend, with the bandwidth usage of 720P, 1080P and 4K video averaging 2, 5 and 25 Mbps respectively. For 4G

WBB, with a series of innovative solutions including massive MIMO, massive CA, high-order QAM, can provide xGbps peak rate, users can enjoy fiber-like broadband experience.

4.4. 4G WBB Continuous Evolution

In order to help operators further expand the boundaries of WBB and unlock the latent growth potential of the market, vendors are targeting advancements to help evolve these opportunities. Examples of this work abound, here we introduce two that are supporting the expansion of TDD WBB. Huawei released its wireless HBB (Home Broadband) solution called WTTx 2.0 at the 2016 Global MBB Forum. Huawei's WTTx 2.0 features significant improvements across the dimensions of broadband capability, network convergence, network operation and maintenance, and service provision. ZTE targets high TDD bands with its high power 4T4R & 8T8R radio units helping to extend single site coverage and increase cell throughput. ZTE's pre5G Massive MIMO product aims to increase spectral efficiency and downlink capacity.

Furthermore some leading operators start to explore the use of 5G technology for fixed wireless access. Fixed wireless access is positioned to be one of the first scenarios for 5G with several operators beginning trials including Verizon, AT&T, Telus and T-Mobile.

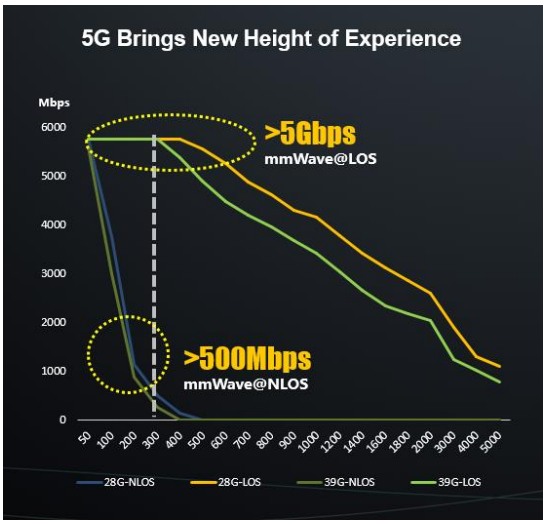


Figure 7: 5G Experience

4.5. 4G WBB Key Features & Advantages

4G WBB can take advantage of the advanced LTE air interface technologies, including carrier aggregation, and multi-antenna technologies such as 4x4 MIMO. Unlike mobile phones, 4G WBB terminals do not have the same stringent power supply and other requirements. In addition, high-gain outdoor CPEs and multi-antenna CPEs are available for 4G WBB application.

All these factors help operators greatly reduce costs, considerably increase gains, and improve user experience. 4G WBB has the following advantages.

4.5.1. Higher Rate: Comparable to Optical Fibres

4G technologies and their evolution provide continuous and significant increase in the WBB users' peak rate experience, from 150 Mbit/s at the initial stage, to 600 Mbit/s, and to the current 1 Gbit/s. User experience of WBB has gone beyond that provided by copper wire transmission and is currently comparable to that provided by optical fibre.

To provide optical fibre-class user experience, 4G WBB adopts 4x4 MIMO to double the transmission rate. In addition, base stations are evolving to super base stations. Single-site capacity increases linearly by using additional carriers. For example, using 100 MHz spectrum, a single base station can provide five 20 MHz carriers, achieving a fivefold capacity increase. Aside from carrier aggregation, many other technologies also greatly improve base station capacity. The Massive MIMO technology, for example, allows spatial multiplexing for a large number of users. Using this technology, a single carrier can provide capacity equal to more than five carriers.

Because of the high transmission rate provided by WBB, Telenor plans to deploy WBB in Norway to improve the coverage and user experience provided by existing FBB networks. To accomplish this, Telenor has obtained the 90 MHz spectrum on the 3.7 GHz frequency band, and performed commercial verification on the WBB. Data reveals that the average experienced rate of a single user can reach 30 Mbit/s when only one 20 MHz carrier is configured. With the 90 MHz ultra-wide spectrum, Telenor is expected to be able to provide an average rate of over 100 Mbit/s in the future.

4.5.2. Improved Coverage

High-frequency coverage is significantly extended thanks to the MIMO technology of RF modules and the higher receive sensitivity of CPEs than mobile phones (even higher outdoors). Using 2.3 GHz, 2.6 GHz, and 3.5 GHz frequency bands, WBB can provide coverage originally allowed by 2.1 GHz and even 1.8 GHz frequency bands.

The super-distance coverage capability of WBB allows network deployment in some typical scenarios, such as suburban and outlying areas. Beyond the standard urban scenarios, Canada provides a great example of a distributed, rural population as well. Canada has a vast, open and sparsely-populated territory. Much of its population lives in big cities, but a considerable part is also distributed in widespread rural areas. Operators have always struggled to serve

this rural segment effectively. Taking advantage of the super-distance coverage capability of 4G WBB technology, Xplornet, the major operator running broadband services in rural areas in this country, is now extending its broadband service scope to every corner of the country. In the process, they are creating grateful customers for life.

4.5.3. Lower Costs: Reduced Time to Market

In comparing WBB with FBB, we see in many countries operators must apply for licenses to perform necessary civil engineering tasks, such as digging trenches and installing poles. They must absorb the cost of up to tens of thousands US dollars on engineering for each kilometer, in addition to sizeable, ongoing costs in cable maintenance. Civil engineering is time-consuming, laborious, and expensive work. However, WBB, offering wireless network advantages, can overcome these obstacles and help operators and users save time and money.

Using 4G technologies such as multiple-antenna technology, WBB improves spectral efficiency, greatly reducing cost per bit and increasing coverage and performance.

Saudi Arabia provides a great example of a challenging environment with its hot climate and drought. Fixed network construction and ongoing maintenance results in high expenses. Because of this, the user base has stagnated and growth has been absent for many years. The original fixed network and 3G WBB operators started to deploy 4G WBB networks in 2012. In the past several years, the user base has taken off again and increased to 3 million.

4.5.4. Flexible Deployment: Available in Both Urban and Rural Areas

WBB networks can be quickly and flexibly deployed. They can be deployed in mainstream urban and suburban areas and also in special scenarios, such as deserts of the Middle East, the islands in the Philippines, rural areas in China, mountainous areas in Canada, and famous historic and cultural sites where cable routing is inconvenient or even not allowed.

4.5.5. Comprehensive Services: Same as Wired Networks

Using WBB services, family members can share wireless connections to the network while watching traditional TV services and enormous videos on the Internet.

Take Netflix as an example. To watch 720P HD videos provided by this company, only 5 Mbit/s WBB connections are required. While for ultra-HD videos, 25 Mbit/s connections must be established.

In addition to video services, WBB networks handle VoIP easily as well. The data, video, and voice triple play of traditional wired broadband is also possible on WBB networks.

In the near future, wireless HBB will be able to use HBB CPEs as a smart home platform to integrate Smart Home services. Video surveillance and intelligent home management will likely become the first batch of applications. This strategy will help expand the blue ocean markets of vertical industries.

5. Market Potential (for TDD LTE)

5.1. Market Opportunity

According to OVUM Total Fixed Broadband Subscription[3], there are 883 million household with broadband access out of approximately 2070 million families in 2016. That is nearly 1200 families that do not have broadband access.

The precise market potential is affected by many factors such as the culture, the economic development in different countries, the distribution/allocation of the users, the construction cost for cabling and base station rental, the telecom budget of user and the strategy that the local operators may take, etc. For the purpose of this analysis, the telecom budget measure approach is used to estimate the potential wireless broadband access market.

Assuming 3% of household income will be used for telecom service (especially families with low income) using a world household income distribution chart leads to the following conclusions. Model-based calculations and research studies on typical-country markets indicate that about 320 to 410 million household users can afford WBB in intensely competitive markets around the world. Fixed broadband users are excluded from the calculation. Factors considered for the calculation and research include essential terminals for household usage such as smart phones, pads, and computers as well as the depreciation of end-to-end (E2) costs.

The figure 8 below shows only the potential market for “connect the unconnected”, no matter which technology will be employed. Certainly we see wireless technology will have huge advantage on aspect of E2E cost, beside the service/performance provided by 4G wireless technology are better than some old facilities like xDSL, therefore we believe that fixed wireless access will have more chance to take the potential market.

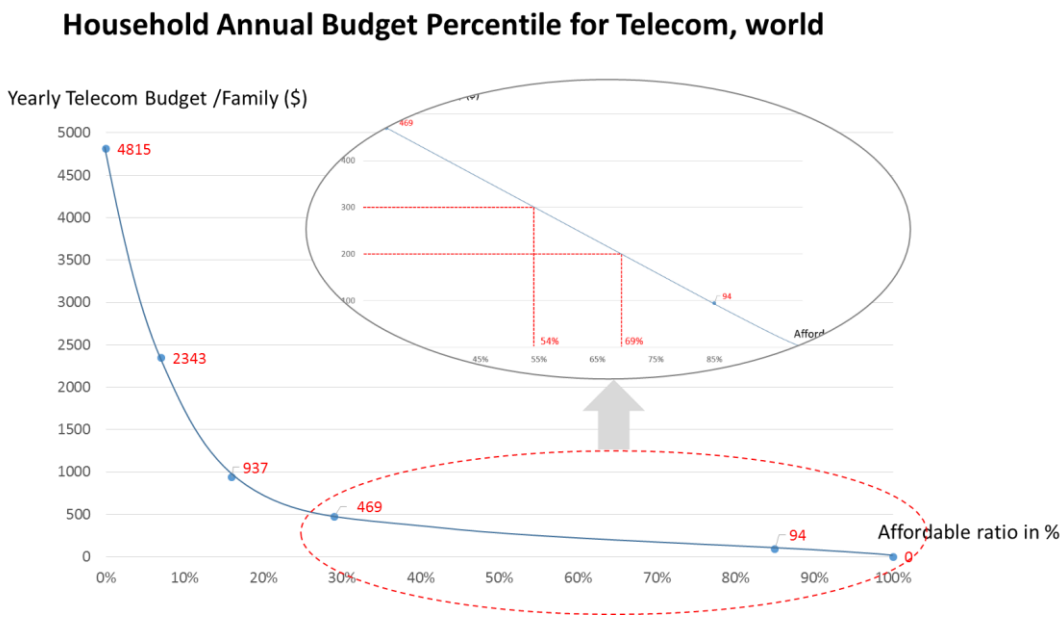


Figure 8: Household Annual Budget % for Telecom

Adjustment to the Previous Estimation

Investigation into users' payment capability enables potential market estimation in the economic dimension. The previous figure illustrates that low- and medium-income families (presented by the red dotted circle) are the focus of market space expansion for WBB. This model is subject to other factors, such as changes in the operators' costs caused by tariff policies, terminal prices in the local markets, and user distribution. In addition, users' selection of WBB is also affected by the regulations, religion, culture, habits, and many other factors.

6. Key Use Cases for TDD LTE 4G WBB

In this section, some of the primary use case scenarios for deploying WBB with TDD LTE spectrum are outlined and defined.

6.1. TDD LTE can be deployed in multiple ways

- Macro RAN combination of 2G/3G/FDD/TD-LTE
- Hot zones
- Wide area coverage, using only TD-LTE spectrum bands
- Fixed line replacement / backhaul

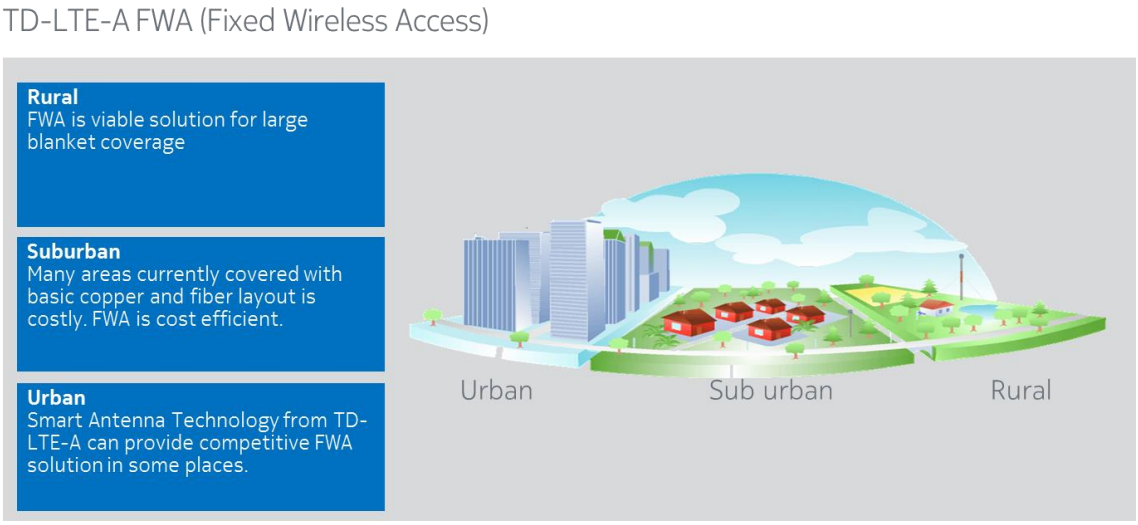


Figure 9: TD-LTE Fixed Wireless Access

6.2. WBB Evolution

WBB features easy implementation, excellent cost efficiency, and has quickly gained huge popularity among global telecom operators as a preferred choice to provide broadband services for more than 30 million households worldwide. Device and Infrastructure vendors can partner with operators to implement and conduct further research into WBB. Some specific examples were sighted in Section 3.4.4.

6.2.1. Four forces propelling of 4G WBB Adoption

Figure 10: Forces propelling 4G WBB Adoption

Force 1: Advanced Broadband Capability

A diverse range of innovative solutions including massive MIMO, achieving a more than five-fold increase in spectral efficiency, as well as a significant decrease in the cost-per-bit, and Gbps access rates. This helps operators deploy WBB networks with lower E2E costs and higher rates for the provision of quality broadband services to additional households.

Force 2: Seamless Convergence

As for operators providing both mobile broadband (MBB) and WBB services and those providing both fixed broadband (FBB) and WBB services, these advanced solutions offers a seamless converged solution. For example, diverse quality of service (QoS) solutions allow for resource sharing between MBB and WBB services, achieving an optimal level of network experience. Converged billing system, which integrates WBB and FBB service billing for operators who provide both services, achieving central service billing without network reconstruction.

Force 3: Efficient Operations & Maintenance (O&M)

Operators must implement a range of systematic operation approaches from number allocation and household CPE deployment to CPE maintenance for the development of a new user, requiring efficient process improvements. There are specific solutions in the market that help operators accurately and visibly allocate numbers. Using cables typically reserved for power supply or satellite TVs, these cables are then used to supply power for outdoor CPEs and transmit signals from outdoor to indoor locations, resolving the last-meter challenge of household CPE installation. Self-adaptive CPE avoid antenna adjustment with omni-antenna, the receive gain of self-adaptive CPE can compare with the best outdoor CPE. CPE management systems are then used to help operators centrally and remotely supervise CPEs.

Force 4: Support for Diverse Services

WBB implemented with advanced features can deliver a diverse range of services, besides simple broadband access. For example, support for IPTV services, facilitating the inheritance of the wired broadband service model. Support for Smart Home, which indicates a transformation from the provision of digital to more smart home oriented services. CPEs can then be used to integrate V-Band broadband access for the

expansion of indoor 4G coverage and deploy virtual private networks (VPNs) for small- and medium-sized enterprise network deployment.

6.2.2. WBB for home broadband development (use case)

4G WBB can be used as connect the unconnected home and home broadband upgrade。

1st. Connect the unconnected home with low cost.

In suburban and rural areas, 4G WBB use of high power RRU to improve the coverage, multi-antenna technology and soft-split to enlarge the coverage and capacity can reduce the single bit cost by 74%, with E2E coordination.

In urban and hot zone areas, Massive MIMO can satisfy the vertical coverage requirement with 3D beam forming. Massive MIMO can provide 5 times capacity compare with 8T8R and reduce the single bit cost by 80%.

2nd. Home broadband upgrade

Massive MIMO technology will be a key 5G technology. Today's implementations can enable reliable communication in crowded places like railway stations and shopping centres, where communication speeds tend to slow. Massive MIMO uses a large number of antennas and beamforming to allocate a private width of radio waves to each user to improve their user experience. It can achieve an average cell throughput of 400Mbps and peak throughput of 650Mbps, 10 times faster than baseline LTE under busy network conditions.

Massive MIMO deployed in WBB implementations pushes the user peak data rate reach up to 1Gbps and maximizes the spectral efficiency.

Some other solutions can be used with the above two scenarios. Combining technologies opens the door for new convergence and new operations. Some examples include QoS MBB + WBB Convergence, FBB + WBB Billing Convergence. Examples of new operations include Last Meter Solutions and LMT CPE Management. As broadband technology evolves, WBB will fully enable new services such as Smart Home and IPTV.

7. Ecosystem Development and Opportunities

7.1. Network and Spectrum

The network architecture of WBB is no different than that of MBB, only with handsets replaced by CPE. What this brings to mobile operators, is to enable the infrastructure sharing with MBB services without additional cost.

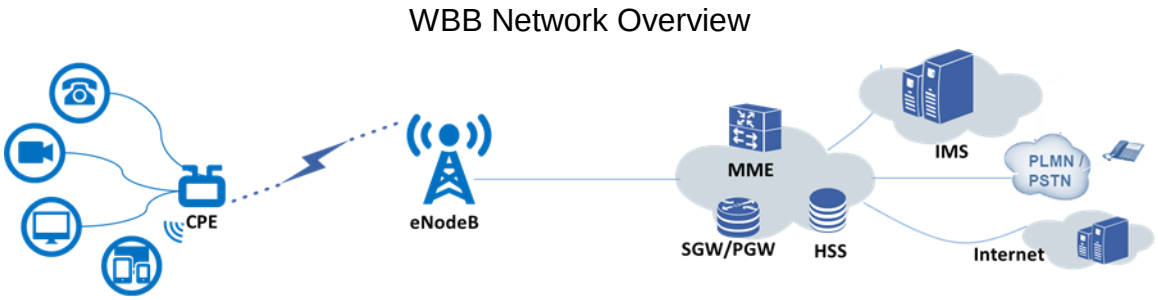


Figure 11: WBB Network Overview

However, as the use case and traffic model of WBB are different from those of MBB, some unique networking requirements should be addressed properly so as to improve the network performance and user experience, including:

A. **Large capacity**: Unlike the data plans of MBB, WBB carriers tend to provide unlimited volume packages. Besides, services including IPTV, PC internet browsing, VoIP are mostly bundled together with WBB packages. Therefore, the data traffic of WBB is generally much higher than MBB within each cell.

B. **Security request**: Besides households, SME (small and medium size enterprises) is also a typical group of customers for WBB carriers. Security services, like VPN, should be enabled to address the need of this market division.

C. **Low CAPEX**: Compared with mobile operators, initial investment as CAPEX is an even more critical issue for WBB operators, especially in the emerging markets, such as South Asia and Africa. Networking solutions, that minimize the initial equipment investment, should be provided to WBB operators.

Existing options to provide broadband service can be hugely expensive or provide poor quality of experience while higher frequency spectrum remains unused. There are numerous reasons why the TDD LTE network ecosystem can provide direct benefit and address the gaps that exist with other broadband service provision.

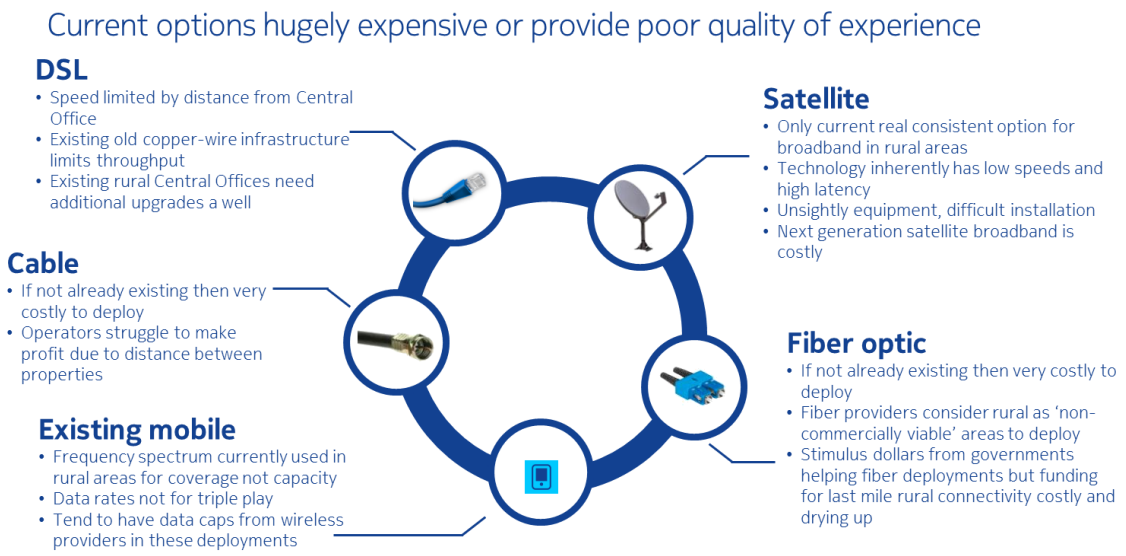


Figure 12: Options for provisioning broadband

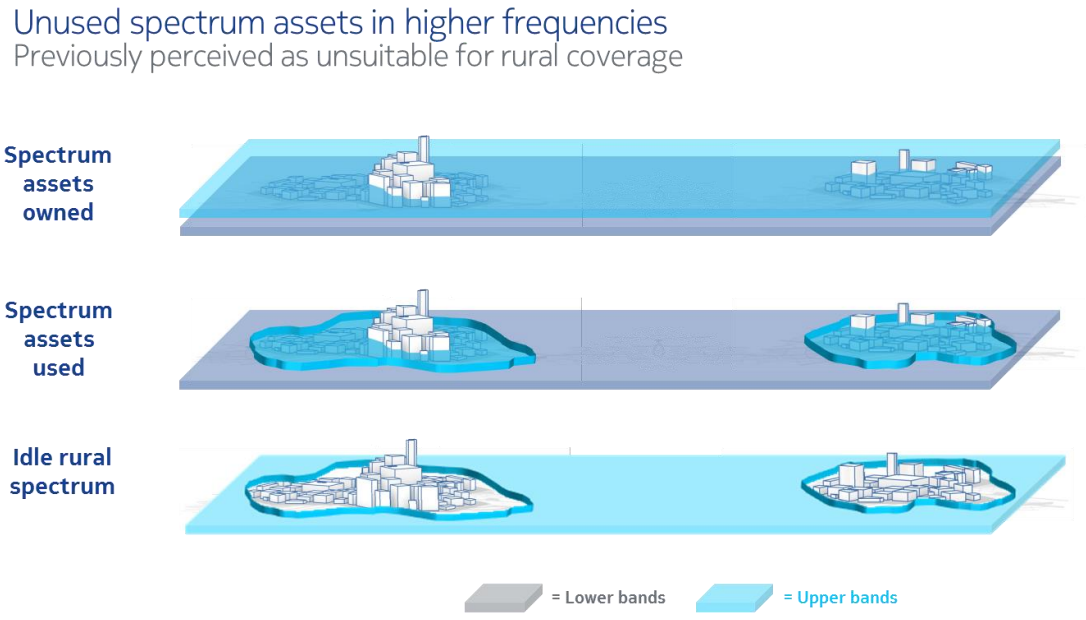


Figure 13: Higher frequency spectrum asset use

There is an aggressive national broadband plan globally to reduce the digital divide while the network eco-system needs to judiciously utilize the higher frequency spectrum to bridge this divide. According to a Boston Consulting Group Study[4], fixed wireless is the most cost effective

solution for densities between 10 and 1000 inhabitants per km2 with a committed DL/UL speed of 10/1Mbps.

Supporting the role of higher frequency, TDD spectrum use, here are some of the stellar results the TDD Industry has achieved in the past few years. According to the latest data released by the GSA, there are 54 countries and regions which have deployed 95 TD-LTE commercial networks, bringing the total number of LTE TDD users exceeding 800 million worldwide. TDD has taken a leading position by becoming "5G Ready", implementing effective testing and performing crucial commercial trials of Massive MIMO and D-MIMO technology, greatly contributing to the successful evolution of 4G. In the area of wireless home broadband, 4G TDD WBB is widely used around the world, providing broadband access services to more than 40 million households. It has greatly promoted the popularity of broadband and enhanced its experience, helped more and more people by bridging the digital divide, and inspired tremendous socio-economic benefits.

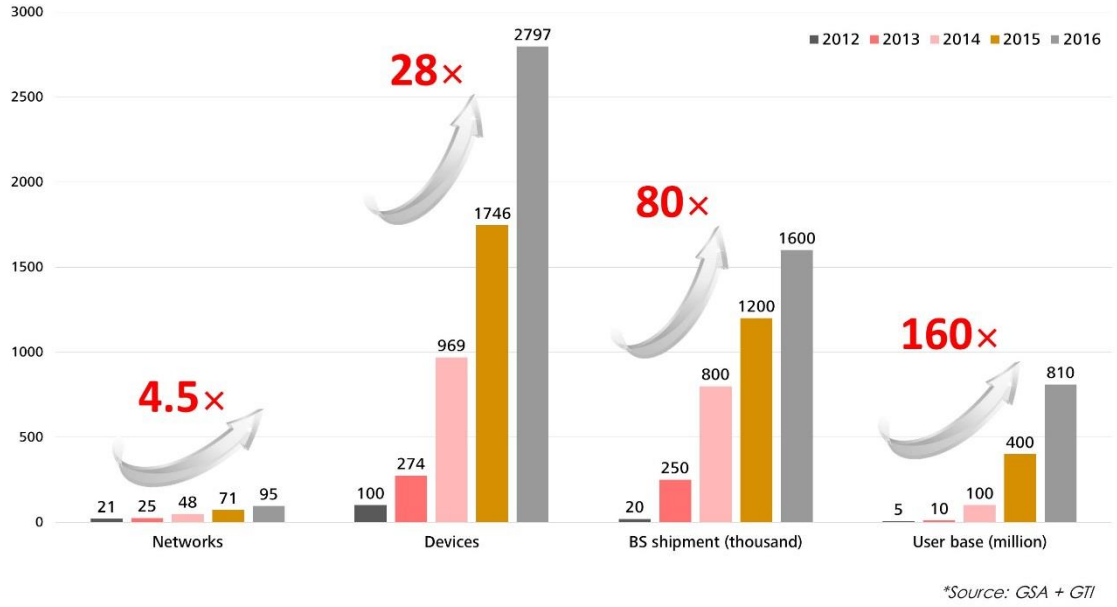


Figure 14: TDD Industry Growth

As the biggest sponsor of TDD technology which was kicked off in February 2011 in Barcelona, the Global TD-LTE Initiative (GTI) is constantly supporting and improving TDD technology and has achieved enormous accomplishments. The GTI community successfully developed and built the global end-to-end TD-LTE ecosystem. In addition, the GTI achieved not only global commercialization of TD-LTE, but also successful convergence of LTE TDD and FDD. For continued development of TDD, GTI 2.0 was officially launched during the GTI summit during

MWC 2016. GTI 2.0 will continue to help the whole industry benefit from the evolution of TD-LTE, TDD and FDD converged networks and global smartphones, promote a unified 5G standard and mature end-to-end ecosystem, as well as explore cross-industry markets and opportunities.

7.1.1. WBB Ecosystem Opportunities

4G WBB is growing very fast by taking the advantage of TDD LTE development and ecosystem. On Network side, there are several solutions in the market, for example, WTTx (Huawei), FastMile (Nokia) and other solutions. All the solutions deliver the following features:

- Greater Capacity delivery
- Support a wide range of desired services
- Advanced terminal technology

Commercial Operators & Users

Many favourable factors will ease operators' transformation. Opening up new markets outside the mobile service scope will help operators maintain healthy businesses as their MBB incomes approach maturity. WBB deployment is an important approach in the overall operator transformation/diversification. In developed markets, the ARPU of HBB services will most likely exceed that of mobile data services. In underdeveloped regions, the lower penetration rate of HBB opens up new blue ocean markets. Marketing for WBB is roughly equivalent to developing new services. WBB can share the existing MBB network resources, promising low network and reconstruction costs. The extremely low expense on network deployment makes the ROI quite attractive.

Accordingly, an increasing number of traditional mobile operators have started to plan and launch the WBB service, including China Mobile, Globe Philippines, Orange España, Optus Australia, and SoftBank Japan. All have begun WBB service provisioning on their 4G networks.

At the same time, and not to be left behind, cable operators, who have plenty of video and media resources, want to speed up service deployment and expansion, thus efficiently seizing more market shares. This demand can be satisfied by adopting WBB, which features quick deployment.

Many fixed network operators like SkyTV Brazil and Internux Indonesia have transformed into multi-service operators (MSO) to grab this chance to extend the marketing reach of their vast content resources.

Statistics show that the number of global WBB operators is nearing 150, serving more than 10 million users worldwide.

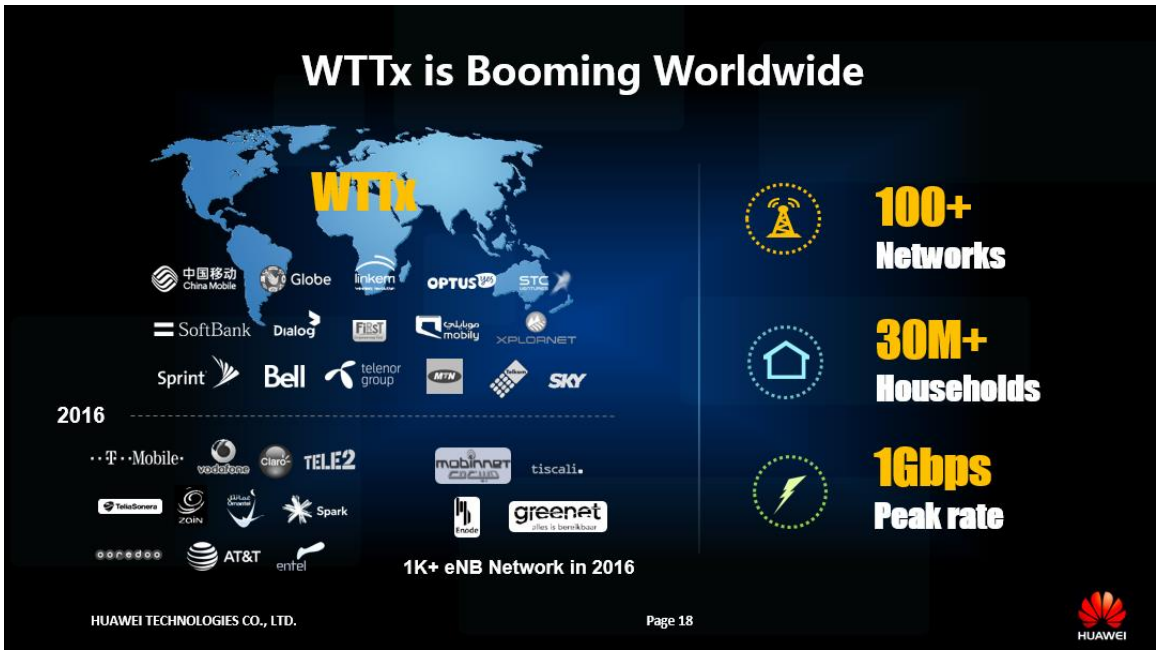


Figure 15: WBB/WTTx Ecosystem, Huawei, 2016

7.2. Terminals

According to the January 2017 GSA report[6], there are more than 40 terminal makers for 4G wireless broadband, providing over 250 types of CPE.

Highlighting the commitment and variety of different WBB products, many terminal makers are contributing CPE products to the WBB market to meet different customer needs, including indoor and outdoor CPE. Many designed for the TDD community, these range from the WiMAX-LTE dual-mode CPE to the LTE single-mode CPE, from the LTE Cat4 low-end CPE to the LTE Cat12 high-end CPE, supporting a variety of segmented markets in 4G based Wireless broadband.

LTE Cat4 CPEs are currently the market leader for these 4G based WBB products, encompassing both indoor and outdoor terminals. Indoor LTE Cat4 CPEs make up the majority of the product category. The 2016 global annual CPE shipment volume reached 100 million terminals.

In terms of commercial use, data provided indicates that the indoor CPE is mainly used in the urban family scenario, especially in dense urban areas, providing a broadband experience. Example operators who have launched these devices include Umniah Mobile Company in Jordan, MTN in Iran, Ooredoo in Tunisia and AT&T in Mexico.

The outdoor CPE is mainly used in suburban and low population density, sparsely populated areas. Currently it is widely deployed in the Philippines Smart, Peru Movil, Oman Nawras and Etisalat ET operators.

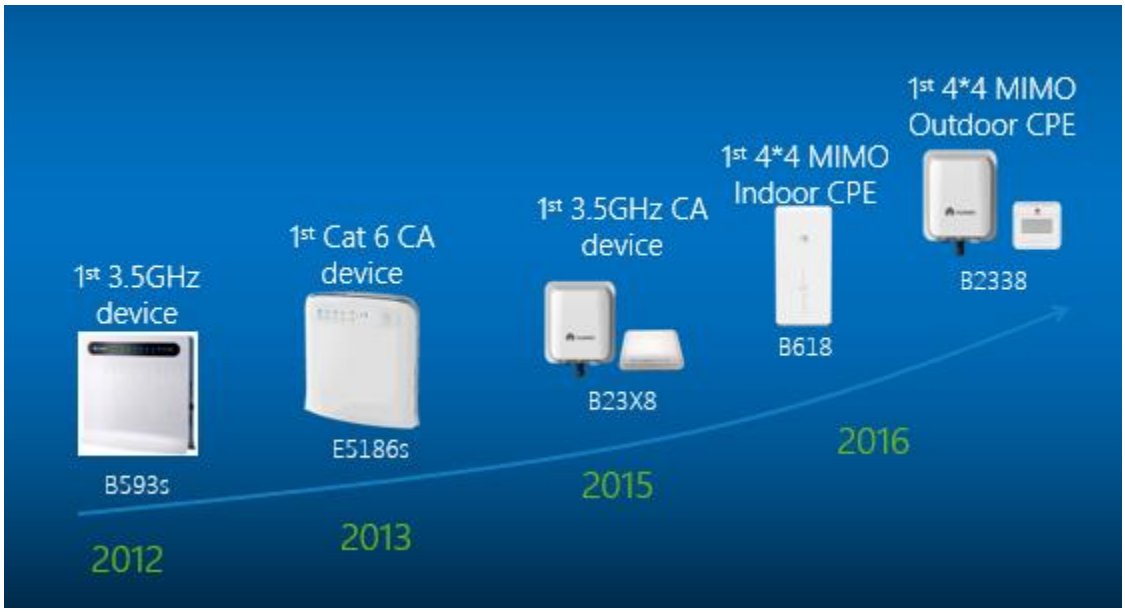


Figure 16: Huawei WBB Device Evolution

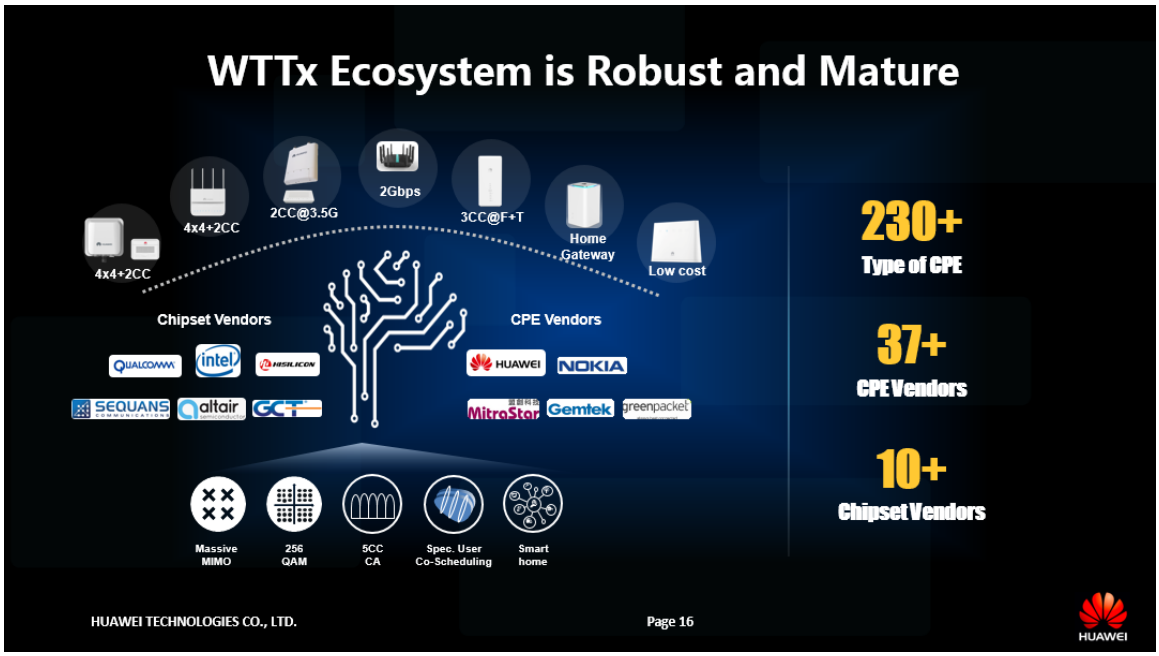
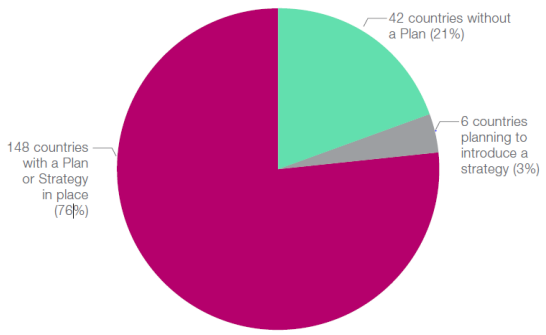


Figure 17: WBB Ecosystem

At present, 4G chips provided by the major vendors in the industry, including Qualcomm, Intel, Hisilicon, GCT, and Sequans, fully support various WBB services and all major TDD WBB frequency bands (2.3 GHz, 2.6 GHz, and 3.5 GHz).

8. Regulatory Impacts

8.1. WBB, an Important Ingredient of National Broadband Policy



3G technologies were the basis of WBB solutions, but 3G WBB provides an access quality that is lower than FBB. The adoption of 4G LTE technologies reinvigorates WBB. 4G WBB inherits advantages from traditional WBB solutions, such as rapid and flexible deployment and low costs, but goes beyond to provide FBB-class access bandwidths and quality. This allows 4G WBB to become a new leading player in the household broadband market. Nowadays, recognizing the value of spectrum, an increasing number of countries have formulated their national Internet and broadband development plans.

With its unique advantages, 4G WBB can be integrated and co-exist with FBB to become an important ingredient of national broadband.

China is a prime example. In 2013, the State Council of China released the "Broadband China" Strategy and implementation plan. In 2014, the Ministry of Industry and Information Technology of China released a notice promoting mobile WBB in rural areas, facilitating the national broadband strategy, and creating a new blue ocean of mobile Internet. In this notice, a three-step goal of urban-rural broadband development was proposed to clarify the significance of WBB in promoting broadband services in rural areas. In large areas with a population density smaller than 200 households per square kilometer, the cost of deploying wired broadband networks ranges from USD $500 to USD $800 per wire or even higher, and the ROI period is 10 years. Maintaining those wired networks is also costly. Under such conditions, operators would suffer a loss, making it hard to sustain this development. WBB networks, on the other hand, are much more cost-effective than optical fiber networks, and they provide a better service experience than xDSL. Since 2015, WBB networks have grown rapidly in rural areas in Jilin, Sichuan, Yunnan, Anhui provinces, and other parts in Midwest China. This demonstrates the unique benefits brought by WBB as an important ingredient of national broadband.

WBB has proven itself an essential component in national broadband in developed countries as well as developing countries.. Governments in Australia, Germany, and Norway endorse WBB and hope to provide universal broadband services and improve broadband experience using WBB networks. To fulfil this goal, they have created preferential policies or concrete measures to promote WBB development. In Germany, the government demands that operators provide universal broadband services in rural areas using the 800 MHz frequency band. The Australian government has set up the NBN Company to implement its national broadband plan. The Norwegian government provides ultra-broad spectrum at preferential prices to operators who build cost-effective and high-quality WBB networks.

Industry Consensus on Spectrum Allocation Facilitates WBB Development

Spectrum is the basis of all wireless solutions. To expand spectrum is to foster and expand the development space of wireless solutions in the future. The more regulators learn about user needs and the growth of emerging industries in the broadband era, the better can they properly and rapidly allocate spectrum to create a multi-win ecosystem for governments, communities, operators, and users.

The popularity of Internet broadband has elevated it to a basic need for modern life, much like electricity and highways. As spectrum is becoming limited and precious and core spectrums have already been used for a variety of other key services, it is difficult to allocate and acquire dedicated spectrum for WBB. What spectrum can be used for WBB and what are the market demands of such spectrum?

Potential WBB Frequency Bands

Technically, all 4G frequency bands can be used for WBB, but carriers are deploying WBB using two methods. The first is sharing medium- and low-frequency MBB carriers, and the second is deploying dedicated WBB carries on medium- and high-frequency bands. Operators can choose from these methods, and each has their advantages and disadvantages.

As for sharing medium- and low-frequency MBB carriers, FDD 800 MHz is commonly used by numerous operators because of its good coverage performance. For example, German operators have used this frequency band to provide ubiquitous coverage in rural areas and basic 1 Mbit/s access rates. As a common frequency band for MBB, 1.8 GHz is also adopted by various operators to enhance broadband access and network capacity. By doing so, operators can use existing MBB networks to distribute CPEs for WBB services. However, networks deployed on FDD 800 MHz and 1.8 GHz frequency bands provide limited capacity due to narrow available bandwidths. This is not conducive for operators to develop high-bandwidth Internet and HD video services. Since these frequency bands are also used to deploy MBB networks, operators must consider how to balance MBB and WBB service quality. Generally, operators preferentially ensure MBB services, which require lower bandwidths. This means they only provide best-effort WBB services, further limiting the performance of these services. Some operators may provide WBB services only in suburban areas with a low MBB usage.

Deploying dedicated WBB carriers on medium- and high-frequency bands is another popular choice for operators. Most countries in Asia Pacific, including India, Saudi Arabia, Indonesia, and The Philippines, choose frequency bands higher than 2 GHz, mainly 2.3 GHz (band 40) or 2.6 GHz (band 41), while countries in Europe, Africa, and Latin America often choose 3.5 GHz (band 42 or band 43). The low coverage performance of these high-frequency bands can be made up for by using multi-antenna technology on base stations and high-gain antennas on UEs. The biggest advantage of deploying dedicated WBB carriers on medium- and high-frequency bands is the abundant spectrum resources they bring. With these spectrum resources, it is convenient for operators to provide optical fiber-class broadband performance better than that of DSL networks. WBB networks with high bandwidth requirements no longer need to share resources with MBB networks, making it easier for operators to ensure WBB service quality. Therefore,

many operators with high WBB requirements choose to deploy dedicated WBB carriers and select frequency bands for such carriers based on service types. In general, provision of video, HD video, and other services requiring large bandwidths is the trend of broadband service development, and WBB demands larger bandwidths.

Allocation of Continuous Large-Granularity Spectrums

While WBB has heavy bandwidth demands, it can provide optical fiber-class performance and is expected to provide a variety of services similar to that of wired broadband. In contrast to using a single carrier, two continuous carriers can lower the single-bit (or single-user) cost for operators. Given this, an industry consensus has been reached on allocating WBB spectrums. Continuous large-granularity spectrums must be allocated at the same time, with 10 MHz and 20 MHz as minimum, basic allocation units for LTE FDD and LTE TDD, respectively. This can lower network deployment costs of operators and usage costs of end users, attracting more end users, provided that the spectrum price remains unchanged.

New Technologies Improve Spectral Efficiency

Multi-antenna technology can improve spectral efficiency and increase network transmission rates by several times. 4x4 MIMO and even higher-order Massive MIMO have become mature. Networks adopting such technologies have demonstrated rates up to 650 Mbit/s on commercial networks in Shanghai in 2016. Advanced technologies are often applied on CPEs earlier, because compared with mobile phones, the size and power consumption of CPEs are not limited and CPEs do not have display or call functions. With the release of commercial 4x4 MIMO chips at the end of last year, 4x4 MIMO CPEs are available, empowering E2E commercial solutions.

Spectrum and Technology Neutrality Facilitates WBB Development

If WBB operators cannot smoothly expand their service scope from wireless HBB services to other services by following certain procedures, they may hold back investment in spectrum, networks, and user development. This will have a negative impact on the broadband ecosystem and even the entire telecom industry.

A technology and spectrum neutral policy or conditional spectrum application must be implemented. Technology neutrality refers to operators' free choices of technologies to deploy certain spectrum obtained by applying and paying for such spectrum. As for conditional spectrum application, for example, WBB operators can apply and pay for licenses to operate fixed or MBB networks. In this way, operators can make long-term plans and increase network investment, creating a triple-win condition for governments, enterprises, and users.

9. Operator Use Cases / Success Stories / Lessons Learned

9.1. Case 1：Softbank

Japan Softbank is a typical MBB (mobile broadband) operator, and its fixed network penetration rate is very low in Japan. In order to change the low market share of broadband and no fiber resources, Softbank starts to develop wireless broadband. Make full use of rich TDD spectrum, Softbank has proposed a strategic collaboration of WBB and MBB to quickly increase the broadband user base.

WBB in Japan has many scenarios and more market potential. For example, in some of the old and underdeveloped areas, there is no fiber resources, and the family needs to have low-cost wireless broadband solutions in order to connect the Internet, or some person especially student, often move from one apartment to another, and they cannot wait in applying the fixed line for 15 days which is usual in Japan. Besides, Japan has 2.9 million households with ADSL low rate, they has the urgent need for higher capacity to enhance the broadband experience.

Figure 18: Japan Potential WBB Market

WBB Application Scenario

Softbank precisely identifies the scenarios of WBB and makes an attractive tariff strategy, then WBB gets a rapid development through all these measures. Just in 2016, the wireless broadband subscribers has reached 500,000 users.

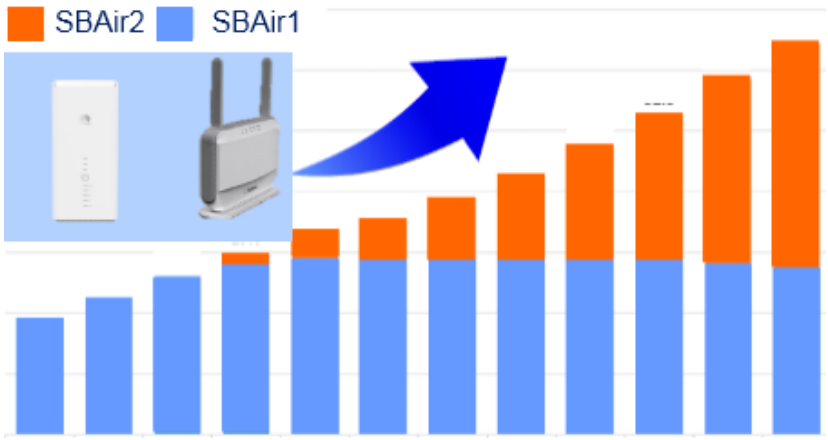


Figure 19: Softbank WBB Subscriber Trends

Softbank WBB subscribes development trend in 2016

In order to provide much better experience, Softbank is now deploying Massive MIMO in hotspot or in-depth coverage regions, which can provide 6 times of capacity comparing to traditional base station. In addition, 3.5G spectrum is reserved as the capacity layer for the future needs form the market.

9.2. Case 2： Dialog in Sri Lanka

Sri Lanka, is an isolated island nation located in the Indian Ocean, with a population of approximately 20.64 million. Dialog, the largest mobile operator in Sri Lanka, has diligently been committed to providing cutting-edge telecommunications services to Sri Lankan enterprises and inhabitants, enriching lives through improved communication. The penetration rate of home broadband in Sri Lanka is approximately 12%, and home broadband is still unavailable for 5 million people, indicating large market capacity and stiff competition among operators. Also there are 5 mobile operators in Sri Lanka, the MBB competition is fierce and it is hard for Dialog to get continuous revenue from mobile market. Meanwhile, the cost of deploying fixed broadband is high and time to market is too long. So Dialog capitalizes on advantages in networks, spectrum resources, and sites, and began to deploy WBB in 2013 to provide broadband service for households and SME. Now, the subscribers have increased to 30M households and is still growing. The YoY growth about Dailog's broadband market share is two digits. There are four success DNAs about Dialog:

1. Precision Marketing Strategy and Marketing Plan, including precise investment focus on target households and SME market, competitive & flexible package covers different income level,

rich tariff packages enable Dialog to successfully expand its subscriber base and user can select package base on demand. Also Huawei's WTTx Map helped to achieve quick user acquisition : Home broadband coverage is available on the official website, the CPE capable of plug & play can be obtained immediately after a purchase order is complete, subscribers can enjoy 7 day free trial home broadband services, with no obligation, and full refund if not totally satisfied. Home-visit speed testing, if required, is also available. All these methods powers subscribers increase greatly.

2. Differentiated Services, Dialog is an integrate operator, possess DTV service, so the channel and content resource is rich. Bundling video and broadband service together can increase ARPU and low subscriber churn rate.

3. Best User Experience, Huawei provided a serial of innovative solution for Dialog, including 4T4R, CA, 8T8R, Massive MIMO. And Dialog signed 4.5G (TDD+) MoU with Huawei in 2016, devoted to supply leading network experience for subscribers. Also Dialog and Huawei cooperatively launched the first 4.5G commercial network in South Asia.

9.3. Case 3： Globe in Philippines

The Philippines, consists of more than 7000 islands and covers an area of 300,000 km2 in Southeast Asia. Special geographic conditions and private land ownership present difficult tasks of deploying home broadband infrastructure. Globe believes that the home broadband market is an opportunity on which it cannot miss out. Up to 65% of the Philippines' population are 15 to 64 years old. This group of people is young, open-minded, and enjoy Internet surfing, online gaming, and online social activities. Strongly influenced by American culture, they are also keen on music and basketball. In 2016, the WBB capacity of busy time is about 1790Gbps, this figure may increase up to 5931Gbps in 2017 and 6734Gbps in 2018. Based on the analysis of its potential market and user needs, Globe has proposed the strategy of WBB to quickly increase the broadband user base. This commercial strategy, which customizes services and packages for target customer segments, has proved to be a success.

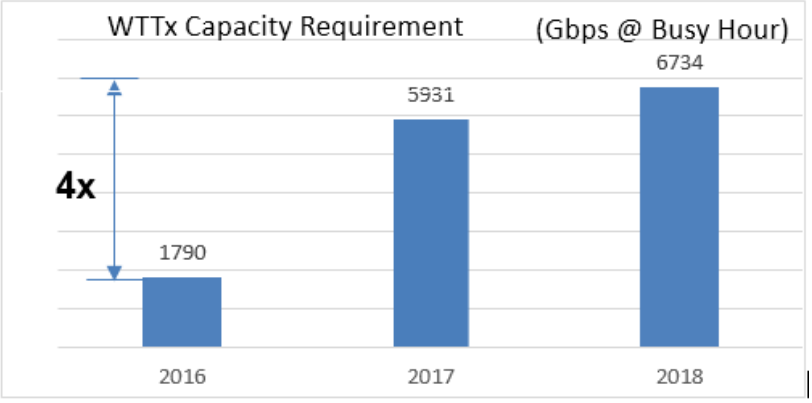


Figure 20: Globe MBB Subscriber Trends

WBB Capacity Requirement Development

Since the commercial release of WBB services in July 2013, Globe has quickly increased the home broadband user base due to its excellent operation especially in Luzon and Metro Manila, and attracted numerous users, successfully changing its unfavourable situation in the market. Globe's 2014 financial report shows that the WBB user base increased by 42%, generating a 22% increase in broadband revenue. In 2015, Globe's broadband user base dramatically increased by 58%, driving broadband revenue up by 37%. According to Globe's 2016 financial report, Globe has taken only one year to increase the total number of WBB users to more than 670,000, while it took four years to acquire such a large number of fixed network users. Meanwhile, Globe has earned considerable revenue and recouped home broadband investment in a short period of time, achieving a record high growth for a new telecommunication service.

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