HUAWEI

4.5G, Opening Giga Mobile World, Empowering Vertical Markets

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Table of Contents

Contents

1 Executive Summary

Given the current explosive development of mobile broadband (MBB), we expect the number of MBB users around the world to reach 6.7 billion by 2020, while each user is expected to use as much as 5 GB of data per month. Meanwhile, there is already a need for wide scale development of an Internet of Things (IoT). By 2020, there will be some 31 billion IoT connections worldwide. These days, mobile network operators are placing more and more importance on the exploration of vertical markets and IoT is a typical example of this trend.

Huawei proposed 4.5G concept based on a deep understanding of the mobile broadband industry. 4.5G has two targets: first is to provide gigabit transmission capability for MBB; second is to explore new vertical markets for operators. 4.5G will need to be able to support 2K/4K video, virtual reality (VR), augmented reality (AR), drones, and IoT services, which may emerge in the next two to three years. 4.5G is based on 4G evolution, so what is required to transition from 4G to 4.5G is only software upgrades or minor hardware changes. Current investments in 4G infrastructure are well protected. 4.5G is the ineluctable way to 5G. 4.5G will coexist with 5G, which will adopt a new air interface, for a long time.

After more than a year of development, 4.5G has already made great progress. The three guiding principles for 4.5G proposed by Huawei have become the new network benchmark in MBB industry: Gbps (A peak rate of over 1 Gbps); Experience 4.0 (Both video and voice services will be delivered in High Definition experience); Connection+ (Empowering vertical markets, including NB-IoT for cellular narrowband internet of things and LiTRA for public safety networks based on LTE integrated broadband trunked radio). With regard to 4.5 standardization, in October of 2015, 3GPP approved LTE-Advanced Pro as a distinctive marker that evolves the LTE and LTE-Advanced technology series. In terms of deployment, over a dozen of the world's leading operators began deploying 4.5G on pre-commercial or trial networks. We can expect that over 60 4.5G networks will be commercially deployed around the world in 2016.

Another important role for 4.5G is to prepare for the arrival of 5G. It allows us to adopt certain 5G candidate technologies in 4.5G networks, benefiting operators before 5G arrives. It also gives the opportunity to adjust network architectures ahead of time for the introduction of 5G. Finally, 4.5G can help investigate and cultivate new services and market sectors for 5G.

• 4.5G – The Essential Path to MBB2020

MBB, cloud computing, big data analysis, IoT, and social networking are the symbols of the ICT revolution, which are reshaping the world. These technologies are sparking a new wave of human society development around the world. Since MBB is the foundation of all the others, it is hard to overstate the significance of the MBB revolution. The rapid spread of smart devices and of 4G network deployment have both accelerated MBB development.

The number of connections needed is growing at a phenomenal pace. Around the world, there are 4 billion people with no Internet access and one billion without any phone or Internet connections at all. That means current coverage still has to grow quite a bit to cover everyone. Another issue is that the average data use per user continues to grow as well. Online video has become the main driver of data consumption. According to YouTube statistics for 2014, 50% of all video traffic came from mobile devices. New Services such as 2K/4K video, VR, AR, drones, and the like, which may appear in the next two to three years, will present even more difficult challenges than we face today. Huawei's mLAB estimates that there will be as many as 6.7 billion MBB subscribers by 2020. Per user consumption is expected to grow tenfold for a total of 5 GB per month.

Not only that, we are just now entering the age of IoT. From wearable devices to smart homes, from smart cities to smart logistics management, IoT is completely transforming society. Cellular networks have the most global coverage and are

particularly well positioned to provide network access. Large scale IoT creates tremendous opportunities for the entire telecommunications industry. According to one GSMA report, by the end of 2014, there were already 243 million Cellular Internet of Things (C-IoT) connections, and by 2020 this number will reach 1 billion. These numbers do not even take into account the potential new technologies which may result in even more explosive growth. The actual figures may be larger by an order of magnitude.

Today's 4G network is not capable of meeting the needs of an MBB network like this one we have just described. That is why 5G is designed to meet the needs. The access speed, the delay, and the number of connections supported of 5G should all be superior to 4G by an order of magnitude. Not only that, 5G deployment should be cost efficient and electrically efficient. But the wireless industry has become aware of a few problems with transitioning from 4G to 5G. These issues make 4.5G an essential step:

- 5G will not be commercially deployed until 2020, a 5-year gap.
- 5G might use higher frequencies, which allow for larger bandwidth but result in higher costs for intensive and widespread coverage. This means that the existing network with lower frequencies will be needed to offer a good coverage for a long time.
- 4G needs to take steps to get ready for 5G. For example, in order to support the coexistence of 4G and 5G, the air interface will need some changes so that the new 5G air interface can be more quickly added to the existing network architecture.
- 4G will have to be used as a testing ground for the introduction of 5G new services. For instance, there are plans for commercial deployment of NB-IoT services in 2016 that will support over 100,000 connections in each cell.

Based on the understanding of these issues, in October of 2014, Huawei proposed the 4.5G concept. Compared with 5G, a revolutionary new air interface, 4.5G is a smoother evolution of 4G network. With just software upgrades, or only minor changes to the hardware, the existing 4G infrastructure can still be used, thereby current investment is protected. 4.5G networks can be deployed quickly, shortening the time to market for related services. 4.5G is the essential path we must take to MBB2020.

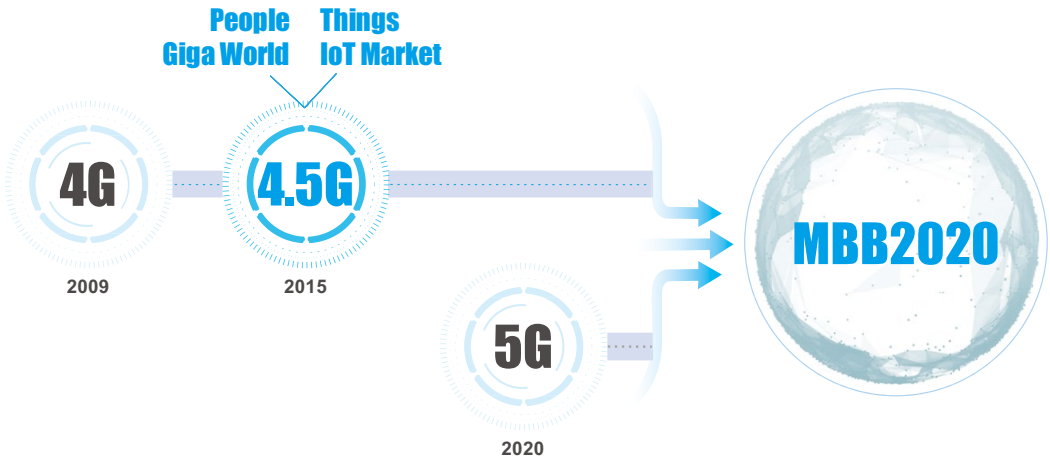


Figure 1: 4.5G - Opening the door to Gigabit MBB and new CIoT market

On October 22, 2015, 3GPP approved LTE-Advanced Pro as a distinctive marker that evolves the LTE and LTE-Advanced technology series from Release 13 onwards. This includes items that previous releases included but were not sufficiently mature until Release 13. The standards for core 4.5G technologies would seem to have been designed specifically with 3GPP's LTE-Advanced Pro in mind. The industry usually thinks of 4.5G and LTE-Advanced Pro as the same thing.

• 4.5G – The New Benchmark for MBB Networks

- Concerning operators' network pain points and business trends, Huawei proposed the following benchmarks for 4.5G networks, which have been widely accepted by global operators:
- Gbps
- A peak rate exceeding 1 Gbps, compared to just 100 Mbps for 4G networks. It also represents more capacity and better user experience in cell edge.
- Experience 4.0
- A mean opinion score (MOS) over 4.0 for voice and vMOS over 4.0 for video services, showcasing the high-definition (HD) user experience
- Connection+
- Empowering vertical markets, including NB-IoT for cellular narrowband internet of things and LiTRA for public safety networks based on LTE integrated broadband trunked radio

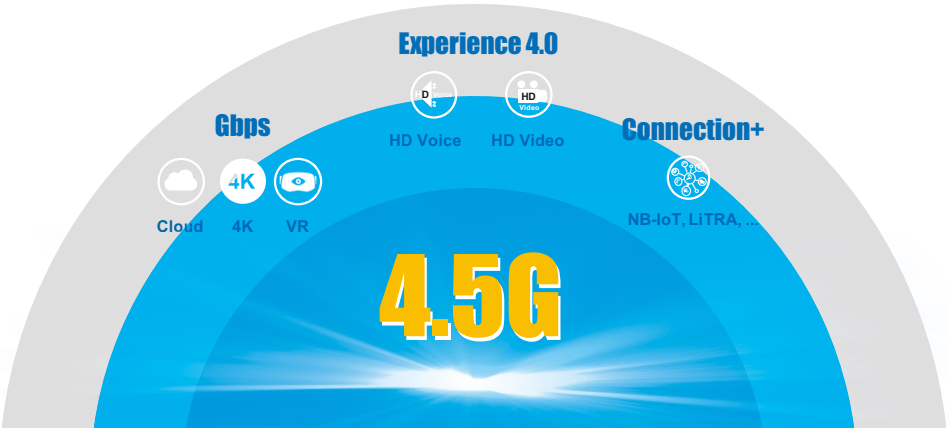


Figure 2: New benchmarks for 4.5G networks

2 Gbps, Opening Giga Mobile World

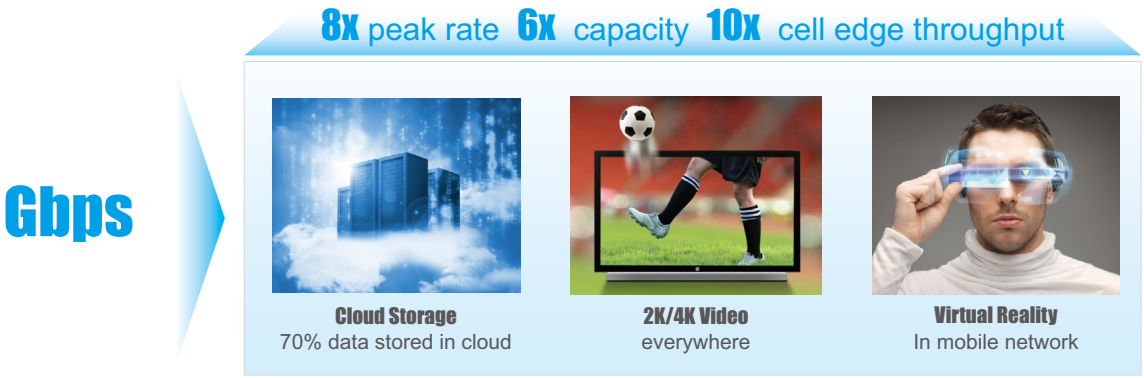


Figure 3: Values of Gbps

Improving MBB transmission capabilities is the primary aim of 4.5G.

Gbps represents an overall improvement in the peak rate, capacity, and cell edge throughput. For example, using 3CC CA, 4x4 MIMO, and 256QAM, 4.5G can deliver a peak rate of 1.2 Gbps. That rate is eight times faster than the 150 Mbps peak rate of 4G. New types of terminals and services such as virtual reality (VR) require these gigabit connections to provide users with a truly immersive experience.

Gbps also means expanded capacity. The average capacity of a 4G eNodeB is 100 Mbps, whereas a 4.5G eNodeB can reach approximately 600 Mbps, a sixfold increase. For 2K video (which requires 8 Mbps), a 4G eNodeB supports 12 program channels whereas a 4.5G eNodeB supports simultaneous video playback on 75 channels.

Finally, Gbps signifies an increase in cell edge throughput. 4.5G will deliver a tenfold increase in average cell edge throughput, from 3 Mbps to 30 Mbps, meeting the requirements of 2K/4K HD video anywhere anytime.

• Key Technologies

• Massive MIMO (FDD)

4T4R RF modules working in medium and high frequency bands will be widespread by 2016. With four TX channels, these RF modules support 4x2 MIMO and 4x4 MIMO. Terminals with two or four RX channels can be used. Massive MIMO fully utilizes spatial multiplexing and diversity technologies, significantly increases spectral efficiency, and improves cell edge user (CEU) experience.

Huawei's innovative enhanced MIMO (eMIMO) can maximize the benefits offered to terminals with two RX channels when RF modules have four TX channels. eMIMO can support Blade RRU with traditional antennas, Blade RRU with split antennas, or AAU (Active Antenna Unit) with 4T4R capability. With enhanced features in Release 12 and beaming forming coordination between cells, eMIMO will provide more gains to UE with two RX channels. Moreover, eMIMO will be further enhanced in 3GPP Releases 14 in order to maximize the value of 4T4R RF deployment.

- **Massive MIMO (TDD)**

Massive MIMO increases spectral efficiency mainly because more antennas can generate more accurate beams and offer better signal quality; provide more chances of transmitting two, three, and even four streams for a single UE; and enable more UEs to share resources to increase system throughput. In September 2015, China Mobile Shanghai and Huawei together launched the world's first massive MIMO eNodeB on a commercial 4G network. The downlink throughput of a sector with a single 20 MHz carrier reaches 650 Mbps, according to the field tests conducted by China Mobile Research Institute.

Distributed MIMO uses distributed multiple-antenna technology inter-cell communication and coordination based on inter-cell high-speed interfaces. It allows multiple antennas to be used for a single UE. It helps networks to evolve from the legacy cell-centric network architecture to a user-centric network architecture. For example, this technology can combine eight 2T2R cells into one 16T16R cell, evaluate the uplink signal quality of terminals, determine their locations, and choose appropriate antenna combinations for transmission to them. In addition, the use of spatial multiplexing technology allows multiple terminals to use the same radio resources, significantly increasing spectral efficiency.

TDD Beamforming evaluates the uplink sounding reference signal (SRS) quality of terminals, determines the weights for downlink transmission based on reciprocity between the uplink and the downlink, thereby increasing the SINR of signals arriving at terminals. 4.5G enhances beamforming by increasing the amount of SRS resources, enabling antenna selection for SRS transmission, and allowing service channel CQI reporting. Enhanced beamforming can increase spectral efficiency by over 30%.

UE pairing enhancement increases the number of orthogonal reference signal (RS) ports and allows the pairing of UEs that require different numbers of RBs, thereby increasing the pairing success rate. In addition, it supports the transmission of 8 or even 16 streams for paired UEs, fully exploiting the potential of spatial multiplexing and further increasing spectral efficiency.

- **Massive CA**

4CC and 5CC CA will be deployed for commercial use in 2016. By aggregating four or five carriers (including FDD and TDD carriers), CA not only increases the peak rate for users but also increases the cell edge throughput and average cell throughput. Huawei's innovative enhanced CA (eCA) implements inter-eNodeB carrier aggregation based on relaxed backhaul to greatly increase the proportion of SCell activations. In addition, eCA allows flexible aggregation of optimal PCells and SCells for CA UEs to significantly increase perceiveddata rates. CA will further optimize PCell and SCell selection, simplify implementation, and decrease inter-cell interference.

- **High-order modulation**

256QAM is expected to be deployed commercially in 2016. It increases the peak rate by 33% compared with 64QAM. While 256QAM can be used for both indoor micro cells and outdoor macro cells. The main target is to maximize the capacity for outdoor macro cells.

- **Flexible bandwidth**

Gbps aims to efficiently utilize any bandwidths ranging from 1.4 MHz to 20 MHz, rather than the few fixed bandwidths used in LTE (including 1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz, and 20 MHz). This technology will improve the use of spectrum refarmed from 2G and 3G.

3 Experience 4.0, Achieving HD Voice and HD Video Experience

4.5G also greatly improves mobile service experience. Voice and video are the mainstream services offered by mobile networks. However, these two services are not satisfactory. According to Huawei mLAB, the average MOS of worldwide mobile voice services is only 3.3 (out of 5 points), while the average vMOS of worldwide mobile video services is only 3.1, based on the vMOS evaluation standard proposed by Huawei in 2015.

By adopting enhanced voice and video technologies, 4.5G aims to provide HD voice and HD video on mobile networks with both voice MOS and video vMOS scoring over 4 points.

• Experience 4.0: VoLTE Plus

In the early stages of LTE network deployment, CS fallback to 2G or 3G is adopted and users cannot simultaneously perform voice and 4G high-rate data services. In this case, originating or terminated calls fall back to a 2G or 3G network with a deteriorated user experience. CS fallback has defects such as long call setup latency and unsatisfactory voice quality.

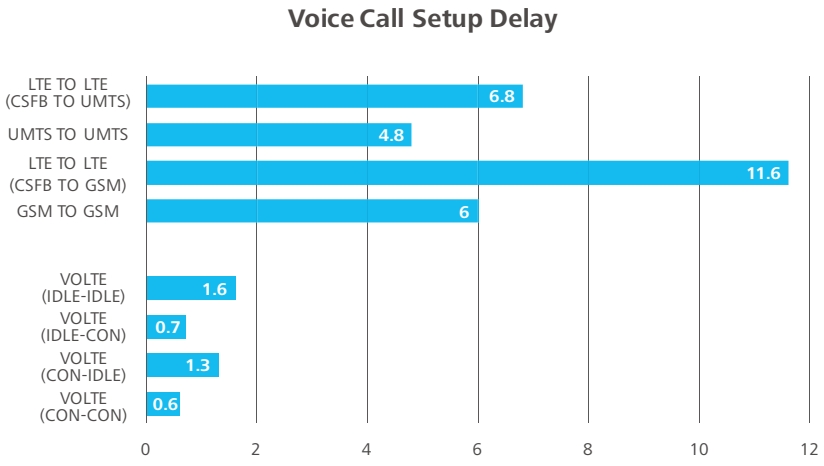


Figure 4: Comparison of call setup latency of different RATs (source: Huawei Lab)

Note: Calling party to Called party. CON: RRC-connected state, IDLE: Idle state.

Generally, the voice MOS of GSM is about 3.0 and that of UMTS is about 3.3. Typical user complaints include unclear voice quality, loud noises, and dropped calls. These networks consistently lag behind other advanced networks during third-party tests. The following figure shows voice quality MOS scores in the first-tier cities worldwide, according to the tests conducted by P3 Group, a global management consultancy firm.

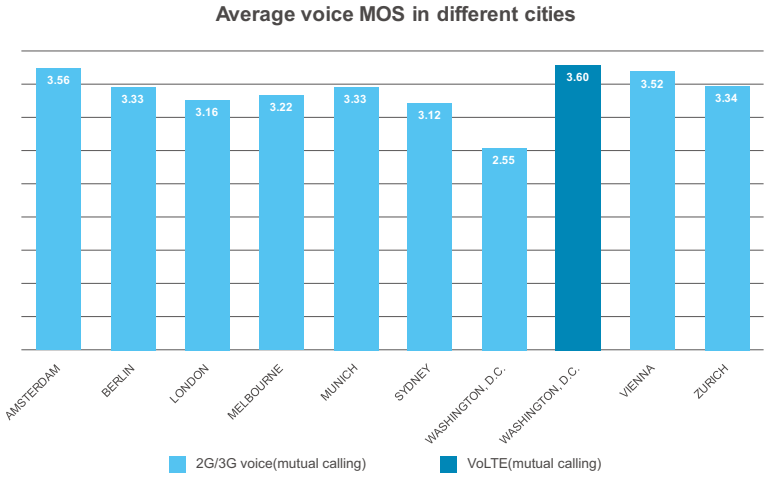


Figure 5: Voice MOSs in different cities

The data in this figure comes from P3_US_Public_Benchmark_2015 released by P3 Group. The MOSs of 2G/3G voice in most cities are about 3.3. In contrast, the MOS of VoLTE in Washington, D.C. reaches 3.6, beyond those of 2G/3G voice; of course, there is still room for improvement.

VoLTE can greatly improve voice experience. However, raising the MOS up to over 4.0 of the entire network remains a challenge, mainly because of signal level and inter-cell interference at cell edges.

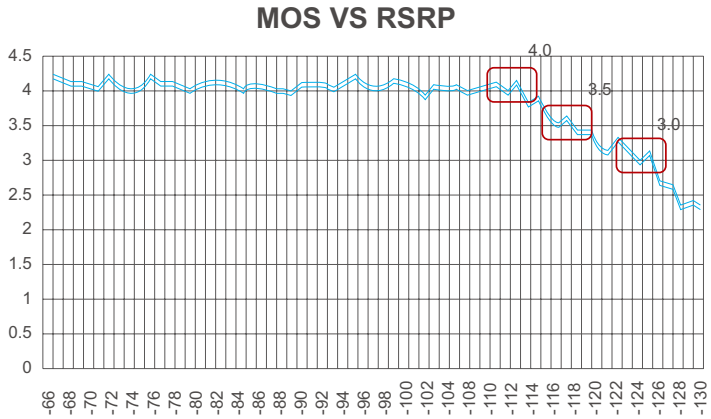
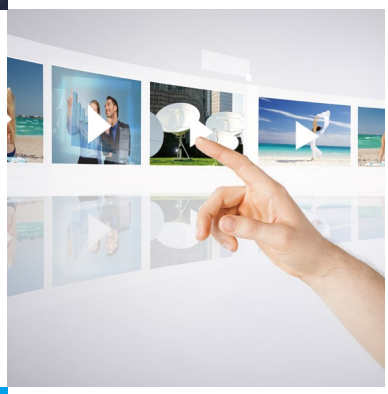


Figure 6: VoLTE test result of an operator's network (source: Huawei wireless)



In addition, operator voice services also face competition from OTT services. Though most OTT services are free, their providers continuously strive to improve voice experience. After attempting many codec methods, from the early Internet Low Bitrate Codec (iLBC), to SILK (used for Skype), to the current Opus, their voice services have reached the HD level, beyond the level of VoLTE, which uses AMR-WB as a codec.

To address previous challenges and raise the voice MOS to over 4.0, 4.5G has the following tasks to accomplish:

- 4.5G uses the VoLTE Plus solution to further improve the VoLTE experience at cell edges.

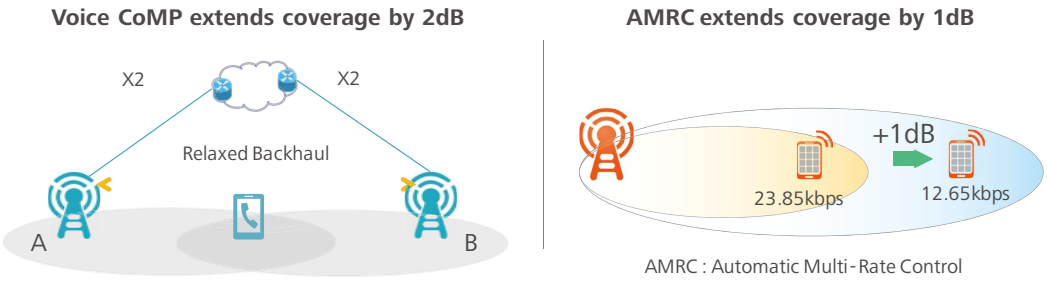


Figure 7: VoLTE Plus improves voice coverage

- 4.5G uses VoLTE Plus to ensure VoLTE quality in interference, handover, and high traffic scenarios.

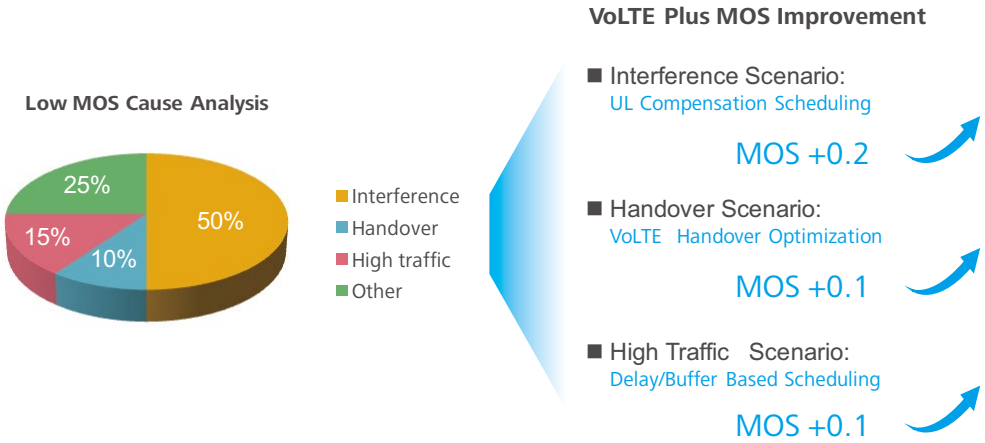


Figure 8: VoLTE Plus improves voice quality

- 4.5G must introduce new codec methods to face challenges from OTT services. 3GPP has standardized the enhanced voice service (EVS) codec in Release 12. The EVS codec supports an audio bandwidth of 20 kHz (achieving MP3 quality) and features high resistance against delay, jitter, and packet loss. 4.5G will continue to optimize air interface performance based on the EVS codec, improve coverage for higher voice quality, and ensure voice quality in the case of high traffic.

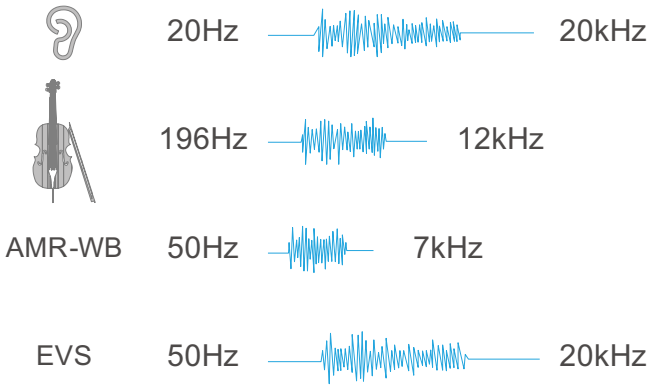
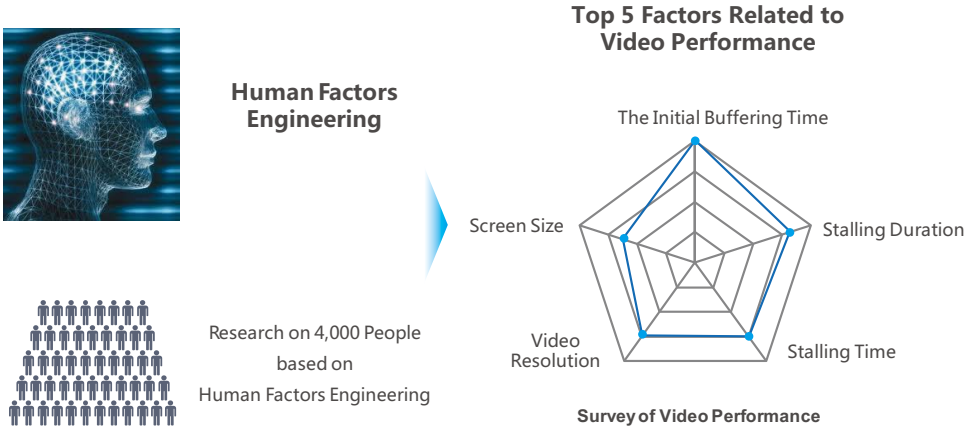


Figure 9: Audio frequency ranges supported by the EVS codec

• Experience 4.0: Video Plus

The first issue that 4.5G should address is the quantitative assessment of video experience. ITU-T started a vMOS standard research project in 2009, which provides a basis for OM systems to accurately monitor video parameters. However, Huawei deems it necessary to optimize the vMOS standard to adapt to new changes such as improvements in video resolution and image quality, developments in screen and codec technologies, the evolution of mobile and fixed networks to ultra broadband networks, and new video experience with multiple screens, networks, and services. Huawei mLAB has designed U-vMOS, a new video experience evaluation standard, based on human factors engineering tests, sample research, and technological research. The work item for the U-vMOS project was approved by ITU-T in September 2015, and model selection has since started with standardization results in its initial stages to be issued in 2016.



Source: Beijing University, Oxford University &Huawei mLAB

The U-vMOS establishes the relationship between video experience and mobile network performance. If the U-vMOS is expected to exceed 4.0, 2K or higher-definition video will be required. To support 2K video, 8.4 Mbps and 8 Mbps must be provided in the video loading and playing phases, respectively. To support 4K video, 32 Mbps and 18 Mbps must be provided in the video loading and playing phases, respectively.

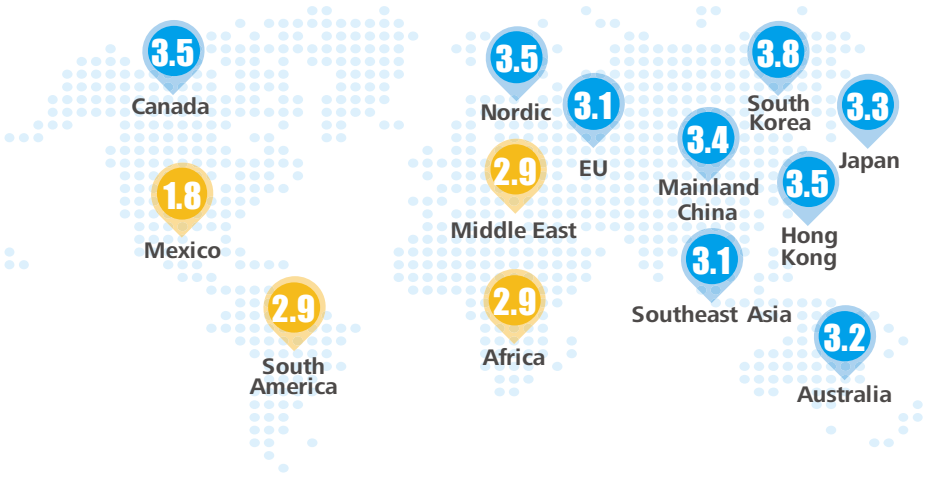
Typical	Experience Indicators				Network Requirements		
vMOS	Video Resolution (Streaming Technique)	Mean Bit Rate (H.264)	Initial Buffering Delay (Second)	Video Stalling Ratio	E2E RTT (ms)	User Data Rate (Initial Buffering Stage)	User Data Rate (Playing Stage)
2.6	480P (HPD)	700 kbps	3	2%	80	3 Mbps	1 Mbps
3.2	720P (DASH/HLS)	1.5 Mbps	2	2%	80	3 Mbps	2 Mbps
3.5	1080P (DASH/HLS)	3 Mbps	2	2%	40	4.1 Mbps	4 Mbps
4.0	2K (DASH/HLS)	6 Mbps	2	0%	40	8.4 Mbps	8 Mbps
4.5	4K	13.5 Mbps	1	0%	10	32 Mbps	18 Mbps

Note:

- HPD: HTTP Progressive Download
- DASH: Dynamic Adaptive Streaming over HTTP
- HLS: HTTP Live Streaming

Table1 Video source requirements for network performance (source: Huawei mLAB)

According to the statistics of the Speed video tool developed by Huawei mLAB, the mobile video experience on most 4G networks is not up to standard. The average MOS score of most networks is lower than 3.5, and user requirements are far from being satisfied. While the video stalling test score is relatively high (> 4), the initial buffering delay test score is relatively low (< 3.5). Therefore, shortening the initial buffering delay is key to improving user experience.



Source: Huawei mLAB, Jan. 2016

Figure 11: Video experience evaluation data of multiple regions

Huawei's innovative Video Plus solution improves mobile video experience on 4.5G networks and increases the U-vMOS to over 4.0.

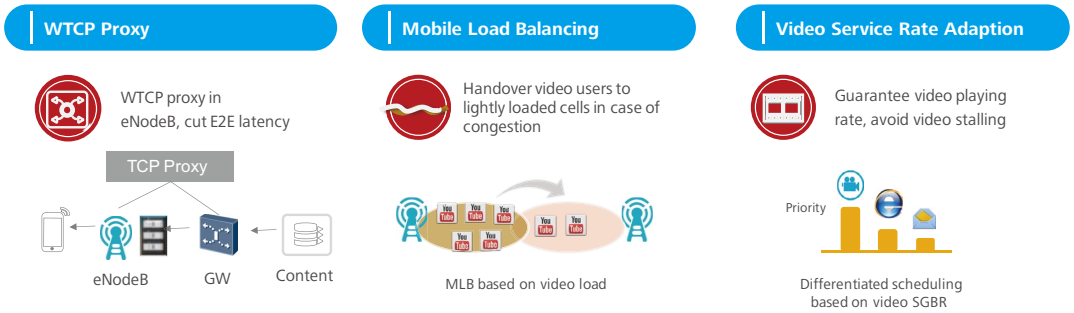


Figure 12: Huawei Video Plus solution

For example, eNodeBs use the WTCP proxy to shorten the initial video buffering delay, perform video load balancing in high traffic scenarios, and adopt an optimized video scheduling mechanism to ensure video service quality while not affecting other services.

4 Connection+, Empowering New Vertical Markets

Another major difference between 4G and 4.5G is that aside from serving the traditional MBB market, 4.5G further empowers vertical markets to create new business spaces for operators and help us explore the possibilities of a fully-connected future world, the real goal of 5G.

Tailored to the market needs of operators, Huawei launched NB-IoT and LiTRA for 4.5G, and started trial deployments for multiple operators around the globe. NB-IoT is well suited to IoT vertical markets, while LiTRA better suited to the vertical markets related to public safety, including the firemen, ambulances, and the police.

- Connection+: NB-IoT

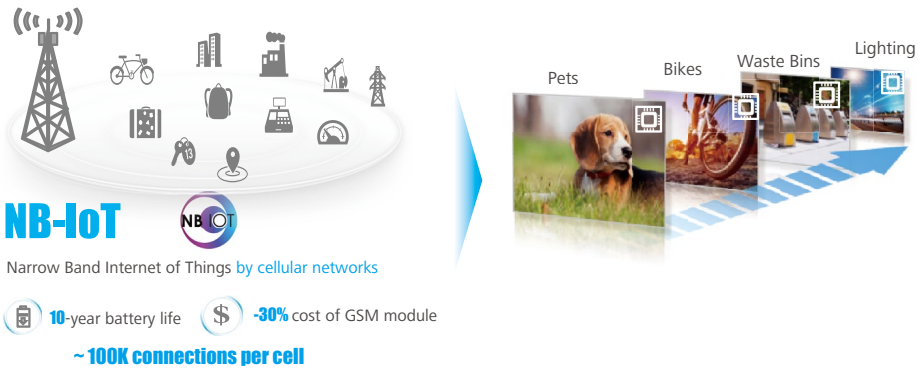


Figure 13: NB-IoT

The emerging IoT market creates tremendous business opportunities for mobile network operators. It is estimated that by 2020 there will be 31 billion C-IoT connections, of which 30 billion will be low power wide area (LPWA) connections.

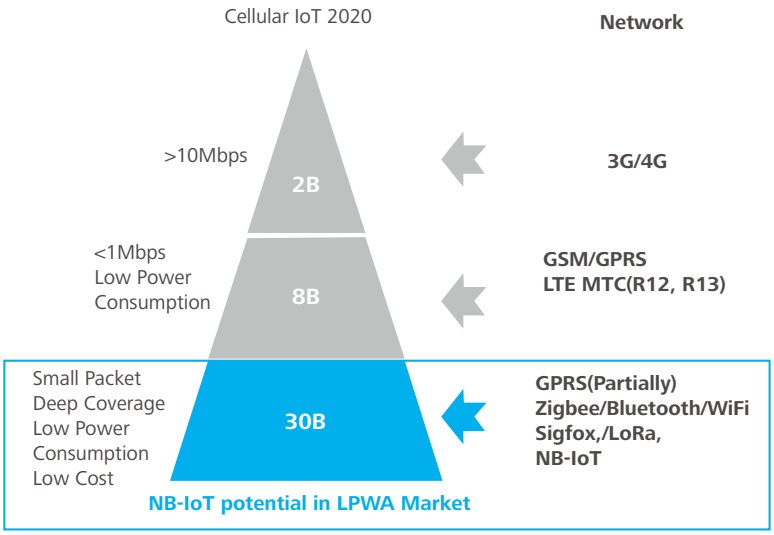


Figure 14: Estimated global C-IoT connections by 2020 (source: Huawei mLAB)

IoT in the LPWA market should have:

- Wide coverage, including coverage in basements and at the outskirts of cities.
- Highly power efficient terminals. The battery should last 5 to 10 years.
- Low costs. A typical communications module should cost less than 5 dollars.
- No sensitivity to transmission delay.
- Downlink transmission capability. The IoT should support downlink configuration and remote upgrade of terminal software, reducing operation and maintenance costs.

In the LPWA market, the NB-CIoT solution for 4.5G has unparalleled advantages in that it provides a 20–30 dB coverage enhancement (compared to GSM), offers 100,000 connection/km2, requires little power (terminal batteries last 5 to 10 years), and uses modules that cost at least 30% less than GSM modules do. As mobile network operators have world-wide network coverage, strong technological expertise, and outstanding service capabilities, they will most certainly be the strongest players in the LPWA market.

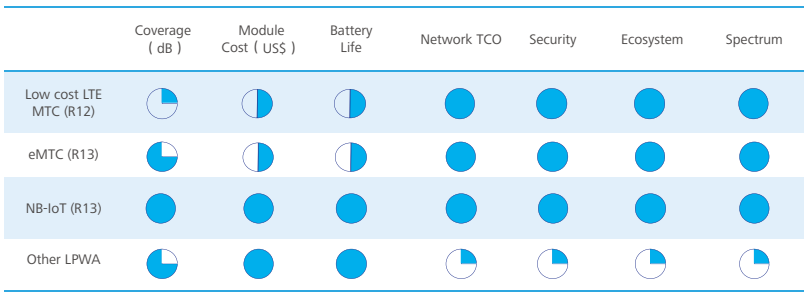


Figure 15: Comparison between NB-IoT and other LPWA technologies (source: Huawei mLAB)

To speed up LPWA development, GSMA launched the Mobile IoT Initiative project in 2015, aimed at deploying LPWA solutions on licensed spectrum, accelerating technological standardization, and preventing market fragmentation. The Mobile IoT Initiative project is currently supported by major mobile network operators, OEMs, chipset and module manufacturers, and network equipment vendors, including AT&T, Alcatel-Lucent, Bell Canada, China Mobile, China Telecom, China Unicom, Deutsche Telekom, Ericsson, Etisalat, Huawei, Gemalto, Intel, KDDI, Nokia, NTT DOCOMO, Ooredoo, Orange, Qualcomm Incorporated, Sierra Wireless, SingTel, Telecom Italia, Telefonica, Telenor, Telstra, u-blox, and Vodafone.

3GPP approved the NB-IoT work item in September 2015 and is expected to complete NB-IoT specifications by June 2016. Some of the world's leading operators, such as China Unicom and Vodafone Spain, have started pre-commercial launches or have conducted tests of NB-IoT based on the pre-standard specifications. They have received satisfactory results in NB-IoT applications, including smart parking, smart metering, smart waste bins, smart lamp poles, smart luggage, and smart bicycles.

- ## Connection+: LiTRA

Figure 16: LiTRA in public safety

Another solution that empowers vertical markets, LiTRA, is well suited to public safety, including the firemen, ambulances, and the police.

Trunked radio systems came into being in the late 1960s and early 1970s. Unlike common point-to-point full-duplex mobile communications, Trunked radio, also known as push to talk (PTT), work half-duplex, point-to-multipoint. PTT has low latency and large capacity. It is good for group communications and allows for instant responses and onsite real-time dispatching. It is widely used in the public safety, public utility, and enterprise fields.

Trunked radio system is currently evolving from narrowband to broadband and from private networks to public networks. Traditional trunked radio technologies were developed for narrowband private-network communications. Narrowband technologies are voice-centric. They do not support high-speed data services, such as video and multimedia services. In addition, the private-network architecture creates a variety of issues, including closed industry chains, high equipment and network construction costs, expensive terminals, and high maintenance costs. These technologies do not meet customers' business needs.

PTT over LTE, represented by LiTRA, addresses these issues. With the high bandwidth and low latency of LTE networks, LiTRA not only rivals traditional trunked radio systems in performance, but also provides professional multimedia trunking services, which include video calls, video surveillance, file transfer, and GIS services. More important, however, is that LiTRA is deployed using operators' existing LTE networks. It significantly reduces network construction and maintenance costs, provides better network coverage and roaming services, and is compatible with smart LTE terminals. In this sense, LiTRA breaks out of the closed industry chain and can now provide more professional, more efficient trunking services.

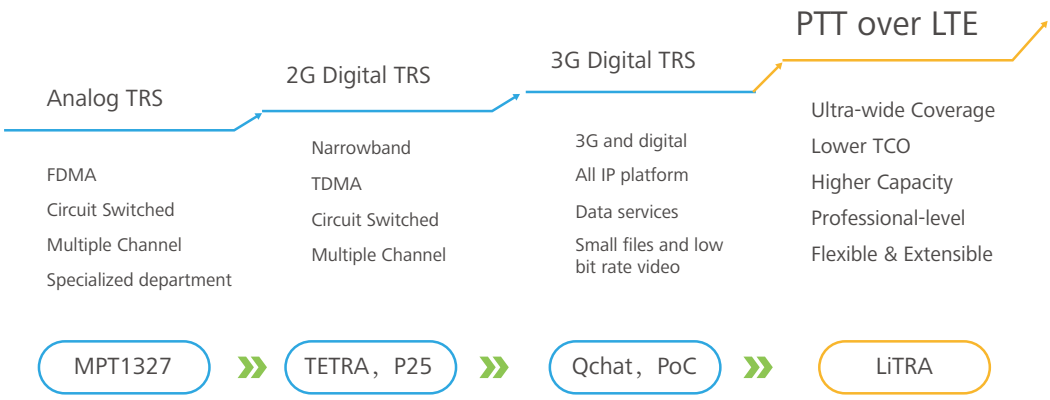
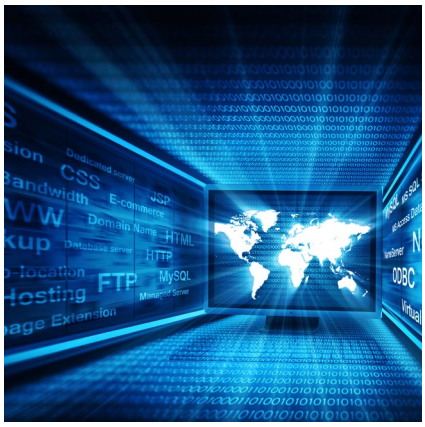


Figure 17: Evolution of trunked radio systems



3GPP is taking a leading role in formulating next-generation trunked radio communications standards. They are working with the world's major trunked radio standards organizations and government agencies, including OMA, ETSI, TCCA, TIA, Home Office of UK, and FCC and Department of Commerce of U.S. In 3GPP Release 12, Release 13, and Release 14, they will establish a complete set of professional trunked radio communications standards that are oriented to public safety and key tasks and solely based on public LTE networks.

LiTRA is a Huawei-developed professional trunked radio solution that complies with 3GPP specifications and is based on public LTE networks. This solution aims at helping operators build secure, efficient, and professional LTE networks to provide public-safety services.

Huawei believes there will be special challenges if commercial LTE networks are directly used for public safety services. To enhance LTE network abilities to address public safety emergencies, LiTRA has made improvements to five different aspects of LTE networks, including QoS, MCPTT, and congestion control. Moreover, LiTRA has released end-to-end products and solutions to help operators rapidly deploy trunking services and seize market opportunities. These products and solutions include the application platform, dispatch consoles, apps, and anti-shock, waterproof and dustproof terminals.

An increasing number of countries are now prepared to deploy national public safety networks using operators' existing LTE networks. We expect 2016 to see gradual, pre-commercial launches of these networks.

5 4.5G – Over 60 Networks to Be Deployed in 2016

Global mainstream operators have unveiled large scale deployment of 4.5G networks, which is dependent not only on terminal maturity, but also on the early verification of key technologies and on the readiness of the whole industry.

After proposing a gigabit target data rate, Huawei started working with major chipset and terminal manufacturers in the industry to promote chipset and terminal support for the multiple antenna, carrier aggregation, and 256QAM technologies. Qualcomm Snapdragon 820, released at the end of 2015, supports a peak rate of 600 Mbps (with 3CC CA and 256QAM enabled), as well as 4x4 MIMO on a single carrier. Balong 750, released by HiSilicon of Huawei in the same period, also supports 600 Mbps (with 4CC CA enabled or 2CC CA and 4x4 MIMO enabled). The commercial launch of 4.5G chipsets for terminals will tremendously push commercial use of 4.5G smart terminals in 2016.

Ever since 2014, when Huawei first proposed the 4.5G concept, global leading operators have started deploying 4.5G gigabit networks with Huawei. By the end of 2015:

- Norway, Germany, Kuwait, Saudi Arabia, UAE, China, Hong Kong, Japan, Canada, Singapore, and other countries have demonstrated a transmission rate of over 1 Gbps on commercial networks.
- UK and Korea have started constructing their national LiTRA-based public-safety networks using broadband trunked radio.
- Countries including Spain, Korea, China, UAE, and Germany have started pre-commercial deployment of NB-IoT.

It is estimated that, in 2016, there will be more than 60 4.5G networks around the globe.

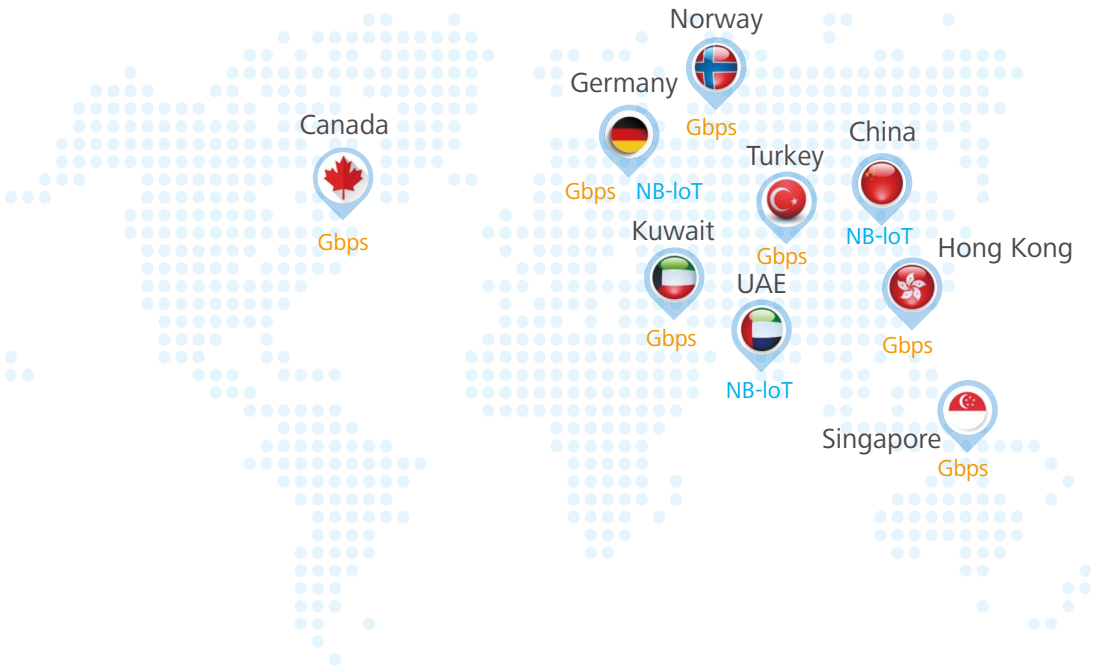


Figure 18: Commercial and pre-commercial 4.5G networks (source: Huawei Wireless, Jan. 2016)

6 4.5G – Paving the Way to 5G

Getting prepared for 5G is one of the most important goals of 4.5G. It involves two aspects:

- Introduction of certain candidate 5G technologies on 4.5G networks phase by phase based on their technological maturity
  These technologies can be implemented by software, with no need for major hardware changes. They have little impact on terminals.
- Network architecture adjustment in 4.5G
  There are two reasons why the network architecture will need to be modified. First, 4.5G and 5G networks will have to coexist for quite some long time. The network architecture must be designed with long term coexistence of 4.5G networks with the new air interface of 5G networks kept in mind. Second, 5G networks will need a network architecture that meets backhaul requirements for lower end-to-end latency and ultra-high bandwidth; accommodates network slicing and capability openness requirements for programmability and adaptation to different service types.

Taking advantage of an in-depth understanding and profound technical expertise with MBB communications, Huawei has started to research both of these issues and the results have been fruitful. With rapid, wide scale deployment of 4.5G networks around the world, and with the constant evolution of 4.5G technologies, in the coming three to five years, we will come to appreciate the tremendous value delivered by a 4.5G network based on upgrades of legacy network infrastructure and how 4.5G has prepared us for successful 5G deployment.

7 Glossary

64QAM - 64 Quadrature Amplitude Modulation
256QAM - 256 Quadrature Amplitude Modulation
AR - Augmented Reality
CA - Carrier Aggregation
CC - Component Carrier
E2E - End to End
IoT - Internet of Things
MIMO - Multi-input Multi-output
NB-IoT - Narrow Band Internet of Things
PCC - Primary Component Carrier
SCC - Secondary Component Carrier
SINR - Signal-to-Interference Ratio
RTT - Round Trip Time
UE - User Equipment
UHD - Ultra High Definition
VR - Virtual Reality

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