5G-oriented Terminal and Chipset Technology White Paper

Terminal-RAN-Chipset Coordination Promotes the Maturity of Industry Technologies

China Unicom

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Acknowledgement

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Content

1. New Trends of Mobile Internet Development

1.1 Trends of Mobile Service Development

As mobile internet grows increasingly popular, there is a rapid increasing demand for more wireless network applications. Innovative mobile network applications are quickly emerging. Traditional industries are undergoing a remarkable transformation that involves several upgrades to unlock huge potential.

1.1.1 Consumer Market

Consumer requirements are growing at an exponential rate. Individual and household users require high mobile network speeds and low latency. Existing networks cannot meet these requirements and are in series need of upgrades in order to fulfill consumer needs in the following scenarios.

Online mobile videos are under rapid development. Video On Demand (VOD), video on-live (VOL), internet TV programs, and mobile video sharing platforms are quickly emerging. Video quality is improving. The standard video bit rate has increased from 720p to 1080p and will further increase to 2K and 4K ultra-high-definition (UHD).

AR and VR markets will witness accelerated development over the next five years. AR and VR require higher network speeds than traditional videos.

Wireless to the x (WTTx) services (home broadband access provided by 4G wireless networks) have been growing increasingly popular. International Telecommunication Union (ITU) has defined WTTx as a new home broadband access technology. WTTx users are online longer, have five to ten times higher monthly data of usage (DOU), and require higher bandwidth.

The rapid popularization of smartphones drives the development of the global mobile gaming industry. Mobile gaming has become an important type of entertainment. With fierce competition rising within the mobile gaming industry, experience is manifesting as a competitive differentiator for many mobile game operators. An optimal game control experience is only possible on stable networks with low E2E latency.

1.1.2 Verticals

According to national communications and internet strategies, traditional industries need to be digitalized and informationalized. Traditional networks cannot adapt to verticals, which are diversified and have ever-changing requirements. Innovative network technologies and applications are required to fulfill the following scenarios.

As the Internet of Vehicles (IoV) develops, vehicles demand lower communication latency, higher reliability, and higher transmission rates.

Smart manufacturing and electronic healthcare are becoming more popular in the industrial circle and also require low latency and high network reliability. Meanwhile, these fields call for flexible network scheduling and configuration management.

The complex and diversified demands from governments, enterprise services, future unmanned driving, AI, and cloud services also elicit higher network requirements.

1.2 Trends of Traffic Volumes on Mobile Networks

Rich contents, rapid growth of mobile users, increasing demands for industry applications, higher bandwidth requirements for mobile applications, and the transformation of the mobile network traffic model will increase the subsequent volume of traffic by several times.

1. The number of mobile users is rapidly growing. Radio access technologies (RATs) are being upgraded, significantly increasing network rates. By 2020, global mobile traffic is expected to increase by seven-fold, and the Asia Pacific will witness the highest traffic growth rate.

2. The development of large-traffic services, such as mobile video, is speeding up. The volume of traffic for mobile video services is expected to increase by 50% each year until 2023.

3. Higher network quality, lower tariffs, unlimited data packages, and other changes have reshaped user behavior, raised DOU, and further propelled the growth of traffic.

More traffic demands wider coverage, better communication quality, larger capacity on mobile networks, and stronger mobile terminal capabilities to improve user experience.

1.3 3GPP Evolution Towards 5G

3GPP specifications continue to evolve in terms of network architecture, network capacity, and low latency to meet new market requirements.

- Architecture

3GPP has proposed two 5G evolution paths: LTE evolution towards Release 15, and 5G NR.

As for LTE evolution, 3GPP Release 15 enhances LTE multi-service capabilities, such as low latency, Cellular Internet of Things (CIoT), and enhanced WTTx, and improves user experience using many technologies, including enhanced multiple-input multiple-output (MIMO), enhanced carrier aggregation (CA), and uplink data compression. As for 5G NR, 3GPP proposes several 5G NR network architectures, including option 2/5 of 5G standalone (SA) networking, option 3/3a/3x, option 4/4a series, and option 7/7a/7x of 5G non-standalone (NSA) networking. 3GPP has completed the specifications for EPC-based NSA option 3/3x and related work on SA option 2.

During the deployment of future 5G networks, operators will choose one or many 5G network deployment solutions based on network scenarios and requirements. NSA solutions allow operators to select potential LTE sites and areas that need upgrades depending on service requirements and rapidly deploy 5G networks based on legacy LTE networks. NSA solutions require close coordination between 4G and 5G. SA solutions feature independent 5G deployment without 4G base station upgrades. SA solutions use the 5G Core Network (5GC) to provide better support for many additional functions, such as 5G E2E slicing.

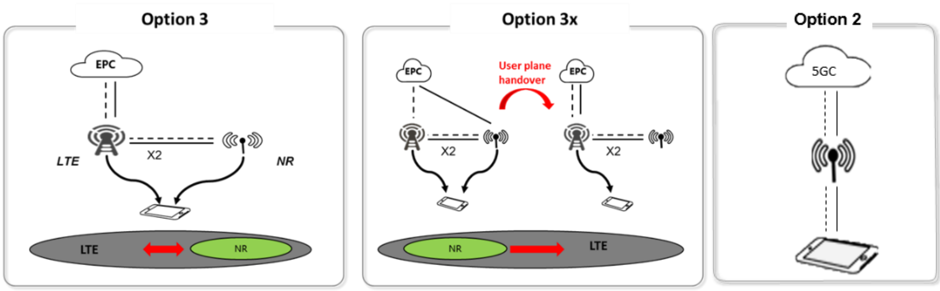

Figure 1 Architecture for option 3/3x and option 2

- Multiple-antenna technology

Multiple-antenna technology is the key to improving wireless network capacity and a fundamental 5G air interface technology. 3GPP has introduced 4-port MIMO in Release 8, introduced TM9 and enabled 8-port MIMO in Release 10, and increased the number of antenna ports to support 32-port massive MIMO in Release 14. Massive MIMO is also an essential technology to help improve spectral efficiency and air interface capacity for 5G NR. As multiple-antenna technology evolves, terminals can support TM9 and 4Rx, maximizing the benefits of massive MIMO.

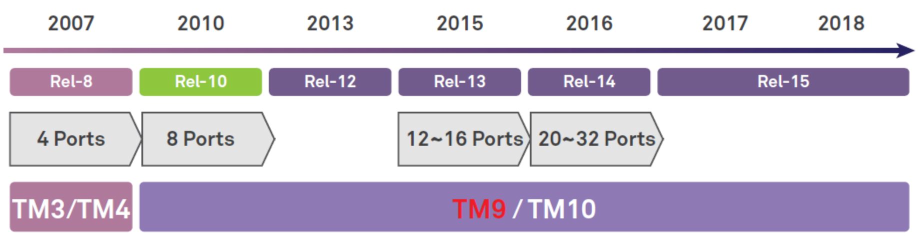

Figure 2 3GPP Evolution

- Low latency

New services, popularization of mobile games, and innovative applications, such as remote control using communications networks, require lower E2E latency on mobile communications networks. Ultra-Reliable and Low-Latency Communication (uRLLC) will be one of the most important 5G application scenarios. 3GPP Release 15 introduces the air-interface low latency technology. This technology shortens the scheduling period and reduces the typical latency over the air interface from 10 ms to 2 ms and enables operator networks to offer more services for many different verticals.

2. Key Technologies for LTE Evolution Towards 5G

The wide application of new technologies requires RAN-terminal coordination. This fully unlocks the dormant potential of these technologies, improves spectral efficiency and network capacity, and enhances user experience. Among key 5G-oriented LTE technologies, several examples are specifically related to terminals and chipsets.

1. 4-antenna reception (4Rx)

4Rx terminals can receive signals from more paths than 2Rx terminals, support higher-order MIMO, and improve network efficiency and user-perceived rate.

2. Multiple-antenna transmission mode 9 (TM9)

TM9-capable terminals can form user-specific beams in TM9 cells and support multi-stream multiplexing. This reduces interference between terminals and helps to significantly improve both network capacity and user data rates.

3. Low latency

The low latency function, which is introduced in 3GPP Release 15, increases the scheduling frequency to shorten the service latency over the air interface. This technology guarantees lower latency and provides higher user-perceived rates for latency-sensitive services, such as mobile games and remote control.

4. CA

A CA-capable terminal can aggregate LTE component carriers to improve its transmission bandwidth and allow for a considerable increase in both uplink and downlink transmission rates.

5. High-order modulation (downlink 256QAM/uplink 64QAM)

High-order modulation allows for more bits to be transmitted in a symbol, effectively helping to increase both air interface efficiency and transmission rates.

As key 5G-oriented technologies, 4Rx, CA, higher-order modulation, TM9, and low latency have gained particular interest as a primary focus of the industry. CA-capable terminals (especially those capable of downlink 2CC CA) are enjoying rapid widespread market penetration. A surprisingly high number of terminals have been launched supporting uplink and downlink higher-order demodulation. 4Rx has become a standard configuration for high-end mobile phones and a target configuration for medium- and low-end mobile phones. Major chipsets have evolved to support TM9. Terminal vendors can simply push software packages using over the air (OTA) to activate TM9 on terminals powered by capable chipsets. Specifications for the low latency function can be considered to be a relatively late comer. Terminals supporting this function are expected to be commercialized by 2019.

3. 4Rx

3.1 Introduction

4Rx refers to the use of four RX antennas for signal reception. By increasing the number of RX antennas, 4Rx in combination with other signal processing technologies (at the TX and RX ends) helps to exponentially improve spectral efficiency, peak rate, and perceived rate for cell edge users (CEUs).

3.2 Benefits

4Rx UEs support transmission of up to four layers of data streams, allowing for exponential increases in the peak rate (compared with traditional 2x2 MIMO).

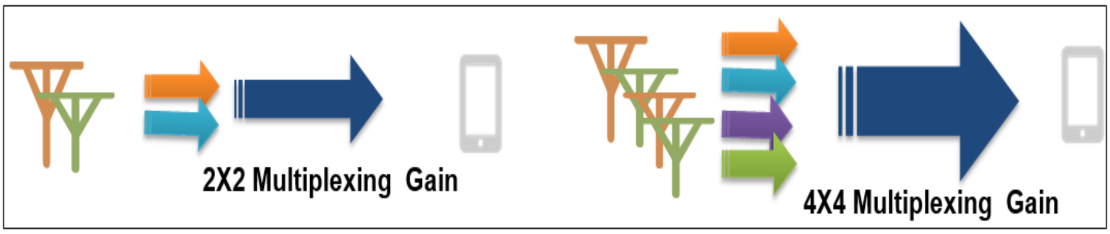

Figure 3 4Rx UEs compared with 2Rx UEs

Channel quality at the cell edge is often poor, which negatively affects CEU experience. In order to achieve substantial diversity and array gains, 4Rx UEs can use the non-correlation between noise and between deep fading on different antennas to reduce fading of combined signals and increase the SINR. This improves reception quality and the CEU-perceived rate.

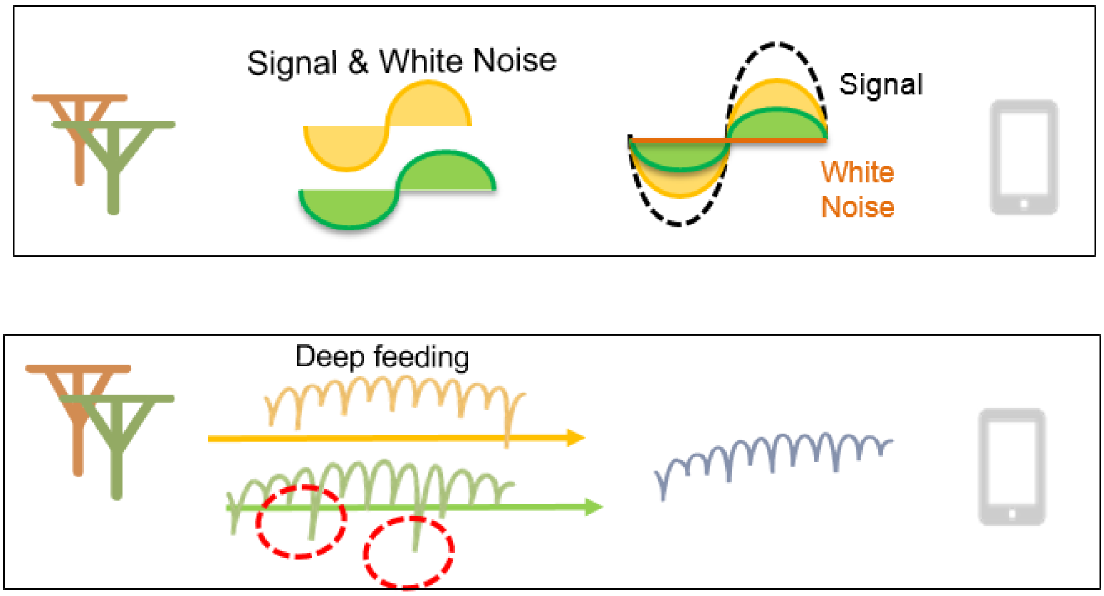

Figure 4 Multiple-antenna diversity gain and array gain

3.3 Network Test Results

Test results on several commercial networks show that 4Rx UEs experienced higher rates than 2Rx UEs.

1. The average downlink user-perceived rate increased by 20% to 90%.
2. The user-perceived rate near the cell center increased by 40% to 60%.
3. The user-perceived rate at the cell edge increased by 50% to 90%.

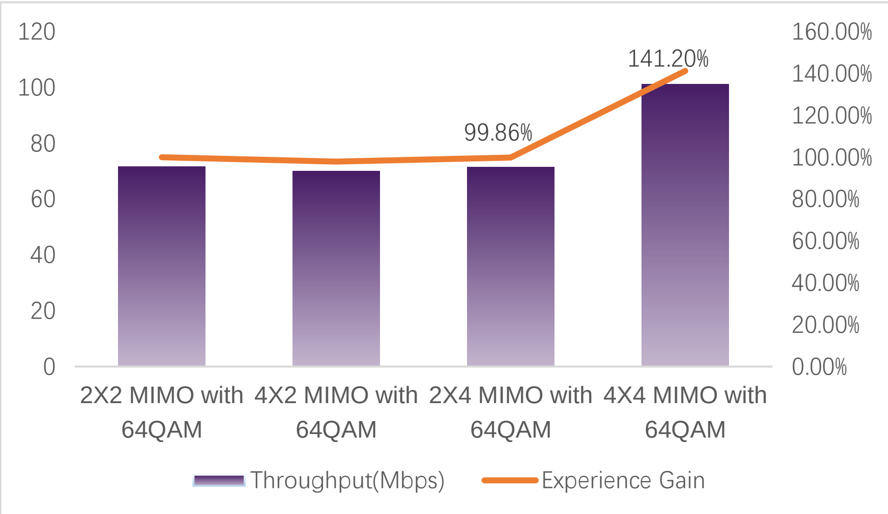

Figure 5 2x2 MIMO and 4x4 MIMO field test at near point (cell center)

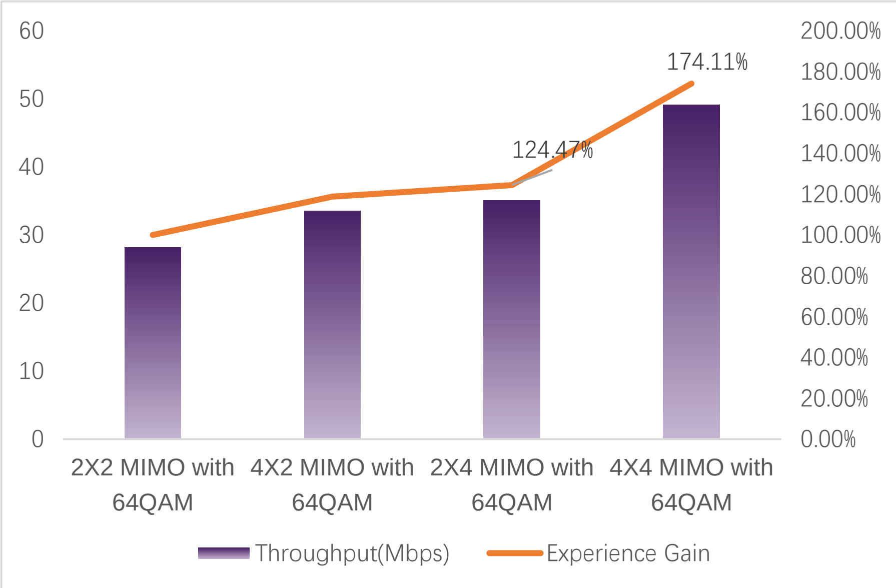

Figure 6 2x2 MIMO and 4x4 MIMO field test at midpoint (cell middle) distance from the cell center

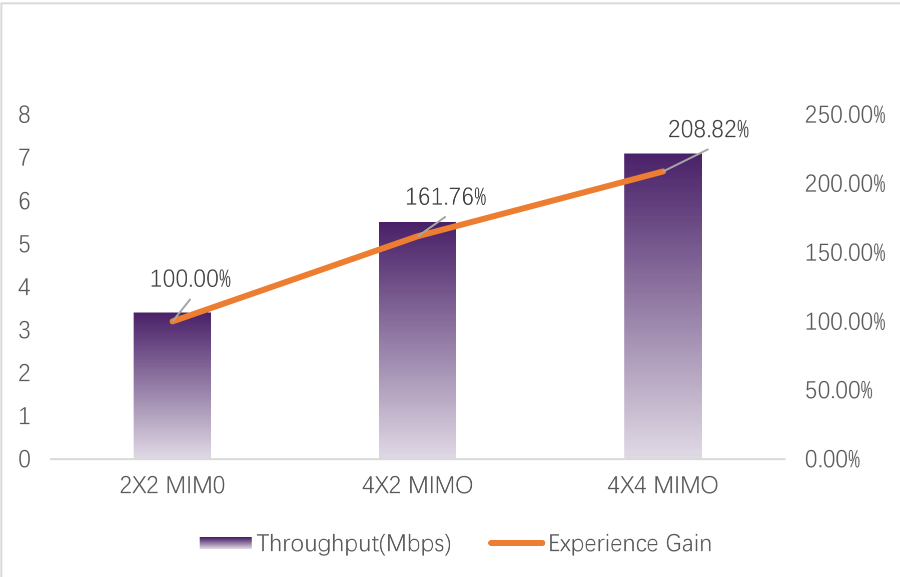

Figure 7 2x2 MIMO and 4x4 MIMO field test in far point (cell edge)

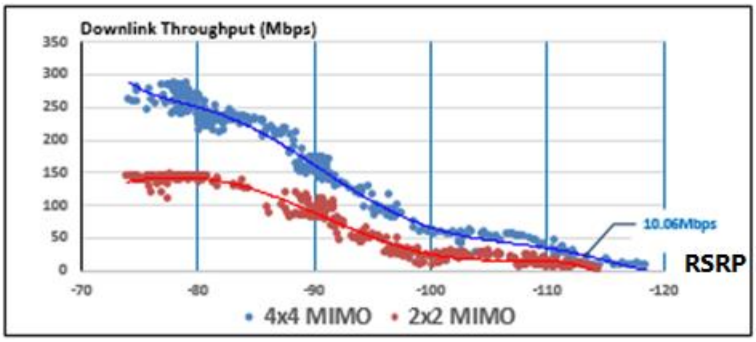

Figure 8 2x2 MIMO and 4x4 MIMO mobility test result

3.4 Industry Progress

As mobile services raise higher requirements for network capacity and rates, 4x4 MIMO has been deployed on more and more LTE networks. Up to 110 4x4 MIMO LTE networks have been deployed worldwide. At the same time, 4Rx has gradually become the standard configuration for flagship models of major terminal vendors. The combination of 4x4 MIMO, CA, and 256QAM has proven instrumental in achieving downlink gigabit rates on LTE networks. In the future, the downlink rate will continue to increase with the constant evolution of related technologies.

4. TM9

4.1 Introduction

MIMO can significantly improve network capacity, user-perceived rates, and cell coverage without increasing the transmit power and bandwidth. In order to further improve the average rate in a cell, rate at the cell edge, and spectral efficiency, 3GPP proposed MIMO in TM9. This transmission mode is fortunate to benefit from the introduction of a new reference signal (RS) pattern, and can be expected to evolve to include higher-order MIMO. The new RS pattern in TM9 enables a base station to generate UE-specific beams. In this way, single-user MIMO (SU-MIMO) and multi-user MIMO (MU-MIMO) can be achieved. Especially when massive MIMO is deployed on a network, TM9-capable UEs can greatly improve network capacity and relieve congestion in hotspot areas, such as central business districts, shopping malls, and academic institutions.

4.2 Benefits

4.2.1 MU-MIMO in TM9 Improves Network Capacity

In traditional TM3/TM4 cells, UEs measure channel quality and demodulate data based on cell-specific reference signals (CRSs). All UEs share the same spatial beam. Each time-frequency resource can serve only one UE at the same time. MU-MIMO cannot be implemented. In TM9, new channel state information-reference signal (CSI-RS) and demodulation reference signal (DMRS) are introduced. TM9 enables a base station to generate narrow beams targeting different UEs by means of precoding and beamforming. The channels between UEs are independent, and each time-frequency resource can serve multiple UEs at the same time, achieving MU-MIMO. In massive MIMO scenarios, TM9 increases the capacity to 6.5 times that of a 2T2R cell.

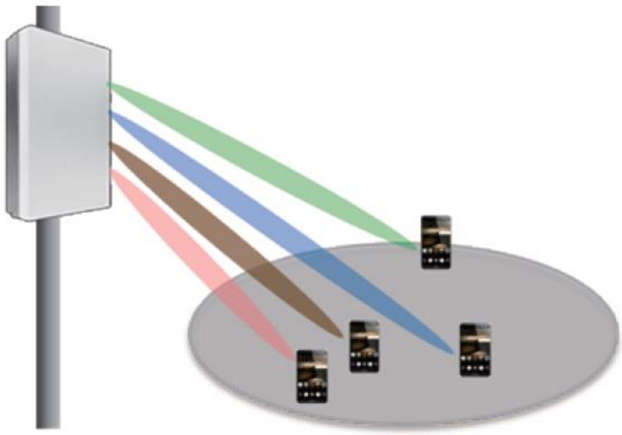

Figure 9 MU-MIMO with TM9

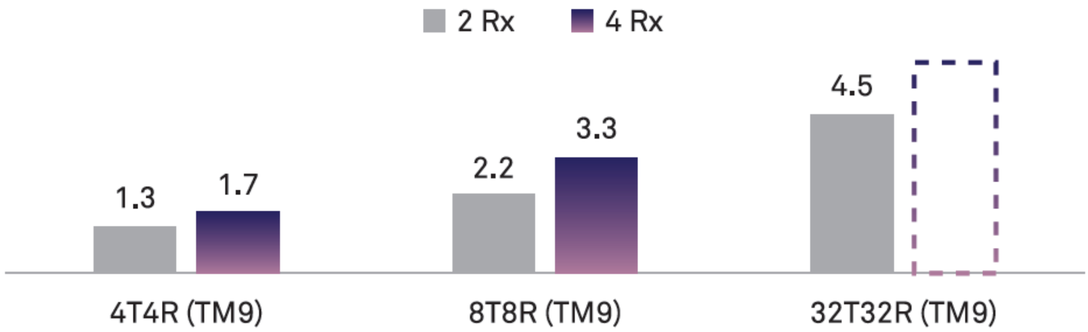

Figure 10 Capacity gains offered by nTnR in contrast with 2T2R

4.2.2 Higher-Order SU-MIMO in TM9 Improve User Experience

SU-MIMO allows a single UE to transmit multiple data streams at the same time, exponentially increasing UE throughput. Networks using multiple-antenna transmission based on TM9 have higher channel independence and a higher multiplexing rate of spatial channels. TM9 supports transmission of up to eight data streams. At present, 8-antenna CPEs have emerged, and four antennas have become the standard configuration of high-end smartphones. TM9-capable multiple-antenna UEs significantly improve user experience.

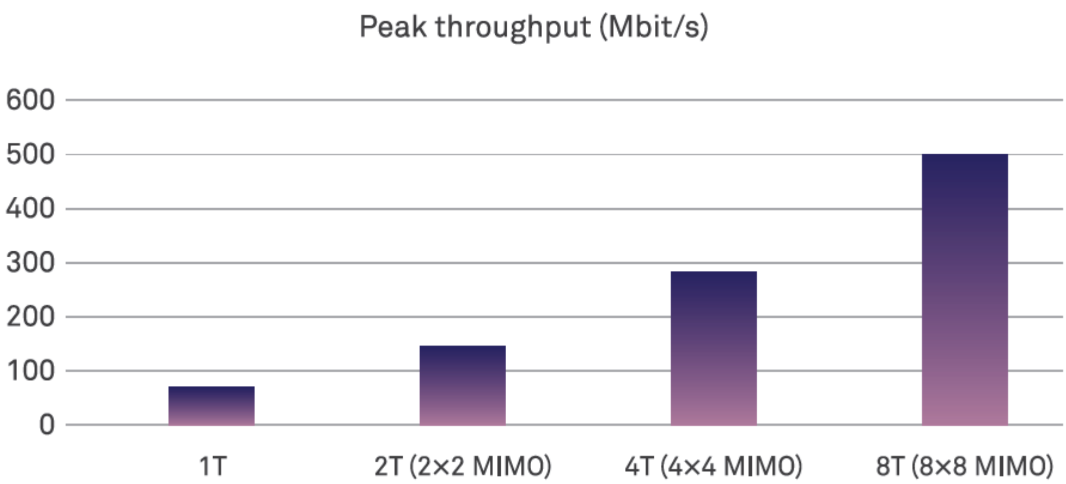

Figure 11 Peak throughput of MIMO

For example, if the number of antennas on a UE is limited, more accurate channel measurement can still be achieved with an increase in the number of antenna ports of the base station, achieving a higher average UE throughput.

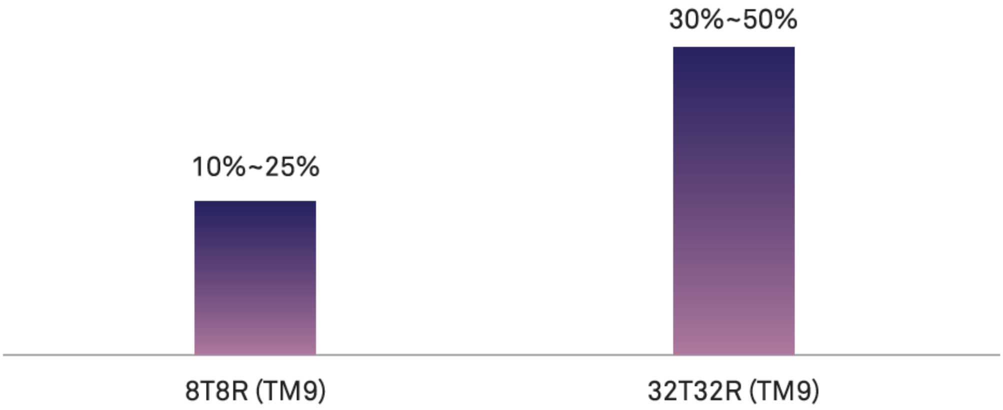

Figure 12 Average throughput gains offered by nTnR in contrast with 4T4R(based on 2Rx UE)

4.2.3 DL-CoMP in TM9 Improves CEU Experience

Coordinated multipoint transmission (CoMP) is a coordinated multipoint transmission and reception technology. DL CoMP enables multiple coordinating cells to transmit PDSCH data to CEUs between these cells, achieving both power and array gains. DL-CoMP can help to significantly improve CEU-perceived rates.

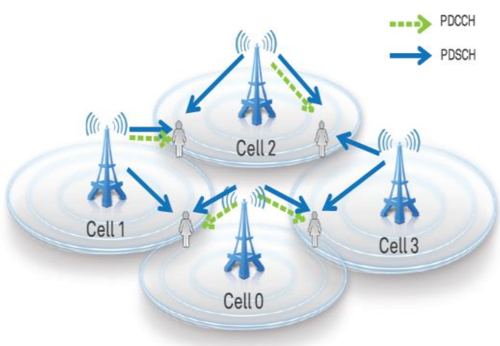

Figure 13 DL-CoMP with TM9

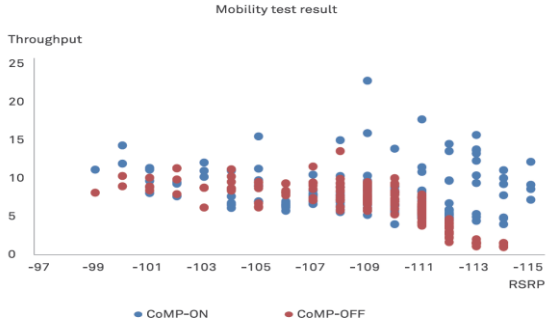

Figure 14 Mobility test result of CoMP

4.3 Network Test Results

TM9 tests in multiple labs and on multiple commercial networks indicate:

1. After TM9 was enabled on a 4T4R commercial network with existing UEs, network KPIs and user experience remained stable.

2. In 8T8R scenarios, certain commercial UEs were used for testing. The rate perceived by a TM9 UE increased by 40% compared with that of a TM4 UE.

3. MU-MIMO with the combination of massive MIMO and TM9 increased the LTE cell capacity by three to five times. The peak rate perceived by a single TM9 UE increased by 30% to 50%.

Network KPIs remained stable before and after TM9 was enabled.

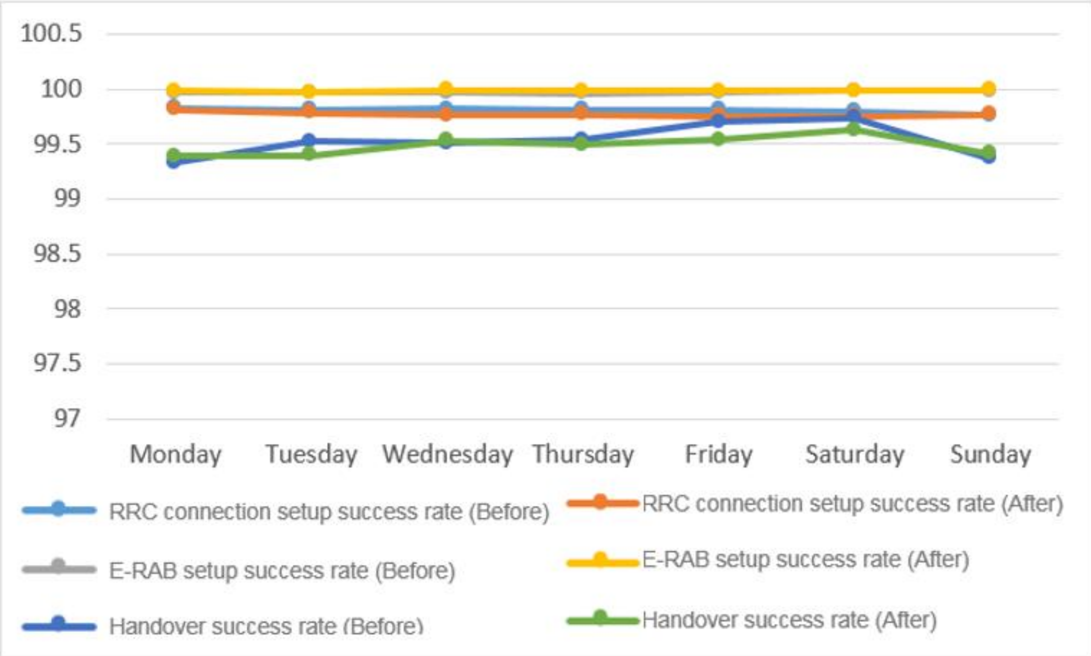

Figure 15 Network KPI remained stable after TM9 activation

The 8T8R field test based on a mainstream UE shows that the rate perceived by TM9 UEs in an 8T8R cell in MU-MIMO scenarios was improved by 1.6 times compared with that of TM4 UEs in a 2T2R cell, and by 46% compared with that of TM4 UEs in an 8T8R cell.

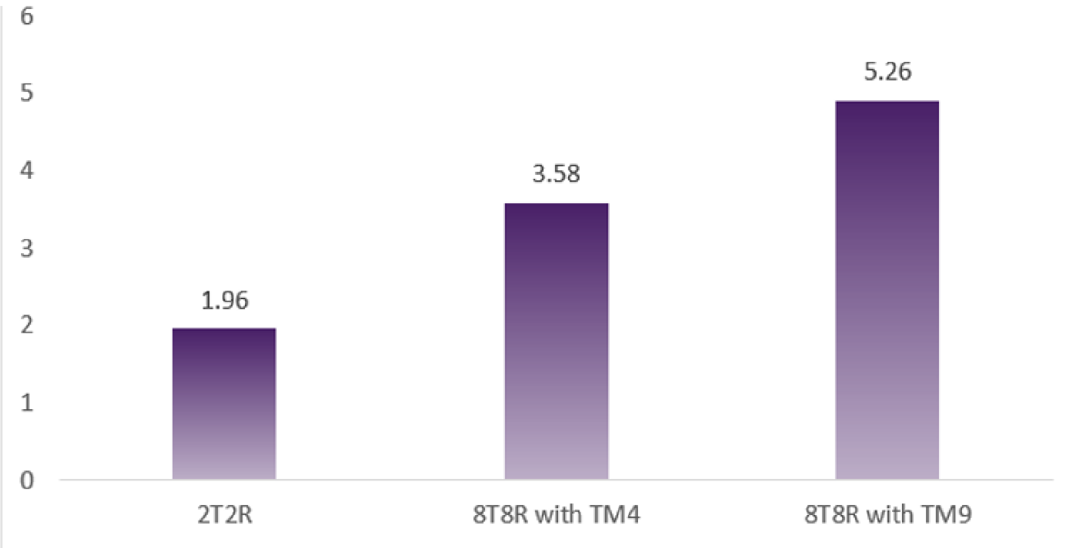

Figure 16 Average downlink data rate(Mbps) at 5 MHz cell

The cell capacity and average UE throughput were better than those of 2T2R networks before and after TM9 was enabled on a massive MIMO network.

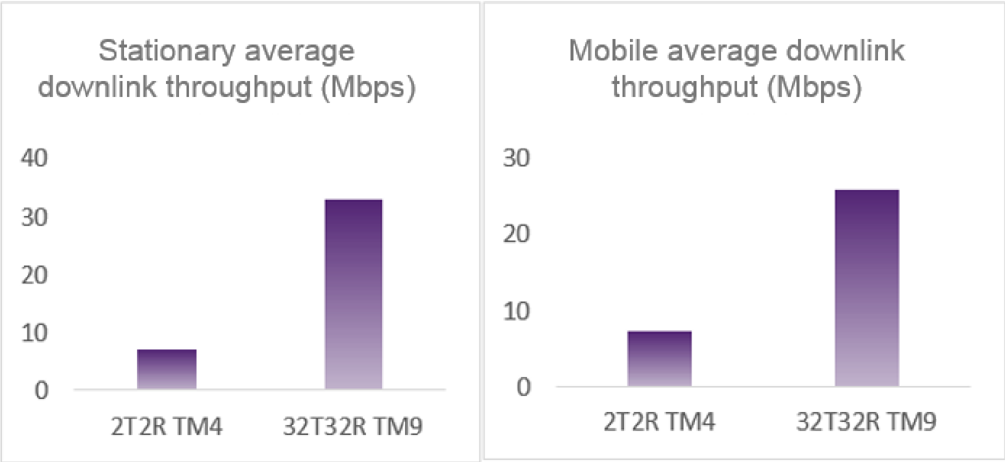

Figure 17 Average downlink data rate in Massive MIMO cell

4.4 Industry Progress

The TM9 industry has finally matured after undergoing several years of evolution. Major chipset vendors, including Qualcomm, Huawei HiSilicon, Intel, and MediaTek, have launched TM9-capable UE chipsets.

More than 20 UE models are powered by these chipsets and can be easily upgraded to support TM9 once vendors launch corresponding software packages through OTA. As massive MIMO matures, major terminal vendors are growing increasingly interested in TM9, and TM9 has been activated for high-end UE models for a number of leading brands.

It is estimated that the global penetration rate of TM9 UEs on the live network will exceed 20% by the end of 2018.

5. Proposals on Collaborative Development of 5G-oriented Terminals, Chipsets, and Networks

5G has become the central focus of mobile network technology development and a catalyst for promoting the use of mobile technologies across general fields. Verticals and general fields require technological innovations of 5G mobile internet in various application scenarios, such as network slicing, Gbps user-perceived rate, and millisecond E2E latency. 5G network architectures and key technologies have completed the verification and all necessary stages for commercial deployment.

Telecom operators play a leading role in the development and cultivation of the 5G industry. China Unicom has completed the planning of 5G E2E network architectures and key technologies in Q4 2016. This involves the setup of a 5G Open Lab, 5G service demonstrations, verifications in single-technology performance, and an exploration into new technical solutions for 4G to 5G evolution.

The multiple-antenna technology is a key technology for 5G evolution. The communications industry chain needs to collaboratively promote the progress and implementation of key technologies. Only collaborative development of network, terminal, and chipset capabilities can enhance mobile network capabilities and improve user experience.

Currently, key technologies for evolution to 5G on the network side are ready for commercial use, and terminal capabilities are still maturing. Since 2018, more and more flagship models support 4Rx. Chipset and terminal vendors have conducted tests on TM9 commercial use and plan to launch TM9-capable terminals.

In order to ensure the rapid launch of new technologies and improve user experience and spectral efficiency, it is recommended that industry terminal, chipset, and network vendors cooperate to develop the core capabilities of terminals for evolution towards 5G. These efforts will enhance coordination between networks, terminals, and chipsets through the Open Lab, and ultimately help to achieve quick interconnection. Vendors jointly accelerate the deployment of technologies on the network side, promote the development of terminal and chipset capabilities, and improve the penetration rate of terminals supporting new technologies. All of these combined activities will prove invaluable in laying a solid fundamental foundation for the new and improved industry ecosystem.