GTI White Paper

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Massive MIMO WHITE PAPER

V 0.1

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Global TD-LTE Initiative

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Executive Summary

With the growing popularity of mobile internet and the explosive growth of smartphones, users' usage habits have dramatically changed. The exploration of mobile broadband access capacity significantly stimulates the demand for mobile internet and boosts the growth in mobile data services, which in turn increases the demand for mobile network capacity.

To satisfy the rocketing traffic demand, introducing a growing number of antennas becomes inevitable in the 4G and 5G eras. Massive-antenna technology promises to be a core technology in the forthcoming 5G era.

Massive-antenna technology enables 4G to retain its continuous evolution. By adopting massive antennas, this technology significantly improves the spectrum efficiency, especially amid large capacity demand and extensive coverage, enabling 4G networks to satisfy growing network demand. From the operator’s perspective and requirement, this technology is envisioned and required to enable 5G hardware to be ready in advance and provide 5G air interface functions through software upgrades, facilitating 5G deployment.

As a massive-antenna technology in the 4G era, Massive MIMO has been widely regarded as an ever energizing technology since 4G rollout. It takes the unrivaled advantages of LTE TDD spectrum to achieve revolutionary breakthroughs in network performance for operators. This revolutionary technology is a great prelude to the future-oriented network.

- By adopting massive antenna arrays, Massive MIMO brings about a three to fivefold increase in the spectrum efficiency when compared with traditional macro sites. This significant gain promises to motivate operators to totally overturn their network build strategies.
- Massive MIMO increases the flexibility of network coverage and operators can adapt the horizontal and vertical coverage scopes of Massive MIMO to coverage scenarios.
- With its astonishingly high capacity gain, Massive MIMO is expected to help operators adopt increasingly flexible charging polices to attract users, provide unimagined user experience and stimulate user data consumption, achieving traffic monetization and increasing operators' revenue.
- Massive MIMO is compatible with 4G terminals and operators can immediately receive the return on investment (ROI) from Massive MIMO deployment on 4G networks. At the same time, this technology also supports 5G-oriented network evolution, which keeps and even raises the returns on current investment.

Contents

1 Introduction

1.1 Background

With services evolving from voice and text in the 2G era to website and data in the 3G era and then to video and online gaming in the 4G era, user requirements for network capacity and delay are becoming increasingly demanding. It is expected to see applications, such as virtual reality (VR) and augmented reality (AR), gaining momentum in the year 2018 and data traffic is bound to increase explosively. According to *Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2015–2020*, the compound annual growth rate of mobile data traffic is expected to reach up to 53% globally from 2015 to 2020, as shown in the following figure.

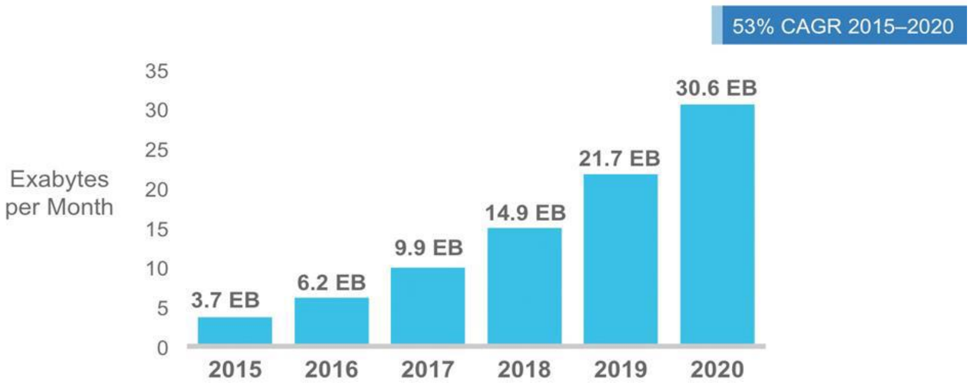

Figure 1-1 Prediction for mobile traffic growth

With a great effort to fight against the preceding challenge, Massive MIMO is introduced on LTE networks to efficiently improve spectrum efficiency (SE), channel capacity and link reliability. 5G is expected to adopt increasingly high frequency bands and LTE TDD has more obvious advantages in deploying high-band Massive MIMO.

1.2 Objectives of This White Paper

Massive-antenna technology is of significant importance for operators during evolution from 4G to 5G. Traffic is growing fast, and how to fully use current LTE investment to constantly meet traffic demands and how to maintain the profitability of existing 4G and 4G evolution systems to satisfy the development requirements of vertical industry and applications are important for operators. All these impose demanding requirements for operators' networks. With ITU's finalization of 5G requirement collection and unveiling of 5G standardization, how to satisfy 5G's requirements for spectrum efficiency is also of priority for operators.

LTE TDD has some inborn advantages in deploying Massive MIMO. With the aim of facilitating massive-antenna technology deployment on 4G networks and 5G rollout, this white paper describes the technical principles and test achievements of Massive MIMO, and serves as a reference for operators and industry partners during 4G evolution and 5G deployment.

This White paper covers:

- Massive MIMO principle and TDD advantage for Massive MIMO
- Field trial results of Massive MIMO in typical scenarios
- Massive MIMO Commercial Roadmap in 4.5G and 5G
- The requirements and further enhancements of Massive MIMO commercial products

1.3 Terminology

Term	Description
AR	Augmented Reality
AAU	Active Antenna Unit
BBU	Baseband Unit
BS	Base Station
DL	Downlink
FDD	Freqency Division Duplex
LTE	Long Term Evolution
MIMO	Multiple In Multiple Out
MU-MIMO	Multi-user MIMO
SE	Spectrum Efficiency
TDD	Time Division Duplex
TRX	Transceiver
UL	Uplink
VR	Virtual Reality

2 Principles of Massive MIMO

2.1 Fundamental Principles of Massive MIMO

Massive MIMO, a candidate for 5G technology, promises significant gains in wireless data rates and link reliability by using significantly more antennas at the base station (BS) than in current BS's. In Massive MIMO system with large antenna arrays, the signal can be adjusted in both azimuth and vertical dimensions dynamically so that the energy can be more focused and accurately directed to a particular UE, thus reducing inter-cell interference and supporting spatial multiplexing with more UEs.

Beamforming combined with spatial multiplexing of many users (enabled with the large number of transceivers and antenna elements), the area spectrum efficiency is increased by an order of magnitude.

In short, Massive MIMO system is defined by:

- A large number of transceivers(TRXs)
- Spatial multiplexing capability
- Multi-user scheduling (MU-MIMO)
- Large antenna array with high gain in uplink(UL) and downlink (DL)

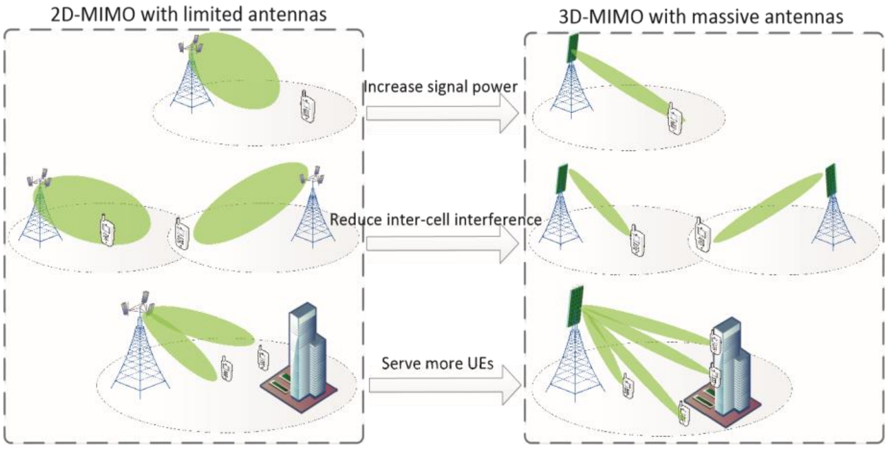

Figure 2-1 Technical principles of Massive MIMO

2.2 TDD facilitates Massive MIMO implementation

Utilization of TDD technology offers significant advantages with respect to spectrum efficiency, network performance and capacity in Massive MIMO system, meanwhile it offers a viable evolution path from 4G towards 5G networks and services.

Due to uplink and downlink channel reciprocity, TDD base stations (BSs) are capable of obtaining complete and unquantized downlink channel state information to achieve increased cell coverage and throughput using more flexible and accurate beamforming. Based on the more accurate unquantized channel state information, the multi-user scheduling in TDD systems can be more flexible and accurate, thus further increasing system capacity. In contrast, FDD BSs can only obtain quantized channel state information through codebook feedback by UE, resulting in limited beamforming and scheduling flexibility.

The advantage of channel reciprocity in TDD systems becomes more prominent, making it inherently suitable for of beamforming with 64 and more antennas. Another advantage with TDD MassiveMIMO deployment is that existing commercial 3GPP Release 8/Release 9 UEs can also be served without any update.

3 Field Trial of Massive MIMO in Typical Scenarios

Massive MIMO is compatible with existing protocols and terminals, and can be deployed through hardware and software upgrades on the system side. This technology significantly improves network coverage, spectrum efficiency, average cell-edge user throughput, and commercial user experience. Massive MIMO has been tested for trial on commercial networks and achieves outstanding performance in some valued scenarios. In large-capacity hotspot scenarios, Massive MIMO enhances the network capacity and adopts spatial multiplexing to serve more users. In 3D coverage scenarios, this technology provides flexible beamforming capacity to better serve users in high buildings.

3.1 Valued Application Scenarios

3.1.1 Hotspot Scenarios

Currently, data traffic volume is towarding a trend where over 70% traffic is generated in 20% areas, which form the hotspot areas. Areas, such as urban CBDs, business centers, transport hubs, residential communities, and campuses, are experiencing common issues, including concentration of people, heavy traffic, and insufficient capacity. Massive MIMO is promising to provide high spatial multiplexing gain and strong beamforming capabilities to satisfy capacity requirements in these areas.

3.1.2 3D Coverage Scenarios

High buildings typically suffer poor network coverage, and extensive coverage is difficult on the current network due to the following challenges:

- Multiple antennas are required for high-building coverage, and site acquisition is difficult.
- Signals become weak after penetrating through the wall.
- Upward signal transmission increases inter-cell interference in high buildings.

High buildings are usually traffic intensive. To meet the traffic demand in such high-value scenarios, Massive MIMO has the following unique advantages:

- Adopts a large number of antenna arrays in the vertical plane to significantly enhance high-building coverage.
- Achieves beamforming gains to compensate the penetration loss.
- Adjusts beam widths and directions flexibly on demand to reduce inter-cell interference, enhancing 3D coverage and capacity.

3.2 Peak Throughput Testing

The peak data rate test is carried out in a typical outdoor scenario in Beijing as shown in Figure 3-1, where multiple UEs are placed as marked with yellow stars under full-buffer traffic. The Massive MIMO BS is equipped with 64 transceivers (64TRXs), while the current commercial BS is with 8 transceivers (8TRXs). The measured downlink peak throughput under Massive MIMO BS reaches 660 Mbit/s, representing a 600% growth over the 8TRXs network.

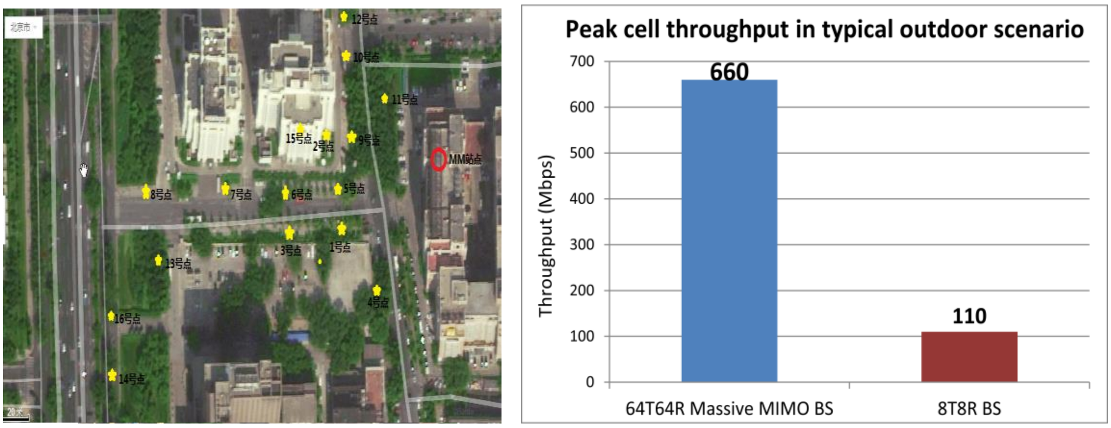

Figure 3-1 Peak cell throughput test result

3.3 Performance in Commercial Network

Currently, Massive MIMO has been deployed on commercial networks. This section analyzes the network KPI improvements of Massive MIMO when no test terminals are available and only commercial UEs exist.

3.3.1 Hotspot Scenarios

At a campus site in Beijing (as shown in Figure 3-2), Massive MIMO significantly improves the system capacity according to the KPI monitoring results, with 255% and 305% growths of the average spectrum efficiency in the downlink and uplink, respectively, over 8TRXs networking with commercial UEs and non-full buffer traffic.

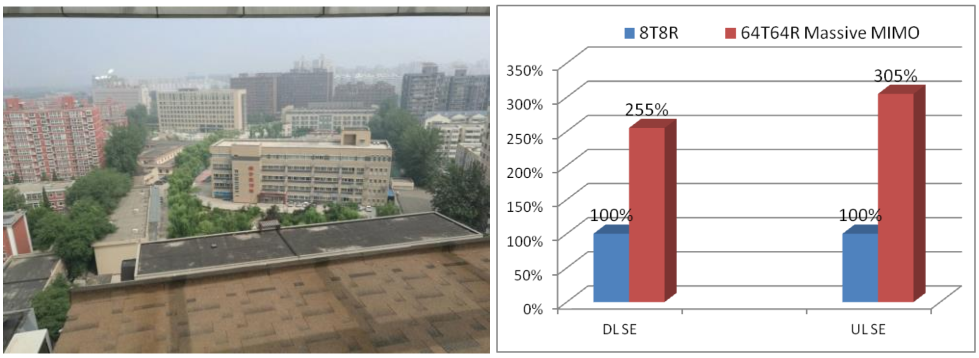

Figure 3-2 Spectrum efficiency improvement in campus scenario

3.3.2 3D Coverage Scenarios

At a site in Beijing (as shown in Figure 3-4), Massive MIMO significantly improves network coverage in high-rise residential areas. Compared with conventional 8TRXs networking, Massive MIMO reduces the number of coverage holes in the vertical plane.

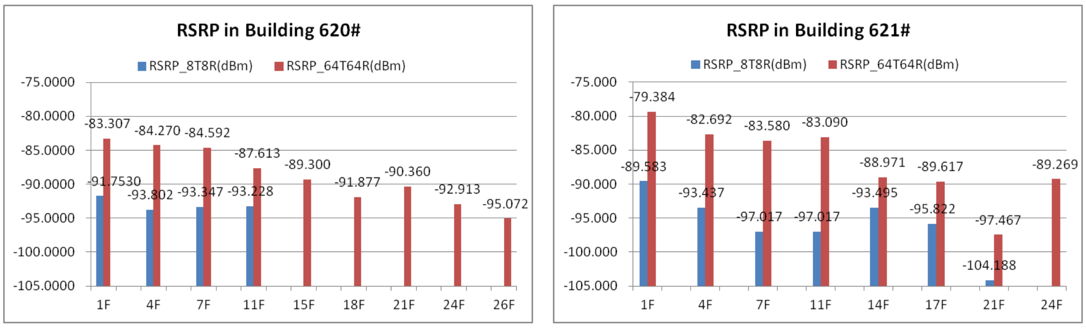

Figure 3-3 RSRP improvement in high-rise residential areas

4 Massive MIMO Paves the Way for Evolution from 4.5G to 5G

4.1 Roadmap of Massive MIMO Evolution Towards 5G

LTE TDD Massive MIMO is expected to further evolve to facilitate its commercial deployment and further development in 4G evolution and 5G systems. The following figure shows the roadmap of Massive MIMO evolution in 4G evolution and forthcoming 5G systems.

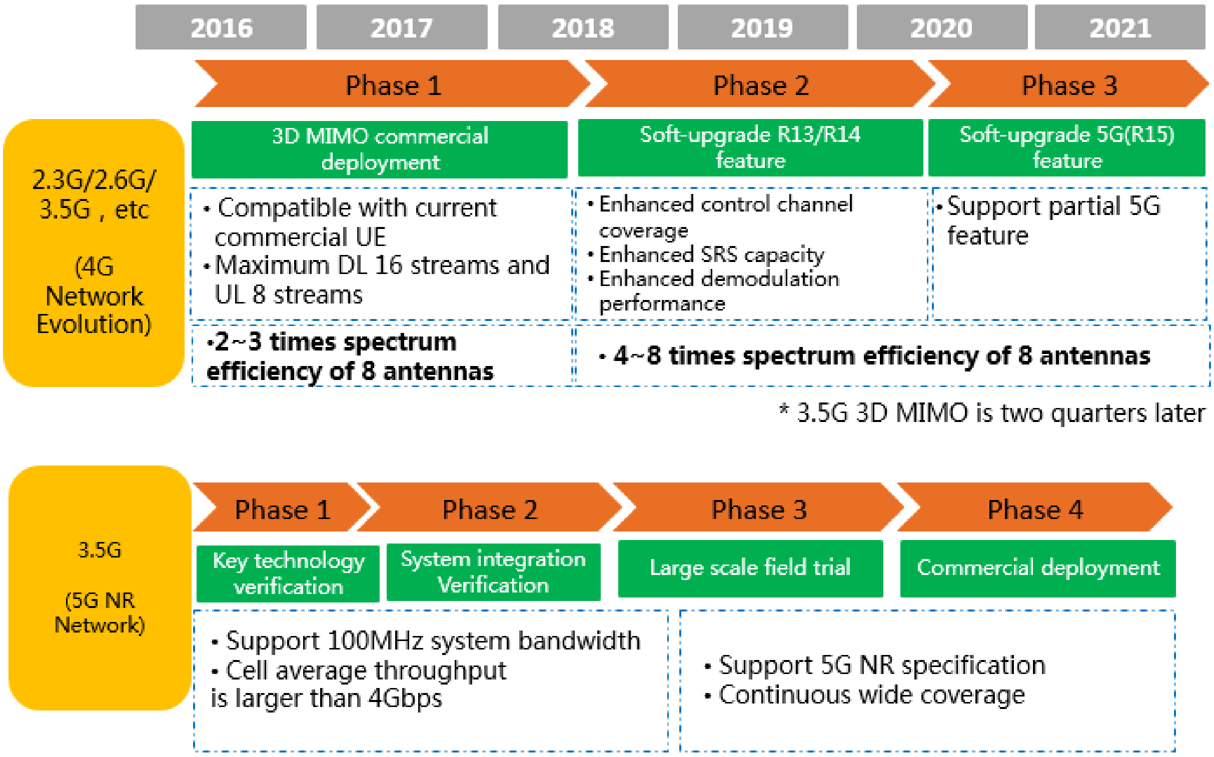

Figure 4-1 Massive MIMO evolution roadmap towards 5G

4.2 Massive MIMO Commercial Products at Current Stage

4.2.1 Huawei's Massive MIMO Products

Table 4-1 Massive MIMO product – Huawei

<table>
<tr><td colspan="2">Product</td><td>MassiveMIMO</td></tr>
<tr><td colspan="2">Commercial Release Time</td><td>2016 Q4</td></tr>
<tr><td rowspan="6">Active Antenna Unit (AAU)</td><td>Number of TRXs</td><td>64</td></tr>
<tr><td>Bandwidth</td><td>60 MHz</td></tr>
<tr><td>Power</td><td>120 W and 150 W</td></tr>
<tr><td>Dimensions</td><td>860 mm x 500 mm x 120 mm</td></tr>
<tr><td>Weight</td><td>37 kg</td></tr>
<tr><td>Heat dissipation</td><td>Natural heat dissipation</td></tr>
<tr><td rowspan="2">Baseband</td><td>UBBPem</td><td>2 x 20 MHz x 64 TRXs for each UBBPem
Each BBU supports S333 full configuration.</td></tr>
<tr><td>Optical Module/Port</td><td>Two 40 Gbit/s or 100 Gbit/s CPRI ports, with each optical fiber supporting three carriers</td></tr>
<tr><td rowspan="2">Product Solution</td><td>Architecture</td><td>Distributed architecture (BBU & AAU)</td></tr>
<tr><td>Benefit</td><td>Multiplexing capabilities: 16 layers in the downlink and 8 layers in the uplink</td></tr>
</table>

4.2.2 ZTE's Massive MIMO Products

Table 4-2 Massive MIMO product – ZTE

<table>
<tr><td colspan="2">Product</td><td>ZTE Massive MIMO</td></tr>
<tr><td colspan="2">Commercial Release Time</td><td>2016 Q4</td></tr>
<tr><td rowspan="3">AAU</td><td>Number of TRXs</td><td>64</td></tr>
<tr><td>Bandwidth</td><td>60 MHz, 3CC</td></tr>
<tr><td>Power</td><td>120W</td></tr>
</table>

	Dimensions	740x477x180(HxWxD,mm)
	Weight	41kg
	Heat dissipation	Natural heat dissipation
Baseband	**BP Board**	support one 64TRXs 20MHz cell
	Optical Module/Port	support four 25G Optical ports
Product Solution	**Architecture**	Distributed architecture (BBU & AAU)
	Benefit	Multiplexing capabilities: 16 streams in the downlink and 8 streams in the uplink

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4.3 Further Enhanced Massive MIMO to Support 3GPP Rel 13/Rel 14 Terminals and Future 5G

4.3.1 Base Station Evolution

Enhancing Integration Capacity and Reducing Large-Scale Deployment Costs

Massive MIMO is a most disruptive technological innovation in the current mobile communications industry. It uses the multiple-antenna technology to significantly improve the spectrum efficiency, and satisfies the mounting demand on network capacity. With the constant effort of the industry led by major mobile operators, Massive MIMO grows from lab prototype tests to commercial deployment, and has become a major method to achieve rapid network capacity growth on the mobile communications network.

In the next few years, the large-scale commercial deployment costs of Massive MIMO need to be further reduced and the engineering specifications need to be constantly improved so that Massive MIMO can be easily deployed and work with low power consumption.

During evolution from 4G to 5G, the industry needs to consider how to share device hardware, spectrum, power, and other resources between 4G and 5G so that Massive MIMO can evolve smoothly towards 5G.

Smooth Evolution Towards 5G

5G specifications are yet to be finalized. Currently, the candidate air-interface solutions are as follows:

- Waveform technology: OFDM-based, with possible inclusion of new waveforms such as F-OFDM and Window-OFDM, etc
- Frame structure: Multiple numerology, 1 ms and shorter TTI, self-contained subframe, dynamic TDD, and flexible duplex
- Multiple access technology: Orthogonal multiple access, and non-orthogonal multiple access
- Modulation scheme: High modulation order, e.g., downlink 1024QAM and uplink 256QAM
- Coding: LDPC code and polar code

At the system level, these candidate technologies either are purely handled by baseband components or can be implemented independent from RF hardware. Therefore, evolution to 5G becomes possible by adopting 5G baseband boards through hardware addition or replacement and upgrading the software of Massive MIMO RF units. In Table 4-3, the key possible candidates for 5G technology and their relationship with Massive MIMO AAU are listed.

These related enhancements need to be considered in the Massive MIMO products, which will be crucial to the enablement of 5G hardware to be ready in advance and provide 5G air interface functions through software upgrades, facilitating 5G deployment.

Table 4-3 Possible candidates for 5G technology and relationship with Massive MIMO AAU

Category	**Key Candidate 5G Technology**	**Massive MIMO AAU**
Coding	LDPC code and polar code	Coding module; unrelated
Multiple access	Orthogonal and non-orthogonal multiple access	Baseband module; unrelated
Modulation	High modulation order	related
Frame structure	Multiple numerology	related
	1 ms and shorter TTI	related
	self-contained subframe	related
	Dynamic TDD	related
	Flexible duplex	related
Waveform	OFDM-based, with possible inclusion of new waveforms such as f-OFDM and Window-OFDM, etc	related
Waveform	Uplink OFDM	Baseband module; unrelated

4.3.2 Terminal Evolution

Terminal is a crucial part in the wireless system. The development of terminal technologies will enable terminals to work well with Massive MIMO, fully exploring the technological potential of Massive MIMO and significantly improving the single-user capacity and network capacity.

Terminal-side evolution to better support Massive MIMO are expected as follows:

- Support Massive MIMO optimizations defined in 3GPP Release 13, 14, and 15 to improve performance.
- Enable terminals to support four or even eight receive antennas so that 4- or 8-layer transmission is supported in the downlink, improving single-user performance.
- Support uplink multiple-antenna transmission technologies, such as antenna selective transmission of SRS, to support uplink single-user transmission of two, four or eight layers and uplink beamforming, improving the uplink single-user data rate and uplink coverage.
- Support higher transmit power to improve uplink coverage.

5 Conclusion

LTE TDD has some inherent advantages in deploying Massive MIMO. By adopting massive antennas during 4G evolution, this technology significantly improves the spectrum efficiency, especially amid large capacity demand and extensive coverage, enabling 4G networks to satisfy growing network demand in the 4.5G era. This technology is envisioned and required to enable 5G hardware to be ready in advance and provide 5G air interface functions through software upgrades, facilitating 5G deployment. The live-network test results are testimony to the benefits of massive-antenna technology in valued scenarios, such as large-capacity hotspot areas and wide coverage scenarios. This revolutionary technology lays a solid foundation for 4G evolution and future 5G deployment and facilitates industry advancement.

6 References