GTI Massive MIMO White Paper

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Massive MIMO WHITE PAPER

V 2.0

GTI

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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.

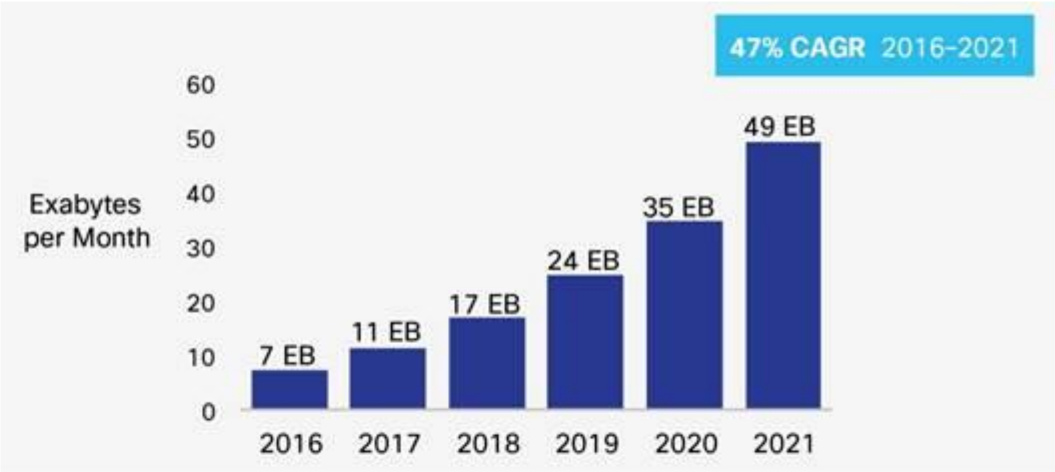
- By adopting massive antenna arrays, Massive MIMO brings about a three to fivefold increase in the spectrum efficiency when compared with traditional macro sites. This significant gain promises to motivate operators to totally overturn their network build strategies.
- Massive MIMO increases the flexibility 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.

Table of 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, 2016–2021*, the compound annual growth rate of mobile data traffic is expected to reach up to 47% globally from 2016 to 2021, as shown in the following figure.



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.

1.1 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

1.2 Terminology

Term	Description
AR	Augmented Reality
AAU	Active Antenna Unit
BBU	Baseband Unit
BS	Base Station
DL	Downlink
FDD	Freqency Division Duplex
FD-MIMO	Full-Dimension MIMO
LTE	Long Term Evolution
MIMO	Multiple Input Multiple Out
MU-MIMO	Multi-user MIMO
SE	Spectrum Efficiency
SUNPT	Scheduling User Number Per TTI
TDD	Time Division Duplex
TRX	Transceiver
UL	Uplink
VR	Virtual Reality

2 Principles of Massive MIMO

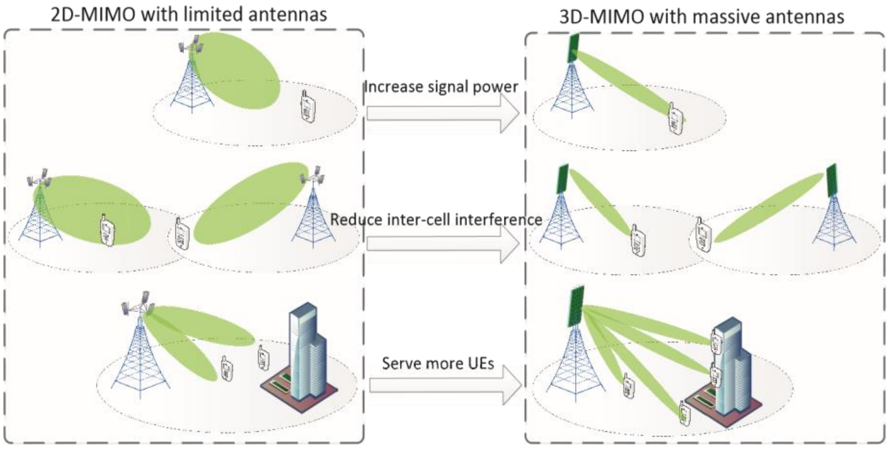
2.1 Fundamental Principles of Massive MIMO

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



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 Performance 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 high traffic areas, 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.

Massive MIMO is suitable for **high traffic, high rising, uplink limited and large-scale vertical distribution of regional users scenarios.** However in the high-speed scenarios, the Doppler frequency shift, will expand the error of channel equalization and channel estimation, affect the Massive MIMO space division advantage of the performance. So the current Massive MIMO is not suitable for high-speed scenarios.

Typical Application of Massive MIMO

Scenarios	Applicability of Massive MIMO	Description
High traffic	suitable	Massive MIMO is suitable for application in high-traffic areas, can give full play to DL / UL space division capabilities of Massive MIMO.
Uplink limited	suitable	Massive MIMO antenna array gain, forming gain and no less than 8 streams of upstream space ability, can effectively solve the problem of uplink limited scenarios.
High rising	suitable	Massive MIMO has a large broadcast coverage in the vertical direction and beamforming ability, is suitable for coverage and capacity of key high-rise buildings.
Large-scale vertical distribution	suitable	In the scenarios where the vertical distribution of users is large and the capacity is high, the vertical coverage and beamforming of Massive MIMO can play its advantages of space division and vertical coverage better.
High-speed （high-speed rail）	unsuitable	The speed of high-speed rail is about 300Km, the time-varying of channel is large, and the Doppler frequency shift affects the performance of space division. So at this stage, Massive MIMO application in high-speed rail scenario is not recommended.

3.1 Typical Application Scenarios

3.1.1 High Traffic Areas

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 from poor 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.

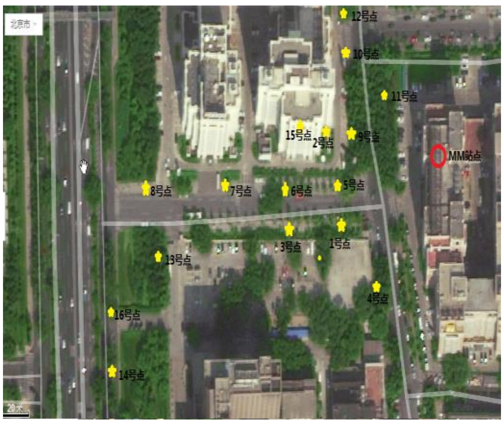
3.1.3 Large Public Events

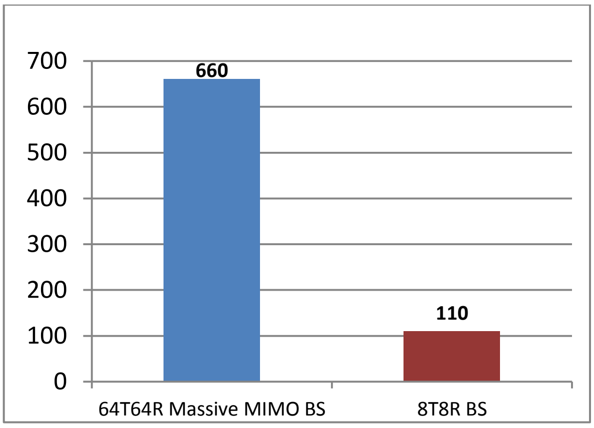
In large public events such like football match, concerts, parades, thousands of people will gather at same place and generate huge traffic. Usually traditional macro capacity will be limited by up to 100~200 active users. However Massive MIMO can effectively offload traffic in these scenarios benefit from:

- Precise user-specific beamforming & multi-user multiplexing
- Further enhancement in downlink control channels
- 3~5x capacity over traditional macro
- Easily serving 500+ active users

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.





Peak cell throughput test result

Some detail information in this test case between 64T64R MM BTS and 8T8R TDD macro BTS：

- B41 20MHz spectrum was used

- UL : DL=1 : 3
- TM2/TM3/TM7 supported Rel-8 test UE or TM2/TM3/TM7/TM8 supported Rel-9 test UE
- 16 1T2R Rel-8 or Rel-9 test UE distributed on strong and middle SNR positions, with average packet data rate around 40-42Mbps for MIMO scenarios.
- Both MU-MIMO multi-layers spatial division enabled in downlink and uplink， with TM7 or TM8 beamforming, maximum 16 layers in downlink and 8 layers in uplink, using DM-RS and not using CSI-RS.
- For MIMO BTS, Downlink PRB using rate 100%, downlink spectrum efficiency 8250bit/RB; For 8T8R macro BTS, Downlink PRB using rate 100%, downlink spectrum efficiency 1375bit/RB.

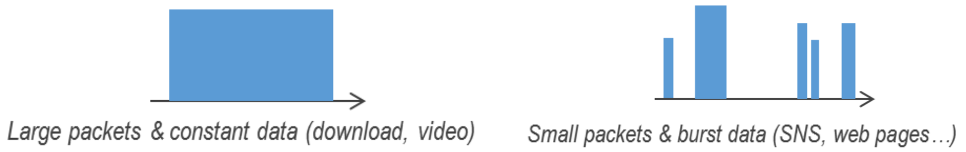
3.3 Performance in Commercial Network

Thousands of Massive MIMO units have been globally deployed on commercial networks till now. This section analyzes the network KPI improvements of Massive MIMO in live network with only commercial UE carrying live MBB traffic.

3.3.1 Massive MIMO Commercial Performance Analysis

The magic of Massive MIMO huge gain mainly benefits from multi-user MIMO technology. However, the multi-user gain in commercial network will impact by various factors.

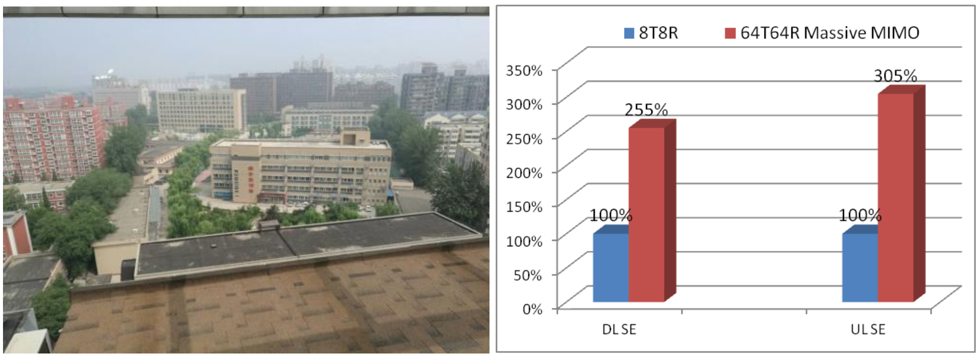
- Active user number: more active users will have more pairing opportunities.
- User channel correlations: higher correlation between users will greatly limit the multi-user paring opportunities and impact on the overall cell throughput.
- Traffic patterns: although download and video services may generate bigger packets (1000+ bytes) and constant data incoming, most mobile apps like SNS have quite different traffic patterns: typically much smaller packets data burst (hundreds bytes) , so users may not be stably paired to another user due to such burst traffic nature.
- User signal quality: edge user usually will not be paired to further impact the SINR.



Different Traffic Patterns

3.3.2 Hotspot Scenarios

At a campus site in Beijing (as shown in Figure 3-3), 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.



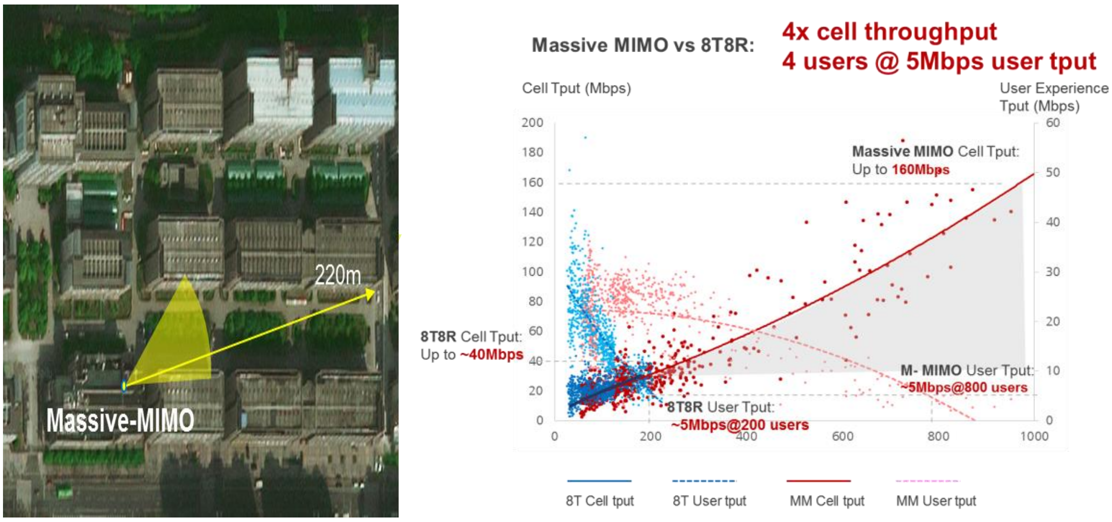
Spectrum efficiency improvement in campus scenario

Some detail information in this commercial network KPI comparing and analyzing between 64T64R MM BTS and 8T8R TDD macro BTS：

- Based on commercial user network KPI analysis, only commercial UEs existed and no full buffer traffic test terminals were used in test.
- Figure data was from network performance KPI data.
- For 64T64R MIMO BTS, cell average downlink packet data rate 60-130Mbps, cell average uplink packet data rate 4-8Mbps, with around 400-800 users, and TM2/TM3/TM7/TM8 used.
- For 8T8R TDD macro BTS, cell average downlink packet data rate 20-40Mbps, cell average uplink packet data rate 2-4Mbps, with around 200-400 users, and TM2/TM3/TM8 used.

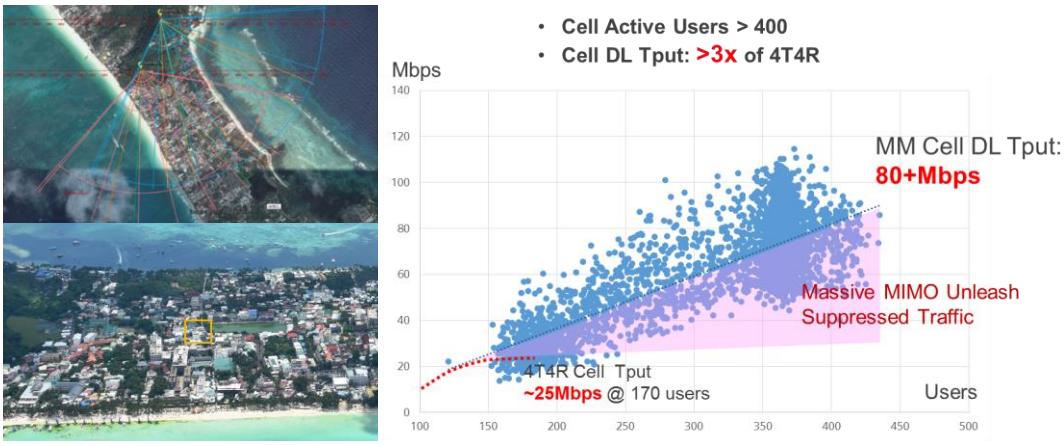
3.3.3 High Traffic Areas (MBB)

At a university campus in Zhejiang (as shown in Figure 3-4), Massive MIMO significantly unleash the traffic at busy hours. The observed cell throughput is almost 4x of 8T8R, and user can experience ~5Mbps even at ~800 active users.



4x cell capacity improvement in university campus

In a famous tourist attractions by the beach, Massive MIMO is deployed to replace the traditional 4T4R. About 3x of traffic is unleashed with Massive MIMO: the max cell throughput can reach 80~100+Mbps, and the active users is more than 400.



3x cell capacity improvement in tourist attractions

3.3.4 High Traffic Areas (FWA)

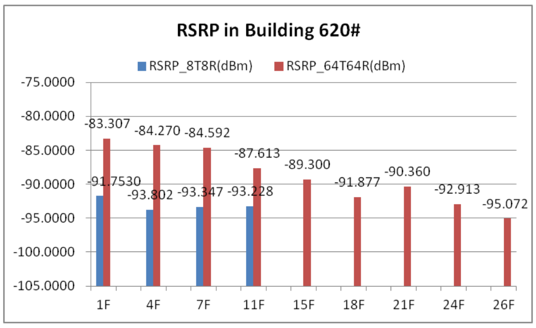
Fixed wireless access is popular in many areas where traditional copper or fiber is either not reachable or too expensive. In Philippines FWA site, 4T4R is replaced by Massive MIMO (as shown in Figure 3-6). Massive MIMO can achieve 3x capacity & 5x user experience improvement in FWA scenario.

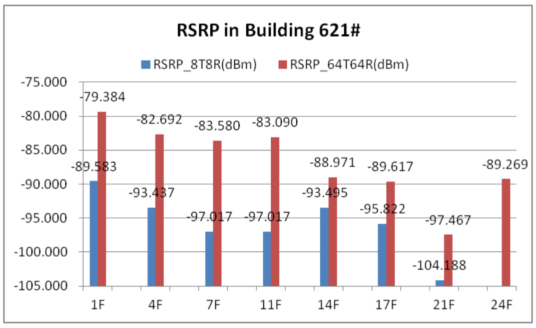
Busy Hour	4T4R	Massive MIMO	Gain
DL Cell Tput (Mbps)	37.28	106.51	**2.9x**
UL Cell Tput (Mbps)	13.19	53.70	4.1x
DL User Experience Tput (Mbps)	1.5	5.84	**4.9x**
UL User Experience Tput (Mbps)	0.20	4.18	21x
DL Traffic Volume (GB)	9.90	30.93	**3.1x**
UL Traffic Volume (GB)	1.18	1.21	1.03x

Spectrum efficiency improvement in campus scenario

3.3.5 3D Coverage Scenarios

At a site in Beijing (as shown in Figure 3-7), 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.



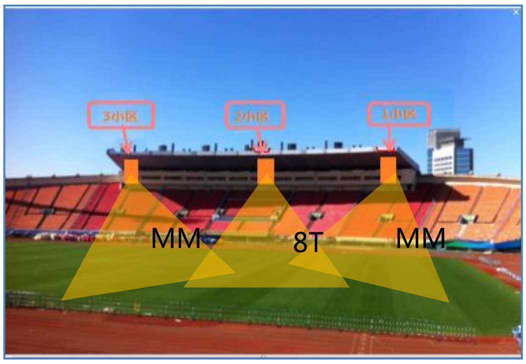


RSRP improvement in high-rise residential areas

3.3.6 Large Public Events

In the 120th anniversary of Zhejiang University, more than 3,000 active users are served by China Mobile with 3 Massive MIMO cells and 6 8T8R cells in emergency vehicles. Massive MIMO offload 56% users and 88% traffic with much less cells for this success event. Each Massive MIMO cells absorb ~2.6x users and ~7x traffic of 8T8R, showing absolute advantage over traditional macro.

The picture below shows the concert in a large gymnasium. Four Massive MIMO cells were deployed at the podium in order to cover the VIP area, the center of the gymnasium. There are 36 cells in the whole area, 4 of them are Massive MIMO cells.



During the concert, the total number of mobile active users exceeded 9,000, and the Massive MIMO community carried more than 3,000 active users. The volume of upload services reached 138GB, more than the download services' volume. The Massive MIMO cells have become the main station that carrying the number of users and the volume of service.

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

4.1 The Evolution from LTE-Advanced to Massive MIMO

Although Massive MIMO is already commercial ready with TDD Rel-8/9 UEs, 3GPP is still actively working in new releases to further enhance its performance.

In 3GPP, Study Item for 3D Channel Modeling was started from 2013, EB/FD-MIMO work item completed December 2015. Several new features were introduced correspondingly for EB/FD-MIMO in R13, for example, CSI-RS enhancement, SRS capacity, so on. FD-MIMO improves both capacity and coverage via SU-MIMO and MU-MIMO. It also triggers moving from passive to active antenna arrays with full flexibility. Based on FD-MIMO of R13, 3GPP R14 further enhanced to eFD-MIMO. Due to the standardized time, Rel-13 FD-MIMO has the following deficiencies:

1. Only supports up to 16 antenna ports;

2. There is no enhancement to CSI reporting for multi-user space division;

3. There is no compensation for loss of CSI measurement (e.g. inter-cell interference, UE high-speed movement).

The above deficiencies in R13 have been enhanced in Rel-14, mainly including:

- Non-procoded CSI-RS

The mechanism for reducing CSI-RS overhead is introduced to support the larger number of antenna ports, extending the number of Non-procoded CSI-RS ports from Rel-13 (1, 2, 4, 8, 12, 16) to (20, 24, 28, 32)

- Beamformed CSI-RS

Non-periodic CSI-RS and other technologies are introduced to optimize the resource utilization efficiency of UE-specific beamformed CSI-RS

- UL DMRS

Enhancing UL DMRS by introducing orthogonal number more than 2 DMRS, used to support MU-MIMO when the user between the overlapping bandwidth allocation.

- CSI reporting enhancements

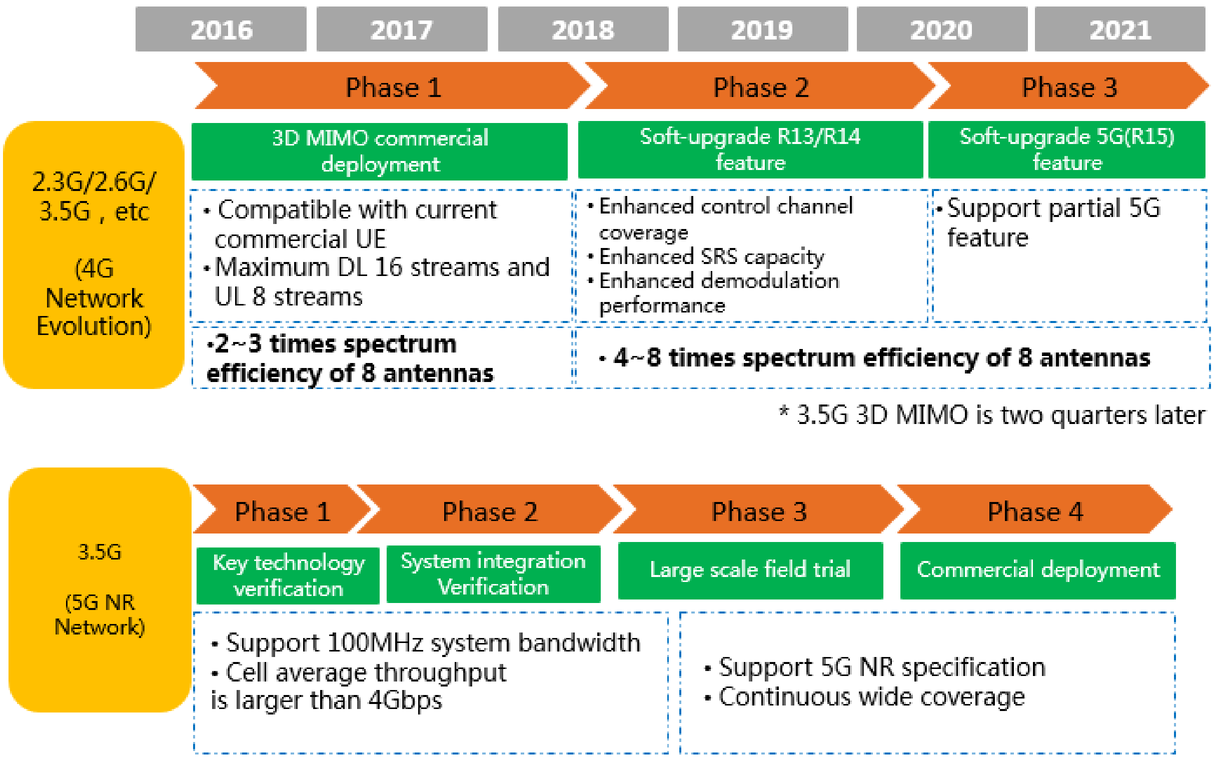
New (20, 24, 28, 32) antenna port codebook is introduced to support more CSI-RS antenna ports

CSI reporting enhancements are introduced, allowing the UE to support mixed non-precoded CSI-RS , beamformed CSI-RS feedback, and beamformed CSI-RS

Based on non-precoded CSI-RS and beamformed CSI-RS feedback is increased. Beside codebook feedback, a new feedback mechanism is introduced to improve the precoding performance of the station, supplemented by effective interference management, and support efficient multiuser transmission.

4.2 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.



Massive MIMO evolution roadmap towards 5G

4.3 Massive MIMO Commercial Products at Current Stage

4.2.1 Huawei's Massive MIMO Products

Table 4-1 Massive MIMO product – Huawei

Product		AAU5270 (CMCC)
Commercial Status		2016 Q3
Active Antenna Unit (AAU)	**Number of TRXs**	64
	Frequency band	2.6GHz
	Bandwidth	60 MHz,3CC
	Power	120 W/160 W
	Dimensions	820 * 498 * 120 mm
	Weight	35 kg
	Heat dissipation	Passive
Baseband	**UBBPf（18Q1）**	3 * 20 MHz * 64T per board
	Optical Module/Port	3 *40/100 G ports
Product Solution	**Architecture**	Distributed (BBU & AAU)
	Benefit	16 layers in the downlink and 8 layers in the uplink

4.2.2 ZTE's Massive MIMO Products

Table 4-2 Massive MIMO product – ZTE

Product		ZTE Massive MIMO
Commercial Release Time		2016 Q4
AAU	**Number of TRXs**	64
	Bandwidth	60 MHz, 3CC
	Power	120W
	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

4.2.3 Ericsson's Massive MIMO Products

Table 4-3 Massive MIMO product – Ericsson

Product Name		AIR 6468
Commercial Release Time		2017 Q3
Active Antenna Units	Number of TRXs	64
	Bandwidth	60MHz
	Spectrum Supported	B41E
	Power	120W
	Dimensions	900 / 500
	Weight	<45kg
	Heat Dissipation	Passive
Baseband Units	Baseband Processing Boards	3CC per board
	Optical Module / Port	2 x 10G ports
Product Solution	Architecture (Distributed or integrated)	Distributed
	Layers of Data Streams	16 layers capability

	Benefits	eCPRI based architecture, which save bandwidth on fronthaul without performance loss, and easy to migrate to 5G

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

4.4.1 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 solution 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.

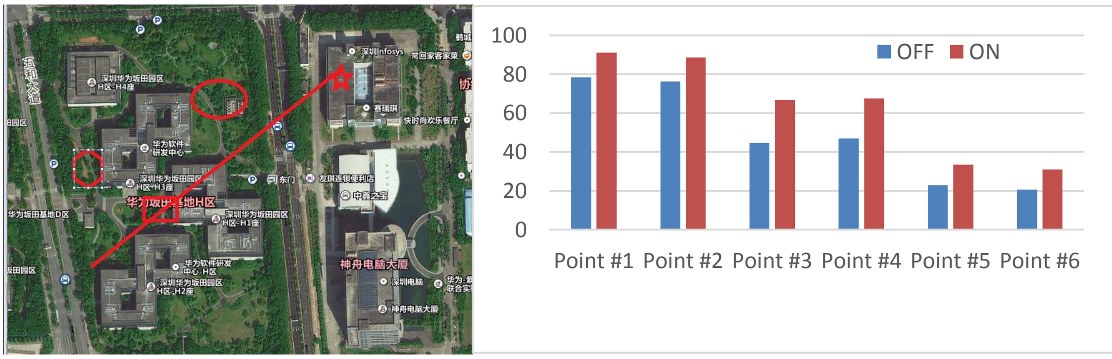
Table 4-3 Candidates for 5G technology and dependency with Massive MIMO AAU

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
	1ms and shorter TTI	related
	Self-contained subframe	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

SRS antenna selection

SRS(Sounding reference signal) antenna selection is an important enhancement in the current mobile communications industry, especially for the future 5G beamforming domain. Now most UEs can only support sending SRS by its primary transmit antenna. Therefore, base station can only derive the channel information to this antenna. However, by utilizing SRS antenna selection technology, full channel information of all antennas could be obtained. Hence, base station may generate more accurate beamforming weights and the beamforming performance could be significantly improved in both single rank and double rank.

Far, middle and near points have been tested respectively. As show in Figure 4-2, the throughput of UE has been significantly improved by SRS antenna selection technology, especially in far and middle points: 40+% gains can be observed.

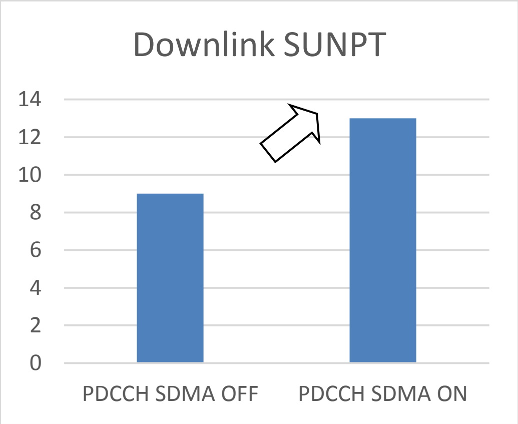


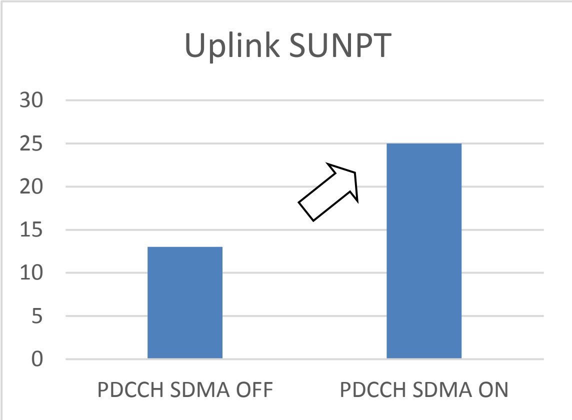
Massive MIMO SRS Antenna Selection Test Result

PDCCH SDMA

PDCCH Spatial Division Multiple Access (SDMA) is an innovative technology to further exploits the rich Massive MIMO spatial resource for PDCCH. In traditional solution PDCCH CCEs is not multiplexed since it is not beamformed and sent via normal broadcasting channel. Given limited CCE resources in maximal 3 OFDM symbols in LTE TDD systems, PDCCH can be very crowded when the amount of scheduled UE reaches a high level. This will be even severe in Massive MIMO due to its enhanced network capacity. With PDCCH SDMA, Massive MIMO will generate multiple beamformed CRS beams, where UEs belonging to non-overlapping CRS beams can multiplexing PDCCH CCEs and the PDCCH capacity will be greatly increased.

Test for PDCCH SDMA in Massive MIMO has been carried out in a commercial network with a heavy load. As is showed in following figures, the downlink SUNPT(Scheduling user number per TTI) and uplink SUNPT increases 44% and 92%, respectively.





PDCCH SDMA gain

4.4.2 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 exploit 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, including TM9 optimization.
- 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