GTI TD-LTE Radio Network White Paper (2013)

Global TD-LTE Initiative

Version:	Version 5.0
Deliverable Type	□ Procedural Document √ Working Document
Confidential Level	□ Open to GTI Operator Members □Open to GTI Partners √ Open to Public
Working Group	Network Group
Task Force	
Source members	China Mobile; Vodafone; Softbank; Clearwire; UK Broadband; Optus
Support members	China Mobile; Vodafone; Clearwire; Softbank; Bharti Airtel; E-Plus; P1; KT; UK Broadband; Optus
Last Edit Date	24-09-2013
Approval Date	22-09-2013

Annex A: Document History

Date	Meeting #	Revision Contents	Old	New
23-06-2013	7th workshop	Final draft before GTI 7th workshop		2.0
15-08-2013	7th workshop	Revised version after discussion on GTI 7th workshop	2.0	3.2
24-09-2013	SC review	Revised version after SC reviewing	3.2	5

Abstract

As the fast growing scale of the global TD-LTE commercial network, TD-LTE has become one of the mainstream for evolution to 4G supported by a very well established and fast growing ecosystem. It has set up a complete end-to-end industry chain involving widespread participation of global industries and highly matured products including system equipment, chipset, user devices and test instrument. By achieving a maximum of commonalities with LTE FDD and offering comparable performance characteristics, TD-LTE can share global market scale with LTE FDD and speed up the network deployment and commercial launch. According to the GTI Plan & Actions announce in Feb. 2012, over 500,000 TD-LTE base stations will be constructed to cover over 2 billion population by 2014. To facilitate to grow market scale of the TD-LTE worldwide, as the network products play an important role in the whole network deployment and pioneer the whole industry chain, it is meaningful to overview the latest progress of the industrialization from the radio network perspective and give the guidance to the other parts. So this white paper intend to introduce the latest progress of the global TD-LTE industrialization from the radio network perspective, including the

commercial deployment status, the matured radio network products, key issues and the corresponding solutions of TD-LTE radio network deployment as well as the further enhancement. This white paper can be taken as a reference for in-depth understanding of TD-LTE industry at the present stage.

As the fast progress in the industrialization and commercial deployment, the latest information will be captured in the later version.

Contents

1 Introduction

1.1 Background

As the most promising TDD radio access technology for mobile broadband applications, TD-LTE growth is accelerating around the world in terms of operator commitments and commercial launches as well as subscriber numbers. By August 2013, 21 TD-LTE networks are commercially launched in 13 countries with over 3 million commercial users. Many more operators are deploying commercial TD-LTE TDD systems, or are engaged in trials and studies, especially China Mobile are building the world's largest TD-LTE network which will cover over 100 cities in China with over 200,000 base stations and more than 500 million populations in 2013.

1.2 Benefits of TDD Technology

Along with value increasingly recognized, TD-LTE has gained wide ecosystem acceptance and backing from leading operators, infrastructure and device vendors. TDD technology presents three advantages as below,

1. Flexible spectrum utilization

TDD spectrum is much easier to release than FDD, which needs to be paired. This benefit is becoming increasingly important as the globally available supply of spectrum falls, meaning the process of releasing new spectrum can be greatly speed up by designating it as TDD.

What's more, capacity benefits of TDD bring comes in the size of available TDD spectrum bands often allocated in large blocks. It isn't unusual to see TDD spectrum auctioned off in 30MHz slices, even wider. From a capacity perspective, this is an advantage over the typical 2x10MHz configuration found in FDD spectrum.

Especially, one big advantage of TDD over FDD spectrum is its cost. Mobile operators have historically been able to purchase TDD spectrum at a lower price than FDD. With TDD, operators can use lower-cost unpaired spectrum with a networking technology that is part of a larger ecosystem. This makes the overall cost of the network lower than those using paired spectrum. From a competitive position this lower cost can make it easier for an operator to roll out a network and achieve a return on its investment. It can also use the lower cost of network ownership to offer lower-priced service and gain a competitive advantage in the market.

2. High spectral efficiency for adaptive UL/DL configuration

The asymmetric nature of TDD brings a number of advantages. One key advantage of TDD's asymmetric nature is the flexibility it allows in the adjustment of the downlink and uplink resource ratios. Commonly employed downlink-to-uplink ratios are 8:1, 3:1, 2:2 and 1:3, and the heavily downlink-oriented configuration fits perfectly with current user behavior, where streaming and downloading take up a high proportion of downlink resources. Cisco previews a dramatic increase of the downlink-centric applications. Based on this prediction, the DL-centric application will generate more than 90% of the mobile traffic in 2017. Therefore, TDD is best suited for user behavior of mobile broadband era.

3. Interference suppression

Thanks to uplink and downlink channel reciprocity (ensured by the fact that the same portion of spectrum is used in both link directions), TDD technology has unique coordination abilities, such as Beamforming, which improving system performance by utilizing channel-state information to achieve transmit-array gain. Results show that, across the 3GPP standard in Release 8~10, single Layer, dual-Layer and multi-user Beamforming can generate cell throughput gain of 15%, 15% and 10% respectively. Adoption of Beamforming and Coordinated Multi-Points (CoMP), called 'Coordinated Beamforming' (CBF), can further enhance network performance because interference is mitigated between inter-eNodeBs.

1.3 Objectives of this white paper

This white paper overviews the latest status of the TD-LTE global industry and its commercial application from the radio network perspective, including the following aspects:

1. Global progress of TD-LTE network commercial deployment and the corresponding information of each operator

2. Status of matured TD-LTE radio network products, including the evolution roadmap and flexible products to match different deployment scenarios

3. Solutions to key issues of TD-LTE networks and the corresponding field test results from operator's perspective

4. Further enhancement features of TD-LTE and their application

GTI invites the industry to contribute continuously to the TD-LTE industrialization and promote TD-LTE globalization.

1.4 Terminology

Term	Description
3GPP	3rd Generation Partnership Project
NGMN	Next Generation Mobile Networks
ETSI	European Telecommunications Standards Institute
ORI	Open Radio Interface
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
WiMax	Worldwide Interoperability for Microwave Access
MOCN	Multiple Operator Core Network
RAN	Radio Access Network
BS	Base Station
BBU	Base Band Unit
RRU	Radio Remote Unit
RRH	Remote Radio Heads
DL	Downlink
UL	Uplink
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
SIB	System Information Block
CRS	Common Reference Signal
PSS	Primary Synchronization Signal
SSS	Secondary Synchronization Signal
PBCH	Physical Broadcast Channel
PDCCH	Physical Downlink Control Channel
PDSCH	Physical Downlink Shared Channel
PHICH	Physical Hybrid-ARQ Indicator Channel
PCFICH	Physical Control Format Indicator Channel
SRS	Sounding Reference Signal
SINR	Signal to Interference Noise Ratio
CCE	Control Channel Element
CSI	Channel State Information
FDM	Frequency Division Multiplexing
TDM	Time Division Multiplexing
SDMA	Spatial Division Multiple Access
SU-MIMO	Single User Multiple Input Multiple Output
MU-MIMO	Multi User Multiple Input Multiple Output
TM	Transmission Mode
MRC	Maximum Ratio Combining
IRC	Interference Rejection Combining
ICIC	Inter Cell Interference Coordination
SFR	Soft Frequency Reuse

FFR	Fractional Frequency Reuse
IR	Inverted Reuse
SFN	Single Frequency Network
CoMP	Coordinated Multiple Points
CBF	Coordinated Beamforming
JR	Joint Reception
JT	Jointly Transmission
CS	Coordinated Scheduling
CB	Coordinated Beamforming
CA	Carrier Aggregation
CC	Component Carrier
QoS	Quality of Service
IOT	Interoperability Test
CSFB	CS Fall Back
VoLTE	Voice over LTE
SRVCC	Single Radio Voice Call Continuity
SON	Self-Organizing Network
PCI	Physical Cell ID
ANR	Automatic Neighbor Relationship
OAM	Operations and Maintenance Center
TMA	Tower-Mounted Amplifier
ECGI	EUTRAN Cell Global Identifier
NRT	Neighbor Relation Table
MLB	Mobility Load Balancing
MRO	Mobility Robustness Optimization
MDT	Minimization of Drive Tests
RLF	Radio Link Failure
CRE	Cell Range Expansion
MCL	Minimum Coupling Loss
FSTD	Frequency Switch Transmission Diversity

2 Commercial deployment status of TD-LTE

In this section, an overview of the global commercial deployment status of TD-LTE networks is reported.

2.1 Demands from the explosive traffic increase

The rise of Mobile Internet has brought acceleration in the evolution of mobile communication industry driving the next generation broadband wireless technology. In recent years, with the rapid growth of Mobile Internet, especially the increasing percentage of video services, the mobile data services have presented an explosive boost, which brought about great burden to mobile telecommunication operators. Smart terminals have served as the catalyst of this phenomenon. For example, the release of iPhone led to around 80 times of mobile data traffic to AT&T in 2010 compared with 2007. When 3G smart terminals were launched by NTT DoCoMo, the data service flow per capita increased sharply up by to 25 times the amount of 2006 in 2010. This trend is expected to be strengthened with the further development of smart terminals and mobile applications. It is predicted that from 2011 to 2016, the global data traffic will increase by 78% compound growth rate per year [1], which poses higher requirements to operators.

2.2 Latest deployment status of TD-LTE network

2.2.1 Global deployment of TD-LTE

By August 2013, 21 TD-LTE commercial networks has been launched by operators including Mobily and STC in Saudi Arabia, Softbank in Japan, SKY TV and ON Telecom in Brazil, Hi3G in Sweden, UK Broadband in UK, Bharti Airtel in India, NBN and Optus in Australia, Aero2 in Poland, Omantel in Oman, MTS and Megafon in Russia, China Mobile in Hong Kong, Dialog Axiata in Sri Lanka, COTA /Murcia4G in Spain, Telkom Mobile(8ta) in South Africa, MTN in Uganda, Sprint in USA and Spectranet in Nigeria. The amount of TD-LTE base stations has reached up to 50,000 by the end of 2012, while the global subscribers of TD-LTE have reached up to 2,700,000 by April 2013.

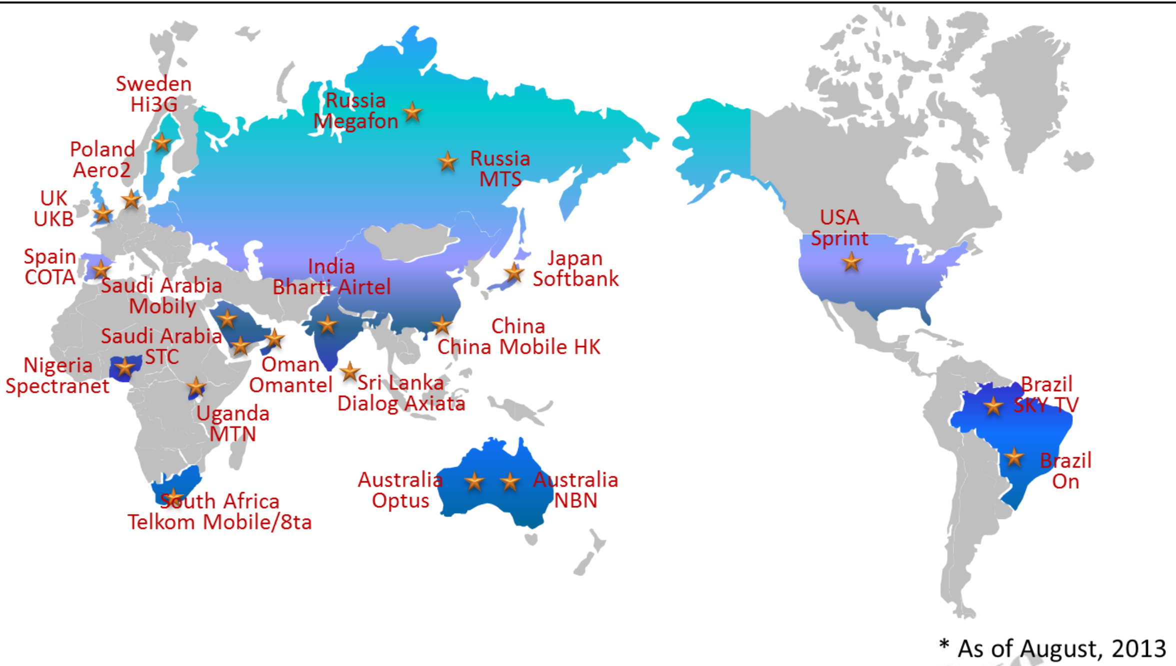


Figure 1: global TD-LTE commercial networks

The 21 commercial TD-LTE networks all over the world are mainly operated on 2.3GHz, 2.6GHz and 3.5GHz. The different TDD spectrum allocation in different region is a challenge for TD-LTE globalization and roaming.

The commercial TD-LTE networks and the corresponding deployment frequency bands are listed below:

Table 1: global TD-LTE commercial networks

Index	Operator	Country	Frequency band
1	Aero2	Poland	Band38 2.6GHz
2	Mobily	Saudi Arabia	Band38 2.6GHz
3	STC	Saudi Arabia	Band40 2.3GHz
4	SKY Brasil Services	Brazil	Band38 2.6GHz
5	Softbank	Japan	Band41 2.6GHz
6	NBN	Australia	Band40 2.3GHz
7	Bharti Airtel	India	Band40 2.3GHz
8	Hi3G	Sweden	Band38 2.6GHz
9	UK Broadband	UK	Band42,43 3.5GHz
10	Omantel	Oman	Band40 2.3GHz

11	MTS	Russia	Band38	2.6GHz
12	Megafon	Russia	Band38	2.6GHz
13	China Mobile Hong Kong	Hong Kong, China	Band40	2.3GHz
14	Dialog Axiata	Sri Lanka	Band40	2.3GHz
15	On Telecomunicacoes	Brazil	Band38	2.6GHz
16	COTA /Murcia4G	Spain	Band38	2.6GHz
17	Telkom Mobile(8ta)	South Africa	Band40	2.3GHz
18	MTN	Uganda	Band38	2.6GHz
19	Optus	Australia	Band40	2.3GHz
20	Sprint	USA	Band41	2.6GHz
21	Spectranet	Nigeria	Band40	2.3GHz

2.2.2 TD-LTE network status

2.2.2.1 China Mobile

Through the execution of the large scale trials and pre-commercial trials, China Mobile's TD-LTE network is ready for commercial launch. By promoting TD-LTE industry and cultivating the global market, China Mobile plans to deploy TD-LTE network in both Mainland China and Hong Kong, with the aim to catch up the commercial progress of LTE FDD.

Large scale trial : China Mobile launched TD-LTE large scale field trial network with scale of 1000 base stations deployed in Hangzhou, Shenzhen, Guangzhou, Xiamen, Nanjing and Beijing, from December 2010 to May 2012. 10 TD-LTE network vendors, 11 terminal chipset vendors and more than 10 testing instrument vendors, including both domestic and global enterprises, were involved in the trial.

Pre-commercial Deployment: China Mobile has launched a pre-commercial network in July, 2012. Targeting for the commercial deployment and operation, with six key aspects investigated and verified: network planning, network construction, network optimization, networking, inter-RAT inter-operation, as well as new technology and product. The network provides coverage for 15 cities in China, including Beijing, Shanghai, Hangzhou, Guangzhou, Shenzhen, Tianjin, Nanjing, Qingdao, Xiamen, Shenyang, Ningbo, Chengdu, Fuzhou, Wuxi and Wenzhou with a total of 20,000 base stations in 2,683 square kilometers area and 500,000,000 population covered.

TDD/FDD convergence network in China Mobile Hong Kong: China Mobile Hong Kong has launched a commercial LTE FDD network in April 2012. After demonstrating TD-LTE/FDD LTE handover and TD-LTE/FDD LTE roaming, China Mobile Hong Kong launched its TD-LTE network in December 2012. The commercialization of first TD-LTE/LTE FDD convergence network in Asia-Pacific area was declared on December 2012, which deployed on 2.3GHz frequency band. By the end of May 2013, China Mobile Hong Kong has deployed 1752 LTE FDD base stations and 549 TD-LTE base stations. By antenna/base station/site sharing, a converged network of TD-LTE and FDD LTE is built, where load balancing between FDD and TDD networks is supported. For the voice service, CSFB is supported between GSM network and LTE network. The commercial terminals include ZTE MiFi MF91, HUAWEI dongle E392 as well as the ZTE smart phone Grand X LTE T82.

By the end of 2013, China Mobile will accomplish the construction of the world's largest TD-LTE network which will cover over 100 cities in China with over 200,000 base stations and more than 500 million populations.

2.2.2.2 Wireless City Planing 'WCP' (SoftBank Group)

Status of commercial network: Wireless City Planing 'WCP' (SoftBank Group) started up the largest AXGP/TD-LTE commercial network at February 2012, which deployed on 2.5GHz (Band41) frequency band. The initial plan is to deploy 13,000 base stations before March 2012, but the process is much faster. By end of April 2013, 28,000 base stations had been deployed to serve 92% of the national population. 1,320,000 subscribers have been developed and the percentage of population covered in main cities has reached to 100%.

AXGP, the commercial network of WCP in Japan, is compatible with global TD-LTE networks. Omni antennas are used to enhance coverage in areas with high population density. WCP has started out commercial services in main cities on November 2011. In the primary stage, MiFi served as the main type of terminal in the commercial network. The first type of MiFi was put into market in February 2012, then later this year, another two types MiFi products (including one Category 4 MiFi product which can reach 110Mbps in downlink data service bit rates) had been released. In October 2012, 6 types of dual-mode (with WCDMA) smart phone had been launched into market, the terminal vendors are HUAWEI, Motorola, Kyocera, SHARP, FUJITSU respectively. Another 5 types of smart phone have been released, corresponding terminal vendors includes SHARP, Kyocera and Fujitsu. One type of MiFi product by ZTE, supporting both of TDD/FDD LTE, is also released into commercial use.

Status of deployment frequency: As a BWA system, the AXGP deployed in 2545MHz-2575MHz（Band41）,with 30MHz bandwidth. In the future, WCP plan to apply for new frequency bands in 2.5GHz (Band 41).

Further deployment plan: WCP hopes to apply for new frequency bands and provide much higher data services by Carrier Aggregation. Meanwhile, the better network performance and attractive commercial terminals meeting the market requirements are also required.

In the near future, by deployment of micro cell and by introducing MIMO technologies and omni-antenna operating experience, the AXGP will be more suitable to apply high speed communication services in areas of high population density。

2.2.2.3 Mobily

Mobily of Saudi Arabia first launched commercial TD-LTE network in September 2011, which kicked off the global TD-LTE commercialization process. The deployed commercial TD-LTE network is a WiMax/LTE TDD dual mode network deployed on 2.6GHz frequency band, with CPEs and dongles serving as the main terminal product forms. By the end of April 2013, Mobily had deployed 2,000 base stations and subscribers had exceeded 1,500,000.

2.2.2.4 Bharti Airtel

Bharti Airtel, the largest mobile telecom operators in India, launched the first TD-LTE network in Southeast Asia on April 2012, which is deployed on 2.3GHz. The commercial network is deployed in four big cities, including Calcutta, Bangalore, Pune and Chandigarh, with 4,000 base stations serving more than 15,000 subscribers. The whole deployment process will complete in 2013. From the terminal aspect, 2 types of TD-LTE terminals, CPE with indoor WiFi and USB dongle, have been released in the primary stage of the commercial network. First 4G TD-LTE smart phone launched in India, known as the HUAWEI Ascend P1 LTE, was released in October 2012. The CSFB feature had also been put into use in the commercial network.

2.2.2.5 Clearwire

Clearwire is currently deploying a B41 TD-LTE network in the US by transitioning an existing WiMAX network to LTE operation. The initial deployment is in cooperation with Sprint and will begin in early 2013 and grow to 5000 sites by the end of 2013. Initial commercial launch with TD-LTE data devices is currently planned for the summer of 2013. These sites are spread across the continental US and deployed in a ‘hot spot’ configuration. These hot spot deployments target areas of significant data usage and are intended to compliment the current 800 MHz and 1900 MHz 3G/4G deployments by Sprint.

Clearwire is the owner of a significant amount of B41 spectrum and holds an average of 160 MHz in the Top 100 USA markets. The WiMAX network was launched in 2009 using this spectrum and currently covers 130 million pops using approximately 16,000 total sites.

Flexible LTE Network Architecture: In order to support a wholesale business model with the potential for multiple partners accessing the Clearwire network, a flexible network architecture is required. The partner requirements could vary greatly depending upon their current network capabilities. Clearwire anticipates partners with capabilities ranging from those who have an existing LTE network to those with no network but wanting to provide a high speed 4G service (MVNO's) to consumers. The Clearwire network has been designed to accommodate a variety of interface requirements and will support several architectures including; Multiple Operator Core Network (MOCN) for direct connection of a partner core to the Clearwire RAN, Home Routed for core-to-core connectivity and a conventional Clearwire owned core for international roaming, MVNO and a potential retail business (see Figure 2).

The initial deployment is being constructed in a MOCN architecture to support Sprint. The MOCN architecture will allow multiple wholesale partners who have existing LTE EPC's to directly connect to the Clearwire eNB's with the first being Sprint. The MOCN architecture has the advantage of allowing a partner to fully utilize their existing EPC and control access of their subscriber UE's to the Clearwire network, independent of other operators/users of the network. Through the use of features like equivalent PLMN IDs, FDD/TDD handovers, fall back to voice and 3G data services, the Clearwire TD-LTE network behaves as a seamless adjunct to an existing partner network.

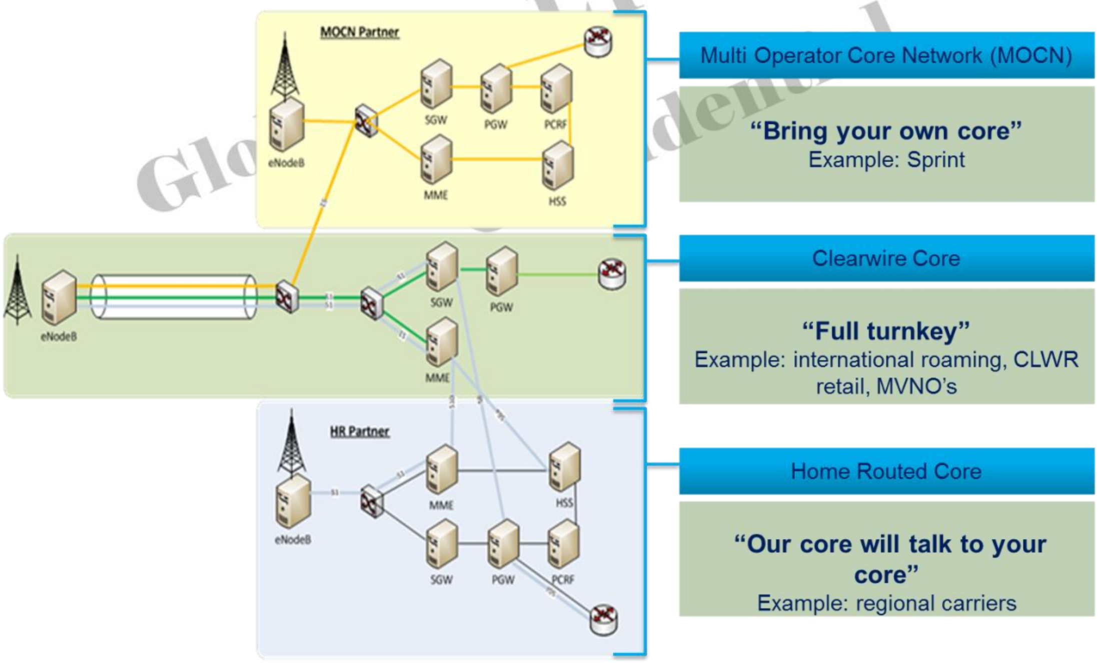


Figure 2: Clearwire Flexible Architecture Support

The Sprint network uses three difference providers of LTE RAN and EPC equipment. Joint IOT has been conducted between the three Sprint EPC providers and the two Clearwire eNB providers with only minor issues identified relative to interpretation of certain 3GPP guidelines. Commercial Clearwire TD-LTE sites have been integrated into the commercial Sprint EPC's in multiple markets across the US.

Wimax and LTE Coexistence: Clearwire has an existing WiMAX network deployed at approximately 16,000 sites in the US. The RAN deployment primarily consists of base stations using remote radio heads (RRH) and baseband units (BBU). A small percentage of the sites are ground based units. Because of the flexible design of the RRH's, a majority of the Clearwire sites can be upgraded to LTE by simply adding LTE modem and controller cards into the BBU located in the cabinet at the base of each tower or in the equipment room of each building. Because of Clearwire's large spectrum holdings, separate frequencies are available to operate WiMAX and LTE simultaneously. However, in order for WiMAX and LTE to coexist at the same site, using the same RRH and without using guard bands or filters; the WiMAX and LTE signals must be synchronized.

Clearwire and its RAN vendors have developed a synchronization technique allowing the simulcasting of WiMAX and LTE through the same radio head. This technique consists of the following key components:

1. TDD frame configuration 1 (3:1 DL/UL ratio) must be used on LTE and a frame ratio of 29:18 on WiMAX.

2. The LTE frame must be time shifted by a little over 1 ms relative to the WiMAX frame.

3. UpPTS is blanked and not used during simulcasting.

These adjustments allow the synchronization of the WiMAX and LTE transmissions so a single RRH is able to broadcast both simultaneously without interference and without the use of guard bands or filters. Also, there is no impact to the WiMAX performance and the potential for a small impact to peak uplink LTE throughput under heavy sector loading.

TD-LTE performance: Clearwire and Sprint have conducted pre-production testing of the TD-LTE network in five major markets across the US. The performance has met or exceeded all expectations. Peak downlink speeds in excess of 55 Mbps and uplink speeds in excess of 15 Mbps have been consistently achieved with category 3 devices. Round trip and handover latency has decreased dramatically as compared to the WiMAX network.

2.2.2.6 UK Broadband

UKB holds spectrum in bands 42 and 43. UKB launched the UK's first 4G LTE network in May 2012. The commercial network continues to grow across London and has been deployed in other locations including Swindon, Scunthorpe and Reading. There are two types of TD-LTE terminals in use: a desktop CPE and an all-outdoor unit. The first mobile WiFi device – incorporating 3.5/3.6GHz TD-LTE, the core LTE bands and 3G is currently being tested. UKB has recently conducted TDD/FDD LTE international roaming trials with PCCW-HKT.

2.2.2.7 Optus

Optus launched Australia's first multiband 4G network in Canberra in June 2013. The network will be progressively rolled out across metropolitan Australia in the coming year; many new mobile sites and upgrades will have the combined 4G technologies of TD-LTE (2300MHz) and FDD LTE (1800MHz). In the future Optus will also utilise its assets in 700MHz and 2600MHz for 4G. Optus has launched a range of dual mode 4G devices, the first being category 4 mobile broadband modems and Wi-Fi devices in June 2013. Recently, Optus announced its partnerships with Samsung and LG to test and bring their dual mode flagship smartphones to market in the coming months.

3 Overview of Radio network products

Radio network products with high reliability, excellent performance and comprehensive functionalities are the basis of TD-LTE industry. At the present stage, TD-LTE RAN products with Release 8&9 features have been matured and met the requirements of commercialization, while several features and diversified base station types for specific application scenarios are in focus of operators and the wider industry. Convergence of TD-LTE products with LTE FDD is also important for TD-LTE radio networks.

3.1 Roadmap of product features

There are three key phases in the road map of TD-LTE network product features: Within Phase I, basic functions of Release 8 were supported by TD-LTE RAN products in aspects of system configuration, multi-antenna capability, and dynamic resource scheduling as well as inter-operation. In Phase II, Release 9 functions are supported while in Phase III, capability and capacity enhancing functions of Release 10 and beyond should be supported by TD-LTE network products.

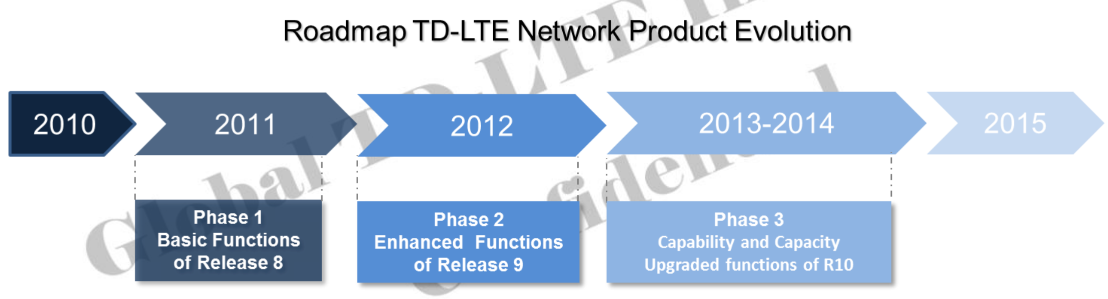


Figure 3: Roadmap TD-LTE Network Product Evolution

TD-LTE radio network products with Release 8 and 9 features have been put into commercial use, by which its reliability, compatibility and usability have been verified. In appendix at the end of the white paper, a list of the currently supported features by both radio network products and terminals is given. Several features which have been introduced in Release 8 and 9 and supported by radio network products for specific application scenarios are as follows:

✓ Inter Cell Interference Cancellation (ICIC)

Cell edge users suffer from severe interference under network planning with frequency reuse factor 1. To avoid the inter-cell interference, the feature of ICIC is introduced into Release 8 for the performance improvement of cell edge users. The detailed application suggestion and its performance will be further introduced in section 4.

✓ Cell combining

For indoor coverage enhancement, multiple RRUs can be utilized to cover a single cell, which represents as the feature ‘cell combining’. By utilize this feature in highway, high-speed railway and indoor scenarios, the coverage area of a logical cell can be enlarged to avoid frequently handover, which improves the performance. Cell combining of four 2-path RRUs can be supported by majority of the TD-LTE network product vendors. The industrial capability of cell combining of six 2-path RRUs is under verification.

✓ PDCCH adaptation

PDCCH carries the control information for multiple users, thus tradeoff between the capacity and reliability is necessary. This feature includes two aspects of adaptation, one is the adaptation of UE specific PDCCH transmission power according to PDCCH demodulation performance; the other is to select suitable transmission resource of CCE size (1CCE, 2CCEs, 4CCEs or 8CCEs). The detailed suggestion and its performance will be introduced in section 4.

✓ Multi-antenna features

- Multi-antenna transmission modes

Various transmission modes (TM) are defined to fully explore the benefit from the multi-antenna system. With 2 antennas, TM2 for spatial diversity gain and TM3 for spatial multiplexing gain can be used. When 4 or 8 antennas are available, TM7 can be used to get beamforming gain. Dual-layer beamforming (defined as TM8) is introduced into Release 9 to achieve both beamforming gain and spatial multiplexing gain.

In LTE-Advanced, TM9 is introduced in Release 10 to support up to 8-stream downlink transmission, thus further enhancement in downlink data rates can be achieved. TM9 and its applications will be introduced in section 5.3

- Transmission Mode Adaption

The different transmission mode fits different radio channel conditions. For R8 terminals, TM3 can improve the throughput by multiplexing gain at high SINR range, while TM7 can enhance the coverage by beamforming gain at low SINR range. This leads to TM3/7 adaption.

For R9 terminals, at high SINR range, TM3 leads to better performance compared to TM8, since TM8 has DRS overhead, while at low SINR range, single layer beamforming (TM7) is better due to TM8’s cross-layer interference. Dual-layer beamforming takes advantage in moderate SINR range thus TM3/TM8 adaption is needed.

- Interference Rejection Combining (IRC)

IRC algorithm improves the uplink performance by the spatial interference cancellation. Better performance can be achieved by IRC in interference-limited environment compared with MRC, which is optimal in white noise environment.

- Uplink MU-MIMO

By pairing two terminal's single transmission antenna to form an uplink virtual MIMO channel, the uplink spatial multiplexing improves the overall cell throughput.

The detailed application suggestion on multi-antenna and their performance will be further introduced in section 4.

✓ Self-Organizing Network(SON)

- Self-starting

At the end of installation of an eNB, there shall be a clear indication if the eNB is in the expected state and well prepared to go on air. It is required that only one site visit will be required to install a new eNB. With self-starting, the eNB checks itself in matter of software and hardware status, and delivers an unambiguous status report to the network management node that eNB is ready for commercial usage and a call is possible.

- PCI self-configuration

The proposed SON use case provides an automated configuration of a newly introduced cell's physical ID. When a new eNodeB is brought into the field, a Physical Cell ID needs to be selected for each of its supported cells, avoiding collision with respective neighbouring cells (the use of identical Physical ID by two cells results in interference conditions hindering the identification and use of any of them where otherwise both would have coverage). Traditionally, the proper Physical ID is derived from radio network planning and is part of the initial configuration of the node. The PCI assignment shall fulfill following conditions:

1. "collision-free": the PCI is unique in the area that the cell covers

2. "confusion-free": a cell shall not have neighbouring cells with identical PCI

Verified by the current network, PCI can be accurately configured during initiating, the performance of self-configured PCI is in accordance with the manual configured PCI. Meanwhile, it is possible to automatically reconfigure PCI after detecting the PCI collision and confusion, the performance of self-reconfigured PCI is in similar to those with manual optimized.

- Automatic Neighbor Relationship (ANR)

ANR achieves optimization of existing neighbour cell list of a cell with all relevant neighbours and the associated parameterization in the neighbouring cells. This is also related to the configuration of an initial neighbour cell list for a new cell.

ANR will remove, or at least minimize, the manual handling of neighbor relations when establishing new eNBs and when optimizing neighbor lists. This will increase the number of successful handovers and lead to less dropped connections due to missing neighbor relations.

ANR is supported by majority of TD-LTE network equipment vendors. Verified in current network, with ANR, neighbour cell of intra frequency and inter frequency of LTE system can be added, optimization and management of neighbor cell list can also be achieved. Success rate of adding neighbor at a time has reached upper than 60%, so that the manual configuration can be saved with ANR.

Besides the above listed specific Release 8/9 features, with the pace of TD-LTE network product evolution, product promotion and verification of Release 10 features, with which the network performance could be further enhanced and optimized, are ongoing. Release 10 features will be briefly introduced in section 5.

3.2 Flexible eNB products

Compared with 2G/3G, TD-LTE system which is oriented to providing high-speed mobile data services faces the following four challenges in terms of network deployment:

1) Strong demand for seamless coverage
2) High data rate is expected everywhere
3) Larger path loss and poor coverage caused by higher frequency band
4) Difficulty in deploying new macro base stations

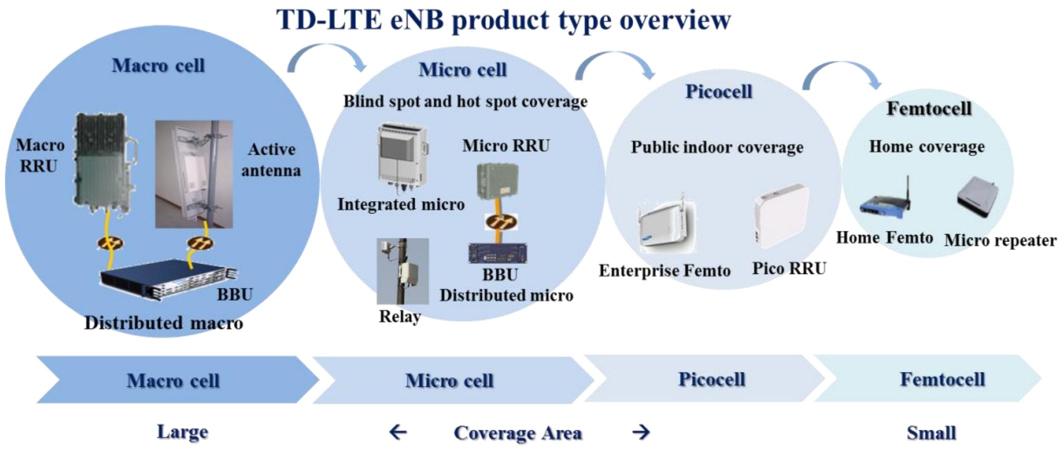


Figure 4: Roadmap TD-LTE Network Product Evolution

In order to meet the demand for different deployment scenarios and overcome the poor coverage issue of higher frequency bands, in addition to the current massively used distributed macro base station (BBU and single-band 8/2/single path RRU), base station types as diverse as 1.9/2.6GHzdual-band RRU, integrated RRU, integrated micro station, micro RRU, Nanocell, Relay, micro repeater, also need to be introduced to meet the requirements of different application scenarios. The details are clarified as below.

1.9GHz/2.6GHz dual-band RRU: Single RRU supports both 1.9GHz and 2.6GHz bands, reduces the difficulty in construction and equipment cost of the 1.9/2.6GHz dual-band site. It is applicable to the macro cell coverage scenario with higher capacity requirements and scarcity of antenna installation space. At the present stage, Huawei has already released 1.9GHz/2.6GHz dual-band RRU product.

Integrated RRU: Integrating 1.9/2.3/2.6GHz 8 elements antenna with built-in combiner and the 2.6GHz-band 8 path RRU, in the scenario where 1.9GHz band and 2.6GHz band deployed in the same site, each sector only has to replace previous antenna, which can reduces the workload of construction new RRU and jumper connection, It is also applicable to the macro cell coverage scenario with higher capacity requirements and scarcity of antenna installation space. At the present stage, Huawei and NSN have already released integrated RRU product.

Micro base station: It includes the integrated micro base station (integrated RF and baseband) and micro RRU, both own the characteristics of small size, light weight and flexible deployment. It can significantly reduce the construction difficulty and the site cost for blind-spot and hot-spot coverage scenarios, such as dense urban, residential areas, schools, streets and scenic areas. At the present stage, Huawei, ZTE, Datang Mobile, Ericsson, ALU as well as Potevio have already released micro base station.

Pico RRU: It is a low power RRU with hundreds of milliwatts output power, and is worked together with BBU and Hub. Hub and BBU is connected with fiber. Pico RRU and Hub is connected with Ethernet cable, and Pico RRU is also powered over Ethernet cable. As fiber and Ethernet cable is easier to be deployed than RF cable of DAS, Pico RRU solution can be used to replace DAS in certain senario that DAS is too difficult or not allowed to be deployed. At the present stage, Huawei has already released pico RRU product.

Nanocell: It includes enterprise Nanocell and home Nanocell [2]. It can support TD-LTE & WLAN dual-modes and can be deployed flexibly and rapidly. Thus, it can effectively support indoor coverage scenarios without distributed antenna system. At the present stage, ZTE, ALU as well as Comba have already released Nanocell product.

Relay: It is an independent base station which owns wireless access link and wireless backhaul link simultaneously. It is mainly used for outdoor blind-spot and hot-spot scenarios without wired backhaul [3]. At the present stage, ZTE and Huawei have already released relay product.

Micro repeater: It is a low power wireless repeater which only has RF filtering and amplifying functions (output power is in the level of hundred mW). It is cost effective and can be deployed flexibly and fast. It is mainly used for indoor blind-spot and hot-spot scenarios without wired backhaul. At the present stage, ZTE has already released micro repeater product.

Similar to FDD LTE, base stations serve as the basic type of TD-LTE network products and their maturity reaches the level of FDD LTE commercial network products. Besides distributed macro base station, TD-LTE base station vendors have released or plan to release diverse base station to meet all kinds of deployment requirements. In respect of micro BS, Relay, Nanocell and micro repeater, all can meet the demands of blind spot and hotspot coverage, as well as integrated RRU could be deployed flexibly with less site space, have already been released by several vendors. In respect of higher output power BS, the release of diversified products such as 80W or 40MHz base stations, could serve more flexible network planning strategy and some specific scenarios.

Beside development aligned 3GPP standard, TDD/FDD converged solutions become an efficient way to fully utilize the spectrum resources and handle the explosive LTE traffic growth.

3.3 Convergence of TDD/FDD products

Thanks to the high commonality on the standards, it is possible for TDD and FDD to share most of the software and hardware of the products. And thus, the global market scale could be enlarged by convergence of TDD and FDD products.

The network product convergence includes base stations, antennas as well as terminals.

Base stations: TD-LTE and FDD LTE typically use BBU + RRU distributed station type, and the shared base station equipment focuses on the BBU equipment convergence. In the deployment, the convergence can be realized by physical stacking FDD/TDD BBU with the same hardware platform and different software in the first stage, then a single board with both TDD and FDD modes could be supported later.

Antennas: When the number of RF channels of FDD and TDD is the same, the antenna sharing in FDD / TDD convergence networking could be realized using combiner. However, the specific scheme of multiple bands support and antenna combining still needs further optimization for the networking deployment. If the number of RF channels is different, the antenna sharing could be realized by sharing shells of the two antennas (e.g. 8 + 2 antenna).

Terminal chipsets: Terminal baseband chips need to support LTE FDD/TDD dual-mode and multi-mode multi-band for roaming. In order to support FDD/TDD convergence networking, re-selection and handover between FDD and TDD are needed.

So we can draw the conclusion that, the maturity of TD-LTE radio network products is close to that of FDD LTE at the present stage. There are 9 network equipment vendors, including Huawei, ZTE, Datang Mobile, Ericsson, Alcatel Lucent, Nokia Siemens Networks, New Postcom, Potevio and Fiberhome Mobile, released matured TD-LTE network equipment supporting Release 8/9 and partly Release 10 features at the present stage. Multiple frequency bands, such as 1.9GHz, 2.6GHz, 2.3GHz, can be supported by TD-LTE network equipment. Similar to FDD LTE radio network products, base station serves as the main type of current TD-LTE network equipment, with 2-path, 4-pathor 8-path RRU. Diversified eNB product types are also released to meet different deployment requirements. Several vendors develop TD-LTE network product on unified platform with their FDD LTE product, thus most of TD-LTE software functions can be reuse with FDD LTE. Convergence of end-to-end FDD/TDD products has also provided solid foundation for FDD/TDD convergence networking, which is an important deployment scenario for TD-LTE in the further.

4 Issues from operator's perspective

With rapid deployment of global TD-LTE networks, operators have gained rich experience in TD-LTE network planning and construction, performance enhancement, operation and maintenance as well as service solution. In this section, following solutions and experiences are provided for these areas.

- ✓ Network planning and construction
  - Synchronization of TDD networks
  - Coexistence of multiple TDD operators
- ✓ Performance enhancement
  - Coverage enhancement
  - Interference mitigation for cell edge performance enhancement
  - Spectrum efficiency enhancement by multi-antennas
  - Performance enhancement by Carrier Aggregation
- ✓ Operation and maintenance
  - Self-organizing network
  - Multi-vendor interoperability
- ✓ Convergence of networking
- ✓ Voice Solutions

4.1 Synchronization of TDD networks

Synchronization has always been of vital importance for telecommunication networks. Rigorous timing requirement should be met to ensure network quality.TDD technologies require even more accurate synchronization to avoid the reverse link interference. When more than one TDD system operating on adjacent channels of the same frequency band coexists in the same geographic area, severe interference might happen if these networks are uncoordinated since some base stations might be transmitting while others are receiving. One way to avoid this issue is to synchronize neighbour BSs and make them transmit and receive at the same time. To be more specific, the synchronization mechanism between different TDD systems includes

1. Synchronizing the beginning of the frame (phase synchronization)

2. Configuring compatible frame structures for coexisting TDD systems, i.e. configure the length of the frame, the TDD uplink/downlink ratio and guard period so that the radio transmission stops in one BS before the reception starts in its neighbour sites.

There are several methods to achieve synchronization of TDD systems, including[4]:

1. Synchronization by GNSS (e.g., GPS): Synchronization by GNSS (like GPS, Galileo, Glonass, BeiDou, etc.) is suitable for base stations with outdoor components which can receive GNSS signal. In fact, this method is widely adopted by macro-cell outdoor TDD systems such as WiMAX, TD-SCDMA, and CDMA2000. However, with cell size getting smaller and indoor-hotspot coverage more of a requirement, this method might not be feasible in certain scenarios due to accessibility or cost issue..

2. Synchronization over backhaul network (e.g., IEEE 1588): Good backhaul condition is a prerequisite to ensure synchronization accuracy over backhaul network. Several techniques have been developed over the years to deliver synchronization over backhauls. IEEE has specified the IEEE-1588v2 standard, which caters to different needs of various groups (e.g. industry/robotics, telecommunications, etc.). IETF Tictoc group has been working on some other aspects, such as security issues, and implementation over IPv4/IPv6 and MPLS. For the moment, 3GPP is considering the possibility of adopting the IEEE1588 protocol. However, it should be noted that there is still challenge to implement this techniques in TDD networks over legacy equipments or ADSL networks, especially when the grandmaster clock and the timing slave (client) are separated by several hops (e.g. legacy routers).

3. Over-the-air synchronization: With this solution, a cell can determine its timing with the help of radio signals. This solution is not limited by the coverage of GNSS signal or the backhaul condition. By listening to the network, a slave cell can directly acquire synchronization by detecting signals from its source cell. The signal could be existing reference signal or some new signal if the choice of this signal is rationally justified. In order to receive these signals, the slave cell would have to stop transmission and listen to its source cell during certain period of time.

Since the research of over-the-air synchronization is still ongoing, and different solutions of this technique are under evaluation, only few TD-LTE products have included this feature for the moment. However, majority of TD-LTE network vendors have put this feature into product development plan. Jointly tested and verified by China Mobile, ZTE and NSN, the time deviation of this technique is less than 1us and the frequency offset is less than 0.1ppm, which is less than 3us as specified in the standard.

4.2 Coexistence of multiple TDD operators

When multiple TDD networks deployed by different operators share adjacent frequency in the same coverage area, interference avoidance techniques should be adopted. Following two approaches can be considered in this scenario.

4.2.1 Synchronization negotiation

When multiple TDD operators operate with adjacent frequency in the same band, it is recommended to use the same UL/DL configuration to fully utilize the spectrum. The cost of deployment, operation, maintenance and engineering can also be significantly reduced by interference coordination negotiation between different operators.

4.2.2 Interference avoidance

If multiple TDD operators use different DL/UL configurations in the same band, interference avoidance techniques should be adopted for both base station and terminal side.

1. Base station:

To avoid the interference, at least 5MHz guard band is needed between each operator's spectrum. Additionally, spurious emissions limits should be -65dBm/MHz, and blocking requirement is -5dBm (when the interference signal is 5MHz LTE signal). Engineering isolation should meet the requirement that MCL (minimum coupling loss) is no less than 51dB. These requirements can be achieved through the customized, costly front-end filter with high performance.

2. Terminal:

According to the roaming requirement, terminals need support the full band. In this case, the cross timeslot interference cannot be suppressed by the front-end filter. In the 5MHz transition zone, terminals from different operators will have serious interference in some circumstance (e.g. all terminals are located at the cell edge and the transmit power is relatively high).

Theoretical analysis showed that, two terminals need to be separated by 32 meters in light load networks to avoid interference between each other. Test results in China Mobile lab showed that 3-meter separation is needed between two terminals to avoid interference in high load scenario. It is also shown that the throughput dropped by 40% and 100% when the separation distance between two terminals is 1 meter and 0.3 meter, respectively.

4.3 Coverage enhancement

Coverage is essential for TD-LTE network since it directly influences the network performance. For 2-antennas sites, the coverage is limited by the link budget on uplink. By using 4 or 8 antennas, the uplink performance can be greatly improved so that the coverage can be enhanced.

For 8-antennas sites, field tests show that the physical shared channel for data transmission rarely suffers from coverage limitation. However, CRS and the physical downlink control channel (PDCCH) are sometimes limited factors for coverage performance, leading to radio link failure. Therefore, enhancement features for CRS and PDCCH are of great importance to solve the coverage limitation issue.

Additionally, various types of base stations, such as Picocell, Nanocell, Relay can also enhance the indoor or outdoor coverage for different deployment scenario, which is not elaborated here.

4.3.1 Multiple antennas for uplink coverage enhancement

For 2-antennas system, the coverage is limited by the uplink channels, i.e., physical uplink shared channel (PUSCH) for data transmission and physical random access channel (PRACH) for initial access. With 4 or 8 antenna elements equipped on the base station, the uplink performance can be dramatically increased through MRC (Maximum Ratio Combining) and spatial diversity gain. Large scale trial of China Mobile showed that 8-antennas base station can get 45% coverage range enhancement comparing to 2-antennas base station in 2.6GHz, under the assumption that 5Mbps data rate is required.

4.3.2 CRS power boosting

Downlink transmission power allocation is introduced in LTE system to assign the transmission power of CRS and PDSCH independently. In the scenario where coverage is given more importance than throughput performance, the coverage of CRS becomes the bottleneck and CRS power boosting is necessary.

One method is to increase the CRS power and maintain the PDSCH power. This method is feasible where there is still room to increase the total transmission power of RRU. Another method is to increase the CRS power by borrowing CRS transmission power in the other port, which usually remains blank in dual-port transmission. In the scenario where the total transmission power of RRU has reached its upper limit, it might be possible to borrow the power of PDSCH to further enhance the CRS power. It should be noted that the PDSCH power is decreased under this circumstance.

The CRS power boosting feature has been supported by majority of TD-LTE network products. It is verified in China Mobile lab that 6dB power boost of CRS power can be achieved to solve the CRS coverage limitation problem. This feature has also been widely applied in current network.

4.3.3 PDCCH adaptation

PDCCH carries cell specific and UE specific control instruction (such as indication of uplink and downlink data transmission resources, uplink power control, etc.). A specific control information can be carried on different size of CCEs (Control Channel Element, includes 36 Resource Elements), such as 1CCE, 2CCEs, 4CCEs or 8CCEs. The more CCEs occupied for specific control information, the higher reliability and better detection performance could be guaranteed.

There are two factors impacting PDCCH detection performance and its coverage range: **PDCCH transmission power** and the **size of CCEs used for transmission** of particular control information. QPSK modulation is used for PDCCH, thus the enhancement of transmission power will not cause any mistake during demodulation. When there is still room for enhancement, it is feasible to increase the PDCCH transmission power. One the other hands, note that PDCCH carries control information of multiple users. Therefore, the choice of PDCCH CCE size is a trade-off: limited CCE resource assignment might cause PDCCH coverage limitation, and too much CCE resource allocation for a specific UE might cause cell capacity limitation.

To achieve trade-off between reliability and capacity, adaptations of PDCCH transmission power and the CCE size for particular control information are necessary. Base station is required to adjust the PDCCH transmission power and the CCE resource allocation, while the terminals are expected to recognize the CCE occupation by blind detection.

Furthermore, if 8 CCEs are not enough to achieve the detection threshold, transmission power of PDCCH can be further enhanced by borrowing other blank REs.

Adaptation of PDCCH transmission has been supported by part of TD-LTE network products. It is verified in China Mobile lab that the number of CCEs used for transmission of a particular PDCCH is determined by the eNodeB according to the channel conditions, and PDCCH power can be increased by up to 4~6dB for coverage enhancement. This feature has also been widely applied in current network.

4.4 Interference mitigation for cell edge performance improvement

As frequency reuse factor one is preferred in TD-LTE radio network, the inter-cell interference is more severe than that in 2G/3G networks. In order to provide ubiquitous user experience across the service area, the cell edge throughput needs to be enhanced.

Intercell interference coordination (ICIC) addresses the interference issue for data channel (PDSCH) performance of macro cells. For control channels (PBCH, PDCCH, PHICH, PCFICH), low coding rate provide more robustness against cochannel interference. However, in heterogeneous deployment, the interference among overlaid macro cell and micro cells is severe, and eICICis an effective method for interference avoidance of control channels in this scenario.

In addition to these frequency/time resource negotiation and allocation methods for cell edge performance improving, TD-LTE also provides more advanced physical layer techniques by jointly using the signal from multiple cells, dubbed CoMP. As will be detailed in section 5, this technique brings a significant gain in terms of cell-edge throughput.

In dense urban scenario, both data channel and control channel are severely impaired by the intercell interference due to the short site-to-site distance (around 100m~200m). Single Frequency Network is used in this scenario.

4.4.1 ICIC

Inter-cell interference coordination (ICIC) refers to the techniques which reduces the co-channel interference at the cell edge by coordinating frequency and power allocation among adjacent cells. The primary objective of ICIC is to boost cell-edge performance with a minimal impact on network throughput. There exist several variations of ICIC schemes such as Soft Frequency Reuse (SFR), Fractional Frequency Reuse (FFR), and Inverted Reuse (IR). Among these techniques, SFR has been supported by several vendors.

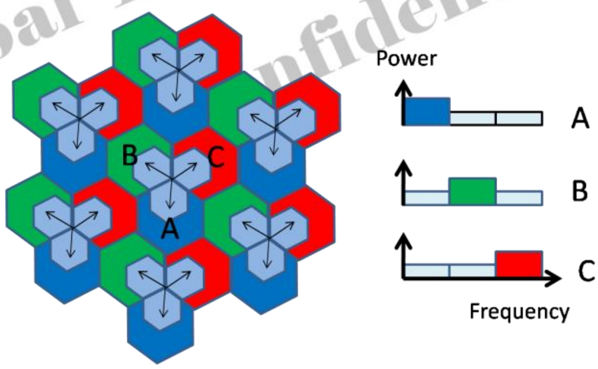


Figure 5: Soft Frequency Reuse

As showed in Figure 5, SFR assigns a portion of the total available frequency band as the reserved band. The transmit power on the reserved band is higher than that on other bands. Adjacent cells assign different reserved band which are orthogonal in the frequency domain. Since the interference signal from adjacent cells is relatively low on the reserved band, the SINR is increased. By allocating the reserved band to the cell edge users, their performance can be improved. However, the cell center users with non-reserved band will be limited to the low Tx power, so as to decrease the throughput of the cell center users.

Large scale field trial of China Mobile showed that, in the interference-limited scenario, throughput of cell edge users was enhanced by 20%~40%, while that of cell center users dropped by less than 10%. The overall cell throughput cannot be increased by SFR. Note also that SFR can only bring reasonable gain for cell edge when the ratio of reserved to non-reserved band resource is proportional to that of cell edge to cell center user number. Therefore, in order to achieve optimal performance, SFR should dynamically adapt the resource allocation according to user distribution and service requirement. Dynamic resource allocation can be implemented by either distributed or centralized schemes. There is still room for further research on ICIC technology, e.g. the interaction of ICIC with beamforming needs to be studied.

4.4.2 Single Frequency Network

In Tokyo, Japan, TD-LTE vendors have developed a micro-cellular solution with station spacing of 100-200 meters to solve the coverage and congestion problem in dense-urban scenario. Additionally, a variety of advanced technologies, including multi-antenna Beamforming, SFN (Single Frequency Network), adaptive ICIC and SON are adopted to suppress the intra-frequency interference. In the third party performance assessment of Japan's four 4G networks, Softbank's TD-LTE network using SFN technology in edge area and SDMA (Space-Division Multiple Access) in non-edge area can significantly reduce interference and enhance the network edge rate.

4.5 Spectrum efficiency enhancement by multi-antennas

Multi-antennas technology is introduced into TD-LTE system to achieve higher spectrum efficiency and better UL/DL performance. The application of multiple antennas products could fully explore the multiple-antenna advantage, including spatial diversity, spatial multiplexing and beamforming. By using 4 or 8 antennas, several enhancements can be introduced in TD-LTE RAN. By beamforming, signals are concentrated from different antennas to the desired user. Single layer beamforming (TM7) can remarkably improve the cell edge performance. The adaptation of openloop dual-layer multiplexing (TM3) and single layer beamforming (TM7) is already supported by TD-LTE products. In R9 products, dual-layer beamforming (TM8) and TM3/8 adaptation is introduced to enhance the downlink throughput. In uplink, IRC can be used for the performance improvement. The uplink throughput can be further enhanced by MU-MIMO.

4.5.1 TM3/8 adaptation

Dual-layer beamforming (TM8) is introduced in Release 9 to achieve beamforming gain and spatial multiplexing gain at the same time. In this mode, two beams transmit independent data streams to the user, doubling the capacity. The TM3/8 adaptation is highly recommended since it can outperform the TM3/7 adaption in moderate SINR range. The TM3/8 adaptation takes advantage of TM3 in high-SINR area since TM8 will bring DRS overhead in this scenario; it adopts TM8 in moderate-SINR regime and benefits from beamforming and dual-layer transmission. However, it should be noted that in poor-SINR area, single layer transmission (TM7) outperforms both TM3 and TM8 since multiplexing gain is not achievable due to cross-layer interference in this scenario. The application of TM3/8 adaptation is shown in Figure 6.

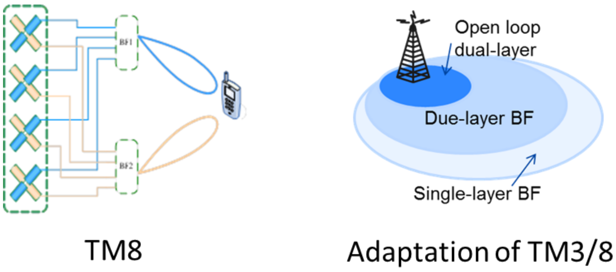


Figure 6: TM8 and TM3/8 adaptation

Verified by large scale trial in dense urban area of China, TM3/8 adaptation can achieve 15% cell average throughput improvement as compared to TM3/7 adaptation. The gain mainly comes from medium SINR range as expected. TM3/8 adaptation has already been supported by most mainstream TD-LTE equipments.

4.5.2 Uplink IRC

Multiple receiving antennas can improve the uplink performance, which can reduce terminal power consumption and extend battery life. The more antennas used in uplink, the more diversity gain can be achieved. When 4 or 8 antennas are available, in addition to uplink diversity, an interference cancellation technique, dubbed IRC (Interference Rejection Combining), can be used to further enhance the uplink performance.

IRC improves the uplink performance by spatial interference cancellation, achieving superior performance in interference-limited environments. This feature takes into account of the instantaneous arrival direction of the desired and interfering signals. By determining the pattern and power level of the interference, the desired signal can be recovered by subtracting the interfering signal from the uplink received signal. On the other hand MRC (Maximum Ratio Combining) is optimal in the white noise environment.

Verified in China Mobile lab, with 8 antennas, 100% throughput gain can be achieved by IRC compared to MRC in cell edge, where the inter-cell interference is severe. Uplink IRC has already been supported by most of the mainstream TD-LTE equipments.

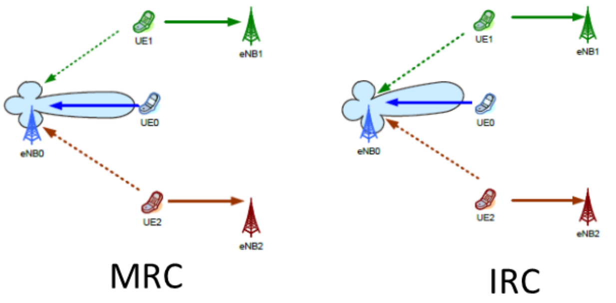


Figure 7: MRC and IRC

4.5.3 Uplink MU-MIMO

Since there is only one transmission antenna per UE, spatial multiplexing gain cannot be achieved by a single user. Uplink MU-MIMO algorithm pairs transmission antennas of two terminals to form a virtual MIMO channel for uplink. Multiple antennas (e.g. 4 or 8 antennas) at base station can provide further interference cancellation capability for this virtual MIMO. MU-MIMO features paired users communicating with the same base station and sharing the same time-frequency resource, thus multiplexing gain can be obtained.

Uplink MU-MIMO does not boost the single user's peak data rate, but the cell throughput can be improved. With MU-MIMO, more users can be served simultaneously and there is more scheduling opportunity for each user.

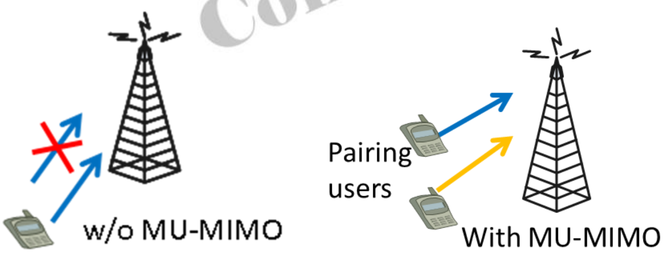


Figure 8: Uplink MU-MIMO

Verified by large scale trial in dense urban area of China, with 8 antennas, MU-MIMO can achieve significant gain in high and medium SINR regimes. In poor channel conditions, terminals are difficult to be paired, limiting the gain of MU-MIMO in this scenario. Test on cell average throughput demonstrated that 40% performance gain could be obtained by MU-MIMO. Uplink MU-MIMO is supported by majority of network product vendors and has been verified in the field test.

4.6 Performance enhancement by Carrier Aggregation

For TD-LTE, both uplink and downlink transmission share the same spectrum resource. Release 8 LTE carriers support a maximum bandwidth of 20 MHz, resulting that the peak data rate of TD-LTE is lower than that of LTE FDD with 2*20MHz. To operators with more than 20MHz spectrum, higher peak data rate for single user is in need but can not be realized in Release 8 LTE. Additionally, some operators have segmented narrow bands. How to fully utilize these bands is demanded by such operators.

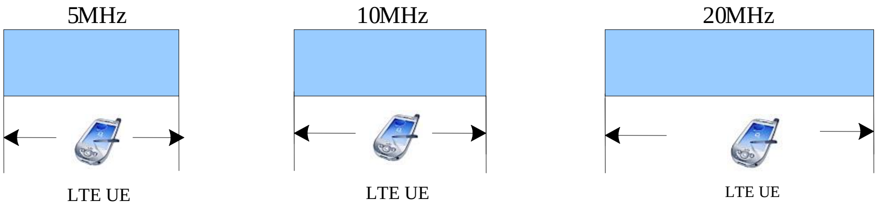
Carrier aggregation (CA) of multiple Component Carriers (CCs) achieves high-bandwidth transmission capacity by aggregate.

The first application scenario of carrier aggregation is to increase peak data rate of a single terminal. For example, in R8/9, TD-LTE radio network can maximally support 20MHz bandwidth, but when two of 20 MHz CCs are aggregated, the peak rate can be simply doubled, i.e., up to 220Mbps (assuming DL:UL = 3:1).

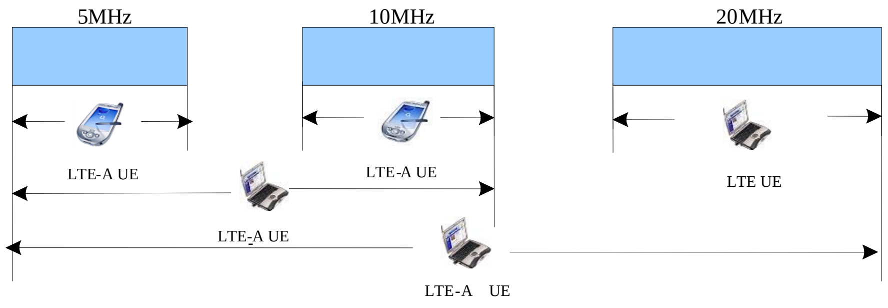
A second application scenario of carrier aggregation is to efficiently use fragmented spectrum (as showed in Figure 9), irrespective of the peak data rate. Carrier aggregation in TD-LTE-advanced can aggregate adjacent or non-adjacent CCs in the same frequency band, and CCs in different frequency bands. Each CC can take any of the transmission bandwidths supported by TD-LTE R8/9, namely 1.4, 3, 5, 10, 15 and 20 MHz respectively. In terms of the frequency location of CCs, there can be different aggregation options:

- ✓ intra-band aggregation with contiguous bandwidth;
- ✓ inter-band aggregation;
- ✓ intra-band aggregation with non-contiguous bandwidth.

A third application scenario of carrier aggregation is to facilitate heterogeneous network. In TD-LTE-Advanced, macro and picocell may respectively transmit PDCCH on each one of allocated CCs, to avoid PDCCH interference. Data transmission is still on both CCs to maintain full frequency resource reuse.



(a) without carrier aggregation



(b) with carrier aggregation

Figure 9: Carrier Aggregation

CA will be appreciated not only by operators with large bandwidth available but also by those with fragmented spectrum allocation. At the present stage, 40MHz intra-band CA of 8-path RRU on 2.6GHz and 40MHz intra-band CA of 2-path RRU on 2.3GHz has been supported by majority of TD-LTE network product vendors.

Field test on several network products by utilizing terminal simulator (TM500) have finished recently by China Mobile. Field test shows that the peak rate can reach up to 220Mbps with the configuration of DL:UL=3:1 and 10:2:2. Meanwhile, the handover performance also accords with expectations (handover success rate exceeds 95%).

4.7 Self-Organizing Network

Network operation today, including many exhausting tasks like network element setup and configuration, radio parameter setting, RAN optimization is manually done through OAM (Operations and Maintenance Center). In order to reduce the complexity of the operation management and the cost of operational maintenance, the Self-Organizing Network (SON) should be introduced, including self-configuration, self-optimization, and minimization of drive tests. Through SON, the human intervention in network design, build and operate phases can be reduced. SON also reduces the amount of errors introduced by humans operation.

4.7.1 Self- configuration

The self-configuration actions will take place after the eNB is physically installed, plugged to the power line and to the transport link. When it is powered on, the eNB will boot and perform a self-test, followed by a set of self-discovery functions, which include the detection of the transport type, Tower-Mounted Amplifier (TMA), antenna, antenna cable length and auto-adjustment of the receiver-path. By self-configuration, a new base station, including its hardware, software and transmission resources can be brought into service with minimal human operator intervention.

In the phase of the connection setup from base station to the OMC and core network, the basic connectivity configurations, such as IP address, security, S1/X2 identities should be automatically set up.

In the phase of radio parameters configuration, the physical cell identity (PCI), neighbour cell relationship and other parameters should be generated. PCI should be carefully allocated to avoid collision, especially to avoid "modulo-3" collision among adjacent cells. ANR (Automatic Neighbor Relation) is a SON function to automatically manage the relations between neighboring cells. During ANR procedure, the terminal reads and reports the information of neighbor cells, including PCI, ECGI (EUTRAN Cell Global Identifier) to its serving base station. The base station can thus automatically populate a Neighbor Relation Table (NRT) for each cell it controls, containing all the neighbor cell relations. The feature has been verified in China Mobile's network.

4.7.2 Self-optimization

Self- optimization includes Mobility Load Balancing (MLB) optimization and Mobility Robustness Optimization (MRO):

1. Mobility Load Balancing Optimization

Due to diverse user distributions and service requirements, the load balance should be performed dynamically. By MLB, the cell load is automatically balanced by exchanging load related information through X2 interface and adjusting the cell reselection/handover parameters (such as handover thresholds).The overall system capacity can be improved and the congestion probability can be reduced.

2. Mobility Robustness Optimization

The Mobility Robustness Optimization (MRO) function can detect and prevent handover or reselection failures. There are of several types of failure, including too-late handover, coverage hole, too-early handover, and handover to an inappropriate cell.

4.8 Multi-vendor Interoperability

As a global industry, there is common that one operator choose base stations and core network elements from different TD-LTE vendors for its network deployment. Base stations from different vendors may also be deployed in the adjacent area. To deliver successful TD-LTE radio network, we need open interfaces to ensure network elements from different vendors can work with each other. In the multi-vendor environment, efficient and low-cost network inter-operation should be guaranteed by interoperability test (IOT).

4.8.1 Open Interface in TD-LTE

In TD-LTE, the multi-vendor interoperability is realized by S1, X2 and BBU-RRU interface.

1. S1 and X2 interface

The interface between LTE radio network and the core network is the S1 interface [5]. By S1, the operator can choose different vendors to build RAN and core network. X2 interface [6] defines the signalling between the eNBs, which enables different vendor's eNB coexisted in the RAN. The TD-LTE radio network equipment is required to support the standardized S1 and X2 open interface.

2. BBU-RRU interface

With widely introduction and application of the distributed base station type, interface between the BBU and RRU in distributed base station produces significant impact on the network architecture and flexibility. Considering that the major cost of RRU is RF module, BBU-RRU interface standardization helps professional RF vendors possess the ability to provide RRU and reduce the investment cost of RRU equipment. Therefore, it enhances the capacity of the industry chain. Moreover, BBU-RRU interface standardization can break the region combined mode, make the BBU and RRU from different vendors interwork, and improve network configuration flexibility.

In order to promote the TD-LTE products to mature as soon as possible, TD-LTE BBU-RRU interface standard has been finished recently. Taking into account the requirements of LTE extensive international operation, NGMN and ETSI also set up a special work group of ORI standard [7], which covers UMTS/FDD-LTE/TD-LTE system requirements simultaneously and will be officially released in 2013. Since the TD-LTE BBU-RRU and the underlying protocol of ORI are the same, the upper layer protocol process can learn from each other. When the standard is improved, ORI standard can be supported to meet the requirements of LTE internationalization operation, according to the actual operational requirements and based on upgrading the existing BBU-RRU interface software.

4.8.2 Interoperability test

Interoperability test (IOT) is used to guarantee the inter-operation between different vendor's network elements, together with the inter-operation between radio network and terminals. IOT is highly important for the ecosystem of TD-LTE network vendors. By IOT, the misunderstanding of the protocol from different vendors can be found and the correctness of the protocol implementation can be guaranteed.

1. IOT for network elements

Several important IOT for network elements includes:

- ✓ S1-based handover procedure on the same frequency and between different frequency carriers.
- ✓ X2-based handover procedure on the same frequency and between different frequency carriers.
- ✓ Cell reselection on the same frequency and between different frequency carriers.
- ✓ Load balance based on X2 interface.

During IOT, the standard procedures, signalling, parameters should be tested. Additional attention should be paid to some features like MTU settings, Data Forwarding functions, etc. The 9 radio network vendors have finished S1 IOT with mainstream EPC vendors such as Huawei, ZTE, Ericsson, NSN and ALU in China Mobile lab, while all the 9 radio network vendors have finished X2 IOT in China Mobile lab as well. The results demonstrated that all S1 interfaces and most of the defined X2 interfaces are mature and interoperable.

2. Air interface IOT

The IOT between network elements and the terminal, i.e., air interface IOT is also necessary for an end to end TD-LTE system. The TD-LTE Uu interface IOT between chipset vendors (Hisilicon, Innofidei, Qualcomm, Altair, ZTE, Sequans, Leadcore, MTK, Spreadtrum, Marvell) and The mainstream network vendors has been verified.

4.8.3 Load balance between different vendors

One example of the importance for open interface is the load balance between two base stations from different vendors. In the scenario where base stations from two or more vendors deployed, load balance will be needed to improve the network quality and utilization efficiency. Load balance includes three processes which is load evaluation, load information exchange, user selection and transfer. If base stations from different vendors use different algorithm or different interface, the performance of load balance cannot be guaranteed. An open interface and the corresponding algorithms have been defined to ensure the expected load balance results for this situation. At present the most network vendors have supported the open interface for load balance, and some vendors have finished lab test, with the results showing improved load balance performance.

4.9 TDD/FDD convergence networking

Beside development aligned 3GPP standard, TDD/FDD converged solutions become an efficient way to fully utilize the spectrum resources and handle the explosive LTE traffic growth. Especially when an operator has both TDD and FDD spectrum, a converged network is an efficient way to fully utilized the available spectrum and meet the increasing data rate requirements. Operators deployed TDD/FDD converged networks at current stage include

China Mobile Hong Kong, as covered in Section 2, and Hi3G in Sweden, which using 800MHz and 2.6GHz for FDD and 2.6GHz for TDD.

LTE FDD/TDD convergence networking needs considering network planning and FDD/TDD handover schemes, as well as performance problems. The goal of network planning convergence is to take full advantage of the different technologies and frequency bands of both FDD and TDD. The goal of handover between FDD and TDD is to improve user experience and guarantee that users do not perceive the handover interruption.

In terms of network planning, specific issues include:

1.Coverage planning of different bands

The coverage strategy is according to the available bands and the coverage performance of different bands. Take Hi3G for example, in urban scenario, 2.6GHz is used for both FDD and TDD for continues coverage; in suburban, LTE FDD on 800MHz is used for continues coverage and TD-LTE on 2.6GHz is used for hot spot coverage. For China Mobile at Hong Kong, since the coverage performance is similar for TDD band (2.3GHz) and FDD band (2.6GHz), both of them are used for continues coverage.

2. Camping priority of different networks

The priority of network camping could be set according to the network coverage strategy and load balance requirements. Since TDD has the advantage of adopting asymmetric data traffic at hot spot, TD-LTE can be set higher priority to accommodate high data rate requirement.

3. TDD timeslot planning considering the FDD network

Since LTE FDD is more suitable for carrying symmetry traffic and TD-LTE is more suitable for carrying asymmetric traffic, the suitable TDD timeslot planning could be selected according to the demand for business development within the same coverage area for FDD/TDD. The downlink/uplink slot allocation with 3:1 and special slot configuration 10:2:2 is recommended for the mobile internet applications.

TDD/FDD convergence network has been deployed and associative operated in Hong Kong, China. LTE FDD and TDD share network resources such as EPC, radio network sites, cabinet as well as antennas. Only RRUs are separately constructed to support different FDD/TDD frequency bands.

In respect of handover performance, handover between TDD and FDD is supported by network, while commercial TDD/FDD dual-mode terminals will be gradually released. Verified by the field test in Hong Kong, the latency of handover between TDD and FDD is about 50~60ms, very close to the handover performance of inter-frequency in LTE system.

Field test is conducted with light loads both in FDD and TDD networks, which may cause a little difference between the trial and the current network performance.

With the development of convergence terminal, the TDD/FDD convergence network will take full advantage of the frequency resource and provide high-quality service performance.

4.10 Voice Solutions

While data service will be dominant in TD-LTE networks, voice service is still important for mobile customers and operators. Voice can be provided by various technologies such as CS fall back (CSFB) [8], VoLTE plus SRVCC [9], or dual-mode dual-standby terminals.

The best approach for a given operator depends on initial LTE coverage and deployment strategy – operators with aggressive LTE deployment plans are likely to introduce VoLTE immediately, making it easier to evolve to richer multimedia services. Some operators are however likely to start with spotty LTE coverage and will then probably deploy CSFB as a first step to avoid excessive call handovers between the CS and LTE domains. Such operators would then bridge the gaps in the LTE coverage or complement their coverage.

4.10.1VoLTE + SRVCC

Based on the IMS system, voice can be carried through TD-LTE radio network and PS domain, which is called as Voice over LTE (VoLTE). In the initial deployment, TD-LTE RAN may not provide ubiquitous coverage. When a terminal involved in a VoLTE call might move out of LTE coverage but enter a 2G/3GRAN with circuit switch only, the continuity of voice service could be realized using SRVCC (Single Radio Voice Call Continuity), which transfers the PS bearer into a CS bearer 错误！未找到引用源。.

4.10.2CS fall back (CSFB)

When a TD-LTE terminal starts a voice call but there is no voice service provided from TD-LTE network, CSFB allows it handovers to the overlapping 2G/3G radio network which provides circuit-switched voice call. R8/R9 redirection can be used at the RAN side and Fast Return is used for fall back to LTE. MSC POOL is used in core network, upgrading the MSC to support CSFB SGs interface and MTRF function.

Since the new circuit voice connection needs to be set up, CSFB will introduce additionally delay during the call setup. The typical call setup delay is around 5~9s in 2G networks. With R8 CSFB, field test in large scale trial by China Mobile shows that the additional delay is 6.3~8.3s, resulting about 11.3~17.3s of the total call setup delay. For R9 CSFB, the additional delay can be reduced to1.2~2.6s and the total call setup delay is 6.2~11.6s in the field trial, which is close to the 2G delay. The field test is conducted in the poor coverage area and the subscriber is with no any extra supplementary services except for basic voice and SMS, thus the performance in current network may be a little different from the trial.

CSFB to GSM has been supported by terminal chipset vendors (Qualcomm, Hisilicon) and the network vendors (Hawei, ZTE, Ericsson, NSN, Alcatel Lucent, Datang).

4.10.3 Multi-mode dual-standby terminals

With the multi-mode supported, terminals can camp on 2/3G network and TD-LTE network simultaneously. TD-LTE mode mainly carries data services, voice services are supported by 2/3G mode. Samsung, Sony and MTK have already provided several smart phones with multi-mode dual-standby capability.

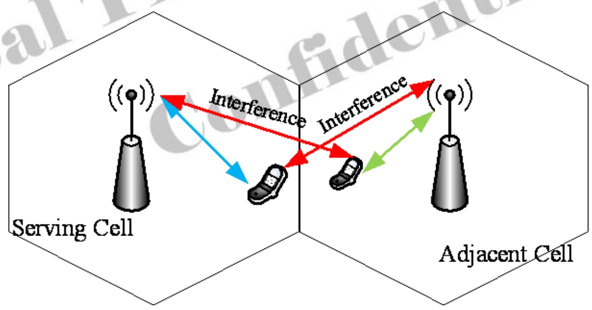
5 Further Enhancement for TD-LTE RAN

With the evolution of TD-LTE industry, enhancement features of Release 10 and further are gradually introduced into product requirements. Features of performance enhancement and operation enhancement for TD-LTE RAN, i.e., TD-LTE-Advanced[11], are introduced in this section, including the increasing of the data rate, reducing co-channel interference, improving network management and maintenance efficiency.

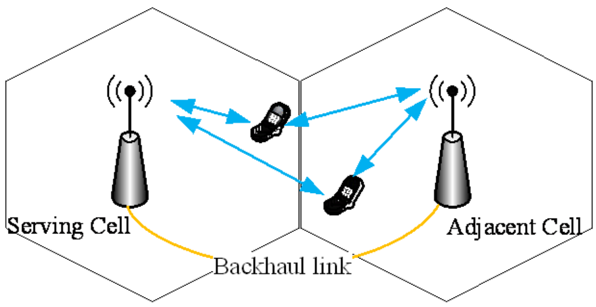
5.1 CoMP

As frequency reuse one is preferred in TD-LTE radio network, the inter-cell interference is more severe than that in 2G/3G networks. In order to provide ubiquitous user experience across the service area, the cell edge throughput needs to be guaranteed. Coordinated Multiple Point transmission and reception (CoMP) is the advanced interference mitigation techniques relying on multipoint coordination to improve the cell edge user throughput in particular, but also benefit for the average cell throughput.

On uplink direction, the data from a terminal can be jointly receipted (JR) by more than one cell. On downlink direction, the data for a single terminal can be either jointly processed and transmitted (JT) or coordinated scheduled and beamformed (CS/CB) with data from adjacent cells, as showed in Figure 10. System simulation results show that it can get more than 30% gain in both downlink and uplink throughput.



(a) withoutCoMP



(b) withCoMP

Figure 10: CoMP

In current stage, products of JR with 2 receiving antennas (2Rx) have been released. Field test shows that with UL CoMP, uplink throughput is greatly improved in the neighboring area between the cooperating cells. The CoMP gain is especially significant in the poor coverage areas. The average UL CoMP gain in the test area is 31% and the cell-edge CoMP gain is 78%. Therefore, the CoMP technology is an effective way to improve the cell-edge throughput and provide more uniform coverage, thus improve the user experience.

5.2 (F)eICIC / HetNet

What HetNet can Offer: Heterogeneous deployments consist of deployments where low power nodes are placed throughout a macro-cell layout. A baseline deployment scenario for HetNet is described in Table 2.

Table2HetNet Baseline Deployment Scenario

Environment	***Deployment Scenario***	***Non-traditional node***
Macro + Indoor	Macro + femtocell	e.g., CSG HeNB
	Macro + Indoor Relay	Indoor Relay
	Macro + indoor RRH/Hotzone	e.g., indoor pico
Macro + Outdoor	Macro + outdoor relay	Outdoor relay
	Macro + outdoor RRH/Hotzone	e.g., outdoor pico

In networks with unbalanced transmit power nodes sharing the same frequency, interference conditions are expected to change from location to location (due to the possibly lower level of network planning of these deployments) and from time to time (due to the variable traffic load at each node). Here coordination of control and data channel interference is important to maintain the downlink and uplink cell coverage and thus good data channel performance. Hence, 3GPP LTE introduces a Rel-10 WI on “Enhanced ICIC for non-CA based deployments of heterogeneous networks for LTE” (eICIC), which provides signalling and performance requirements in relation to the support of co-channel deployments of heterogeneous networks.

Due to time limitations, some identified techniques to enhance ICIC were de-prioritized for Rel-10, which motivates a WI in Rel-11 on “Further Enhanced Non CA-based ICIC for LTE” (FeICIC) to complete the associated specification work.

Features of eICIC technology are as follows:

1. Almost blank subframe:

Severe interference from aggressor cell dominants the performance of victim cell. Interference varies from one subframe to the next. Then one approach to restrict transmission in time domain is naturally to be considered as valid tool to create an interference-free subframe among cells. The subframes that enable the interference free among cells are the so-called “almost blank subframes”.

In a time-domain scheme, the resource for almost blank subframe shall be coordinated among neighboring cells in a semi-static way. Time synchronization between the cell layers is also required for this approach.

Features of FeICIC techniques are as follows：

Muting the whole subframe is sufficient enough to create interference free resources. However, in order to keep backward compatibility to legacy UEs for the purpose of broadcasting system information, maintaining UE measurement and UE synchronization, in most cases the following part are still left from backward compatibility perspective, e.g., CRS, SIB-1 and PSS/SSS/PBCH. These identified issues are left in Rel-11 as FeICIC techniques to enhance ICIC Rel-10 eICIC.

2. UE Interference Cancellation (IC)

Network assistance is introduced to simplify UE implementation of cell detection for 9 dB Cell Range Expansion (CRE) bias. UE performance requirements in such condition are improved in order to cancel interference from neighboring cell on PSS/SSS/PBCH/CRS.

3. Signalling approach for common channel acquisition improvement

Signalling approach is introduced in Rel-11 FeICIC technique to avoid interference from neighboring cell on SIB-1.

5.3 Enhanced MIMO

TD-LTE-advanced includes some important MIMO enhancements in both uplink and downlink, aiming at substantially increasing peak data rates and system spectral efficiency.

In downlink, transmission mode 9 (TM9) is introduced to support eight layer DL transmission (8×8 SU-MIMO), which improves peak spectral efficiency. In contrast, in TD-LTE, maximally four layers DL transmission is supported. With the 8×8 DL SU-MIMO capability, the peak spectral efficiency can be boosted to 30bps/Hz. Besides the peak data rate, TM 9 can also reduce the CRS overhead and thus improve the system spectral efficiency.

When 4 antennas are used for downlink transmission, there is 3dB power loss by FSTD (Frequency Switch Transmission Diversity) because only 2 antennas are transmitting simultaneously. Under this circumstance, TM9 is encouraged for downlink transmission.

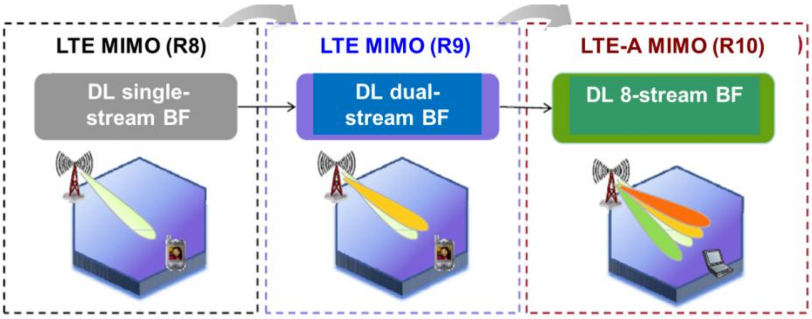


Figure 11: Enhanced Downlink MIMO

In uplink, 4×4 SU-MIMO for uplink data is introduced, which increases uplink peak spectral efficiency. Moreover, aperiodic SRS transmission is enabled for both accurate TDD CSI feedback and flexible SRS resource allocation, which improves both DL and UL system spectral efficiency.

5.4 Relay

Stationary relay has been specified by 3GPP in E-UTRAN Release 10 timeframe as one of the main LTE-Advanced functionalities[3]. It is regarded as an important way to improve cell coverage for high data rates, indoor, temporary network deployment, cell edge throughput, etc. The main feature of the relay node with respect to the typical eNB in Release 8 and Release 9,is the wireless backhaul to the donor cell. In this case, the node for UE accessing to could avoid relying on the wired backhaul, and the deployment could be much more flexible and accurate.

Currently, the relay could be classified as in-band and out-band relay. For in-band relay, the relay link shares the same carrier frequency with relay-UE links; while for out-band relay, the relay link does not operate in the same carrier frequency as relay-UE links. R10 relay could support both cases. Furthermore, multiple relays could be connected to the same donor cell. And relays are assumed to be owned by the network operators and deployed in both indoor and outdoor scenarios. Furthermore, since there are both base station feature and terminal feature on relay node, the introduction of relay will bring lots of changes to the LTE network.

The architecture for supporting relay is shown in Figure 12. From UE perspective, relay is the eNB, and from core network perspective, relay is like one cell belonging to the donor eNB. Here, the relay terminates the S1, X2 and Uu interfaces, while the Donor eNB provides S1 and X2 proxy functionality between the RN and other network nodes like other eNBs, MMEs and S GWs. Furthermore, the Donor eNB also provides the S-GW/P-GW-like functions required for relay operation, including a session creation and EPS bearer management, as well as the S11 interface termination towards the MME serving the RN. The mapping of signalling and data packets onto EPS bearers is performed by relay and Donor eNB based on existing QoS mechanisms.

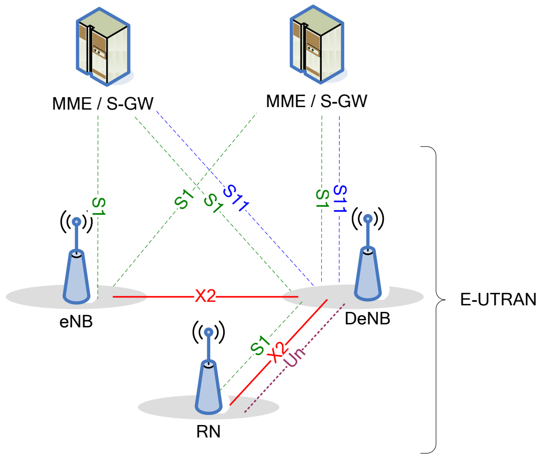


Figure 12: Architecture of Relay

5.5 eDDA

The range of device types utilizing current mobile networks continues to expand, encompassing smart phones, laptops, etc. Many are capable of running a wide variety of data applications in parallel. Numerous applications require that an always-on mobile-broadband experience is seamlessly delivered and presented to the end user. Furthermore, many applications may be designed without specific consideration of the characteristics of cellular networks, and consequently may exhibit traffic profiles not well suited to those connections. When attempting to provide such always-on connectivity at the RAN level, trade-offs are often encountered between network efficiency UE power consumption, user experience, and data transfer latency.

In order to decrease signalling for UE due to frequent RRC state transition, network can set longer RRC inactivity timer (the details can depend on the application characteristics and UE speed). For UE power consumption issue, DRX configurations may be optimized primarily for latency (e.g. for interactive content pull traffic) particular applications by power preference indication from UE. Further enhancements to improve the transmission efficiency will be discussed in Release 12.

5.6 IDC

In order to allow users to access various networks and services ubiquitously, an increasing number of UEs are equipped with multiple radio transceivers. For example, a UE may be equipped with LTE, WiFi, and Bluetooth transceivers, and GNSS receivers. One resulting challenge lies in trying to avoid coexistence interference between those collocated radio transceivers. For some coexistence scenarios, e.g. different radio technologies within the same UE operating on adjacent frequencies, current state-of-the-art filter technology might not provide sufficient rejection. Therefore 3GPP introduced the functionality called interference avoidance for in-device coexistence (IDC) in order to fix the problem through signalling-based solution.

In Release 11 two kinds of solutions were figured out, which are frequency division multiplexing (FDM) and time division multiplexing (TDM). For FDM solution, the main idea is to move one RAT from the problematic frequency to the clean frequency. For TDM solution, the main idea is to make the two RATs transmission alternately in time domain. There are five usage scenarios which the mentioned solutions can be applied, which are LTE + Bluetooth earphone (VoIP service), LTE + Bluetooth earphone (Multimedia service), LTE + WiFi portable router, LTE + WiFi offload and LTE + GNSS Receiver.

5.7 Minimization of drive tests (MDT)

Using drive tests for network optimization purposes is costly and causes also additional CO2 emissions, so it is desirable to develop automated solutions, including involving UEs in the field. Therefore 3GPP introduced the functionality called minimization of drive tests (MDT) from Rel-10 and forward. The basic idea of MDT is to collect UE measurements tagged with geography location information and time information to enable a more efficient network optimization. MDT focuses on the four use cases as follows:

- Coverage optimization
- Mobility optimization
- Capacity optimization
- QoS verification

So far in Release 11, there are two modes of MDT, which are logged MDT for UE in IDLE and immediate MDT for UE in connection. Additionally there are two special MDT events, which are RLF report and access failure report. From operator point of view, MDT not only offloads some burden of manual drive tests, but also performs some tests which manual drive tests cannot do, e.g., indoor measurements and timely problem detection.

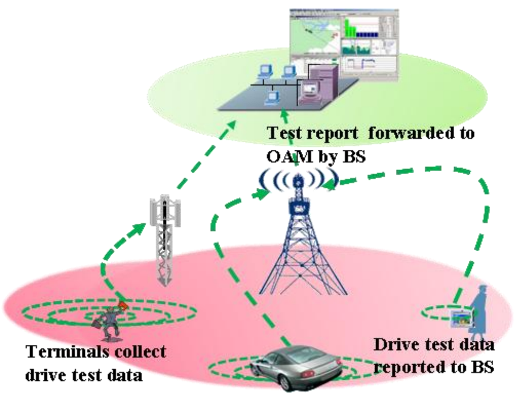


Figure 13: Minimization of Drive Tests

6 Summary

As demonstrated in this white paper, as a promising TDD radio access technology, TD-LTE networks have been widely deployed globally with sharply increasing subscribers. 21 commercial TD-LTE networks have been deployed worldwide on 2.3GHz, 2.6GHz and 3.5GHz. These networks provide plentiful information and experience to operators looking to TD-LTE deployment and operation. It also approves that TD-LTE has been the mainstream choice for operators who want to deliver high performance 4G mobile services.

TD-LTE network products already have all required features with verified performance, together with flexible eNB products, all matured for commercialized deployment. The maturity of TD-LTE radio network products are close to that of FDD LTE commercial equipments. Experience from current commercial TD-LTE network deployment and operation will facilitate the operators who own the TDD spectrum to accelerate their business plan for TD-LTE network launch.

Based on enhancement features of Release 10 and beyond, TD-LTE is on its continuing evolution path for a competitive and mature technology, which targets to meet the requirements of Mobile Internet with explosive traffic volume growth.

7 Reference

[1] Prediction of Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2011–2016

[2] http://www.smallcellforum.org/

[3] C. Hoymann, W. Chen, J. Montojo, A. Golitschek, C. Koutsimanis, and X. Shen, "Relaying operation in 3GPP LTE: challenges and solutions," IEEE Comm. Mag., vol. 50, no. 2, pp. 156 -162, Feb. 2012.

[4] White Paper On TDD Synchronization, GTI, June 2013.

[5] 3GPP, TS36.413, Evolved Universal Terrestrial Radio Access Network (E-UTRAN); S1 Application Protocol (S1AP)

[6] 3GPP, TS 36.423, Evolved Universal Terrestrial Radio Access Network (E-UTRAN); X2 Application Protocol (X2AP)

[7] http://portal.etsi.org/ori

[8] 3GPP, TS 23.272, Circuit Switched (CS) fallback in Evolved Packet System (EPS); Stage 2

[9] 3GPP, TS 23.216, Single Radio Voice Call Continuity (SRVCC); Stage 2

[10] VoLTE White Paper(2013 Edition),China Mobile. June 2013

[11] P. Bhat, S. Nagata, L. Campoy, I. Berberana, T. Derham, G. Liu, X. Shen, P. Zong, and J. Yang, "LTE-Advanced: An operator perspective," IEEE Commun. Mag, vol. 50, pp. 104-114, Feb. 2012.

8 Appendix：key features supported by radio network products and terminals

Category	Key features	Supported by network products	Supported by terminal
Basic system configuration	Bandwidth: 10MHz, 15MHz, 20MHz	√	√
	Subframe configuration: 2DL:2UL, 3DL:1UL	√	√
	Special time slot configuration: 3:9:2, 10:2:2	√	√
Basic procedure of Uu interface	Shared control/data channel configuration	√	√
	Random access	√	√
	Power control	√	√
	Scheduling and link adaptation	√	√
	Paging	√	√
	Multi-band indication	√	Partly
Radio resource management	Access and congestion control	√	√
	Measurement and mobility control	√	√
	Inter Cell Interference Cancellation (ICIC)	√	N/A
	Load balance	√	√
	Cell combining	√	N/A
Security algorithm of Uu interface	Integrity protection algorithm	√	√
	Ciphering algorithm	√	√
Coverage enhancement	CRS power boosting	√	√
	PDCCH adaptation	√	√
Terminal energy saving	Default paging DRX during idle mode	√	√
	Long DRX during connected mode	√	√
QoS	QCI configuration	√	√
	QoS parameter configuration	√	√
Carrier Aggregation	Intra band carrier aggregation (2.3GHz，	√	Not yet

	2.6GHz)		
Multi antenna features	Diversity	√	√
	Spatial multiplexing	√	√
	Beam forming	√	√
	Uplink MU-MIMO	√	√
	Interference Rejection Combining(IRC)	√	√
	Adaptation of TM2/TM3/TM7/TM8	√	√
Basic function of S1/X2 interface		√	√
InterRAT inter-operation functions	InterRAT inter-operation of data service	√	√
	InterRAT inter-operation of voice service	√	√
Self-Organizing Network(SON)	Self-starting and testing	√	√
	PCI self-configuration and self-planning	√	√
	Automatic Neighbor Relationship(ANR)	√	√
Transmission Functions		√	√