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Further Vision on TD-SCDMA Evolution

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***Abstract*- As the data rate of the mobile service increases fast, 2Mbps is not enough any more for Time Division-Synchronous Code Division Multiple Access (TD-SCDMA). While the new B3G system to provide high data rate service is still in research, TD-SCDMA must be enhanced and evolved to provide higher data rate service with better QoS. Considering the status of Long Term Evolution (LTE) of 3G which is been researching and standardizing in 3GPP, the evolution map of TD-SCDMA is presented in this paper, and the requirement on TD-SCDMA LTE and the potential features of LTE TDD is presented. By introducing the advanced techniques step by step, e.g., MIMO, OFDM, AMC, distributed Antenna Array, Ad Hoc and cooperative relaying, distributed network architecture and scalable bandwidth, the evolved TD-SCDMA can provide much higher data rate with low latency, low cost, improved coverage and capacity step by step.**

I. INTRODUCTION

Time Division Duplex (TDD) is a very promising duplex mode for wireless communication, because the channel reciprocity can be exploited to improve the transmission efficiency by advanced transmission, no frequency duplexer is needed, and the radio resource can be allocated very flexible to adapt the variable ratio of traffic in downlink and uplink, and unpaired frequency band can be exploited. As the radio frequency for wireless communication become rare and rare, TDD becomes more and more attractive for B3G system.

As a commercial TDD system, Time Division-Synchronous Code Division Multiple Access (TD-SCDMA) [1] is a fully new system, which adopts many newest techniques, such as TDD, synchronous CDMA, smart antenna, joint detection, software defined radio, baton handover, dynamical channel allocation, etc. All these technologies make TD-SCDMA a very advanced 3G standard.

However, as fast increasing of data rate required by the mobile services, 2Mbps is not enough any more for TD-SCDMA in several years. New mobile system to provide high data rate service is expected. As predicted by ITU, the new B3G commercial system should provide 100Mbps~1Gbps data rate service, and the enhanced or evolved 3G should provide 10~50Mbps data rate. As the B3G is not available until 2010, 3G and WLAN should fulfill the requirements on higher data rate and capacity before 2010. Although WLAN can provide much higher data rate, e.g., 54Mbps by IEEE 802.11a, it only supports indoor deployment and very slow mobility, and the full mobility can only be supported by cellular network. 802.16 can provide up to 76Mbps in 20MHz frequency band, and 802.16e is been modifying to improve its performance on mobility. To be competitive, 3G systems must be enhanced and evolved. Besides the HSDPA, HSUPA, Long Term Evolution (LTE) is being researched and standardized in 3GPP. The idea of LTE is to enhance and improve the system performance of 3G with the matured technologies which can be adopted in B3G in several years. The objective of LTE is to provide packet-based high-data-rate service with enhanced coverage, capacity, low latency and low cost.

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As the special feature of TDD system, it's a natural and wise choice for TD-SCDMA to evolve towards FuTURE B3G TDD [2] in China since the system design of FuTURE B3G TDD has taken the main features of TD-SCDMA into account at the beginning of system design.

This paper is organized as following: The requirements on the evolution of TD-SCDMA are presented in section II; the evolution map proposed is presented in section III; the potential features of LTE TDD are presented in section IV and the conclusion is drawn in section V.

II. REQUIREMENT ON THE LTE TDD

As discussed in 3GPP [3], the long term evolution of TD-SCDMA (LTE TDD) should be required to provide higher data rate services with low latency, low cost, improved coverage and capacity.

The first requirement is high data rate and high spectrum efficiency. The data rate of 50~100Mbps in downlink and 30~50Mbps in uplink are expected. Significantly improved spectrum efficiency, e.g. 2-4 times of Release 6, is required. To provide high data rate and high spectrum efficiency, new technologies, e.g. MIMO, OFDM, may be introduced, but new technologies should be compatible back forward to the existing ones.

The evolved system should be able to utilize any available cellular spectrum efficiently, such as current 3G spectrum, extension bands, migration of 2G spectrum, etc., and the scalable bandwidth (1.6MHz, 5MHz, 10MHz, and 20MHz) is supported to provide flexible data rate required by the user. Existing and extra 3G spectrum can be used for the new technologies.

Low latency [3] is required for LTE. The Radio-access network latency should be below 10 ms. Significantly reduced C-plane latency is required (e.g. including the possibility to exchange user-plane data starting from camped-state with a transition time of less than 100 ms (excluding downlink paging delay)).

The bit rate at the cell edge should be guaranteed whilst maintaining same site locations as deployed today [3]. For this target, the macro diversity is a good choice though the low latency should be considered. Meanwhile, as a TDD system, cooperative relaying can be adopted very conveniently to improve the bit rate at the cell edge and the coverage efficiency.

The LTE TDD should target all 3G environments, such as wide-area coverage in Urban, sub-urban, rural environments, Outdoor and indoor, and low and high mobility.

Besides the requirements above, compatibility back forward, distributed and scalable network architecture and smooth system deployment are required to improve the network efficiency, avoid the network bottleneck, lower the cost of the system migration and deployment, and make the investment on the network scalable. And thus the proportional investment can be appended as the scale of system grows, investments of the operator equipment and manufacturer development is protected, and smooth integration in existing networks is guaranteed.

On the UE, low cost and low power consumption is expected. The tradeoff vs. performance and capabilities, the relevant complexity/cost aspects, and the aspects related to multi-mode and multi-band terminal should be understood well.

III. EVOLUTION MAP FROM TD-SCDMA TO FUTURE B3G TDD

The target of the LTE TDD is to enhance its capabilities of coverage, service providing, and mobility supporting step by step, and provide similar performance as that of FuTURE B3G TDD or 4G finally. For these targets, advanced technologies should be involved, such as MIMO, OFDM, distributed antenna array, cooperative relaying, Ad Hoc, and scalable bandwidth, etc., as in Figure 1. .

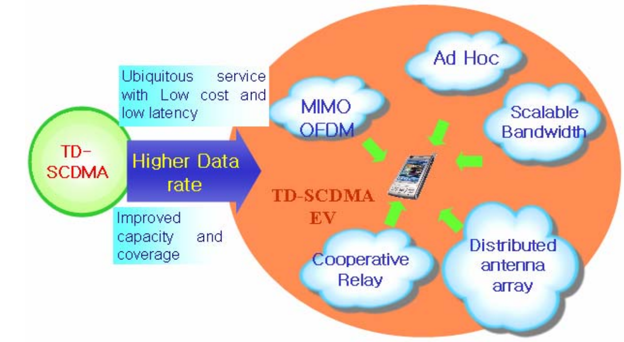

Figure 1. Key features of the evolved TD-SCDMA

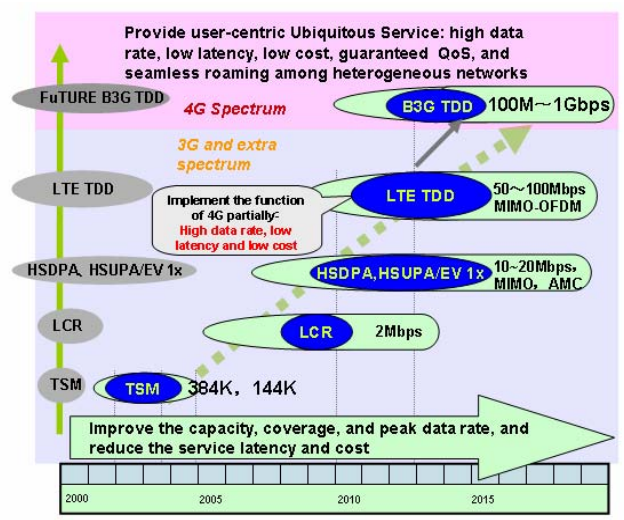

Figure 2. Evolution map for TD-SCDMA

However, to save the investment and make full use of the network infrastructure available, the system evolution must be smooth, which means that new features are introduced into the evolved system step by step to enhance the coverage, capacity, data rate, and mobility supporting. Meanwhile, the design of FuTURE B3G TDD should take into account the features of TD-SCDMA and its evolved system, and keep FuTURE B3G TDD compatible to TD-SCDMA and its evolved system back forward.

Based on the consideration above, the reasonable evolution map from TD-SCDMA to FuTURE B3G TDD is as Figure 2. The evolution map is proposed as 5 phases: TSM (TD-SCDMA System for Mobile), LCR (Low Chip Rate TDD), HSDPA (High Speed Downlink Packet Access)/HSUPA (High Speed Uplink Packet Access) and TD-SCDMA EV 1x, LTE TDD, and FuTURE B3G TDD /4G.

The main features of TSM, LCR and HSDPA/HSUPA, have been described in [4], and only the potential features of LTE TDD are explained in detail in this paper.

IV. POTENTIAL FEATURES OF LTE TDD

LTE TDD is the last phase before FuTURE B3G TDD, its performance targets and the parameters are similar to that of FuTURE B3G TDD. New features are introduced to fulfill the requirements of 3G LTE, e.g., MIMO, OFDM, cooperative relaying, distributed antenna array, Ad hoc, and scalable bandwidth (1.6MHz, 5MHz, 10MHz, 20MHz bandwidth). With MIMO and OFDM, the peak data rate is expected to be 50~100Mbps in downlink and 30~50Mbps in uplink. Cooperative MIMO relaying is used to improve the coverage and the peak data rate. The Ad hoc network architecture is supported to provide flexible deployment; and all the services are transmitted based on packet.

1) OFDMA

OFDM is very suitable for high data rate transmission in wide band wireless channel for the excellent capability to mitigate the frequency selective fading and inter-symbol interference (ISI). The adaptive modulation and coding (AMC) on every subcarrier and adaptive frequency domain scheduling can provide high spectrum efficiency. Meanwhile, the implementation of OFDM is very convenient by IFFT/FFT. All these features make OFDM very competitive and promising for LTE TDD. It has been adopted in IEEE 802.16, the peak data rate can be 76Mbps with 20 MHz frequency band.

OFDMA is a multiple access scheme based on OFDM, in which different users transmits on different subcarriers, and the subcarriers of different users are orthogonal to each other if the synchronization among different user is perfect. An example of OFDMA system is 802.16. Combined with TDMA, CDMA, SDMA, OFDMA can provide very flexible multiple access schemes.

Generally, small enough resource granularities of LTE TDD is necessary to make full use of the spectrum and support low data rate and large number of users, so OFDMA/TDMA is preferred in LTE TDD system. If only the TDMA is adopted, the resource granularity is a timeslot and few users can be supported in a cell. For low data rate service, one user will occupies one time slot, and the wasting on the radio resource is very serious. While the resource granularity of OFDMA/TDMA system is only one time-frequency grid as Figure 4, the smallest unit is 1 subcarrier of a timeslot. As the range of the data rate for all kind of services varies much, e.g. from several Kbps to 100Mbps, it is necessary for LTE TDD to provide small enough radio resource granularity to guarantee the high spectrum efficiency and avoid the wasting on limited radio resource. On the other hand, to obtain high spectrum efficiency and low guard period overhead between continuous timeslots, the timeslots number of LTE TDD should not be too large.

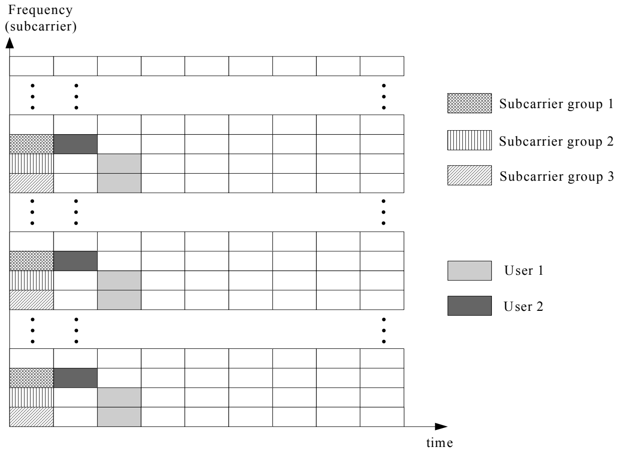

Figure 3. The resource structure of OFDMA/TDMA system

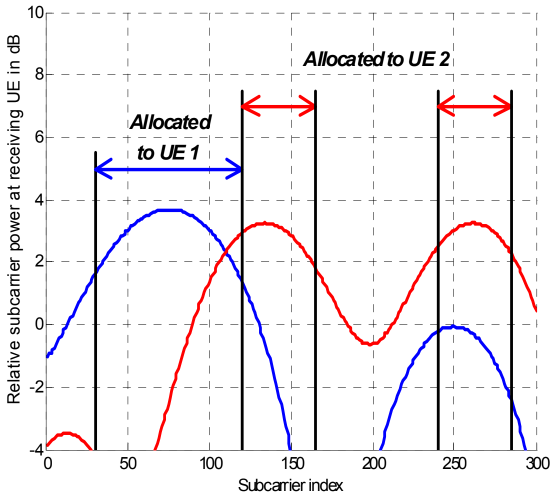

Figure 4. Multiuser diversity

Further, multiuser diversity gain can be exploited to improve the cell throughput in OFDMA system. For the locations of different users are independent, their frequency selective fading are also independent, so some users experience deep fading is some subcarriers, while the other users experience little fading on them, E.g. Figure 5. By advanced subcarrier allocation, the subcarriers are almost allocate to those user who experience little fading, and thus the total cell throughput will be improved. Such gain is called as multiuser diversity gain [5]. The more the user number, the higher the multiuser diversity gain.

Besides, the AMC can be adopted on every subcarrier according to the SNR principally, high SNR can support high modulation order, and thus more information bits will be transmitted. And thus the total cell throughput and power efficiency will be improved further.

So OFDMA/TDMA is preferred in both downlink and uplink of LTE TDD system. Thus the channel reciprocity can be exploited to do link adaptation on subcarrier basis directly, and the heavy signaling overhead will be avoided.

2) QoS guaranteed Scheduling in Frequency Domain

Studies in [5] have showed that the subcarrier and power allocation plays a very important role in maximizing the system throughput of OFDMA system. By selecting proper subcarriers for different users according to their QoS, channel gain and co-channel interference [5], every user can obtain a subset of good subcarriers to meet his QoS requirement for their independent fading, and thus the multiple user diversity gain is exploited in OFDMA system by the scheduling in frequency domain. On the other hand, all kinds of service with different QoS will be provided over the LTE air interface, their different QoS must be guaranteed. When the subcarrier and power allocation of OFDMA/TDMA is designed, the tradeoff between the throughput efficiency and the QoS guaranteeing should be taken into account.

3) MIMO

MIMO [6] is a very exciting technology to improve the spectrum efficiency. When the channel fading is independent at the antennas of Node B and UE, the MIMO channel capacity will be approximate to the less antenna number at the both ends of the channel. However, for the limited size, it's difficult to configure multiple antennas at the UE. As required by the 3GPP LTE [3], 2 antennas will be configured at both the Node B and UE.

As much broader frequency band will be used and more multi-paths will be identified, the single carrier system will have much higher complexity in MIMO equalization in time domain. Although the equalization in frequency domain may decrease the processing complexity, it's difficult to exploit the gain from adaptive modulation on subcarriers. Combining OFDM with MIMO, the frequency selective fading MIMO channel can be separated into many flat fading MIMO sub-channels, and thus the decoding of the MIMO channel can be processed as a flat fading channel on every subcarrier and the adaptive modulation on subcarrier basis can be adapted conveniently.

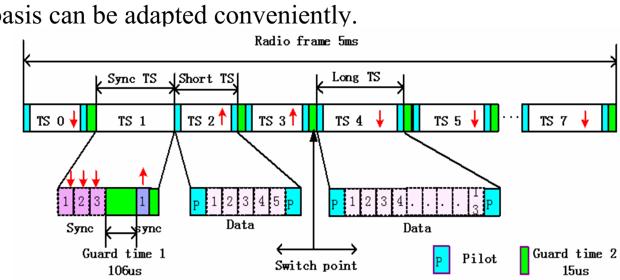

Figure 5. Frame structure of FuTURE B3G TDD

In this section, the throughputs of a VBLAST-OFDM system with 2 antennas at transmitter and 4 antennas at receiver are shown as Figure 6. The bandwidth is 20MHz, and the data subcarriers are 832 of 1024. The RMS of the channel time delay is 50ns. Based on the frame structure in of Figure 5, the peak data rate of 16QAM modulation without channel coding is more than 70Mbps with ideal channel estimation. With higher modulation order and more antennas at the transmitter and receiver, higher data rate more than 100Mbps can be obtained in 20MHz bandwidth. Although the channel coding may decrease the peak data rate, it can guarantee the reliability of the transmission and decrease the SNR required. So it is very possible for LTE TDD to offer 50~100Mbps data rate in both uplink and downlink with 20MHz bandwidth.

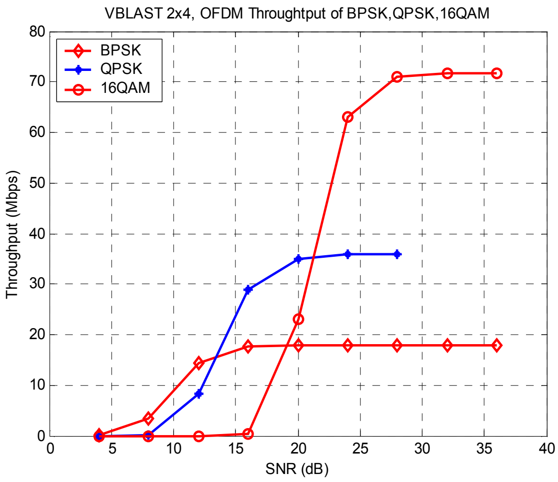

Figure 6. The throughput of the VBLAST OFDM system

4) Scalabel Bandwidth

As the service market increasing, more spectrums are expected to meet the demand from traffic load. However the radio frequency band becomes scare and scare, it's very difficult to find new wide enough frequency band for LTE. So any spectrum available should be exploited by LTE TDD. The scalable bandwidth is a good solution. According to the system load, the service requirement, and the spectrum available, the bandwidth can be configured dynamically, and thus any spectrum available can be utilized. Besides, as the guard band between neighboring carriers can be used to transmit data when both the carriers are occupied for one user or one base station, the capacity and the data rate may be improved further as Figure 7. As OFDMA is adopted, the scalable bandwidth can be implemented by adopting different number of data and guard subcarriers very conveniently.

Further, the design of the pilot and the synchronization of OFDMA system should take into account the feature of scalable bandwidth, and the system can work with any configuration of bandwidth, e.g. 1.6MHz, 5MHz, 10MHz and 20MHz.

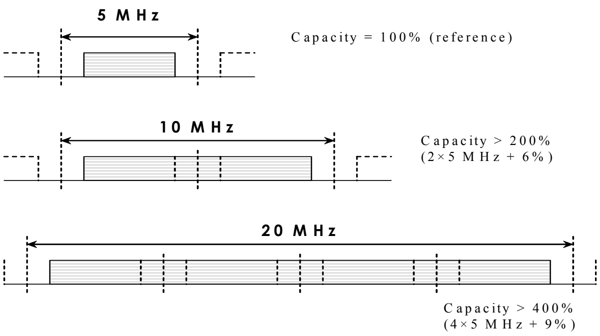

Figure 7. Capacity Vs. scalable bandwidth

5) Adaptive Air Interface

For the LTE TDD must cover all 3G environments, its air interface must adapt to any environments and any applications.

Adaptive CP Generally, the CP of OFDM should be short enough to minimize the overhead loss, but long enough to avoid the ISI. To adapt to all application and cover all the environments, it's difficult to design a unified CP length to provide spectrum efficiency as high as possible. In [7], different length of CP is suggested for unicast and multicast service. For short CP can lead to small overhead loss in every OFDM symbol in unicast case, while longer CP is necessary to do soft combining of OFDM signal from different sites in multicast case to improve the performance at the cell edge or to support the application in wide-area coverage. It's possible for the air interface to adopt different CP length for different application.

Adaptive switching point For TDD, flexible switching point between uplink and downlink can make full use of the radio resource according to the traffic load ratio of uplink and downlink

Adaptive pilot As required by the coherent detection, different pilot density in time and frequency domain for different wireless environment is required to estimate the channel information accurately. The shorter the coherent time, the denser the pilot in time domain is required. The narrower the coherent bandwidth, the denser the pilot is required in frequency domain. The enough pilot density in frequency domain and time domain is necessary to estimate out the channel information accurately to guarantee the detection performance. On the other hand, more pilots will lead to less peak data rate. So there is a tradeoff between the detection performance and the peak data rate. Naturally, the best method is to adapt the pilot density in frequency domain and time domain according to the channel information, and reduce the pilot overhead as much as possible.

Adaptive coverage radius In a TDD system, besides the power, reception sensitivity, the guard period between downlink and uplink decides the upper bound of the cell radius. For different application environment, the requirement on the coverage capability varies. For wide-area application, large coverage radius is preferred. While for micro environment, higher spectrum efficiency is preferred. The fixed guard period between the downlink and uplink time slots leads to a fixed coverage radius. The guard period should be variable to adapt to different application environment. A good solution is the idle OFDM symbol period [8] at the beginning of uplink time slot to extend the coverage radius as need.

Adaptive interleaving and coding Besides Turbo code, convolution code, LDPC is also considered for LTE TDD. For their performance varies with the coding length, constraint length, different coding is preferred for different application scenario. For the low latency is required in LTE TDD, the transmission time interval (TTI) will be shorter, so the time diversity gain to be exploited will be less than that of 3G. To guarantee the reliability of the transmission and provide higher transmission efficiency, the spatial diversity gain and frequency diversity gain should be exploited by spatial-temporal-frequency interleaving and coding [9].

Adaptive MIMO Usually, the MIMO gain can only be exploited in the environment with scattering enough. Among the environments covered by LTE TDD, only the urban or indoor case satisfies such condition. For the other environment, e.g. the rural area, the MIMO gain will be less than that is expected. In different environment, different gain can be exploited by MIMO with different algorithms. LTE TDD air interface should adapt to different environment and change the MIMO scheme to exploit the best MIMO gain, e.g. diversity, spatial multiplexing and interference suppression.

6) Cooperative relaying and Ad Hoc

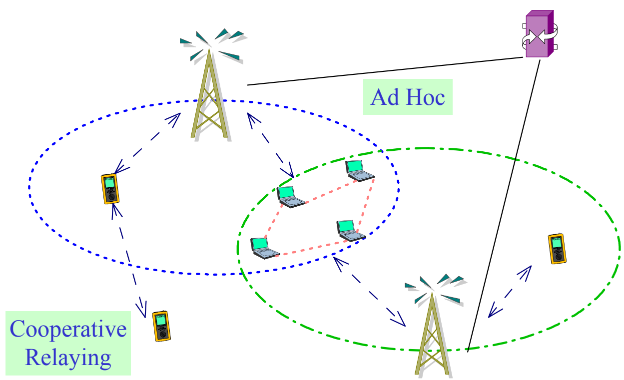

Figure 8. Cooperative Relaying and Ad Hoc

As a TDD system, the interference between UE may happen, which put an upper bound on the cell radius. However, the large cell radius is often required in the wide area, where the cell capacity is not required very high. In this case, the capacity may be scarified to improve the cell coverage. Take this into account, cooperative relaying can be adopted to improve the coverage here, and part of the time slots may be allocated for cooperative relaying to avoid the interference between the relaying links and the cellular links between UEs and Node B.

Ad Hoc supports the flexible network construction when the network infrastructure is not available. So the Ad Hoc may be adopted to support flexible and urgent application.

7) Distributed network architecture

The evolution target of the RAN structure is the flexible distributed IP based network, where the data and control signaling are separated to improve the transmission efficiency and the network efficiency, avoid the bottleneck, decrease the cost of the system integration and deployment, make the investment increased as the scale of the network increases. It is unnecessary to invest for the whole network at the beginning of the network deployment. The network function is optimized, and the scalable functionality provide flexible and efficient transmission infrastructure. Thus the RAN of B3G or 4G can be introduced into the system easily by changing the air interface only. It is also compatible to the RAN of original TD-SCDMA and provides seamless roaming among the heterogeneous networks by interworking. Figure 9 is an example of such RAN architecture [10].

Meanwhile, the cooperative relaying is supported to improve the coverage, and the Ad Hoc is supported to provide flexible deployment and application.

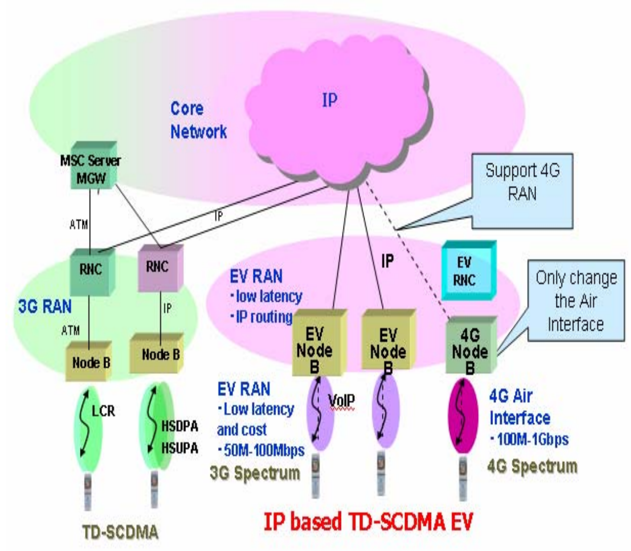

Figure 9. The distributed architecture of LTE

V. CONCLUSION

As the data rate of the mobile service increases fast, 2Mbps peak data rate of TD-SCDMA will be not enough any more in several years. To be competitive, it must be evolved and enhanced. Considering the status of 3G LTE research and standardization in 3GPP, the evolution map of TD-SCDMA and the requirement on LTE TDD is presented first. Then the potential main features of LTE TDD are given out in detail. By introducing new technologies step by step, e.g., MIMO, OFDM, cooperative relaying, Ad Hoc and scalable bandwidth, evolved TD-SCDMA system can provide higher data rate service with low latency, low cost, improved coverage and capacity.

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