The Requirements, Challenges, and Technologies for 5G of Terrestrial Mobile Telecommunication

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ABSTRACT

In this article, we summarize the 5G mobile communication requirements and challenges. First, essential requirements for 5G are pointed out, including higher traffic volume, indoor or hotspot traffic, and spectrum, energy, and cost efficiency. Along with these changes of requirements, we present a potential step change for the evolution toward 5G, which shows that macro-local coexisting and coordinating paths will replace one macro-dominated path as in 4G and before. We hereafter discuss emerging technologies for 5G within international mobile telecommunications. Challenges and directions in hardware, including integrated circuits and passive components, are also discussed. Finally, a whole picture for the evolution to 5G is predicted and presented.

INTRODUCTION

International Mobile Telecommunications (IMT)-Advanced Specifications of Fourth Generation (4G) Terrestrial Mobile Telecommunication were approved by the International Telecommunication Union Radio Standards Sector (ITU-R) in January 2012. Meanwhile, the dramatic growth of mobile data services driven by wireless Internet and smart devices has triggered the investigation of 5G for the next generation of terrestrial mobile telecommunications.

Mobile traffic requirements have shown different features that introduce significant impact on future mobile system architectures, technology developments, and evolution. These features include:

Big traffic volume: increases on the order of several magnitudes. The compound yearly growth rate for the period 2012–2016 is 78 percent [1]. Now the industry is preparing for an astounding 1000-fold of data traffic increase for 2020 and beyond.

Increased indoor or hotspot traffic: dominates mobile traffic. Currently, 60 percent voice traffic and 70 percent data traffic happens indoors; in the future, indoor/hotspot traffic may approach 90 percent.

Higher traffic data asymmetry: The ratio of downlink to uplink traffic was around 6:1 in 2010, and the ratio could rise to 10:1 over the next five years [2] as the proportion of video traffic in the total mobile traffic grows.

Huge numbers of subscribers: will be created from machine-to-machine (M2M) applications, which are estimated at 100-fold or more of mobile phone subscribers.

Energy consumption: for future mobile networks may need to be reduced on the order of several magnitudes.

Future mobile networks will face great challenges, including higher capacity, higher performance, lower power consumption, higher spectrum efficiency, more spectrum resource, and lower cost.

The legacy architecture of terrestrial mobile systems will hardly meet those requirements and challenges in 5G. We predict that a step change will eventually happen in 5G.

STEP CHANGE: FROM MACRO DOMINATED EVOLUTION TO MACRO-LOCAL COEXISTING AND COORDINATING EVOLUTION

A concept of nomadic/local area wireless access has been mentioned early in the IMT framework model in ITU-R. But in the actual 3G/4G system, the system designs are mainly based on the perspectives and requirements of the macrocell. The first reason is that the main goal of 3G/4G is to achieve consistent coverage for the same services in both outdoor and indoor scenarios. The second reason is to keep backward compatibility for devices both outdoors and indoors. Thus, those designs based on the macro scenario are not always good for the indoor scenario. In 3G, those considerations were reasonable. But in 5G, where conditions will be completely different, the services are layered and inconsistent. The voice services and moderate data services are always consistent in the whole system, but most high-data-rate services are always isolated

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and lie in only indoor or hotspots. Furthermore, 5G will be a heterogonous framework, and backward compatibility will not be mandatory both indoors and outdoors. The improvement of user equipment (UE) provides the ability to support simultaneous connections both indoors and outdoors. The previous barriers will be broken.

Thus, a fundamental change will occur in 5G. It is predicted that there will be two coexisting and coordinating evolution paths of a macro-based IMT path and a local-based IMT path instead of one macro-dominated path as in 4G and before. A general profile for the change is shown in Fig. 1, and the reasons are analyzed based on the following key aspects.

REQUIREMENT ON HEAVY DISTRIBUTION OF MOBILE DATA SERVICES

In 5G, high data rate services indoors and at hotspots occupy the main traffic volume of mobile services. The previous macro-dominated design will not be suitable to meet this change. As a result, a new design, local-based IMT, optimized for both indoors and hotspots, will be necessary. Local-based IMT needs to coexist and coordinate with macro-based IMT.

STUNNING MOBILE DATA CAPACITY (1000-FOLD) REQUIREMENT

The increasing of cell numbers will be a very efficient way to improve the system capacity in an almost linear ratio [3] when the signal-to-interference-plus-noise ratio (SINR) is guaranteed. However, it is impossible to increase the number of the current small cells by orders of magnitude because of the limitations from current macro-based design such as backward compatibility, cost, interference, cell management, and cell sites. But in 5G, local-based IMT can be introduced, and small cells can be designed from local perspectives. It is completely possible to increase the number of small cells by orders of magnitude when new architecture and new technologies are adopted. According to [3], the increase of small cell numbers in the future may far exceed 100 times the current number.

ENERGY CONSUMPTION REQUIREMENT

Energy consumption shall be decreased significantly in orders of magnitudes in 5G. But it is impossible in the current framework and current base stations [4]. For example, the goal of EC FP7 EARTH is to decrease energy consumption for base stations by 50 percent, mainly based in the current framework. However, it is possible to reduce power down to orders in magnitude by offloading majority data to local small cells, letting inactive cells sleep, in the macro-local coexisting and coordinating framework.

NEW AVAILABLE SPECTRUM REQUIREMENT

For 2G/3G and even 4G, most allocated spectrums are mainly below 3 GHz. In addition, the spectrum usage reaches almost the maximum efficiency. A new work item was thus established to seek new potential spectrum for the future terrestrial mobile communication. It seems that the new available spectrum for the future gener-
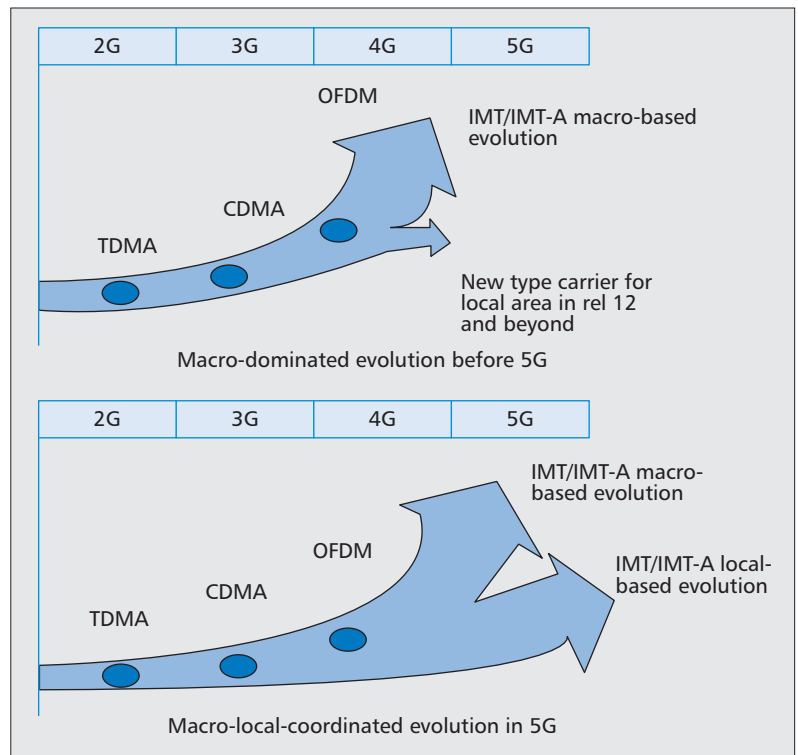

Figure 1. Evolution change for 5G.

ation is mainly above 3GHz or even higher. Those spectrums will be suitable for local scenarios to improve capacity rather than for a macro scenario to improve coverage. This provides the fundamental condition to the new design of local-based IMT.

SIGNIFICANTLY RELAX THE REQUIREMENT ON COST

Since the RF and baseband requirements on the current terminal chipset are based on the physical parameters meeting high mobility and large cell radius, the cost is hard to be significantly reduced. When local-based IMT is introduced, the cost of the RF and baseband chipsets for the local scenario can be decreased because the RF and baseband performance requirements are relaxed to meet low mobility and small cell radius. Moreover, the cost of a small cell, including the cost of maintenance and a cell site, will also be significantly reduced.

From 2G to 3G and to 4G, the design principle is macro-based for the design of either the primary physical parameters or the framework. In order to change the situation to some extent, a work item for small cells, probably using a new type of carrier, is introduced in 3GPP Release 12. However, great changes will be very difficult in 4G due to the limitations in the framework and backward compatibility. This work item was terminated at the RAN #61 meeting in September 2013. That is why only a small branch has spun off from the main macro-dominated branch in Fig. 1.

Together with the requirements for 5G, this step change will bring in some technical trends, described in the following sections.

POSSIBLE TECHNOLOGIES IN 5G

In this section, several technical trends are discussed for 5G mainly based on IMT, including local IMT small cells, heterogonous layer coordination, flexible separation and combination of the C/U plane, technologies for asymmetric traffic, hybrid networking topology, and signal processing technologies.

LOCAL IMT SMALL CELLS

It is believed that small cells will play a very important role in 5G to meet the 5G requirements in traffic volume, frequency efficiency, and energy and cost reduction. It is predicted that small cells will be designed differently from 4G to 5G. Local IMT small cells is a branch of IMT local-based evolution. Local IMT small cells will be designed based on the indoors and/or hotspot scenario. There are significant differences between the indoors or hotspot scenario and the macro scenario. First, the indoor or hotspot scenario supports only nomadic or pedestrian speeds (e.g., 0–30 km/h) and small cell radius (e.g., 150 m) compared with high mobility (e.g., 350 km/h or higher) and large cell radius (e.g., > 30 km) in macro scenarios. These differences will impact the principal parameter design. Second, the propagation characteristics of the indoor or hotspot scenario are quite different from those of the macro scenario. Those lead to different designs for multi-antenna technology and bring more performance benefits to local IMT small cells. Third, the transmission power of local IMT small cells will be orders of magnitude less than that of today's macrocells. This provides more flexible spectrum usage and energy savings.

Design of the Principal Physical Layer Parameters — Since the target cell sizes and maximum speeds are significantly different between the macro and the indoor or hotspot scenarios, the principal physical layer parameters are supposed to be quite different for those two kinds of scenarios. However, in current mobile systems, those principal physical layer parameters are mainly determined according to the characteristics in macrocells. For example, in Third Generation Partnership Project (3GPP) Long Term Evolution (LTE) systems, the principal physical layer parameters are the cyclic prefix (CP) length and the subcarrier spacing Δf. Those two parameters are determined to support mobility conditions (up to 350 or even 500 km/h) and cell sizes of tens of kilometers [5]. In the indoor or hotspot scenario, the CP length can be decreased by several times, and subcarrier spacing Δf can increase several times. This optimization can not only improve the performance, but also reduce the cost of RF and baseband integrated circuits (ICs) of terminals and small cells by relaxing the RF requirements.

Design for Multiple-Input Multiple-Output — MIMO technology is one of the most important technologies to significantly improve system performance in coverage, capacity, and user data rates. The performance improvement of MIMO depends on propagation characteristics of each deployment scenario. One factor impacting MIMO performance and design is the distance between antenna elements. This distance actually impacts the mutual correlation between the radio-channel fading on signals on different antennas. But the relationship between the element distance and the mutual correlation in the indoor or hotspot scenario is significantly different from that in the macro scenario. In the indoor or hotspot scenario, the environment as seen from the base station is more similar to the environment as seen from the terminal [6]. In this case, smaller antenna distance in a base station, such as half a wavelength (0.5λ), not the 10 times wavelength (10λ) usually in macro scenarios, is typically sufficient to ensure relatively low mutual correlation between antennas [7]. Examples are shown in Fig. 2. This will bring a large benefit to small cells in that a small cell can support more antennas (e.g., 8 or even 16 antennas) based on its small size in Fig. 2a. The system capacity can thus be significantly improved. Moreover, the ability to supply both MIMO and beamforming technologies simultaneously to different UEs by one small cell can be provided according to different usage in Fig. 2b. In addition, in the indoor or hotspot scenario, there is a richer scatter environment than that in the macro scenario. Excessive scattering environments are a challenge. Multi-user MIMO (MU-MIMO) is a perfect solution of the challenge in downlink and uplink, as shown in Figs. 2c and 2d. MU-MIMO can improve system capacity; it is especially valuable to terminals by combining space multiplexing using antennas from different UEs since each UE always has few antennas, limited by size and cost. A key factor having an impact on the performance of MU-MIMO is the fast and accurate feedback of channel information. The focus of the macro scenario is on supporting high UE mobility, so it is very difficult to quickly get accurate channel information when the UE is in high mobility in a macrocell, and thus improvements of performance is limited. Indoors or at a hotspot, low mobility is required. It is therefore possible to obtain timely and accurate feedback of channel information so that a more dedicated method can be designed. In time-division duplex (TDD), channel reciprocity in the uplink and downlink will be one of the advantages, offering availability of fast and accurate feedback of channel information. In general, local IMT small cells will potentially have a large role in improving MIMO design.

Energy Saving Design — As shown in Fig. 3a, power efficiency is low in current macro base stations due to the site support system consumption and transmission loss [8]. But small sells of local IMT can have different system architecture and product types. Local IMT small cells do not need cooling systems. Excessive transmission loss can be avoided thanks to the shorter transmission range. An intuitive view might be excessive power consumed by hundreds of small cells deployed to replace one macrocell. However,
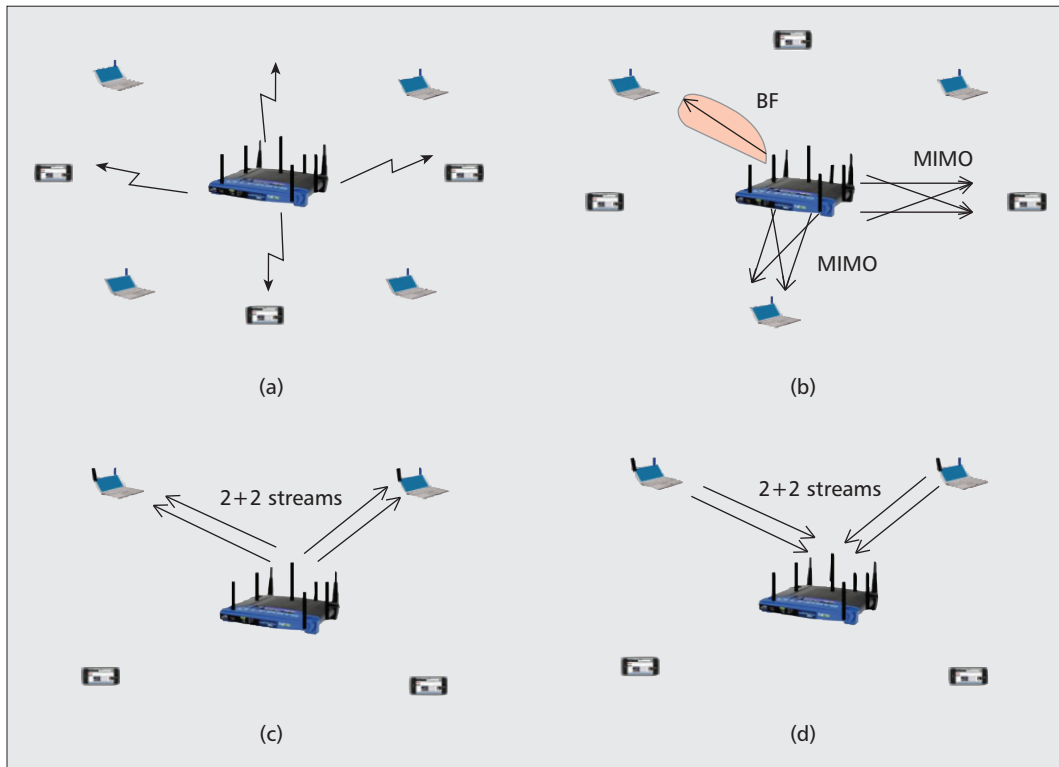
Figure 2. More antenna elements and more advanced antenna technologies for local IMT small cells.

inactive small cells will actually sleep most of the time and consume much less active power. For example, as shown in Fig. 3b, small cells in offices may turn off, and small cells in hotspots may turn on at night, while small cells in offices may turn on and small cells in hotspots may turn off during the day. The power consumption of a local IMT small cell can be reduced by several orders of magnitude from that in a current base station. In 5G, the mobile broadband traffic can be balanced and offloaded by high-volume local IMT small cells. Thus, the energy efficiency of the whole wireless access system will be dramatically increased.

Design for Flexible Spectrum Usage — It is envisioned that a great number of small cells will be deployed in 5G networks. However, the requirements on spectrum resources cannot be fulfilled by simply increasing spectrum. A promising technology to deal with this issue is cognitive radio (CR). Although CR offers flexibility in spectrum usage, the flexibility seems difficult to use in a macro base station. Since a small cell has low transmission power and small size, the coverage zone providing very high data rate services can be very isolated, and in turn CR can be more easily used in small cells than in macrocells. Moreover, new sharing of spectrum bands might be allocated for flexible spectrum usage, especially to small cells. The FCC has considered implementing shared use of the 3550–3650 MHz band [9].Because of using the same single channel for uplink and downlink operation, only one signal band need be sensed, TDD has advantages over frequency-division duplex (FDD)

since FDD requires a traditional design of paired spectrum using two fixed channels with fixed spacing between them [9]. Also, there is a TDD drawback, which is the need for extra guard bands when small cells are deployed for different operators in TDD mode.

In addition, local IMT small cells have more opportunities for design optimization for wireless backhaul and self-organized networking (SON) by which more flexibility and cost reduction can be achieved. Furthermore, ultra-wide bandwidth in very high frequency (e.g., $6 \sim 60$ GHz) might be a good choice to provide huge capacity improvement to small cells in the future.

HETEROGONOUS LAYER COORDINATION

The future 5G network will be a heterogonous layer network consisting of macrocells, traditional micro/picocells, new Local IMT small cells, and relay and other low-power nodes. According to whether the same or different frequency is used in different layers, two deployment models are defined as co-channel frequency deployment and dedicated frequency deployment. Co-channel frequency deployment uses the same frequency in different layers to deal with radio coverage, while dedicated frequency deployment uses different frequencies in different layers to provide radio capacity. Since the capacity of high rate traffic is the main focus in 5G, dedicated frequency deployment will be the main method in 5G.

In 5G, the two-path design for macro and local cells will gain many benefits. It also brings obvious technical challenges in the coordination between macrocell and local cells, espe-
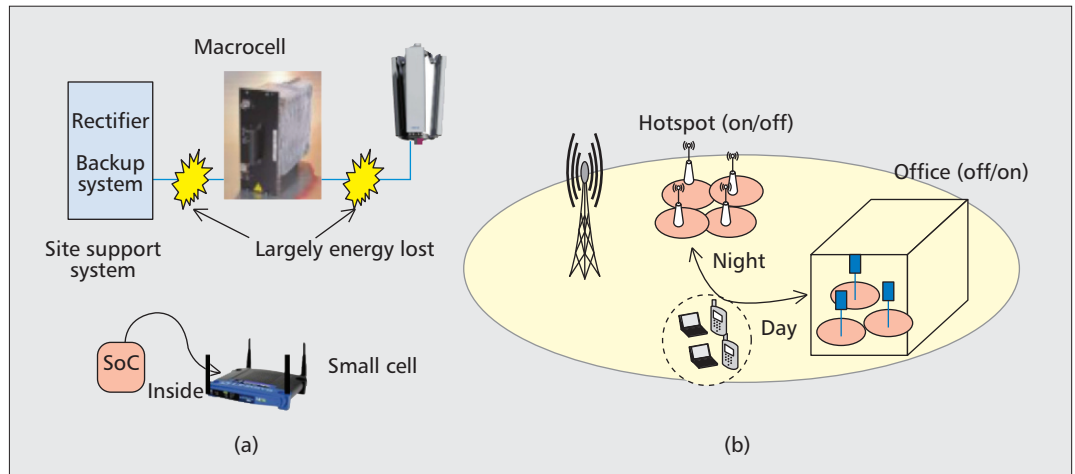
Figure 3. Energy savings from local IMT small cells.

cially when one macro eNB may manage tens or even hundreds of small cells in the future. It is predicted that multiple coordination methods, including coordination in the core network, radio resource and mobility management, layer 2, and the physical layer and RF, will be introduced and/or enhanced. Thus, more benefits from the heterogonous layer coordination can be achieved, not only in system performance, but also in energy saving and service provisioning.

FLEXIBLE SEPARATION AND COORDINATION OF C/U PLANES

To support coordination between macrocells and local cells, a feature of flexible separation and coordination of C/U planes will be introduced and enhanced. In 5G, the control plane (C plane) and user plane (U plane) for one UE can be connected to multiple eNBs or small cells by separation and combination of C/U. A simple example is given in Fig. 4. In this case, signaling radio bearers (SRBs) in the C plane and low-rate data service data radio bearer 0 (DRB0) are allocated to the macro eNB in frequency band f1, while DRB1 for high data rate service is allocated to small cell in frequency band f2. In this architecture, the main data traffic is offloaded from the eNB to small cells in a dedicated frequency band. A much higher rate can be achieved locally, so its transmission power can be significantly decreased, dynamic flexible frequency usage can be supported, equivalent signaling load from the current system to the core network is kept, and better service provisioning is given to customers. The benefits are due to decreasing unnecessary handover when UE is moving fast among the overlap areas covered by the macrocell and small cells. Furthermore, more advanced coordination technology such as advanced coordinated multipoint (CoMP) technology can be developed based on this architecture. However, there are challenges that must be carefully studied: dual receivers may be needed on the UE side, UE cannot work without macro coverage, and legacy UE cannot access new 5G systems.

TECHNOLOGIES TO HANDLE ASYMMETRIC TRAFFIC

Another big challenge is handling highly asymmetric traffic in mobile communication systems; thus, technologies to handle asymmetric traffic need to be enhanced in 5G.

In general, because of the traditional and equally paired frequency usage in downlink and uplink, FDD has more difficulties dealing with asymmetry issues. There are some technical solutions, and those solutions will be improved further in 5G.

For FDD, asymmetrical FDD carrier aggregation (CA) and supplemental downlink only (SDL) have been taken into consideration. The principle is to aggregate more frequency bands in downlink than in uplink to cater for asymmetric traffic in downlink and uplink. Limited by the current UE capability and spectrum resource, for example, FDD supports the combination of four blocks, one of three with the band size of 5 up to 20 MHz in the downlink, and one with band size of 5 up to 20 MHz in the uplink. In 5G, it is predicted that more blocks and larger block sizes will be supported. The first challenge is the limitation of frequency allocation. For asymmetrical FDD CA, the total frequency bandwidth equality allocated for downlink and uplink cannot be changed. For SDL, the ITU regulation needs to be changed by introducing a new SDL allocation mode. The second challenge is that two receivers will be needed, which will unavoidably increase terminal cost and power consumption.

In contrast, TDD has some natural advantages in supporting asymmetry traffic due to its unpaired usage of the downlink and uplink. Thanks to the possibility of semi-dynamic slot allocation in uplink and downlink, TDD systems are able to decide an asymmetric slot configuration in uplink and downlink in a wide area according to the estimated traffic. Similar to FDD, TDD can also use carrier aggregation, especially high-low frequency TDD CA to support asymmetrical traffic in uplink and downlink. Furthermore, for TDD, dynamic slot allocation in downlink and uplink can be used in a small cell. It can provide dynamic and flexible adapta-
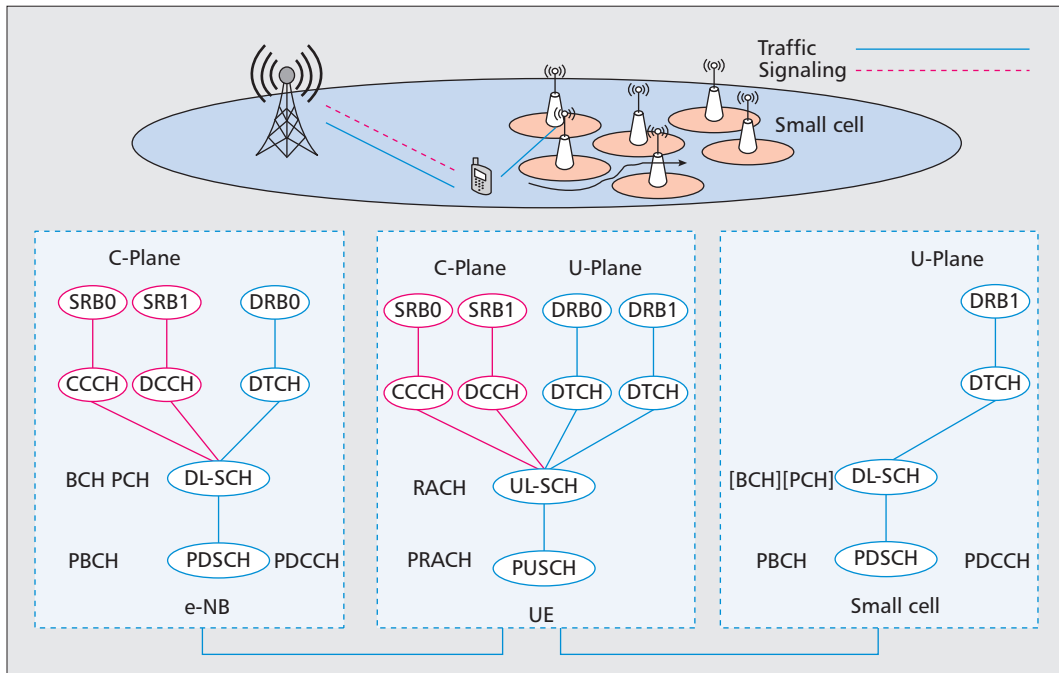
Figure 4. Example of flexible separation and combination of the C and U planes.

tion to traffic. TDD solutions can use the nature of TDD to meet asymmetrical traffic in both wide areas and local areas/hotspots.

HYBRID TOPOLOGY NETWORKING

The basic topology of current mobile systems is the star structure with control points. One advantage is simple, and the central control provides guaranteed quality of service (QoS).

As for 5G, this topology will be difficult to use. First, the robustness of its access network is insufficient. Efficient offload is limited since all user data needs to go through the core network. The performance and energy efficiency of UE on the cell edge will not yet be efficient. This topology is also not efficient to meet the requirement for social networking services. It will also be difficult to meet the tremendous accesses of machine-to-machine (M2M) users with this topology. Thus, the cellular topology needs to be optimized, and relay and device-to-device (D2D) communications will play important roles.

In 5G, as shown in Fig. 5, technologies include small cells, D2D, different kinds of relays, and wireless backhaul. Thanks to the introduction of these technologies into the current central controlled star network, different kinds of connections (UE to UE, small cell to small cell, small cell to eNB, relay node to eNB, relay node to relay node, etc.) can therefore be established. Multihop connections and mobile relay are also possible. Thus, the hybrid topology radio network will naturally be the future mobile access network, which can help to efficiently overcome the difficulties and challenges listed above.

D2D Communications — D2D is considered a promising technology for future mobile systems. In 5G, cellular D2D technology can be integrated into the cellular network as a sup-plemental part of the system. Based on how frequencies are used, D2D can be divided into two types: co-channel frequency D2D and dedicated frequency D2D. In co-channel frequency D2D, D2D works in the same frequency as that between UE and cell. Its advantage is the reuse of the legacy receiver/transmitter with a certain impact on the current protocol architecture. That is why this method is currently discussed [10–12]. It will bring serious interference to the cellular system and will be difficult to control when taking UE mobility into account. Moreover, most D2D applications or services need large bands to support high data rates, which is hard to obtain since the bandwidth between UE and eNB is not wide enough.

On the other hand, dedicated frequency D2D owns a specific frequency which is different from that between UE and cell. Since separate frequencies are used in D2D and cellular service, D2D causes less interference to the cellular system. Meanwhile, D2D can use much wider bands at higher frequencies to support high data rate D2D services. Since D2D in a cellular system is always network controlled or network assisted, two connections need to be supported simultaneously in UE. One connection is for D2D service, and the other is for the cellular cell. This support is very difficult to achieve in the current cellular system. However, it is not difficult in 5G when new architecture and technologies, as described in previous sections, are introduced. Thus, it is predicted that dedicated frequency D2D will be the main type of D2D, while co-channel frequency D2D is also kept to support D2D between legacy UE.

Duplex mode is another important feature in D2D design. For FDD, two receivers and two antennas are needed. The Tx antenna and Rx
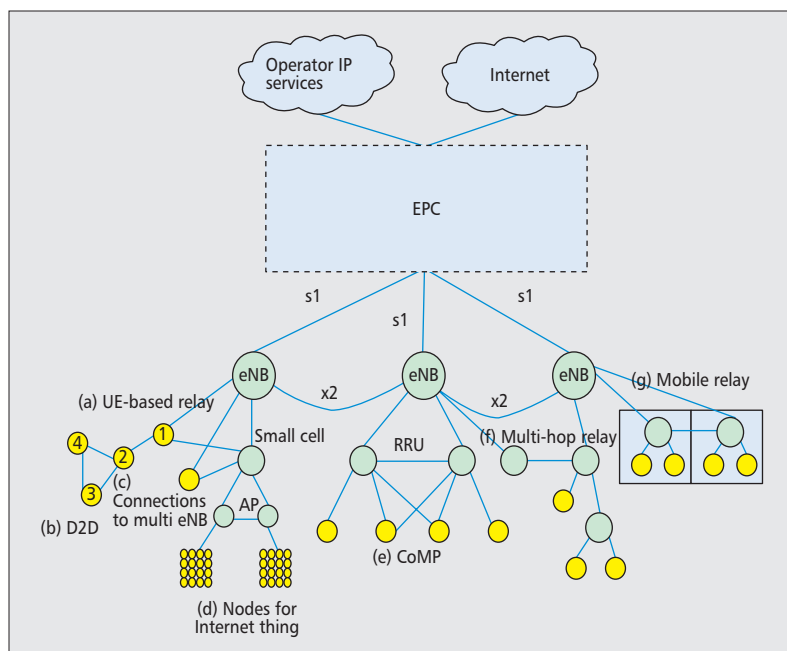
Figure 5. Hybrid topology networking in 5G.

antenna should have enough isolation distance. It is always difficult to implement into UE with small physical size. TDD has the natural advantage that the uplink and downlink transmission and receiving are in different time slots in the same frequency band, which is why many D2D researchers are currently focused on TDD mode [10–12]. It is predicted that in 5G for both TDD and FDD, D2D shall be supported, but D2D in TDD mode will be the main type with the considerations of lower cost, lower complexity, and the possible benefit of better frequency availability.

Relay Technologies — Relay technology is also promising in 5G. In 5G, relay can have many more functions in a cellular system. As shown in Fig. 5, advanced cellular relay can improve the topology of the cellular system, improve the robustness of a network, and decrease power consumption. A multihop structure can efficiently support tremendous access of M2M terminals. Mobile relay can deal with mobile group access. A UE-based mode can construct new M2M services by letting UE be a core access node in Internet of Things (IoT) networks.

Similar to cellular integrated D2D, relays can be divided into in-band relay and out-of-band relay. In-band relay is similar to co-channel frequency D2D without using extra frequency resources, and sharing similar advantages and disadvantages; out-of-band relay is similar to dedicated frequency D2D. 5G advanced cellular relay can be supported by both FDD and TDD. TDD will have some advantage over FDD by its nature with the uplink and downlink in different time slots using the same frequency band. Relay in TDD mode might be the main type in 5G with enough consideration of the lower cost, lower complexity, and possible benefit of better frequency availability.

SIGNAL PROCESSING AND IC PROGRESS DRIVING TECHNOLOGIES

The progress in signal processing and IC always drive technology development. In mobile communication, the adoption of an advanced technology always depends on the status of signal processing IC including CPU, digital signal processing (DSP), analog-to-digital (A/D), RF, and passive components including antennas and others. Although a bit saturated, Moore's law still provides us twice the computing performance and scale of IC every 18 months. It will drive technical progress in 5G just as it has for 2G, 3G, and 4G. There are several significant indications.

First, the macrocell will continue to be the key provider of capacity and coverage in 5G, although small cells will be widely deployed. As for macrocells, one promising technology is active antenna array technology in which multiple RF components (power amplifiers and their passive components) will be integrated directly into the antenna's radiator elements with flexible local control. Significant benefits can be achieved, including capacity, coverage, flexible frequency usage, and heterogonous layer coordinating. It already seems feasible to implement active antenna array in 4G, and it will be easier to implement the technology on a large scale in 5G due to further RF component integration.

Second, 5G UE needs ultra high computing performance to support data and signal processing for much larger bandwidth such as 40 MHz, 100 MHz, or higher, so the standby time becomes a key factor. Also, more advanced IC and passive component technologies shall be used in 5G. The technologies that have to be used are configurable low-power software-defined baseband chipsets, wideband RF receiver and transmitter ICs, digital RF chipsets, adaptive-powered RF power amplifiers, digital RF power amplifiers, multi-mode integrated passive components, and micro electro-mechanical system (MEMS) switches with better isolation and lower insertion loss.

Finally, all those chipset modules will be integrated into a single chipset. To support those technologies, more advanced semiconductor device and IC technologies will be developed; for example, 14 nm or better complementary metal oxide semiconductor (CMOS) technologies may be the driver of 5G to meet the requirements in both performance and power consumption. By introducing more spectrum bands, passive components will dominate the total cost and set up a new challenge. Its requirements and the cost of TDD will be relatively lower thanks to the nature of TDD.

CONCLUDING REMARKS AND FUTURE TRENDS

In summary, future traffic development brings new requirements and challenges to future mobile broadband systems, including higher traffic volume, indoor or hotspot traffic, traffic asymmetry, and spectrum, energy, and cost effi-

ciency. Technologies are thus needed, including local IMT small cells with redesign of the physical layer, MIMO, energy saving strategy, and flexible spectrum usage. More technologies, including heterogeneous layer coordination, C/U plane flexible separation-coordination, handling of asymmetrical traffic, and hybrid topology networking shall be sufficiently developed. The development of 5G is impacted significantly by industrial scale and smooth evolution of the current mobile system. Moreover, state-of-the-art IC technologies are needed to support high-performance computing for signal processing, RF transceivers, and power amplifiers.

To conclude the article, a whole profile of 5G is shown in Fig. 6. Besides the research in the evolution from IMT to 5G mentioned, there are some new possible revolutionary technologies in the pre-study phase of 5G including orbital angular momentum encoding [13], full duplex [14], non-orthogonal waveforms, and more. We believe new research will benefit 5G in the long run, and new revolutionary technologies might be used in some specific scenarios integrated with IMT. Thanks to TDD's nature and specific characteristics [15], it has great potential in the development of 5G.

Figure 6. Illustration of evolution from 3G to 5G.

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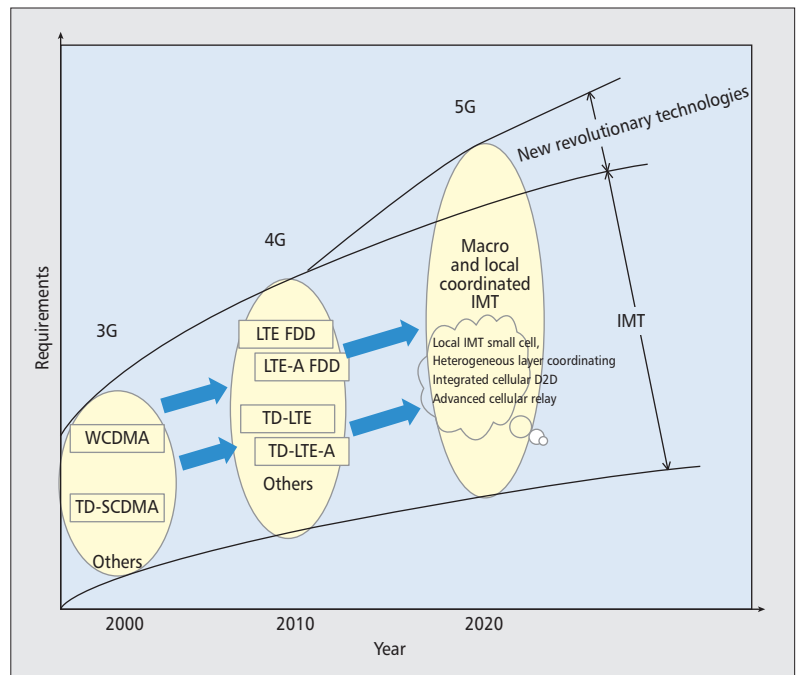[12] M. S. Corson *et al.*, "Towards Proximity-Aware Internetworking," *IEEE Wireless Commun.*, vol. 17, no. 6, Dec. 2010, pp. 26–33.
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