Chapter 2
5G Requirement and UDN

2.1 5G Scenarios and Requirements

International Telecommunications Union (ITU) has defined the framework and overall objectives of the future development of IMT-2020 in light of the roles that IMT could play to better serve the needs of the networked society in the future [1]. There are three usage scenarios for 5G as shown in the following Fig. 2.1.

1. Enhanced Mobile Broadband (eMBB) addresses the human-centric use cases for access to multi-media content, services and data. This scenario will come with new application areas and requirements in addition to existing Mobile Broadband applications for improved performance and an increasingly seamless user experience.
2. Ultra-Reliable and Low Latency Communications (URLLC) use cases have stringent requirements for capabilities such as ultra-low latency and higher availability. Some examples include wireless control of industrial manufacturing or production processes, remote medical surgery, distribution automation in a smart grid, transportation safety, etc.
3. Massive Machine Type Communications (mMTC) use cases are characterized by a very large number of connected devices typically transmitting a relatively low volume of non-delay-sensitive data. Devices are required to be low cost, and have a very long battery life.

For the eMBB scenario, it covers a range of cases, including wide-area coverage and hotspot, which have different requirements. For the hotspot case, i.e. for an area with high user density, very high traffic capacity is needed, while the requirement for mobility is low and user data rate is higher than that of wide area coverage. For the wide area coverage case, seamless coverage and medium to high mobility are desired, with much improved user data rate compared to existing data rates. However the data rate requirement may be relaxed compared to hotspot. Based on above three scenarios, eight key performance capabilities are defined by ITU-R as shown in the Fig. 2.2.

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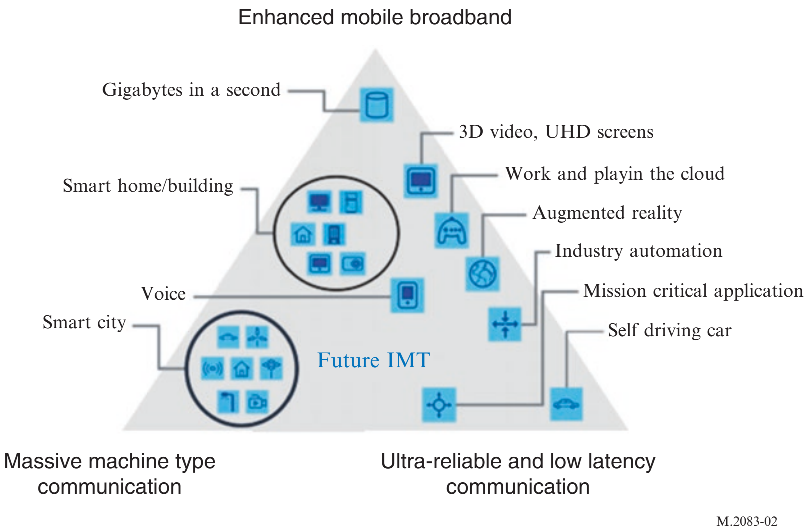

Fig. 2.1 Usage scenarios for 5G. Reprinted from ITU-R M.2083-02 [1]

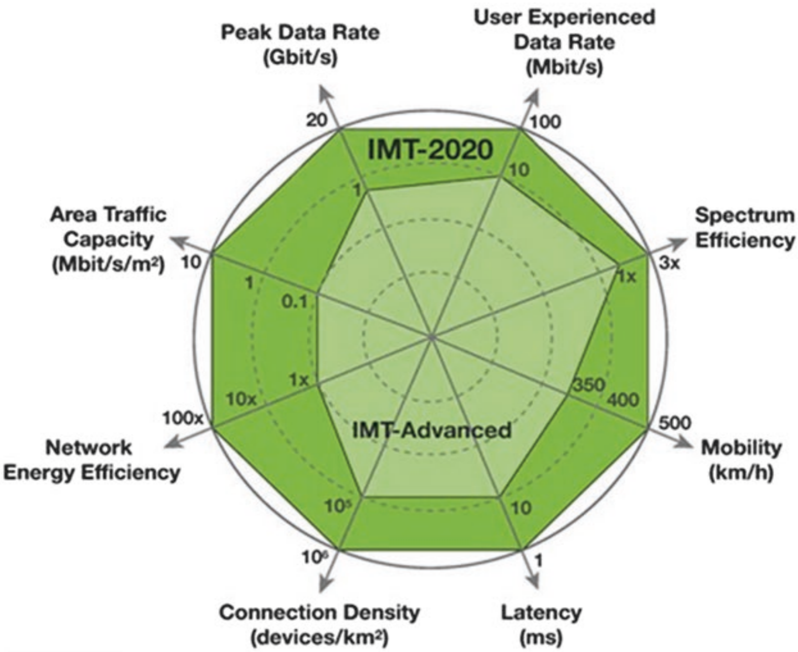

Fig. 2.2 Key performance requirement for 5G. Reprinted from ITU-R M.2083-03 [1]

The peak data rate of IMT-2020 for eMBB is expected to reach 10–20 Gbit/s. IMT-2020 would support different user experienced data rates covering a variety of environments for eMBB from 100 Mbit/s to 1 Gbit/s. The spectrum efficiency of 5G is expected to be three times higher compared to IMT-Advanced for eMBB. And IMT-2020 is expected to support 10 Mbit/s/m^2 area traffic capacity, for example in hot spots area. The network energy efficiency should therefore be improved by a factor at least as high as the envisaged traffic capacity increase of IMT-2020 relative to IMT-Advanced for eMBB. IMT-2020 would be able to provide 1 ms over-the-air latency, capable of supporting services with very low latency requirements. IMT-2020 is also expected to enable high mobility up to 500 km/h with acceptable Quality of Service (QoS). This is envisioned in particular for high speed trains. Finally, IMT-2020 is expected to support a connection density of up to 1 million connections/km^2, for example in mMTC scenarios.

Among all those requirements, data throughput capacity like area traffic capacity and user experienced data rate is most important for 5G eMBB. We can see that 5G is expected to support up to 10 Mbit/s/m^2 area traffic capacity and 1 Gbit/s user experienced data rate. In order to meet above stringent requirement, based on the analysis in Chap. 1, it is critical to rethink the 5G cellular network structure and introduce UDN technologies [2–5].

2.2 UDN in 5G

2.2.1 UDN Deployment Scenarios

The characters of typical UDN scenarios, such as office, apartment, open-air gathering, stadium, subways and railway station, include:

1. Very high user density: Given the office as an example, assuming the grid for each employee is 2 m × 2 m, the corresponding user density is 0.25 person per m^2;
2. Very high traffic density requirement: Open Air gathering as an example, nearly all the people would like to share the video clips with their friends through mobile phone APPs at the moment of exciting show. This will lead very high traffic density requirement, which will reach almost 10 Mbps/m^2;
3. Very high AP density: All those scenarios are capacity limited, so the AP coverage will be very small to ensure enough throughput. For example, the ISD between APs in office can be as low as 10 m.

Based on above analysis, in UDN, the AP coverage range is about 10 m and there are thousands of APs in 1 km^2. But in traditional cellular network, cell range is more than 500 m and usually less than around 3–5 Base Stations (BSs) in 1 km^2. Correspondingly, only one or several terminals are connected to one UDN AP, whereas hundreds or even thousands of active users are resident in one macro cell. Table 2.1 gives the differences between the UDN and traditional cellular network.

Another key point is that the type of APs in UDN is diversified. Small cell station, relay station, distributed Remote Radio Head (RRH) and User Equipment (UE) itself can act as an AP in UDN. However the macro BS in traditional cellular network is the dominate unit for user connection.

Table 2.1 Comparison between UDN and the traditional cellular network

Item	UDN	Traditional cellular network
Deployment scenarios	Indoor, Hotspot	Wide coverage
Site/AP density	More than 1000/km^2	3–5/km^2
User density	High	Low/medium
Site/AP coverage	Around 10 m	Several hundred meters and more
Deployment	Heterogeneous, Irregular coverage	Single layer, Regular cell
Site engineering	User deployment	Operator deployment
AP style	Small-cell, Pico, Femto, UE relay, Relay	Macro/micro BS
AP Backhaul	Ideal/non-ideal, Wired/wireless	Ideal, Wired
User mobility	Low mobility	High mobility
Traffic density	High	Low/medium
Typical bandwidth	Hundreds of MHz	Tens of MHz
Spectrum bands	>3 GHz (up to mm Wave)	<3 GHz

Besides the above features, higher spectrum frequency and wider bandwidth, heterogeneous and irregular deployment, flexible backhaul, lower user mobility are also the obvious differences between UDN and traditional cellular networks.

2.2.2 UDN Technologies in 5G

In ITU-R Report M.2320 [6], UDN is promoted as one of the technology trends to meet the high throughput requirements of 5G. In this report, key issues of UDN include following aspects:

1. Network architecture and protocol procedure enhancements: to optimize data and control paths, mobility management and signalling procedure. These enhancements will reduce the end-to-end latency and overhead;
2. Interference avoidance and inter-cell coordination: interference management and other coordination mechanism among the cells will increase the whole system throughput and guarantee the users' experience;
3. Energy efficiency: including network energy saving and UE power saving;
4. Super Self-organized Network (SON): release the operators' burden for network optimization and increase the flexibility of deployments.

In Ref. [4], METIS defines UDN as a stand-alone system that will be optimized for hotspot areas where the highest traffic increase will be observed. The core concept of UDN includes Radio Access Technologies (RATs), small cell integration/interaction and wireless backhauling. Beside considerations on a new spectrum flexible air interface, it foresees a potentially tight collaboration of nodes w.r.t. resource allocation coordination, a fast (de-)activation of cells and inbuilt self-backhauling support. An extended UDN concept offers additional performance improvement by: (1) context awareness for mobility, resource and network management, (2) inter-RAT/inter-operator collaboration, (3) tight interaction of a UDN layer with a macro layer holding superior role in control and management functions over common area, and (4) macro-layer based wireless backhaul for flexible and low-cost UDN deployments.

In Ref. [7], UDN is one of the most important technology directions to meet 5G traffic density requirement. To meet the requirements of typical scenarios and cope with the technical challenges, cell visualization technology, interference management and suppression technology, joint access and feedback technology, are important research areas in UDN. Cell visualization technology includes user-centric virtual cell technology, virtual layer technology, and soft sector technology.

The authors in Ref. [8] suggested that UDN is a major technology to meet the requirements of ultra-high traffic volume density.

In general, UDN is a new wireless network solution for hotspot scenarios, to provide sufficient area capacity and better user experience in 5G. In UDN, the AP density is comparable to or even higher than the user density. So, authors in [9] propose user-centric UDN, different types of APs will be tightly cooperated as a very flexible network to serve each user and achieve higher spectrum efficiency, lower power consumption and seamless mobility.

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