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Cellular technologies have been evolving since 1990, from second generation systems like GSM to fourth generation systems (4G) such as long term evolution (LTE)-Advanced. The motivation behind this evolution in the past two and a half decades has been the need to achieve the following goals:

- Higher data rates
- Higher spectral efficiency (more bits per second per Hz)
- Improvement in the quality of service
- Reduction in capex and opex
- Higher mobility.

The fifth generation of wireless technology is not only motivated by these goals but also by additional applications and use cases with a corresponding range of requirements and characteristics. For mobile broadband services, 5G technology aims to achieve user-experienced data rates of at least 1 Gbps. In addition, the growing interest in machine-type communication is bringing in new applications and use cases with network requirements, which are both significantly different from mobile broadband applications. Mission-critical machine communications such as vehicle-to-vehicle communication or the electrical grid will have very strict requirements with regard to low latency and ultra-high reliability. For battery-powered sensor networks, which are part of the internet of things vision, low energy consumption and low device cost are extremely important. Another important consideration for 5G is ultra-high network and device energy efficiency.

Having set the vision for 5G, the technology is still inchoate and research is being conducted to build the foundations. These foundations are as elementary as frequency spectrum, bandwidth, radio access technology, and network architecture. This article aims to provide an insight into 5G technology and its enablers, as the industry continues its deliberations, investigation, and research in this regard. It discusses the performance and efficiency matrices for 5G, which will shape the course of this futuristic technology. 5G will bring in revolutionary as well as evolutionary technology to achieve its targets.

How do we turn this vision into reality: Few choices or a plethora of ideas?

Let us revisit the targets set for 5G in order to understand the technologies that would enable us to meet them. The following are the targets that 5G aims to achieve upon deployment.

- 10 Gbps of peak data rate
- £ 1 ms of round-trip latency
- 10 Tbps per km2 (mobile data volume per geographical area reaching a target)
- 1M terminals per km2 (thousand times the number of connected devices reaching a density)
- 1/10 times the energy consumption as compared to that in 2010
- Near 100 per cent reliability (especially for mission-critical applications)

These targets or goals look great on paper, but converting at least some of them into commercial reality within the next five years or less is a phenomenal task for the research and development community. As every technological evolution gives birth to newer paradigms, so will 5G. However, certain fundamental limits, which laid the foundation of wireless communication, will remain in place. One of these is Shannon’s channel capacity theorem, which explains the relation between channel capacity (bits per second), bandwidth and signal to noise ratio. The following is a modified version of Shannon’s channel capacity theorem, which includes the effect of multiple transmit and receive antennae.

In order to achieve ³10 Gbps of peak data rate, 5G would certainly need to have bandwidth of the order of a few hundreds of MHz to a GHz, or even more. Such magnitude of bandwidth is difficult to find in sub-6 GHz bands; therefore, researchers are exploring possibilities in the 10 GHz to 100 GHz frequency bands and beyond. Currently, millimetre wave (mmWave) frequencies are used in wireless communication as microwave backhauls with a serious limitation of being used in line-of-sight mode. There are many questions regarding the use of mmWave for mobile multiple-access communication, related to propagation in particular. Channel sounding is necessary for these new radio frequency (RF) bands in order to understand the radio channel behaviour and to create accurate channel models for cellular communication. In addition to the new frequency bands and bandwidth, higher-order MIMO or massive MIMO techniques can help maximise the use of the available channel.

The targets for network capacity and device density per geographical area are set to thousand times that of the 4G network. New network architectures, including advanced heterogeneous networks (HetNet) and centralised RAN, will need to be evolved to meet 5G requirements.

In order to achieve better spectral efficiency and increase capacity, newer wave forms such as filter-bank multi-carrier (FBMC) transmission and new radio access technologies including non-orthogonal multiple access (NOMA) are under consideration, among many other equi-probable choices. These developments will require new designs for physical and media access control layers.

Latest releases of LTE propose single-user MIMO, multi-user MIMO, and three-dimensional MIMO for improving spectral efficiency and capacity. Massive MIMO further augments multi-user MIMO to a new level by drastically increasing the number of antennae and data streams at the base station. This concept of incorporating numerous antennae for downlink will help 5G in catering to the demands of the increased density of connected devices.

Technology enablers: Some will stay, some will fade away to evolve to better ones

As 5G continues to take shape, some or all of these technology enablers will become a deployable reality. We will discuss a few of these technologies in a little more detail in this section.

mmWave

The use of frequencies above 6 GHz for commercial mobile multiple-access communication is currently only a research topic. Although these high frequencies in the centimetre and millimetre wave range have been used by the aerospace and defence industries, the use cases there are not exactly the same as those for commercial mobile communication. Nevertheless, some research can be leveraged to understand the channel behaviour and material physics in those frequency bands. The use of mmWaves for cellular communication presents high performance gains by opening up wider bandwidths, less crowded spectrum, reducing interference and the size of the RF components. It will also help achieve improved performance in crowded scenarios. However, mmWave entails some challenges like higher losses, complex antenna arrays and power management. The emergence of centimetre and millimetre wave range frequencies for cellular communication will have to go hand in hand with the existing sub-6 GHz frequencies in terms of backward compatibility and interoperability.

New waveforms

Many 5G research projects are investigating new waveforms to counter the limitations of the orthogonal nature of current waveform design, which is orthogonal frequency-division multiplexing (OFDM)-based. Orthogonality is implemented by allocating adjacent subcarrier f2 at the null of subcarriers f1 and therefore, it can achieve zero inter-carrier interference. OFDM provides good spectral efficiency, along with resistance to multipath interference. One of the limitations of OFDM is the need for perfect synchronisation, the lack of which causes loss of orthogonality and, in turn, degrades performance. A large number of subcarriers, each with complex modulations, create the final signal or waveform. This leads to a high peak-to-average power ratio, which significantly increases the demand of power amplifier linearity and dynamic range. In addition to this, in order to maintain a low noise floor, both in band and out of band, subcarrier intermodulation distortion needs to be reduced. All these limitations of OFDM adversely impact round trip delays, energy efficiency and spectral efficiency, which are key matrices of 5G.

Advanced multi-carrier waveforms like FBMC and generalised frequency division multiplexing could be possible choices in centimetre wave bands and possibly in existing sub-6 GHz bands. The filter banks address the main limitation of OFDM mentioned above. First, each sub-channel can be optimally designed in the frequency domain to have the desired spectral suppression. Next, FBMC systems do not require redundant cyclic prefix, making them more spectral efficient. Given this high level of isolation between passband and stopband of the sub-band filters, the filter bank itself can provide sufficient frequency isolation for better reception and selectivity. From a design standpoint, this enables researchers to move signal processing functions, after the filter bank, to the low sampling rate. The need for synchronisation is eliminated by spectrally separated sub-channels as FBMC allows spectrum sensing and transmission with the same device.

New radio access technologies

One major issue with current cellular systems is the interference problems caused by the need to send a high-power signal to a user at the cell edge. Research has shown NOMA to be a promising candidate for 5G evolution. Since device processing capabilities are matching those of a computer, NOMA, with its successive interference cancellation (SIC) receiver, is a worthy choice for improving capacity as well as for enhancing the user experience at the cell edge. In order to provide a robust performance gain without being impacted by UE mobility, LTE uses hybrid automatic repeat request, turbo coding, and open-loop MIMO. These do not depend on UE feedback about the transmission channel, which will pose a challenge at wider frequency bandwidths and higher frequencies. A NOMA with SIC receiver can utilise wideband channel quality indicator for improving capacity as well as cell edge throughput performance. Other probable candidates for new RATs are random, scheduled and hybrid modes.

Heterogeneous networks

LTE Release 11 talks about HetNet and methods of countering the challenges of HetNet. In a heterogeneous network, a high power node coexists with multiple low power nodes to enhance cell edge coverage and total system throughput. It also poses interference challenges due to the presence of a high power emitter in the vicinity of picocells and femtocells. The evolution of inter cell interference cancellation over the past few releases of LTE has improved the performance of HetNet. In addition to this, LTE Release 11 introduced the concept of co-ordinated multipoint to ensure that UE uses the best uplink and downlink carriers in a heterogeneous network. The success of HetNet in LTE makes it another key technology enabler for 5G and therefore, it becomes all the more important for centimetre wave and millimetre wave frequency bands.

Massive MIMO

Multi-user MIMO in downlink is already a part of LTE. Extending this concept to a large scale, where hundreds of transmit antennae are used in the downlink is massive MIMO. Achieving thousand times the improvement in device connections and capacity are the goals of 5G, which can be addressed by massive MIMO in an energy-efficient manner. Massive MIMO uses phase coherence and spatial multiplexing as its foundation, which, in turn, utilise uplink and downlink channel knowledge. On the uplink, each UE sends the channel information on the respective pilots and it is a simpler process. On the downlink, the same process does not seem feasible, owing to the sheer magnitude and challenges of the high mobility scenario of devices. A possible solution is the time division duplex approach, to take advantage of its inherent reciprocity of uplink and downlink channels. As further research and experimentation are carried out in this field, new concepts and solutions will emerge for successful deployment.

Getting there by 2018?

This article has discussed the vision of the fifth generation of cellular communication and some of the key technologies that are being investigated as possible enablers for achieving its goals. Technology enablers like centimetre waves and millimetre waves, massive MIMO and HetNet are being considered as disruptive technologies, which will give direction to 5G evolution. Although 3GPP has set 2020 as the target year for formalising IMT-2020 specifications, some sections of research and industry are upbeat about 5G and have set 2018 as the target year for the first trial deployments. This will be quite a feat for cellular communication, as it will allow us to experience its fifth generation after around three decades of the first.

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