5G: A Tutorial Overview of Standards, Trials, Challenges, Deployment and Practice

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Unlike previous generations of cellular technologies, 5G standardization took a different path, where development of standards and testbeds have gone in parallel. When 5G standards were in very early stage and still discussing key objectives of 5G, Verizon released a pre-5G specification based on popular ideas for 5G and involved all major vendors in producing a pre-5G testbed.

This paper explores and illustrates key requirements of 5G and various technologies that can be helpful in supporting them. It identifies the key services that 5G aims to support:

1. eMBB: Enhanced Mobile Broadband – Providing high throughput to large number of users.
2. URLLC: Ultra Reliable Low Latency Communication – Supporting services with stringent latency and reliability constraints like tactile internet, intelligent transport systems*, etc.*
3. mMTC: Massive machine type communication: Supporting communication between large number of devices like IoT sensors.

Several RF techniques can facilitate the capacity gains required by 5G:

1. mmWaves: Use of millimeter waves (28-300GHz) can allow 5G networks to use much larger bandwidth and hence support higher data rates. However, mmWaves suffer from high propagation and penetration losses, which needs to be carefully addressed.
2. Massive MIMO: Use of mmWaves can further allow 5G networks to place 100s of antennas at the base station, allowing it to exploit high antenna gains and spatial multiplexing gains.
3. Network densification is required to ensure good coverage with 5G; however, ICI (Inter cell interference) can restrict these gains.

mmWaves and Massive MIMO are complementary to each other, mmWaves allows us to place 100s of antennas in a practical form factor, and Massive MIMO allows us to create highly direction beam-formed transmissions that can counter the high propagation and penetration loss of mmWaves.

The paper claims that OFDMA is unsuitable for mMTC and is designed for bulk transmissions and hence 5G needs to look for different waveforms. However, our discussions led to a conclusion, that this claim is not justified, and it is the high scheduling overhead of cellular networks that makes it unsuitable for mMTC. Further, 5G standards did adopt OFDMA as the waveform of choice later.

The paper identifies key sources of attenuation for mmWaves – Atmospheric attenuation, Absorption by vegetation, high penetration loss (making it difficult to transmit from outdoors to indoors), shadowing by objects and humans (due to lack of penetration and diffraction). These make it extremely challenging to deploy mmWaves in dense urban settings and standards are actively looking for solutions/architectures that can counter this (*e.g.,* Mesh networks).

Several key signal processing techniques that can support 5G apart from the “big 3” – Massive MIMO, mmWaves and network densification involve:

1. Hybrid Beamforming – Which allows us to support MU-MIMO and strike a balance between performance of digital beamforming and low hardware requirements of Analog beamforming.
2. Use of linear receivers to meet the timing deadlines
3. NOMA: Multiplexing users on non-orthogonal resources and using SIC to decode their signals.
4. SM: Spatial Modulation MIMO, that allows us to encode data in the selection of transmit antennas
5. Cognitive Radio: for efficient scheduling and interference mitigation
6. Full Duplex communication

Two key physical layer features agreed upon by the standards are:

1. Multi-Numerology: Which allows different sub-carrier spacings to be used in different parts of the bandwidth.
2. Bandwidth part operation: Which allows users to only monitor a configurable part of the bandwidth and not the entire bandwidth.

The current testbeds are highly limited in the extent of features they can test. The challenge of implementing 5G goes beyond just the radio technologies. It requires changes at system software levels with high-speed interfaces (40G) and enhancement of existing interfaces like CPRI, which are insufficient for 5G.

5G Core network proposes clear separation between data path and control path and introduces new features like: SDN, NFV, Network slicing and a cloud ran architecture where RAN functionalities can also rest in a datacenter. 5G also defined a clear separation in the RAN functionalities (RRU, CU, DU) which allows different components to be produced and deployed independently.

5G provides an exciting path to much higher data rates and futuristic applications like tactile internet and remote surgeries.