5G and 6G networks

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The following paper traces the evolution of mobile networking. From the early days of phone lines requiring a direct hardline connection between devices to the modern high speed mobile data carried by 5G and into the future with 6G. We will mainly focus on the innovations between 4G LTE and 5G, such as frequency modulation, CDMA, LTE, and now 5G, which utilizes cellular mesh networking, small cell networks, and network slicing to expand access and increase mobile internet speeds. We will discuss how cellular mesh networks actually operate in comparison to wifi mesh networks, how network slicing creates specific use case virtual networks, 5G network reliability and speeds,advances in network security and the elimination of certain vulnerabilities, the challenges brought on by these new networks. Finally, the document mentions the upcoming 6G technology and its expected advancements in speed, latency, and connectivity.

Mobile networks originally required direct connections, wires connecting phones to switchboards and then back to phones. In the 1980s frequency modulation was applied to phone calls, allowing analog sound to be transmitted to a tower, then down to another phone. In the ‘90s, code division multiple access, or CDMA, was implemented, allowing a greater quantity of phone calls to be made over the same network. CDMA was replaced with Long Term Evolution, LTE, in the 2010s. 5G, which started rollouts in 2020, uses a mix of mesh networking and small cell networks, along with network slicing, to expand access and increase mobile internet speeds.

Mesh networks are linked routers, allowing for multiple access locations. As opposed to a star network, where a central point is connected out to other access points, as with a central server, or a tree network, which has cascading access nodes, where each node connects to one above it and multiple below, mesh networks allow access to any, or almost any, point, connected through a web rather than any hierarchy. This allows for much greater connectability, as any node can interact with any other node, without the need for go-betweens or complex routing trees. It also allows for greater redundancy: a single node failing can be re-routed around, rather than having a knock-on effect for every node down the line. Each node can also change what it connects to, rather than being locked in place in the network, altering paths and routing depending on availability.

Small cell networks are much smaller antennas, which each collate user calls to send to the larger antennas, or the server. The small cells allow for greater access, as each user can connect to any of potentially hundreds of small cells rather than a single main tower. These small cells create the mesh network that extends the range of 5G. By leveraging multiple access points it distributes the signal evenly over an area allowing more users access to the network. Due to the even distribution of access points mesh allows for load balancing, reducing network congestion, and an even distribution of network resources. Because of this decentralized nature of mesh networks, 5G networks are more resilient to down time. When a given access point or tower is down for maintenance, or any other reason, nearby towers and cells help to fill the gaps in coverage.

Network slicing is another method of making 5G much more accessible. By using the same physical systems, but breaking them into different architectures, the network can accommodate a wide variety of users and use cases. This allows for everything from individuals having very high download speeds, to massive networks of devices being interconnected, all on the same system. By dividing up each physical network into specialized virtual ones. Resources are then allocated in specific ways. VLANs are a simplified version of network slicing. Take a coffee shop or a store for example, they may have 2 or 3 networks in the building, a public guest network, private employee network and a third systems network. In 5G these networks would all run from the same system however their authentication and resource allocation may be very different. The public network is likely allocated an inconsistent connection and lower speeds. The private employee network is likely meant for productivity so it gets a consistent connection and speed. The third network is vital to infrastructure so it requires the best and most consistent connection with minimal down time and the highest speeds. There may even be a fourth backup network to eliminate down time when each of the others are being maintained. By dividing a single network, slicing it into a variety of access points, many different use cases can be created and accessed through a single antenna or node.

Network security is also a big deal in 5G. As discussed earlier, 5G networks are decentralized. Because of this there are multiple points of failure or attack as opposed to a single point of vulnerability. This spread out nature creates redundancies that protect against attack as well as down time. Because of these redundancies 5G networks have a somewhat self healing capability making them able to quickly reconfigure and optimize themselves in real time. This protects from failures and the external attacks as mentioned earlier. Enhanced privacy is also a benefit of these cellular mesh networks. User data is encrypted using end to end encryption and passes through multiple cells in the network making it harder for malicious actors to gain access to the data. These mesh networks also employ dynamic topology which further increases the difficulty of attacks on networks.An ever changing topology makes it harder for these malicious actors to gain access to these cells.

Cellular Mesh networks also encounter many technical challenges. Scalability is one major issue with these networks. As device count increases data routing and communication efficiency become much more complex. To combat this engineers need to develop adaptive algorithms that process the data. Interference is another major problem in cellular mesh networking. As more devices come online, more bandwidth is needed to account for this higher device count. Another major issue is many of these small cells are battery powered so energy efficiency and regular maintenance are necessary. Overall the biggest hurdle for 5G and next gen networks is integration within existing networks and hardware. This requires standardization between and within ISPs. Collaboration between these network stakeholders is a must in order for new hardware and software protocols to be developed. All this allows for a seamless transition from older systems to the newest standards.

With MIMO, 5G towers are redesigned. The antenna arrays are arranged in a 2 dimensional grid, with variable overlap depending on the requirements for the system. Denser systems, like cities, allow for many more antennas as well as far denser

5G towers implement massive multiple-input multiple-output or massive MIMO. MIMO is used to increase the number of receivers and transmitters on both the user's end and the tower or cell's end. All this allows data to move back and forth more freely without data being tied up by hardware limitations. With all of these inputs and outputs, 5G must allow for multiple signals to pass along the same, or nearly the same, route. This is not a new concept, wired connections gave one wire per call, or Space Division. Radio uses a type of Frequency Division or Amplitude Division, allowing for tightly packed radio waves. 5G does something similar, using a type of frequency division called Orthogonal Frequency Division Multiplexing. This allows for far more overlap in signals than standard frequency division, meaning that each tower can carry far more signals. The technique combines Frequency Division and Quadrature Amplitude Modulation, along with Fast Fourier Transforms, to create a much more tightly packed input stream.

“The antenna array can be either uniform or non-uniform, depending on the design and application requirements. The spacing between the antennas can also affect the performance of the system, as closer spacing can increase the correlation between the antennas and reduce the diversity gain.To transmit multiple beams towards different UEs (user equipment), the base station needs to know the channel state information (CSI) of each UE. This information can be obtained through channel estimation and feedback, which involves transmitting pilot signals and measuring the response at the receiver. The CSI can then be used to design the beamforming vectors, which determine the direction and power of each beam. The beamforming vectors can be optimized to maximize the signal-to-interference-plus-noise ratio (SINR) at each UE, which can improve the performance of the system." - https://www.telecomtrainer.com/massive-mimo/

With MIMO these networks support more devices at higher speeds. MIMO does this by spreading the data to more UE at a wider bandwidth and more direct beam forming. By directing a wider bandwidth in more populated areas and allocating less to more rural areas where the data would be wasted. As discussed before, more access points spreads the load evenly so users get an unimpeded connection. However this also means more end users can connect to the same network increasing its capacity.

Increased tower and cell proximity to each other allow for lower latency. 5G is the first standard to use fiber to connect these towers and cells. Whereas previous standards used copper cabling to connect these sights to the Mobile backhaul network. The Mobile Backhaul network(MBH) is the intermediary between the cellular network and the internet. The MBH has shown its age in recent years due to the hardware limitations of copper cabling. With the advent of 5G, Fiber optic cabling has begun to be installed at these access points to lower latency and increase speeds. Fiber has a max speed of around 1000 mbps compared to copper cabling's measly 300 mbps. With this key innovation in 5G, distance still remains an issue for latency. The farther data must travel physically the longer the delay in transmission and return time. Fiber helps to solve this by increasing the speed at which data is traveling.

This all uses additional hardware, but it also uses plenty of software. Much of the software is used in optimization. Planet for example is a network planning and optimization software. For 5G rollout Planet is capable of advanced artificial intelligence based propagation modeling. Using this AI, Planet takes in real world network data from an existing network and re-develops it into an optimal layout. Planet also includes automation tools. These are used to automate repetitive tasks freeing up time for planning engineers and eliminating redundant tasks. Planet also has a suite of troubleshooting tools. Since Planet takes in real world data it is capable of producing live analytics that aid in maintaining uptime and reducing down time.

Similar to Planet, Unifi Design center is an open for public use network planning software developed by Unifi for their enterprise level LANs and WANs hardware. You simply input all devices on the given network and a layout of the building and it generates a network diagram over the floor plan. It optimizes the hardware layout to maximize coverage and speeds.

5G is much faster than previous generations of mobile data, and 6G is slated to be much faster still.6G is expected to be leaps and bounds better than 5G. It does this by implementing and optimizing the technologies discussed throughout this paper. Lower latency is a big expectation of 6G, about 1 microsecond when 5G is a round 1 millisecond about 100x longer then 6G latency. As discussed earlier, enhanced connectivity is a big deal with 5G cellular mesh. Continued optimization should enable better connections and wider coverage especially in rural areas. 6G is also expected to be much more energy efficient for all devices, both those transmitting 6G and the end users devices.And finally 6G cellular is expected to have much larger speeds, 1000 GBPS(or 1 TBPS) whereas 5G is up to 10 GBPS. Increased bandwidth ranges, better network slicing, larger mesh networks, all allow 6G to be much faster. Moving into millimeter waves, which allow for greatly increased capacity, and into lower frequency bands for longer range coverage. Through maximizing the ways a network can be sliced, many more use cases can be created. This will allow for even greater personalizations, allowing both large companies and individuals to take better advantage of the network's capabilities. By increasing the nodes available, there can be better redundancy, more consistent connections, and even less user-driven latency through the towers. The mesh network will also allow for even more things to be connected to the internet, allowing for a more thorough internet of things experience.

The evolution of mobile networks is a long history full of advancement. From the simple beginnings of requiring a hardline connection to the modern advancements of 5 and 6G engineers strive to connect everything and everyone. It has never been easier to connect due to 5Gs innovative features like mesh networking, small cells, and network slicing, has significantly expanded network access, boosted speeds, and enhanced resilience. With challenges like scalability and energy efficiency, continued advancement is necessary to pave the way for 6G. As we look to the future, 6G promises to advance mobile communication further, offering unprecedented speeds, lower latency, and broader connectivity, ultimately shaping the future of how we connect and interact with the world around us.

sources

https://www.qualcomm.com/5g/what-is-5g

https://www.telecomtrainer.com/

https://www.telecomtrainer.com/untitled/

https://www.telecomtrainer.com/1g-to-5g-timeline/

https://www.celltowermaps.com/resources/emerging-technologies

https://www.cnet.com/tech/mobile/at-t-makes-the-call-100-years-ago/

https://www.telecomtrainer.com/6g-6th-generation/

https://www.telecomtrainer.com/planet-a-powerful-rf-planning-and-optimization-software/

https://www.pure.ed.ac.uk/ws/files/32883461/network_slicing_5g_final_version_1.pdf

https://en.wikipedia.org/wiki/Mesh_networking

https://www.infovista.com/5g-network/planet-rf-planning-software

https://www.linkedin.com/pulse/leveraging-cellular-mesh-networks-enhanced-security-5g-ankit-jogi

https://www.telecomtrainer.com/evolution-of-5g-towards-6g/

https://thenetworkinstallers.com/blog/fiber-optic-cable-speed/

https://www.telecomtrainer.com/massive-mimo/

https://nextgalliance.org/white_papers/6g-spectrum-considerations/?dl=19802008

https://www.5gtechnologyworld.com/the-basics-of-5gs-modulation-ofdm/