5G: The Internet for Everyone and Everything

With the introduction of the smartphone, wireless data has become an indispensible part of everyday life for many. Few actually acknowledged the transformational impact of the "mobile Internet" as Apple and others introduced highly functional smart devices. We simply reveled in all of the new and useful things we could do with our mobile devices. For many, wireless data and the mobile Internet simply equate to streaming YouTube videos anytime, anywhere, but they have changed our lives much more than that.

Though today's 4G networks incorporate the latest technologies and continue to offer faster data access, the road beyond LTE and LTE-A is far from clear. The rapid consumption of wireless data continues to outpace the industry's ability to meet demand. However, faster data and greater access are only part of the story. The mobile Internet has painted a picture of continued innovation and inspired researchers all over the world to think beyond faster data and greater capacity. These new networks, referred to as fifth generation or 5G, may transform our lives yet again and unleash enormous economic potential.

What is 5G?

It is clear: 5G networks must accommodate many more users and devices while delivering more data to each user at any instant in time. Since the dawn of digital communications in the 1990s, the cellular technology roadmap has followed a rigid path focused on increasing capacity and data rates to ultimately arrive where we are today. Now that the mobile Internet is a reality, a new vision has been cast. Researchers envision not only a 5G network with unprecedented data rates and mobile access but also an opportunity to redefine the network to accommodate a wealth of new and diverse connected devices. 5G also presents researchers with a challenge to improve more known, but no less important, issues such as the coverage uniformity across a served region and more energy-efficient networks.

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1,000X Faster Data Rates

5G targets peak data rates per user in the range of 10 Gb/s (over 1,000X 4G). To provide a frame of reference, a user can download an HD video in 40 minutes using the highest speed networks in good conditions. With 5G, a user can download this same video in a matter of seconds.

Faster data access is certainly exciting, but there are challenges to achieving this. The spectrum that service operators paid governments billions of dollars to acquire has simply run out. Today's networks use spectrum anywhere from 700 MHz to almost 3 GHz, and a variety of public and private entities already claim this spectrum. This challenge can be met in two ways: (1) explore new spectrum or (2) develop new technologies to send more bits to users in the currently allocated spectrum.

Billions of Connected Devices

By 2020, industry analysts predict 50 billion devices will be connected to mobile networks worldwide, and these aren't just devices connected to a human hand. Embedded devices sending bits of information to other devices, servers, or the cloud will account for a large percentage of the devices.

The explosion of devices connected to the Internet has been dubbed the Internet of Things (IoT). These devices may incorporate sensors to measure pressure, temperature, or stress and perhaps include actuators to turn on and off devices or make adjustments in real time.

One example is traffic lights that are not just timed but connected and controlled remotely so that traffic congestion sites are immediately known and offloaded. If vehicles were connected directly to a traffic controller, then traffic lights may not even be necessary.

Buildings, bridges, and roads could be monitored continuously for structural health. Corporations and governments could use air-pollution monitoring data to regulate emissions and apply corrective action. Patient vital sign data could be logged and monitored to better understand the cause and effect of certain health conditions. The possibilities are endless.

The 5G systems needed to turn these possibilities into realities are composed of heterogeneous devices encompassing both low and high bandwidth, which presents significant design challenges. To unlock the potential of IoT, 5G must address network response times (latency). Control without deterministic response times limits the utility and adoption of these technologies. It's estimated that latency on current networks is on average in the tens of milliseconds range with a very wide standard deviation. If researchers succeed in reducing latency and improving determinism, then control applications—that is, connected

devices with sensors, actuators, and so on—could be controlled and operated remotely or autonomously in the cloud.

5G on the Horizon

With fixed spectrum allocations below 3 GHz, researchers are investigating waveforms that make better use of the existing spectrum to essentially increase the number of bits through a given amount of spectrum. Current standards based on orthogonal frequency-division multiplexing require more frequency to separate transmit and receive data with sufficient efficiency. New 5G waveforms attempt to address spectrum efficiency using the existing network infrastructure to accommodate more users and devices and to squeeze out more bits per hertz. The Technical University in Dresden (TU-Dresden) has prototyped one of these new waveforms called generalized frequency-division multiplexing and prototyped a complete link. TU-Dresden realized 30 percent improvement in data rates compared to 4G.

Another option is densification, which means increasing the number of access points, including macro cells, small cells, and pico cells, deployed in a geographic region. Densification relies on the theory that adding more access points to a served area divides the spectrum by geography rather than the spectrum itself. In addition to densification, new network topologies such as Cloud RAN or C-RAN enable service operators to locate their equipment in the cloud, which significantly reduces the heating and cooling costs of locally deployed equipment as well as the power consumption of a network. A critical challenge of distributed network control is latency. Researchers in the Connectivity management for eneRgy Optimised Wireless Dense (CROWD) networks project, which is funded by the European Union, have shown successful prototypes with these new architectures. This indicates that distributed control within a dense network is possible.

New base station technologies such as massive multiple input, multiple output (MIMO) promise more bandwidth and energy efficiency. Massive MIMO base stations incorporate hundreds of antenna elements to focus the energy per user, which increases data rates and improves the quality of the communications link particularly at the cell edges. Recent experiments by Lund University in Sweden indicate that massive MIMO can increase data rates by 100X or more.

New spectrum frontiers in the millimeter wave (mmWave) frequency range are being explored around 28 GHz, 38 GHz, and the 71 GHz to 76 GHz range. These frequency bands are "lightly" licensed and offer plentiful high-bandwidth spectrum. In the past, communication at these frequencies was thought impossible due to the propagation characteristics of electromagnetic waves and the cost of developing and implementing networks in these bands. But NYU WIRELESS has conducted channel-sounding measurements, and the channel profiles indicate that mmWave communications may in fact be feasible. Nokia Networks has prototyped a mmWave communication link and is achieving data rates 100X above current 4G rates with deterministic latency.

Making the Vision a Reality

5G will happen and its impact will be transformational, but researchers need the tools and technologies to design and rapidly prototype their concepts faster to expedite the time to market and, ultimately, the time to deployment. New 5G waveforms, network densification, massive MIMO, and mmWave communications may be incrementally deployed along a time curve and as such are not mutually exclusive and may be complementary. These 5G technologies are moving forward, and the vision of an Internet for everyone and everything comes closer to reality every day.

WIRELESS TO COME

Watch as 5G expert, Prof. Fettweiss, summarizes the wireless solution engineers must create to match the needs of today's tactile Internet world.

youtube.com/nationalinstruments

NAVIGATING 5G TECHNOLOGY CHALLENGES

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