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Final Report:
A survey for the Fifth Generation Cellular System

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Introduction

Most of today's modern telecommunications run on what is known as 4G technology. The next generation of networks, conveniently called 5G, promises great advances to the overall performance of telecommunications networks worldwide. 5G promises several improvements over 4G. Some of these improvements include a tenfold decrease in latency, a tenfold increase in connection density, a tenfold increase in throughput, a threefold increase in spectrum efficiency, a one hundred times increase in traffic capacity and a one hundred times increase in network efficiency[3]. In further sections we will discuss how 5G works, its history and potential use cases.

History and the current status

- 1G
    - The first generation of mobile networks – or 1G was launched by Nippon Telegraph and Telephone in Tokyo in 1979. By 1984, NTT had rolled out 1G to cover the whole of Japan.
    - The US approved the first 1G operations in 1983 and the Motorola's DynaTAC became one of the first 'mobile' phones to see widespread use stateside. Other countries such as Canada and the UK rolled out their own 1G networks a few years later.[4]
    - 1G technology suffered from a number of problems. Some of the included coverage was poor and sound quality was low. There was no roaming support between various operators and, as different systems operated on different frequency ranges, there was no compatibility between systems. Worse of all, calls weren't encrypted, so anyone with a radio scanner could drop in on a call.[4]

- 2G
    - The second generation of mobile networks, or 2G, was launched under the GSM standard in 1991 in Finland. With 2G calls could finally be encrypted and digital voice calls were significantly clearer with less static and background noise.[4]
    - But 2G was about much more than telecommunications; it helped lay the groundwork for nothing short of a cultural revolution. For the first time, people could send text messages (SMS), picture messages, and multimedia messages (MMS) on their phones. The analog past of 1G gave way to the digital future presented by 2G. This led to mass-adoption by consumers and businesses alike on a scale never before seen.[5]
    - 2G's transfer speeds were initially only around 9.6 kbit/s. By the end of the era, speeds of 40 kbit/s were achievable and EDGE connections offered speeds of up to 500 kbit/s. Despite relatively sluggish speeds, 2G revolutionized the business landscape and changed the world forever.[5]
- 3G
    - 3G was launched by NTT DoCoMo in 2001 and aimed to standardize the network protocol used by vendors. This meant that users could access data from any location in the world as the 'data packets' that drive web connectivity were standardized. This made international roaming services a real possibility for the first time.[6]

    - 3G’s increased data transfer capabilities also led to the rise of new services such as video conferencing, video streaming and voice over IP. [4]

- 4G
    - 4G was first deployed in Stockholm, Sweden and Oslo, Norway in 2009 as the Long Term Evolution (LTE) 4G standard. It was subsequently introduced throughout the world and made high-quality video streaming a reality for millions of consumers. 4G offers fast mobile web access (up to 1 gigabit per second for stationary users) which facilitates gaming services, HD videos and HQ video conferencing. [7]
    - The catch was that while transitioning from 2G to 3G was as simple as switching SIM cards, mobile devices needed to be specifically designed to support 4G. This helped device manufacturers scale their profits dramatically by introducing new 4G-ready handsets. [4]
    - While 4G is the current standard around the globe, some regions are plagued by network patchiness and have low 4G LTE penetration. [7]
- Internet of things
    - The term Internet of things was likely coined by Kevin Ashton of Procter & Gamble.[8]
    - MIT's Auto-ID Center, in 1999,[11] though he prefers the phrase "Internet for things". At that point, he viewed radio-frequency identification (RFID) as essential to the Internet of things, which would allow computers to manage all individual things.[8]
    - Defining the Internet of things as "simply the point in time when more 'things or objects' were connected to the Internet than people", Cisco Systems estimated that the IoT was "born" between 2008 and 2009, with the things/people ratio growing from 0.08 in 2003 to 1.84 in 2010.[9]

Market trends of 5G systems

As high speed internet and data connectivity becomes one of the most important entities, deemed as necessary for the survival of today's digitally advanced workplaces as food for the survival of living beings, research activities focused on the development of next-level wireless broadband technology are becoming more intense and wide-ranging. With 3G having become the de-facto wireless broadband technology and 4G rapidly expanding its horizons across numerous applications and regional markets, the focus has naturally shifted on the development of the 5G technology - the next face of development across the highly dynamic broadband industry. [11]

This report on the global 5G technology market presents a thorough overview of the present state of technological advancements in the field and predicts the future scope of development over the period between 2016 and 2024. The report gives detailed insights into the vendor and competitive landscape of this yet-to-be-marketed technology, profiling the developments achieved by notable bodies operating in the market through their research and development work. [11]

The study also provides a thorough overview of the key aspects expected to have a significant influence on the overall development of the market in the future years. As such, factors such as drivers, restraints, key trends of past and present times, regulatory obligations, and level of competition are explored in depth. Qualitative as well as quantitative details pertaining to the key segments of the market and these factors and the growth prospects of the market across key regional markets are also examined in the study.[11]

- Emerging applications and business models, coupled with falling device costs, have been instrumental in driving the adoption of IoT and, consequently, the number of connected devices - connected cars, machines, meters, wearables, and consumer electronics.[10]
- According to Ericsson, it is estimated that the 400 million IoT devices with cellular connections in 2016 are projected to reach 1.5 billion in 2022. This robust growth is expected to be driven by increased industry focus on deploying a connected ecosystem and the standardization of 3GPP cellular IoT technologies.[10]
- While existing 4G and 3G, Wi-Fi, and wireless mesh networks are already being utilized in these smart devices around the world, they are limited by the number of connections they can support, the data can transmit, and most importantly, the speed they can offer, which are hurdles to the IoT revolution.[10]
- Industrial Revolution 4.0 is aiding cellular connectivity throughout the industry, through the rise of IoT and machine to machine connections, which have been instrumental in driving the market.[10]

Applications of 5G systems

The fifth generation of wireless technology—5G—represents the changing face of connectivity. Designed for maximum speed and capacity, 5G has the potential to vastly expand how data is moved and will enable a wide range of new applications and use cases that go far beyond the smartphone.

While broad 5G rollouts are expected by 2021, engineers are already hard at work on applications and devices that will make use of the benefits of 5G. From the evolution of the IoT to revolutionary advances in how AI is used in the real world, many of tomorrow's most exciting technological advances will depend on 5G connectivity.

- **IoT**
  - When the term "Internet of Things" was coined in 1999, it was largely conceptual. Two decades later, everything from home thermostats to smart city sensors depend on IoT technology. Now, 5G and IoT stand ready to enable applications that would have seemed impossible just a few years ago.
  - 5G's promise of low latency and high network capacity helps to eliminate the biggest limitations to IoT expansion. Giving devices nearly real-time ability to sense and respond, 5G and IoT are a natural pairing that will impact nearly every industry and consumer.
- **Broadband-Like Mobile Service**
  - Upgraded mobile service is among the most noticeable of the initial impacts of the 5G network rollout. All major US wireless carriers, as well as many smaller communications service providers, intend to deploy 5G mobile networks that will deliver broadband-like services, such as high-definition streaming video without dreaded buffering. With a vastly increased network capacity, 5G is also predicted to reduce slowdowns during usage spikes—for example, sports fans can still stream during the big game.
- **Connectivity for Edge Computing**
  - With the move to cloud-native 5G networks, enterprises can take advantage of strategically distributed computational power, allowing more data to be processed and stored in the right place based on the needs of the application. Intelligent edge computing

operates at the convergence of 5G’s ultra-low latency, IoT, and AI technologies. Devices and applications can tap into edge cloud computing resources without needing to access a centralized data center potentially thousands of miles away.
    - As 5G edge computing becomes more pervasive, industries will be able to dramatically scale up their use of data and act on insights faster—often instantly and autonomously.
- **Artificial Intelligence**
    - Applying AI to an immense amount of data at scale will be accelerated with fast, efficient connectivity. For example, smart city AI could correlate traffic light data automatically and implement new patterns after an apartment complex nearby is opened. Smart security and machine vision can keep secure facilities safe with automatic recognition of potential security breaches or unauthorized visitors.
    - While 5G will help enable AI inference at the edge, it will also play a role in delivering data from devices to the central cloud to train or refine AI models. For example, real-world data about road conditions collected by connected vehicles can improve cloud-based mapping services.
- **Immersive Gaming and Virtual Reality**
    - For gamers, 5G promises a more immersive future. High-definition live streaming will get a big boost from 5G speeds, and thanks to ultra-low latency, 5G gaming won’t be tied down to devices with high computing power. Processing, storage, and retrieval can be done in the cloud, while the game itself is displayed and controlled by a mobile device.
    - Low-latency 5G will drive major innovation in virtual reality (VR) applications, which depend on fast feedback and response times to provide a realistic experience. These applications are likely to explode in number and sophistication as 5G networks and devices become the new normal.
    - As 5G edge computing becomes more common, industries will be able to dramatically scale up their use of data and act on insights faster—often instantly and automatically.
- **Industry Applications**
    - Whether their goal is to increase revenue opportunities, reduce total cost of ownership (TCO), or improve customer experiences, today’s enterprises are expected to see major benefits from the 5G upgrade.
- **Healthcare**
    - 5G healthcare use cases will enable doctors and patients to stay more connected than ever. Wearable devices could alert healthcare providers when a patient is experiencing symptoms—like an internal defibrillator that automatically alerts a team of ER cardiologists to be ready for an incoming patient, with a complete record of data collected by the device.
- **Retail**
    - For 5G retail applications, the customer experience will be everything. Stores of tomorrow may no longer look like today’s aisles of stocked shelves. Imagine a store that’s more like a showroom—one that lets you add items to a virtual cart rather than shopping with a physical one.
    - Stores may also use 5G to manage inventory and stocking in real time. Consumers could even see changes like cashierless stores that simply track what you put in your cart in lieu of the traditional checkout line.
- **Agriculture**
    - Farms of the future will use more data and fewer chemicals. Taking data from sensors located directly in fields, farmers can identify with pinpoint precision which areas need water, have a disease, or require pest management.

- As wearables become less expensive and 5G makes it easier to scale networks containing large numbers of IoT devices, health monitoring for livestock may also emerge. With more accurate health data, farmers can reduce the use of antibiotics without compromising the safety of the food supply.

- **Manufacturing**
  - Factory floors will be totally transformed by the convergence of 5G, AI, and IoT. Beyond predictive maintenance that helps control costs and minimize downtime, factories will also use 5G to control and analyze industrial processes with an unprecedented degree of precision.
  - With the connectivity boost provided by 5G, manufacturers can also change traditional quality assurance processes, streamlining them with sensor technology and AI.
- **Logistics**
  - In shipping and logistics, keeping track of inventory is expensive, slow, and difficult. 5G offers the potential for greater communication among vehicles, as well as between vehicles and infrastructure itself.
  - Fleet monitoring and navigation will become significantly easier at scale with 5G. Driver navigation could potentially be powered with an augmented reality system that identifies and flags potential hazards without diverting a driver's attention away from the road.

Key Technologies

- **Physical Layer**
  - **Massive MIMO**
    - MIMO stands for Multiple-input multiple-output. While it involves multiple technologies, MIMO can essentially be boiled down to this single principle: a wireless network that allows the transmitting and receiving of more than one data signal simultaneously over the same radio channel. Standard MIMO networks tend to use two or four antennas. Massive MIMO, on the other hand, is a MIMO system with an especially high number of antennas. There's no set figure for what constitutes a Massive MIMO set-up, but the description tends to be applied to systems with tens or even hundreds of antennas. For example, Huawei, ZTE, and Facebook have demonstrated Massive MIMO systems with as many as 96 to 128 antennas.[13]
  - **mmWave**
    - The term mmWave refers to a specific part of the radio frequency spectrum between 24GHz and 100GHz, which have a very short wavelength. This section of the spectrum is pretty much unused, so mmWave technology aims to greatly increase the amount of bandwidth available. Lower frequencies are more heavily congested with TV and radio signals, as well as current 4G LTE networks, which typically sit between 800 and 3,000MHz.[14]

- **Data Link Layer and MAC sub-layer**
  - **Non-orthogonal multiple access (NOMA)**
    - Non-orthogonal multiple access (NOMA) is one of the most promising radio access techniques in next-generation wireless communications. Compared to orthogonal frequency division multiple access (OFDMA), which is the current de facto standard orthogonal multiple access (OMA) technique, NOMA offers a set of desirable potential

benefits, such as enhanced spectrum efficiency, reduced latency with high reliability, and massive connectivity. The baseline idea of NOMA is to serve multiple users using the same resource in terms of time, frequency, and space. The available NOMA techniques can broadly be divided into two major categories, better known as power-domain NOMA and code-domain NOMA. Code-domain NOMA can further be classified into several multiple access techniques that rely on low-density spreading and sparse code multiple access. Other closely related multiple access schemes in this context are lattice-partition multiple access, multi-user shared access, and pattern-division multiple access. [15]

- **Network Layer**
  - **Software-defined Networking**
    - Software-defined networking (SDN) technology is an approach to network management that enables dynamic, programmatically efficient network configuration in order to improve network performance and monitoring making it more like cloud computing than traditional network management. SDN is meant to address the fact that the static architecture of traditional networks is decentralized and complex while current networks require more flexibility and easy troubleshooting. SDN attempts to centralize network intelligence in one network component by disassociating the forwarding process of network packets from the routing process. The control plane consists of one or more controllers which are considered as the brain of the SDN network where the whole intelligence is incorporated. [15]
  - **Network function virtualization**
    - Network Functions Virtualization is the decoupling of network functions from proprietary hardware appliances and running them as software in virtual machines. The different functions — such as firewalls, traffic control, and virtual routing — are called virtual network functions. NFV uses virtualized networking components to support an infrastructure totally independent of hardware. The standard resources of compute, storage, and network functions can all be virtualized and placed on commercial off-the-shelf hardware like x86 servers. Having virtualized resources means that VMs can be given portions of the resources available on the x86 server. That way, multiple VMs can run on a single server and scale to consume the remaining free resources. This also means that resources are less often sitting idle and data centers with virtualized infrastructure can be more effectively used. Within the data center and the outside networks, the data plane and control plane can also be virtualized with NFV. [16]
  - **Network Slicing**
    - Network slicing is a type of virtual networking architecture in the same family as software-defined networking and network functions virtualization, two closely related network virtualization technologies that are moving modern networks toward software-based automation. SDN and NFV allow far better network flexibility through the partitioning of network architectures into virtual elements. In essence, network slicing allows the creation of multiple virtual networks atop a shared physical infrastructure. In this virtualized network scenario, physical components are secondary and logical partitions are paramount, devoting capacity to certain purposes dynamically, according to need. As needs change, so can the devoted resources. Using common resources such as storage and processors, network slicing permits the creation of slices devoted to logical, self-contained, and partitioned network functions.
- **Other major issues**

- **Network densification**
  - Network densification, essentially means adding more cell sites within the existing infrastructure to increase the amount of available capacity. These would be located in areas that are currently strained in terms of capacity and require the most support to offload existing traffic. This would be high density urban areas for example.This straight-forward approach is one of the simplest ways for operators to quickly and efficiently add more capacity to a network.[18]
- **Edge Computing**
  - Edge computing is any type of computer program that delivers low latency nearer to the requests. Karim Arabi, in an IEEE Keynote and subsequently in an invited talk at MIT's MTL Seminar in 2015 defined edge computing broadly as all computing outside the cloud happening at the edge of the network, and more specifically in applications where real-time processing of data is required. In his definition, cloud computing operates on big data while edge computing operates on "instant data" that is real-time data generated by sensors or users. [19]
- **Internet of Things**
  - The internet of things, or IoT, is a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers (UIDs) and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction.

  - An IoT ecosystem consists of web-enabled smart devices that use embedded systems, such as processors, sensors and communication hardware, to collect, send and act on data they acquire from their environments. IoT devices share the sensor data they collect by connecting to an IoT gateway or other edge device where data is either sent to the cloud to be analyzed or analyzed locally. Sometimes, these devices communicate with other related devices and act on the information they get from one another. The devices do most of the work without human intervention, although people can interact with the devices -- for instance, to set them up, give them instructions or access the data. The connectivity, networking and communication protocols used with these web-enabled devices largely depend on the specific IoT applications deployed.

- **Cellular vehicular to everything (C-V2X)**
  - Cellular vehicle to everything (C-V2X) refers to the network that combines features of V2V (Vehicle to Vehicle), V2P, V2 G (Vehicle to Grid) and V2N (Vehicle to Network). The mobile vehicle is based on 3GPP-based V2X technology using LTE technology in V2X applications. Many automakers use C-V2X connectivity in cars to allow communications between cars. The cellular vehicle-to-all based on LTE cellular technology is intended to link cars, road infrastructure, cloud service, pedestrian cars and etc. A powerful solution that allows trustworthy, real-time communication and provides various services including pay-as-you-drive insurance, linked infotainment, car diagnoses and safety characteristics. Cellular vehicle-to-all can improve the independent driving of cars by means of sensors and communication systems.
  - Vehicle-to-all communication technology, commonly referred to as V2X, enables cars to interact directly with each other and to provide road infrastructure and other road users with a range of advantages such as highway safety, traffic effectiveness, intelligent

mobility, environmental sustainability and driver comfort. V2, which enables cars to recognize prospective hazard, traffic, and road conditions from a longer distance earlier than other vehicle sensors such as camerastones, radar and LiDAR (Light Detection and Ranging), also helps paves the way for fully autonomous driving through their distinctive, non-line visual sensing capacity. [20]

The future of cellular systems

There is no doubt: The world has gone mobile. More than 85 percent of the world's population now enjoys access to a mobile phone; in 105 countries around the world, there are more mobile devices than there are people.Global mobile traffic will continue to explode, growing at a rate three times faster than that of fixed IP traffic over this same time period. While the demand for mobile is unquestionable, the definition of mobile is rapidly changing. A number of key changes in technology, the market, and customer behavior are beginning to redefine what a mobile network is and what it needs to deliver: Ubiquitous Wi-Fi-enabled devices: All mobile devices, except for smartphones, are now Wi-Fi-enabled and have limited cellular connectivity.

Mobile is increasingly less about an "on-the-go" lifestyle such as walking or driving, and more about the convenience of a "nomadic" lifestyle—moving, sitting/stopping, connecting, and then moving on again. Mobile devices are now used on average 2.5 hours per day in the home and 1 hour per day at work compared with less than 0.5 hours while on the go. Wi-Fi is everywhere: The majority of homes and businesses now use Wi-Fi, and there are more than 5 million public hotspots throughout the world. People are happy with Wi-Fi: Given the near-pervasive availability and improvements in Wi-Fi, mobile device users, including smartphone users actually prefer Wi-F to mobile cellular to connect to the web.

Mobile pricing: Tiered mobile data pricing and caps are encouraging people to connect to the Internet at a lower cost or via free Wi-Fi. Technology advances: The Next-Generation Hotspots initiative greatly improves the Wi-Fi experience and enables seamless integration with mobile networks. The rise of small cells: To solve coverage, capacity, and spectrum issues, there are now more licensed small cells deployed globally than macro cells. As we witness the rise of Wi-Fi and small-cell networks, the fundamental question becomes: How do these networks relate and interact with existing macro cellular and newer LTE networks? Are they complementary, compatible, or competitive? Specifically, what should an existing mobile operator do given this future outlook? Alternatively, is there an opportunity to become a next-generation mobile operator without huge investments in a macro cellular network?

Conclusions

5G technology is very different. Previous systems had evolved driven more by what could be done with the latest technology. The new 5G technology has been driven by specific uses and applications. 5G mobile communications has been driven by the need to provide ubiquitous connectivity for applications as diverse as automotive communications, remote control with haptic style feedback, huge video downloads, as well as the very low data rate applications like remote sensors and what is being termed the IoT, Internet of Things. 5G is able to provide much greater flexibility and therefore it is able to support a much wider range of applications, from low data rate Internet of Things requirements through to very fast data rate and very low latency applications. In a 5G-powered tomorrow, entire supply chains can be fundamentally reshaped. With its gigabit speeds and unprecedented response times, 5G Ultra Wideband can be thought of as the "secret sauce" that can make connected cars, cloud-connected traffic control and other applications that depend on essentially instantaneous response and data analysis live up to their potential. From healthcare to emergency response to smart energy solutions to next-level gaming, the possibilities are virtually limitless.

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