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How 5G technology enables the health internet of things

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INTRODUCTION

Imagine a world where you can download an interactive 3-D video in a few seconds, a smart home anticipates your needs, and autonomous vehicles take you to your destination safely. This is the world of fifth-generation (5G) broadband technology. It promises speeds of more than 100 megabits per second,[1] more data bandwidth, and fewer delays due to built-in computing intelligence that handles data very efficiently.

This new era of 5G will bring together improved connectivity, cloud-based storage, and an array of connected devices and services. Extensive computing capability combined with virtual system architecture will open up a mobile internet of things (IoT). Advanced digital networks will bring together a system that connects billions of devices and sensors enabling advances in health care, education, resource management, transportation, agriculture, and many other areas. While much of this work is underway today, we will see big strides soon at the 2018 Winter Olympics. Korean mobile operators there will provide internet service at ultra-fast rates of 20GBs per second.[2] Other developed countries expect to offer commercial 5G networks by 2020. With the number of digital devices expected to rise dramatically, much of the world will be connected around the clock.[3]

In this paper, I show how 5G differs from previous generations of advancement (3G and 4G), discuss emerging applications in health care, and demonstrate how these developments will enable new systems of care delivery. I show that connected medicine will help people get quality care through improvements in imaging, diagnostics, and treatment.[4] Within a foreseeable period of time, consumers and businesses will have a more immersive relationship with their digital devices, and this will allow them to obtain high-quality medical care in real time and at affordable prices. Rather than having computing equipment that is disparate and separate, the 5G world will allow us to enter an era where real-time health services will become the norm rather than the exception. That will bring patients closer to a science fiction concept of digital integration than ever before.

HOW 5G DIFFERS FROM 3G AND 4G

5G is not simply an extension of 3G and 4G. Instead, it is a transformative ecosystem that includes a heterogeneous network that integrates 4G, Wi-Fi, millimeter wave, and other wireless access technologies. It combines cloud infrastructure, a virtualized network core, intelligent edge services, and a distributed computing model that derives insights from the data generated by billions of devices. According to Asha Keddy, Vice President in the Platform Engineering Group and General Manager of Next Generation and Standards at Intel, "5G is much more than a G. It is much more transformative. With 5G, we will be moving from a user centric world to one of massive machine type communications where the network will move from enabling millions to billions of devices—an era that will connect these devices intelligently and usher in the commodification of information and intelligence."[5]

The emerging network capitalizes on a variety of interfaces across licensed, licensed shared, and unlicensed spectrum in low-, mid-, and high-frequency bands. By design, it will not only increase capacity, it also will enable even the smallest devices to perform high-level computations and connect quickly to processing power that is diffused throughout the system.[6]

It is important to note that 5G is an end-to-end system that shifts communications to a computing platform. 5G represents an evolution from a point-to-point system to one that senses data from billions of devices and works to move those communication packets seamlessly to the right device, using the appropriate processing platform.

Four factors distinguish 5G from its predecessors: connected devices, fast and intelligent networks, back-end services, and extremely low latency. These qualities enable a fully connected and interactive world with a variety of applications. This includes enhanced mobile broadband, machine-to-machine communications, artificial intelligence, and advanced digital services.

50 billion devices and 212 billion sensors

By 2020, the 5G network is expected to support 50 billion connected devices and 212 billion connected sensors as well as enable access to 44 zettabytes (ZB) of data.[7] This will range from smartphones and tablets to smartwatches, cars, machinery, appliances, and remote monitoring devices.[8] All of these will generate a massive amount of "useful data" that can be analyzed. Indeed, researchers estimate that this connected ecosystem will make it possible to utilize a much larger percent of digital data (35 percent) than before (5 percent).[9]

Connected devices will enable people to enjoy more personalized, more immersive, and more enhanced experiences whenever and wherever they are. With the costs of devices and sensors coming down considerably, connectivity will be ubiquitous and unobtrusive. Rather than having to make a conscious decision to issue a computing command, people will have systems that take actions based on the predetermined preferences of that individual.

A wide array of networked sensors will link appliances, home security systems, energy grids, and entertainment systems to the internet. People will not need to be home in order to turn a security alarm on or off. They can change their thermostats from miles away. They can determine what foods are in short supply in their refrigerators. Connecting wireless sensors throughout their appliances will turn even the tiniest of devices into minicomputers. That will help individuals harness the power of the internet for a wide variety of tasks.

Fast, intelligent networks

High broadband speeds and intelligent networks will characterize the 5G network. Currently, it takes about eight minutes to download a feature movie using 4G; people will be able to do this in less than five seconds with 5G.[10] The speed of the network will enable applications such as social gaming, interactive television, high definition and 3-D video, virtual reality, robotics, driverless cars, and advanced manufacturing, among others.

With the billions of devices that will be online, not all data need to be moved simultaneously. Some applications require instantaneous communications, while others can transmit during off-peak hours. Having networks that automatically determine data traffic prioritization and make split-second decisions is vital to a 5G world.

The 5G network will have digital hubs designed to handle traffic flow. Sophisticated equipment will gauge alternative routes for data and decide which one is the most efficient given the time of day, information being delivered, and type of infrastructure that is needed. Most of these functions will be performed in the background and therefore will be invisible to the individual user. People will be free to focus on the usage, not the digital engine that powers the ecosystem.

Intelligent networks are a key aspect of defining 5G and will direct traffic and configure systems in ways that facilitate efficient navigation and decisionmaking. But 5G also will infuse intelligence throughout the network and the application of data analytics will be an explicit part of the services delivered. 5G will enable real-time aggregation and analysis, therefore allowing users to make sense of data in order to optimize and customize the capability of each application.

Back-end services

The emerging network will enlist back-end data centers, cloud services, and remote file servers into a computational behemoth. There will be “computing at the edge,” which means that computations can be performed near the source or in the cloud, depending on the immediate need. These 5G innovations will allow applications to quickly process content and provide an experience that is very responsive. This will make computing more economical, more efficient, and we’ll see savings on storage costs. At the same time, as devices make their way into the hands of users, data center network infrastructure and cloud services are evolving to meet the needs of new business. Systems will be optimized so that software can perform complicated tasks and network functions untethered from physical hardware. That increases network agility, and allows for rapid and customized configurations.

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Low latency

Latency refers to the time between when people request that a computing command be executed and the actual execution of that task. In today’s mobile world, execution takes place in around 50 to 80 milliseconds. That is a sufficient amount of time for voice, email, and web surfing, which is the bulk of current usage.

With the advent of 5G, however, the goal is to reduce that interval to a few milliseconds.[11] This low latency means current user experiences will improve. Webpages or

mobile applications would load very quickly and transactions will be instantly processed. It also means new services and experiences will be possible. For example, autonomous car technology, which allows a vehicle to sense its environment and navigate without human input, requires great speed in digital computation. Even small delays from a vehicular sensor could produce catastrophic results.

In a related vein, current video streaming and high-definition television require fast downloads. Users get frustrated when their screens freeze and movies are interrupted. 5G will improve the user experience and, at the same time, allow for new applications involving virtual reality, augmented reality, and multiplayer games which need very short latency times. Whether the goal is training, public safety or entertainment, these online platforms require fast engagement in order to function properly. Pauses in the user experience harm operations and make it more difficult to reap the benefits of 5G applications.

NETWORK ADVANCEMENTS

There are several developments in 5G spectrum usage and network optimization that are expected to expedite digital connectivity and network capability. These include the utilization of high-frequency signals, radio access technologies, software-defined networks, and network function virtualization.

Radio communications in high-frequency bands

Much of commercial mobile (cellular) communications currently takes place in the 3.5 MHz range. These low-frequency bands are good at penetrating buildings, and therefore facilitate communications regardless of where someone is. But these bands are being crowded as demand for bandwidth has increased.

With 5G, we will see the integration of radio access technologies in a homogenous manner, tapping into licensed, licensed shared, and unlicensed spectrum beyond frequency ranges currently in use.

In the near future, wireless communications will occur in high-frequency bands around 60,000 MHz or even higher. Spectrum experts say that both millimeter wave spectrum (mmWave) and microwave frequency bands (cmWave) will aid in implementing 5G.[12]

These networks are designed to break the limitations of new spectrum bands. They will use new technologies such as massive antenna array and steerable beamforming designed to optimize cmWave and mmWave frequency ranges for new applications. These new bands combined with technology advancements will provide faster uploads and downloads, and make it easier to access digital services. They will help signals travel more quickly and have shorter latency periods.

A challenge in using these new spectrum bands is that they are not as effective as lower frequencies are at penetrating thick walls and dealing with bad weather such as rain or snow. In order to overcome these issues, a 5G system will require minicell towers known as “small cells” or antenna arrays that expedite signal transmission.[13] These stations relay signals from user devices, sensors, and monitoring devices at high rates of speed and will be instrumental in rolling out innovative services. In a world of high-speed broadband and connected devices, there is going to be a need for a substantial increase in base stations that provide mobile connectivity.

Among the possibilities for 5G connections are a combination of more numerous base stations, massive multiple input multiple output (Massive MIMO), and beamforming signal amplitude and phase.[14] The more antennas you use in the transmitter and receiver stages, the more possible signal paths you can create, and the better the performance people will receive in terms of data rate and link reliability. Massive MIMO takes this concept a step further by combining dozens or hundreds of antennas to achieve large improvements in data throughput and energy efficiency. These types of systems will be critical to achieving the reduced latency, data speeds and capacity demands that are key for 5G and the internet of things.

When combined with beamforming technology, Massive MIMO has the capacity to integrate networks and devices into smoothly functioning hubs. By providing multiple access points and different layers of connectivity, the goal is to enable high-speed access and reliable service to billions of devices *without* congestion problems. Having some means of offloading traffic during peak times will help 5G networks manage digital services effectively.[15]

Software-defined networks and network function virtualization

Internet pioneer Marc Andreessen is famous for predicting that "software is eating the world." By that, he means that businesses increasingly are using software to deliver online services. Rather than having brick and mortar industries that offer what customers want, he thinks that "software programming tools and internet-based services make it easy to launch new global software-powered start-ups in many industries—without the need to invest in new infrastructure and train new employees."[16]

Software-defined networks allow businesses to scale up their bandwidth on an instantaneous basis. According to Ralph de la Vega, vice chairman of AT&T, "if that customer had a 5 Mbps circuit and they want to go to 20 Mbps, they can go to the portal and in less than 90 seconds the service is provisioned."[17] This type of "on-demand" capability helps companies gain efficiencies because they use only the infrastructure that they require at any given time and have the means to increase or decrease their service capabilities as needed.

With advances in computing speed and networking, 5G is going to move the world even closer to Andreessen's vision of software-defined networks. Digital innovators are creating intelligent networks that use algorithms to analyze data and make decisions. Rather than putting humans in the middle of computational structures, the emerging digital economy will rely extensively on network function virtualization, machine-to-machine communications, remote sensors, and automated decisionmaking. This will speed execution and make more efficient use of computational power.

Network function virtualization enables systems to provide reliable service at an inexpensive cost. This allows firms to offer digital services effectively through online platforms, without the need for human interaction. As noted by technology experts, "the end goal for a fully software-driven and virtualized network is clear: a dynamic, on-demand global fabric where each application can order, set up and tear down services, performance and features as they are needed through automated API function calls."[18] That kind of system will generate an explosion of new services and business models.

HOW 5G ENABLES AN INTERNET OF MEDICAL THINGS

The internet of things (IoT) is a network of physical objects, machines, people, and other devices that enables connectivity and communications to exchange data for intelligent applications and services. These devices consist of smartphones, tablets, consumer electronics, vehicles, wearables, and sensors that are capable of IoT communications. The internet of things allows objects to be controlled remotely across existing network infrastructure, creating opportunities for direct integration between the physical and digital worlds resulting in improved efficiency, accuracy, and economic benefits.[19]

Technologies such as cellular, Wi-Fi and Bluetooth will enable IoT communications across use cases and 5G is the network that will connect these things. IoT devices are going to have varying capabilities and data demands and the 5G network needs to support them all. With the internet of things, we are going to see services that only need a tiny amount of data and a long battery life as well devices that require fast speeds and reliable connectivity.

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To work well, a fully realized internet of things ecosystem must have a 5G network that connects all of these devices and takes into consideration the use of power, data demand, and spectrum. Industry analyst IDC expects American firms "to invest more than $232 billion in IoT hardware, software, services, and connectivity this year" and for these investments to grow to over $357 billion by 2019.[20]

With its superfast connectivity, intelligent management, and data capabilities, the 5G network enables new possibilities in terms of health care including imaging, diagnostics, data analytics, and treatment. Part of the so-called "internet of medical things," it includes devices such as clinical wearables and remote sensors as well as many other devices that monitor and electronically transmit medical data such as vital signs, physical activity, personal safety, and medication adherence. These devices will provide never before seen telemedicine diagnosis and treatment services as well as high resolution video conferencing, all the while delivering quality care at affordable prices.

These devices and capabilities generate better data and more precise analytics providing greater context for interpreting information. Some mission-critical medical functions require high reliability and availability with latency intervals that are down to a few milliseconds. 5G will make this possible and bring consistent, reliable user experiences to improve medical care. Today, there are a number of health applications that will benefit an array of industries that require high bandwidth and reliable connectivity, and these applications are part of the emerging 5G test cases.

Imaging

One of the virtues of digital medicine is remote access to images and the ability to rapidly share information across geographic areas, therefore compressing time and distance. If a physician in one part of the country (or world) needs a second opinion, he or she can transmit the medical image or test result to another doctor and get that person's view of the medical situation. This helps doctors gain access to much needed expertise and enables the health care system to overcome disparities based on geography, income, or class status.

This is especially the case in regard to rural areas or underserved urban populations. Patients in these settings typically do not have access to the latest medical expertise. Through digital technology, however, they can gain the benefits of specialists who practice far away. That reduces health disparities and helps to bridge the urban/rural divide that exists in most countries. Patients don't have to travel physically in order to get access to high quality medical assistance.

High-speed transmission of X-rays or CT scans enables patients to quickly obtain second or third opinions. They will not be limited to specialists who live in their home city, but will be able to access a global network of medical professionals. For patients, this will expand the talent pool and bring highly responsive health expertise to small communities without much health infrastructure.

Diagnostics

The advancement in diagnostics is an important capability, as new applications will expand the use of monitoring devices and wearable medical equipment. For patients suffering from serious or chronic health issues such as cardiovascular disease, diabetes or cancer, remote monitoring devices can track vital signs and glucose levels and electronically transmit this information to health care providers. Rather than wait for an emergency to happen, this equipment and immersive connectivity provides an early warning system that helps physicians detect possible problems and get medical care to patients in a proactive manner. This capability is being used today with existing 4G networks and devices, but what is unique to 5G is the facilitation of machine type communications which will help to expand monitoring and provide real-time analytics that can improve health outcomes.

As an example, the Michael J. Fox Foundation has pioneered work on devices that track the tremors associated with Parkinson's disease. Rather than relying on patients' self-reporting of the number and duration of tremors and how they have varied over time, doctors are deploying wearable motion sensors that provide reliable data in real time for many different aspects of the disease. This level of data is unprecedented and the ability to analyze it and identify patterns will help in determining things like whether symptoms are deteriorating and the possible causes of deterioration. Information regarding whether a particular kind of medication is helping patients or not and how that medication is being affected by the data points the devices are monitoring such as food intake, exercise, and the like, will also allow for novel applications.

These kinds of monitoring tools are especially useful for senior citizens. Many of these individuals lack mobility and are not able to travel to a doctor's office or hospital. If the diagnosis is not very complicated, they can get medical help through video conferencing and telemedicine. Physicians and nurses can track vital signs, motion, falls, and speech slurring, among other things, in order to provide real-time diagnosis of people's health problems.[21]

In Taiwan, for example, the city of Taipei has implemented a system for managing health care information called the "Citizen Telecare Service System" (CTSS). Using a telecare information platform, the government seeks to surpass geographical constraints, reallocate medical resources, and give elderly citizens a sense of comfort being home when monitoring their physiological functions. The program aims to fully integrate technologies that allow for continual biometric monitoring, tracking and alerting of early warnings related to abnormal health scenarios, health education, and medical assistance for patients with chronic diseases like hypertension.

The system allows for real-time management through the tracking the thousands of metabolic activities taking place on a daily basis in the body while reminding the patient to develop a healthy lifestyle. Benefitting from seamless connections using the city's free WiFi network, mobile devices or notebooks via GPRS/2G/3G, the program includes a smart medical services system for managing chronic disease. In addition, it has implemented algorithms to help prevent critical care situations. Today, there are a lot of medical devices on the market but it remains a challenge to provide a smart index for risk assessment of hypertension, arrhythmia, stroke, and other conditions. CTSS has implemented a cardiovascular disease risk analysis algorithm on mobile devices, notebooks, and servers and this smart algorithm for early warning of arrhythmia. It has been validated by clinical trial with excellent sensitivity and specificity for practical applications in homecare.[22]

Remote devices also are helpful for babies. There is clothing with respiratory sensors that "monitor the baby's body position, activity level and skin temperature. Parents can see all that data in an iOS/Android app or, potentially, a light-up smart mug that shows the baby's respiratory patterns."[23] Similar to a baby monitor, wearable devices help patients keep track of infant health and smart diapers track moisture levels and let parents know when diapers should be changed or whether sores are developing that could be problematic. There have been pilot projects on sudden infant death syndrome in the United States as well as in the United Kingdom.

Precision medicine takes advantage of personalized information regarding a patient's genes or environment to target relevant medical treatments. Many medications do not work on all people but are effective for those with a specific genetic makeup. The same is true for side effects or adverse reactions. Incorporating detailed information about the patient helps doctors bring the most relevant treatments to those individuals.[24]

These advances are particularly relevant for cancer genomics which is the application of genetic therapy to cancer diagnoses and treatment that is customized to people's individual circumstances. Most cancers are complex and interact with people's genetic composition. Having knowledge of how genes affect cancerous growth is valuable for patients and doctors.[25] Despite the established benefits, "less than 1% of cancer patients receive advanced genetic sequencing," according to Eric Dishman, director of the Precision Medicine Initiative of the National Institutes of Health.[26] This makes it difficult for patients to get the advantage of treatments targeted on their particular needs.

In order to personalize the treatment, physicians need access to detailed knowledge about genetic composition, social environment, and lifestyle characteristics. The billions of devices and sensors deployed with 5G will make possible the gathering of this data and, while most desktop computers or tablets lack sufficient storage for that level of detail, storing that data on a cloud makes it available to physicians and researchers who need access around the clock. The cloud provides the extensive storage capabilities that doctors need in order to take advantage of these latest developments.

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The National Institutes of Health (NIH) has created a precision medicine initiative that will enable research for a wide range of diseases and will apply statistical power to detect correlations between genetic environmental exposures and a wide variety of health outcomes. The

NIH has launched a one million volunteers program designed to compile detailed genetic information on a large group of people and use that research to help other individuals.[27] This long-term study will examine "the interplay among genetics, lifestyle factors, and health."[28] Participating subjects will gain access to their own detailed medical information in return for allowing researchers to mine their DNA for health insights. With sequencing tools dropping below $1,000, genetic testing can bring precision medicine to large numbers of people.

Combined with clinical decision support systems, physicians can tap into the latest knowledge on diagnosis and treatment. Computer software lets doctors enter basic symptoms and vital signs and get advice on likely medical issues and drug interactions. Rather than relying on anecdotes or limited personal experience, these clinical systems mine enormous sources of information to provide up-to-date material regarding an array of problems, therefore helping them be more accurate in treating their patients.

Finally, through predictive modeling, doctors can anticipate which patients are at greatest risk from various conditions. Assessing detailed medical informatics and lifestyle characteristics can pinpoint those whose health or genetic makeup is problematic. The Penn Signals program at the University of Pennsylvania Medical School integrates past and current data to determine which individuals might be susceptible to risks such as heart failure or sepsis. When the hospital is discharging patients, nurses get text messages regarding the patients' post-discharge care. Depending on their risk profile, patients can be enrolled in monitoring programs or specialty care designed to deal with particular symptoms.[29]

Data analytics and treatment

Trusted data analytics offer concrete advantages in digital medicine. The opportunity to mine health data will grow as digital infrastructure becomes more powerful and will help providers and patients get the information needed to make informed decisions. Indeed, having the ability to assess data in real time will enable rapid learning on treatment effects. Through the use of data analysis, physicians can aggregate and analyze information in new and ingenious ways. They can use this information to uncover "actionable insights," learn in real time, and use the accumulated knowledge to determine the treatments likely to be most effective. Alerts can inform physicians or even patients themselves when vital signs run outside acceptable ranges.

The Collaborative Cancer Cloud is an analytics platform that integrates patient information from a variety of organizations. It allows participating institutions to "securely share patient genomic, imaging and clinical data for potentially lifesaving discoveries. It will enable large amounts of data from sites all around the world to be analyzed in a distributed way, while preserving the privacy and security of patient data at each site."[30]

This has transformed cancer treatment and made it possible to fine-tune cancer therapies. The cloud platform allows researchers to make discrete queries about particular cancers and get aggregated information on those individuals. The Collaborative's federated model is a way to share de-identified material while organizations retain control of their own medical data.

Machine learning is a valuable part of the emerging landscape. Artificial intelligence helps doctors make sense of complex databases. Increasingly, medical records combine structured data such as heart rates, blood pressure readings, and vital signs with unstructured text that needs to be analyzed through natural language processing. The latter can include text summaries of symptoms or imaging pictures from X-rays or CT scans. Machine learning can

"analyze unstructured data and keep the context" and provide "far-reaching implications for health care," according to Bob Rogers, chief data scientist for big data solutions at Intel.[31]

Wearable devices are helpful in treatment because they can send out medical alerts if the individual suffers an acute crisis or health emergency. A patient who falls and can't get up can use such a device to summon help. Heart attack victims or those who are incapacitated by a stroke receive assistance from others with smartphones or wearable devices. This equipment informs people when their prescription is about to run out or reminds them to take medication at a certain time.[32]

Remote surgery will be possible once latency levels are reduced to small intervals. Surgeons will be able to use virtual tools for certain kinds of procedures. This would enable experienced doctors to mentor young physicians from a distance on proper techniques. It also helps areas lacking certain medical specialties to benefit from the expertise of more densely-populated areas. Other innovations are already in use, for example there already are operating robots that assist in minor procedures.[33]

There is an enormous opportunity for data analytics in health care. Health information is complex and varied, and the industry currently reduces information to a diagnostic code. This is an incredible loss of valuable information for the patient, the care provider, and the health system. With big data analytics enabled by 5G, more can be done than simply reducing information to a code. Researchers will be able to garner more insight as to the drugs taken by patients, how they react to them, and how it all relates to a unique patient.

According to Bob Rogers, "with the coming 5G system, we will see systems that are closer to the edge and an opportunity to have more intelligence to determine what information to send back and when to send it. Machine learning is integrated from the very edge to the data center with analytics bridging all the way across. In a world of connected devices, a 5G system will allow us to move from algorithms based on static information to those that can be optimized in real-time using data from the user."[34]

THE 5G IMPACT ON MEDICAL ACCESS, QUALITY, AND COST

Public opinion studies find that many people are enthusiastic about these kinds of medical devices and services. In fact, a survey of 12,000 adults across eight nations showed that "70 percent are willing to see a doctor via video conference for non-urgent appointments" and "70 percent are receptive to using toilet sensors, prescription bottle sensors, or swallowed health monitors."[35]

In addition, the use of 5G technologies has the potential to safeguard quality, and reduce overall medical costs. Some examples of this are:

- The use of sensors and remote monitoring devices that help patients living in isolated areas gain access to top medical assistance. Using video conference facilities or telemedicine can reduce the geographic divide and bring high quality care to underserved communities.

- Newly-emerging point-of-care testing (POCT) can save money by avoiding costly hospital visits. Rather than going to a large medical facility, patients can take advantage of mhealth technologies, digital platforms,

or remote monitoring devices. It is estimated that the POCT market will be $27.5 billion by 2018.[36] These devices increase patient accessibility by making technologies available at bedside or in the home.

- Home health therapies represent a way to deliver quality care without patients having to travel great distances to hospitals or medical facilities. They can transmit medical information electronically and have distant doctors provide advice on diagnosis and treatment.

- Research by the Veterans Administration (VA) found significant advances in chronic condition management via telemedicine. Its study of over 17,000 VA patients showed "a 25% reduction in numbers of bed days of care, 19% reduction in numbers of hospital admissions, and mean satisfaction score rating of 86% after enrollment into the program."[37] Its researchers concluded that telehealth was a "cost-effective way of managing chronic care patients in both urban and rural settings."

- A study undertaken by the University of Virginia Health System found a 37 percent improvement in hospital readmissions after home visits and post-acute care assistance.[38] Monitoring real-time vital signs and medical needs helped that system decrease readmissions for a variety of different illnesses ranging from heart failure and strokes to pulmonary disorders. That translated into millions of dollars of medical savings.

- Analysis of congestive heart patients in Indiana found that remote patient monitoring reduced hospital readmissions. Only three percent of those whose biometrics were tracked daily and who had weekly video conferences with health providers were readmitted, compared to 15 percent of those not getting that kind of attention.[39] Nationally, the admission level for people with congestive heart failure is 21 percent. This helped those individuals plus the participating hospitals save considerable money on treatment, without compromising the quality of medical care.

- Diabetes is a major problem in many communities. The state of Mississippi found that 13 percent of its adults suffered from diabetes and 54 percent of those individuals are located in rural areas with limited access to quality care. However, after creating a Diabetes Telehealth Network with remote care management, medical authorities saw cost savings of $339,184 for 100 patients enrolled in that project and projected Medicaid savings of $189 million annually.[40]

- By keeping people out of hospitals, Health IoT has the potential to keep costs low and save money without compromising quality care. Not every medical problem warrants a visit to a doctor's office or hospital. Routine issues can be diagnosed at a distance and that will offer patients greater alternatives to conventional care.

- Voice recognition software can streamline administrative operations. A study of this technology in hospitals found that it helped health professionals "provide care without being interrupted with data entry and querying tasks."[41] The software enables people to record medical information without having to stop to enter data.

- Advancements in intervention management are coming online. Medical facilities can better manage care resources–highly valuable assets like operating theatres, electrocardiogram monitors, and other equipment. The ability to monitor the use and status of massive amounts of equipment aids facilities in ensuring patient safety and efficiencies. Capability like real-time tracking of value assets enables better management along the supply chain.[42]

Examples of impact like these have also garnered the attention of private sector innovators. For example, AT&T is working on technology solutions that can help improve the health quality of life. Through the AT&T Foundry for Connected Health, the company focuses on digital health innovations that benefit those in and out of the clinical care environment working to provide patients and their caregivers with a solution to bridge the gap between the clinical setting and the home.

When looking at the industry opportunity as a whole, according to a Paul Budd Communications report, "cost savings through e-health are expected to be between 10% and 20% of total healthcare costs."[43] Digital medical services allow consumers to shop around across different health care providers. Patients go online for health information and use that to refine their questions to medical professionals.

And advanced data analytics will help businesses keep a handle on costs. A McKinsey study found that "between $300-$450 billion [in] healthcare costs could be saved in the US alone by embracing Big Data."[44]

In short, 5G solutions connect devices for smarter and timelier decisions. These data provide real-time visibility into people, diseases, and symptoms, which in turn make it possible to develop new insights for caregivers and policymakers. Interoperable devices work together with intelligent notification systems to ensure appropriate treatment for each patient.

RECOMMENDATIONS

From this analysis, it is clear that there are considerable opportunities to improve health care through 5G networks and the medical services they enable. The fast speed and intelligent design of these systems are creating new applications and devices that have the potential to transform the way health is diagnosed and treated. A McKinsey study found that "fundamental changes to the sector would have to be made to obtain those benefits."[45]

The key challenge going forward is to expand technological opportunities and make 5G and the health internet of things a reality and not just a hope. There are a number of steps that are needed to advance the vision of 5G health care. This includes infrastructure development; spectrum harmonization; adequate technical standards; effective regulation; and changes in reimbursement policy, privacy protection, and research data.

Infrastructure development, trials, and prototyping

Superfast broadband is required for 5G networks and private firms are investing billions to develop the infrastructure needed for a connected society. This is paving the way for faster systems and more intelligent networks. Having access 90 percent of the time is insufficient for mission-critical functions. Certain 5G applications require continuous access without interruption in order to maintain the internet of things.

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A number of government agencies are devoting resources to train professionals and develop new treatments that take advantage of

a 5G network. For example, the National Institutes of Health is spending $130 million to train millions of volunteers to encourage "a new way of doing research through engaged participants and open, responsible data sharing." The National Cancer Institute is studying genetic markers that can lead to cancer therapies that are better targeted than is the case today. The Food and Drug Administration is devoting $10 million on changes in "the regulatory structure needed to advanced innovation in precision medicine."[46]

A number of companies are launching trial programs. For example, both Verizon and AT&T are starting pilot projects this summer and a number of other firms are experimenting as well. In addition, both the 2018 Winter Olympics in South Korea and the 2020 Summer Olympics in Japan will be test grounds for 5G-based television coverage and digital programming. These expenditures are vital because they are an important first step to building the digital network and facilitating the workforce development required in a 5G world.

Harmonized spectrum

An important thing to understand about 5G spectrum is the need for a variety of frequency ranges to support various applications and use cases each having their own, sometimes competing, requirements. We need a combination of licensed, licensed shared, and unlicensed spectrum in low-, mid-, and high-frequency bands. No single one of these frequencies will suffice for the emerging applications.

Frequencies that are near, or adjacent to, one another can be leveraged for inclusion in a single product design even if they are not all available in a single geography. Finding frequency ranges which are available in major markets, or where the available frequency bands are close enough to be supported within a single radio signal, is critical to achieving the economies of scale necessary to support the business case for both manufacturers and operators. Harmonization of major markets creates commonalities in regulatory requirements and technical specifications which will then aid in reducing the cost and complexity of implementing and enabling 5G on a global scale.

Different types of applications require various kinds of spectrum. For example, signals that must penetrate through and around obstacles to reach devices in obstructed areas need low-range spectrum below 1 GHz. Autonomous vehicles and industrial applications might need mid-range spectrum below 6 GHz more than other types of spectrum due to needed balance between connection speed and radio link reliability. Virtual reality, 3-D video, and gaming applications need high-range spectrum perhaps above 24 GHz where large chunks of spectrum could be made available. Leaders need to marshal spectrum in several different ways to take full advantage of 5G enabled applications.

The 28, 37-40, and 64-71 GHz ranges are an important part of the emerging landscape in the high-range bands. The U.S. is organizing an incentive auction of the 600 MHz band, and the Federal Communications Commission soon will release an order that will allocate new spectrum to 5G usage and provide greater flexibility to existing licensees in this range. The hope is that this will free up new resources and allow various companies to try out new products. This new administrative action could bring together spectrum in ways that are likely to propel health IoT opportunities and many others.

Standardization and interoperability

With the complexity of interconnected devices, it is important to work through standards-setting bodies to ensure security and interoperability. Maintaining data sharing networks and the easy exchange of trusted information is

vital for 5G and the internet of things. With the billions of connected devices, it is a complex undertaking to make sure devices work correctly and data flows smoothly and securely. Mutually-agreed upon open standards are vital, according to Bridget Karlin, the managing director of the IoT Group at Intel, because "without them, we won't see the scale of IoT connected things and realize the $4 to $6 trillion economic opportunity that we envision."[47]

Organizations such as the National Institute of Standards and Technology and a variety of technical societies such as the 3rd Generation Partnership Project (3GPP), the Open Connectivity Foundation, the Industrial Internet Consortium (IIC), and the Institute of Electrical and Electronics Engineers are working to harmonize system specifications across companies and countries.[48] One of the advantages of the internet has been the free flow of data and trade across borders, which has been facilitated by international agreements and multistakeholder bodies of experts. These agreements and experts work to identify the most promising technologies and aim to get them adopted on a widespread basis.

It is important to understand that the best way to work through technical obstacles, definitions, coexistence and certification is through a transparent and open standards process. For example, much of the work to enable 5G is being established through 3GPP endorsed standards based technologies which are built for fair coexistence in licensed and unlicensed bands.

In the area of health care, there also exist widely-accepted standards for vital signs devices, wearables, heart rate monitors, motion sensors, weight monitors, and blood pressure cuffs. This has spurred a proliferation of wearable devices and remote monitoring equipment that enables health providers to receive data in real time on a range of consumer information.

Application developers need open standards and a clear computational architecture in order to have international interoperability. Those kinds of systems provide the basis for scalable solutions that can transform health care delivery.

Finally, secure and effective connections are vital across the 5G network. Users need to have confidence that security will be maintained and intruders will not damage high-speed networks. Having a means to ensure interoperability is very important to the evolving ecosystem.

Effective regulation

Policymakers must be careful regarding how they regulate technology innovation. They need to balance innovation on the one hand with societal values designed to protect consumers, safeguard privacy, and protect security on the other. In the United States, regulatory agencies such as the Federal Communications Commission and Food and Drug Administration play a key role in setting the agenda for 5G markets in other countries. What they decide sets the framework in which business firms operate.

As an example, the Food and Drug Administration is moving towards new ways to assess next generation sequencing technologies. It wants to encourage new approaches to gene sequencing that increases physician ability to improve therapy targeting. They want to make sure that sequencing is accurate and reliable, and provides up-to-date information for health care providers.[49] Devices with the potential to harm patients require careful oversight, but some new applications based on information measurement or fitness tracking are consumer devices that don't require

Devices with the potential to harm patients require careful oversight, but some new applications based on information measurement or fitness tracking are consumer devices that don't require regulation. Having clear rules on where medical sensors and remote monitoring devices fall on this regulatory continuum is important to the digital ecosystem.

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In thinking about new approaches such as clinical decision support, government agencies should encourage innovation and regulate software when there is a discernible high risk to patients. Industry tools based on best practices and peer-reviewed recommendations are designed to help physicians and nurses to make sure they have the most comprehensive information that is available. They should not be put in the same regulatory category as medical devices that monitor patients or remote surgery that actively involves people.

Reimbursement policy

Government officials need to update reimbursement policy in light of new advances in digital medicine. Currently, it is hard for health care providers to receive reimbursement for telemedicine, video conferencing, or home health therapies. Reflecting a "brick and mortar" perspective, most of the official rules advantage personal over digital approaches to health care. In many cases, doctors need to physically be with a patient to qualify for reimbursement.

That ignores the many examples of imaging, diagnosis, and treatment described in this research. Treating patients via phone or video conference often is not reimbursable. Nor is the use of home therapies such as dialysis. For example, Medicare stipulates that "beneficiaries receiving home dialysis treatment may receive a clinical assessment via telehealth only if the telehealth visit conforms to the existing Medicare requirements for telehealth reimbursement."

Experts who comprise the agency's working group suggest that "the geographic limitations on Medicare reimbursement are lifted so that free-standing dialysis facilities outside an HPSA constitute acceptable originating sites, and the second, that a dialysis patient's home might be considered an originating site as well."[50] These changes would allow patients and doctors to take advantage of recent developments in home health care delivery. They would speed the movement to a 5G world.

Medicare programs also need a more nuanced and dynamic approach to reimbursement. Currently, there are a dizzying array of diagnostic and treatment codes based on specific illnesses. Yet due to its static nature, it is difficult to aggregate this information to link treatments with health outcomes. We require a reimbursement system that incorporates information on patient well-being.

Value-based reimbursement represents a way to reward providers whose patients get healthy, rather than covering them on a "fee-for-service" basis. Linking health outcomes to diagnosis and treatment records enables assessment of results. Both providers and patients will be able to see what treatments had the most positive effects and whether treatment costs were worth the expenditure.

Data privacy and research needs

The Health Insurance Portability and Accountability Act of 1996 (HIPAA) established strong privacy protections for health care information. Lawmakers understood that medical data are quite sensitive and patients need assurances that medical providers and health payers don't compromise the basic privacy and security of health data.

Individuals participating in clinical trials must provide "informed consent" and have stringent safeguards designed to protect their medical information. According to the so-called "Common Rule," researchers must de-identify (or anonymize) personal information. They can combine data from a large number of individuals and analyze the aggregated material, and glean insights into what works and doesn't work.

Making sure that researchers have access to quality data is crucial moving forward. With the vast increase in the quantity and quality of data analytics in a 5G world, researchers are primed to assess medical treatment in real time and give patients the benefits of their knowledge with quick turnaround times. Additionally, people who want to donate their medical information in return for access to the insights of aggregated research studies should be encouraged to do so. That will advance "rapid learning" in medicine that helps everyone gain the insights of clinical researchers. Adopting new consent procedures that go beyond specific projects will help analysts provide benefits for the community as a whole.

CONCLUSION

There are tremendous opportunities through 5G across a variety of sectors to connect the health care world in creative ways. The use of mobile devices, sensors, and remote monitoring equipment is going to grow and there will be a dramatic advancement in patients receiving imaging, diagnosis, or treatment through digital technology.

To ensure all of this becomes a reality, though, work needs to be done to facilitate an end-to-end system. Devices must connect to networks and the cloud in ways that are interoperable and secure. That will enable health providers and patients to receive the benefits of digital innovation for wellness and health care. If we can overcome these barriers, both health care consumers and providers will see substantial advances in medical treatment.

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