THE DAWN OF 5G ERA

The mobile telecommunications industry is one of the richest business sectors in the recent times. With 5.3 billion users and US$1.38 trillion service revenues, ABI Research estimates that the sector contributed 5.2% to the world’s Gross Domestic Product (GDP) in 2019. Indeed, each mobile network generation, including 2G, 3G, and 4G, has contributed massively to boosting demand for mobile services and creating business opportunities for new use cases.

Today, the industry is tasting the benefits of 5G, what new business opportunities it will introduce, and how its deployment will improve global economic growth. 5G is expected to further improve the average GDP as a result of the extended growth of mobile data traffic and network efficiency. However, the biggest value of 5G will not come from connecting humans only, but from its ability to provide seamless connectivity to various infrastructure, machines, and devices.
Since the launch of world's first 5G New Radio (NR) network in South Korea, the network deployment has garnered significant momentum in major markets like the United States and China. Thus far, 5G services have been offered in over 80 cities in the United States. In China, three major Communication Service Providers (CSPs) have earmarked over US$25 billion in rolling out 5G related network infrastructure in 2020 alone. Likewise, CSPs in many more countries are expected to accelerate 5G deployment once they receive their 5G spectrum allocations from the regulators.

In order to realize 5G's full potential, 5G deployment requires a more complex network with more powerful network elements, Internet of Thing (IoT) end nodes, and gateways. As compared to previous generations, 5G is expected to be flexible and agile, capable of supporting independent network slices for different applications. In addition, 5G is expected to have ubiquitous presence across different markets, so addressing energy consumption issue right at the onset of 5G deployment is a timely and effective way to make 5G as sustainable as possible.

The best place to start is to ask what impact the cellular network, including network elements and user devices, will have on the environment and CO2 emission. A detailed look at 5G energy impact requires close assessment of various components of the overall cellular infrastructure, from radio access network (RAN) to core networks, edge computing servers, passive network equipment and end devices. Based on the analysis outcome, key stakeholders can define their deployment strategies based on the recommendations in this whitepaper to address 5G energy consumption at every level.

AGGRESSIVE GROWTH IN ENERGY CONSUMPTION

In order to better evaluate the energy consumption of cellular consumption and its impacts, ABI Research has developed an energy consumption model based on various features and components in the cellular network. As mentioned earlier, the cellular network is a combination of network elements and end devices. Therefore, the energy consumption model needs to capture energy consumed by the following components:

- **Network Elements**: Key network elements include baseband unit, remote radio head, small cells, core networks, passive equipment for cooling, monitoring and control function. The model does not include network equipment for backhaul and transport.

- **End Devices**: This includes personal mobile devices such as smartphones and tablets, as well as cellular-powered IoT devices, including those connected to LTE Cat1, LTE Cat M1, and NB-IoT network.

To better estimate the energy consumption of network element and end device, the following methodology is adopted:

- **Network Elements**: A cell site is consisted of several network elements. The utilization rate for each element is first identified based on annual traffic pattern, traffic capacity, geographical location, and connectivity technologies, namely 2G, 3G, LTE and 5G. The utilization rate is then mapped with the compute resource required by each element to calculate the energy required for computation. By adding up all the necessary network elements for a site and estimating the energy requirement for passive elements, this will generate an estimated figure for energy consumption per site. The total energy consumption for network elements can be then calculated by multiplying the energy consumption per site with the total number of sites. The market data and
forecast used in this model are taken from ABI Research’s Mobile Infrastructure (MD-INFR-104), Network Technology and Market Tracker (MD-NWMT-104), and Network Functions Virtualization Tracker and Forecasts (MD-NFV-102).

- **End Devices**: Using figures from ABI Research's Worldwide IoT Market Tracker (MD-IOTWW-107), the total number of end devices are broken down based on their connectivity technologies, namely 2G, 3G, 4G, LPWA-LTE and 5G. An average energy consumption value is used for each device type. This figure is then multiplied with the total device count in our IoT forecast.

After estimating the energy consumption of each component, we estimate that the overall energy footprint of cellular technology to reach 19.8 million tonnes oil equivalent (Mtoe) per year in 2020. This is expected to grow to 51.3 Mtoe in 2030, with a CAGR of 10%. This would be equivalent to the total energy consumption of Sweden or Norway, or roughly the same amount consumed by all the households in Australia or the United Kingdom in 2030.

*Chart 1: Total Energy Consumption of Network Elements versus End Devices
Worldwide: 2019 to 2030
(Source: ABI Research)*

In mid-2020, most of the 5G applications remains consumer oriented. Major 5G devices in the market right now are smartphones. High speed mobile broadband offered by 5G network facilitates more media content consumption and live broadcast through smartphones.

That said, following the track of previous generation cellular networks, 5G does possess the potential to further augment the way humans interact with smart devices and machines. The technology will enable the emergence of immersive experiences. In that way, humans will naturally interact with and control machines around them using human language control, whether that be voice, touch, or gesture. Furthermore, 5G will help in improving asset and people tracking across a wide range of industries, improving workforce safety, enhancing operational and process efficiency, and minimizing waste.

As enterprises begin to adopt cellular devices on a wide scale to enjoy the aforementioned benefits, ABI Research believes the devices connected to cellular network will grow rapidly. By 2030, the share of end devices in overall energy consumption is expected to increase to 37%, due to massive deployment of IoT.
devices and wide availability of powerful 5G devices. This highlights the importance of device-side energy management the industry needs to address imminently to overcome the challenges of the on-going CO2 emission associated with mobile devices.

While consumer devices are getting increasingly powerful and therefore power-hungry over the years, network infrastructure are also demanding more processing capabilities. In order to handle more end devices and to provide the best 5G user experience for both consumer and enterprise customers, CSPs need to deploy new network architectures such as a dense network of millimeter-wave basestations, virtualization radio access network (vRAN), massive multiple input and multiple output (MIMO) antenna with beamforming, carrier aggregation, dynamic spectrum sharing, network slicing, orchestration of network functions and slices, and edge servers and gateways. Over time, all these architectures and capabilities add additional layers and complexity to existing cellular network, leading to higher energy consumption of cellular networks by 2030.

5G NETWORK TO TAKE OVER IN 2028

5G network will take a few years before it becomes globally available. Driven by the wide adoption in both consumer and enterprise, the inflection point for deploying 5G networks is expected to happen in 2028 leading to a huge increase of power consumption of the technology, which could overtake legacy LTE networks.

(Source: ABI Research)

As an existing standard, the energy consumption of LTE is estimated to peak in 2022 and gradually decline. However, until 5G overtakes LTE in 2028, LTE will remain as the dominant technology for several reasons:

- **A True Global Standard**: After winning the standard race against WiMAX, LTE is the world’s first truly global cellular connectivity standard. As compared to leading markets like South Korea, China and the United States, the growth of CSPs in emerging markets is driven by the continuous improvement of LTE networks under LTE-Advanced and LTE-Advanced Pro. The sales of LTE smartphones and devices are dwarfing their 5G cousins in 2020 as consumers are slowly converting their existing smartphones to 5G-enabled ones.
- **Fallback Option**: The sunset of legacy technologies such as 2G and 3G makes LTE an important fallback option for cellular technology. Emerging economies such as India, Brazil and Nigeria will wait until 2021 to consider their 5G strategy. This means these markets will be relying on existing LTE technologies to power their cellular networks.

- **NSA Deployment**: In the early stage of 5G deployment, CSPs are opting for 5G Non-Standalone (NSA) deployment. NSA deployment leverages existing LTE Packet Core to serve as 5G core network. 5G Standalone (SA) core will gain momentum in 2021, once CSPs such as China Mobile, Singtel, DISH Networks and Rakuten start to activate their 5G SA deployment.

By 2028, 5G is expected to overtake LTE. By this stage, both 5G NR Radio Access Network (RAN) and SA core network will be fully commercialized. As such, 5G energy consumption is expected to increase by 61x from 2020 to 2030, due to the following reasons:

- **More Powerful Network Elements**: The proliferation of massive MIMO antennas, edge computing servers and the deployment of more compute-intensive 5G Core will propel the energy demands of 5G network. These network elements are necessary to deliver the ultra-high throughput and low latency experience, as well as the flexibility and agility of 5G network.

- **5G Requires More Cell Sites**: As 5G predominantly operates on mid to high spectrum band, the spike in cell site will be required for network densification and seamless user experience. This translates into more baseband units and remote radio heads, more cellular masts and towers, and more basestation shelters and cooling equipment.

- **Ideal for Both Consumer and Enterprise Use Cases**: The flexibility and agility of 5G network makes it capable to handle high demanding consumer applications and business- and mission-critical enterprise applications. Legacy use cases traditionally served by wired network and new mobility-centric use cases will opt to rely on 5G network for better user experience and quality of service.

Since most of the energy consumption of 5G network is due to energy consuming massive MIMO antenna and 5G Core, CSPs would have been able to reduce energy consumption by over 60% if they only focus on LTE rollout in the next 10 years. However, doing so will not only cause poor user experience due to network congestion, but also means forgoing lucrative revenue opportunities in enterprise segment, rendering CSPs even more less competitive in the digital economy.
ENERGY CONSUMPTION ANALYSIS BY NETWORK ELEMENT

While the power consumption of 5G network is expected to soar, this is mainly driven by power consumption in active network elements, namely baseband unit, remote radio head, small cell and core network. Due to a combination of passive cooling technologies, energy optimization strategies and new cell site deployment practices, passive cooling technologies, which are mainly responsible for cooling, monitoring and control function, will only grow in half the pace of active network elements.

(Source: ABI Research)

Being aware of the massive energy consumption and carbon footprint of existing cellular network, 5G network infrastructure vendors have been very diligent in reducing the power requirement of passive network equipment. New generation of basestations are designed for full outdoor deployment. Reduction in size, ruggedized casing and efficient energy dissipation allow them to be deployed through pole-mount or wall-mount configuration, benefiting from outdoor cooling while reducing the need for air-conditioning in shelter room and power cabinet. At the same time, intelligence cooling is implemented in existing cell sites to reduce air-conditioning through coordination between multiple air-conditioning units in a shelter room.

Chart 4: Energy Consumption Ratios of RAN, Core Networks and Edge Server in Percentage Worldwide: 2019 to 2030
(Source: ABI Research)
In addition, a combination of techniques is used to control network topology and optimize energy consumption. Through better and smaller semiconductor footprint by semiconductor vendors and intelligent and integrated system from network infrastructure vendors, CSPs have turned to more power-efficient active network elements. Among all three major active network elements, namely RAN, core network and edge server, RAN is the more power consuming category. Massive MIMO antennas deployed in dense population areas are powered by Artificial Intelligence (AI) algorithms to perform beamforming and feature AI chipsets such as Graphic Processing Unit (GPU) or Application Specific Integrated Circuit (ASIC). In order to further optimize energy in RAN, new cell sites are designed to feature better battery management system. These systems can initiate power saving mode by switching off certain network elements when the traffic load is low. Real time monitoring allows network optimization, adjusting network coverage according to network traffic condition. This is likely to further decelerate the growth of power consumption in RAN. As such, the CAGR of RAN in overall energy consumption is estimated at 3% from 2020 to 2030, commanding 81.4% of the total energy consumption.

Similarly, the core network has undergone changes in 5G era. Gone are the proprietary monolith components in LTE. They are replaced by virtual machines and containers that run on general-purpose data center grade servers. In some cases, these software programs are based on open source solutions. Using general purpose solutions inevitable will lead to higher energy consumption as compared to the traditional monolith components in LTE. As such, the CAGR of core network in overall energy consumption is estimated at 10% from 2020 to 2030, resulting in 15% of the total energy consumption in 2030.

The deployment of network slicing and edge computing capabilities also gives rise to the emergence of edge servers in cellular networks. Predominantly responsible for computing, caching and hosting of user plane functions in a distributed manner, edge servers deliver ultra-high network performance and flexibility at the network edge. CSPs can also utilize edge servers to perform real-time network and customer behavioral insight and enhance operational efficiencies. At the same time, enterprises can benefit from edge computing architecture by hosting their enterprise functions closer to where the workloads locate, reducing data storage and transport cost, fulfilling stringent latency requirements and enabling quick onboarding and deployment of new services and revenue streams. The edge computing server is expected to grow at a CAGR of 35% from 2020 to 2030 and command 3.5% of the overall energy consumption by 2030, as edge computing become more widespread and common among both CSPs and enterprises.
TOP 20 IN THE WORLD

In order to place energy consumption of global cellular network in the right context, we need to compare cellular network with country-level energy consumption in terms of household or domestic energy consumption. In 2020, the global cellular network is expected to consume 19.8 Mtoe per year, roughly the same amount of energy as all the households in Argentina and the Netherlands.

*Chart 5: 5G Energy Consumption Versus the Household Energy Consumption of Selected Countries Worldwide: 2019 versus 2030 (Source: ABI Research)*

As 5G deployment continues to gain momentum, the energy consumption of cellular network will outpace the energy consumption growth in many countries. Growing at 9% CAGR, the cellular network is expected to grow at the same rate as prominent emerging economies in the world, such as Vietnam and Bangladesh. By 2030, global cellular network will break into the top 20 ranking for the global household or domestic energy consumption ranking by country, consuming 51.3 Mtoe per year, or roughly the same amount of energy as all the households in Australia and the United Kingdom.

Assuming that global household or domestic energy consumption will reach 3,315 Mtoe by 2030, this also means the cellular network will represent over 1.5% of total global energy consumption by 2030. This has doubled from the 0.7% in 2019. According to the World Bank, the CO2 intensity of oil is 2.57 kilogram per kilogram of oil. As such, the total CO2 emission of cellular network is expected to reach 132 million tonnes, or 132 megatonnes in 2030. The total is estimated to increase further, if no action is taken to reduce the overall carbon footprint of the cellular network.
KEY STEPS TO MAKE 5G GREENER

Among the overall energy consumption of 51.3 Mtoe per year by cellular network in 2030, 60% and more shall be borne by CSPs. At the moment, nearly 20% of operating expenditures (OPEX) of CSPs are already energy related, as reported by many infrastructure suppliers and CSPs. Since the pace of energy consumption growth is expected to outpace future ARPU projection and OPEX spending, CSPs need to pay close attention to this matter and actively manage the energy consumption of their cellular network.

Over the years, many CSPs have been focusing on their green strategies and reducing their carbon footprint. In 2018, AT&T claimed that they have reduced their carbon emissions by 50% against projected carbon emissions of the same year, and the CSP aims to increase this to a factor of 10 in 2025. In 2019, Telefonica claims that they have achieved a global reduction of almost 50% of their CO2 emissions since 2015. Other major CSPs, such as BT Group, Deutsche Telecom, Orange, Verizon and Vodafone have made similar pledges to actively manage and reduce their carbon emissions.

In their efforts to reduce carbon footprints, CSPs have adopted the following strategies:

- **Reduction of Energy Consumption Through Standards Formulation**: Over the years, the 3rd Generation Partnership Project (3GPP) has made significant effort to reduce energy consumption from one generation of cellular technology to the next. The energy efficiency of network elements and user devices is improved through enhancement in data transmission, reduction of control-signaling overhead, and improvement in link adaption.

- **Adopting Renewable Energy**: CSPs have been championing the adoption of renewable energy. In the past, CSPs relied on petrol and diesel to power their off-grid basestations. These off-grid basestations are currently powered by solar energy. In addition, CSPs are working with local renewable power supplies such as winds and thermal power to design more energy efficient network architectures.

- **Make Data Center Green**: CSPs are aware of the carbon footprint of their legacy data centers and have made significant effort in managing energy efficiencies. A green data center minimizes energy consumption through efficient cooling involving airflow design and management.

- **Partnering with Regulators and Industrial Associations**: CSPs have been actively pushing for best practices and global eco-friendly standards by influencing stakeholders in the industry value chain, including technology suppliers, service providers and end users to adopt similar standards and help to bring down the overall carbon footprint. Such initiative includes the Science-Based Pathway, a methodology emerging from the collaboration between International Telecommunication Union (ITU), GeSI, GSMA and the Science Based Targets initiative (SBTi), which will allow CSPs to design emission reduction targets to meet the requirements laid out in the Paris Agreement.
WHAT’S NEXT IN THE HORIZON

Nonetheless, the efforts from CSPs, industry associations, and standardization bodies will not be enough. As more and more 5G network infrastructure are getting deployed, more aggressive energy optimization methods and technologies need to be developed to address the increase in carbon footprint. While this forecast presents a realistic scenario of future energy consumption, the actual scenario might turn out to be less aggressive and more environmentally friendly, if the following technological advancements were to be adopted and implemented:

- **More Energy Efficient Equipment**: CSPs need to deploy more energy-efficient baseband units and antennas. This means selective switch-off of certain active RAN components. Basestations and small cells can be put dynamically into a sleep state when there is no traffic through pre-defined rules and algorithms that could contribute to significant energy saving.

- **Speed Up AI Integration**: Network infrastructure vendors need to speed up the integration of AI algorithms that can optimize RAN subsystem performance based on network activity. This helps to reduce unnecessary energy consumption by RAN equipment that are idle during low traffic scenario. This also translates to increased longevity of cell site power generation and fuel cells for off-grid basestations.

- **Accelerate the Use of Renewable Energy and Passive Cooling**: Coordination of energy saving between the main equipment and energy supply can be achieved via selective activation of RAN based on data traffic and usage pattern. Aside from harnessing solar energy as one of the possible options, CSPs should consider resorting to passive equipment cooling instead of active equipment cooling when possible.

- **Real-Time Site Status Monitoring**: Real-time site status monitoring help reduce maintenance workload in remote rural areas. This not only reduces the frequency of field trips by network engineers by 50%, but also provides a better overview of the network performance to CSPs, leading to overall efficiency enhancement.

At the same time, with end devices constituting 37% of the overall energy consumption of the cellular network by 2030, device manufacturers also have a key role to play in reducing the carbon footprint of the cellular network:

- **Continue to Focus on Device Energy Management**: Device manufacturers must put power-management central to their overall system designs to improve resource management in line with the overall usage of the device. This is aided by advancement in chipset technology, the emergence of AI, and software defined designs that manage power utilization by various hardware and software components in a device.

- **More Power Efficient Display**: Device manufacturers should also make power efficiency as key requirement in procuring displays and display processing units. As display technology in mobile devices are getting larger and more powerful, designing power-efficient display is critical for device manufacturers to maintain current power budget and halt the increase in future energy consumption.

- **More Power Efficient Video Transmission and Capturing**: Technology vendors should also look into developing more power efficient video codec. The optimal video codec will be able to maintain frame rate and resolution at lower energy. Nowadays, majority of the cellular data traffic consist of live streaming and recorded content on various social media platforms. The reduction of video bit rate and resolution through better compression technologies will also help to lower the overall energy consumption of end devices. This will also benefit many applications in autonomous vehicle, public safety and industrial and manufacturing that rely on machine vision.
Better Battery Technology: New battery technology has become the next frontier for electronics. Factors such as recharge cycles, aging, and temperature can degrade the performance of the lithium-ion battery over time. R&D has been actively conducted to find chemistries that are cheaper, denser, lighter and more powerful, which will lead to the development of battery that is capable to hold more power with the existing capacity.

The most important takeaway of this whitepaper is that the advancement in cellular technology does not need to be accompanied by higher energy consumption and carbon footprint. If all key stakeholders continue to demonstrate goodwill in improving the carbon footprint of components and system they are involved with, adopt the best practices recommended above, coordinate with each other and work hand-in-hand, the telecommunication sector will be able to achieve their goals in creating an environmentally friendly and energy efficient cellular network.
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