MARCH 2021

Global Networks 2030

Developing Economies and Emerging Technologies

AUTHORS
Jonathan E. Hillman
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A Report of the CSIS Reconnecting Asia Project

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Acknowledgments

This report was made possible by support from Japan's Ministry of Internal Affairs and Communications and Mitsubishi UFJ Research & Consulting Co., Ltd.

Center for Strategic & International Studies
1616 Rhode Island Avenue, NW
Washington, DC 20036
202-887-0200 | www.csis.org

Contents

FIGURES

1

Executive Summary

The U.S.-China technology competition is set to intensify in third markets as developing countries decide which communications systems to adopt. China is already advancing its own vision—the Digital Silk Road—and positioning itself to benefit commercially and strategically as populations grow and more of the world comes online. At stake is who designs, builds, and operates the systems that underpin global communications, finance, and other functions essential to daily life. The next decade could be decisive.

To help policymakers chart a strategic course, this report examines key trends in developing economies and emerging communications technologies through 2030. The developing world is poised to play a much bigger role in global networks, particularly Asia and Africa—where nine of the world's ten new megacities will emerge by 2030—as well as Latin America. Rapid urbanization and population growth will also drive demand for investment in digital infrastructure. Nearly half of the world's population does not have access to the internet. Closing that digital divide could cost $428 billion, and fully realizing the benefits of the global digital economy could cost significantly more, upwards of $701 billion a year in additional investment.

Emerging communications technologies could help bridge the digital divide while benefitting the United States and its allies. The software and key components for Open RAN networks, which allow operators to mix and match equipment from different vendors, are produced in the United States and allied countries. Low-earth orbit satellite constellations could allow U.S. companies to provide high-speed, low-latency broadband to rural markets where Chinese firms are the incumbent providers. Urbanization will drive demand for "smart city" systems that could improve traffic, public services, and safety. Advances in photonics could create networks that are exponentially faster, higher-capacity, and more energy efficient.

But making the most of these opportunities and building a position of strength in global networks will require action. The United States should articulate its own vision for global networks, one that benefits middle-class Americans, aligns with allies, and appeals to the developing world. To realize that vision, the United States should scale promising technologies by leveraging domestic investments, creating an allied accelerator fund, and partnering with regional anchor markets. Competing in tomorrow's markets will also require the United States and its allies to expand financing, provide technical assistance, and promote a high-standard model for smart cities.

2

Introduction

The speed and scope of China's push to connect the world has caught U.S. policymakers off guard. Even if some of today's warnings that the United States is "losing the 5G race" are exaggerated, Huawei's emergence as a leading supplier of next-generation networks has provided a much-needed wake-up call for a much larger competition that is now underway. The United States and China are competing over who designs, builds, and sets the standards for global networks. The next decade could be decisive.

China's rise as a leading provider of telecommunications equipment did not happen overnight. A decade ago, the top three suppliers from the United States and Europe (Ericsson, Nokia, and Cisco) collectively controlled over half of the global market. But China's champions, benefitting from vast state support and eager to serve overlooked markets, expanded steadily, even reaching into their competitors' backyards. By 2015, Huawei was the world's top supplier. Four years later, Huawei and ZTE's combined share of the global market matched the combined share of the top three U.S. and European suppliers.[1]

The story of how China's national champions emerged, and how North American companies like Lucent and Nortel fell, goes even further back and is beyond the scope of this report. What is clear, however, is that early warning signs were ignored. Only relatively recently did U.S. policymakers come to view telecommunications as a strategic sector and China's expanding global activities as concerning. Because U.S. telecommunications companies were dominant during the 1990s, competition was largely left to market forces. If the strategic implications of these developments were taken more seriously earlier on, today's telecom landscape would look very different.[2]

Learning from this experience, the United States and its allies need to look ahead and formulate their own visions for global connectivity. As the CSIS Global Infrastructure Task Force concluded in 2019, the stakes are highest in the digital domain.[3] Information and communications technology (ICT) exports support well-paying jobs and investments in research and development that are critical for maintaining the United States' innovation edge. History underscores that ICT capabilities are closely linked to national power—fueling economic growth, military capabilities, and intelligence. The stakes are rising as more "things" are connected to the internet and more of the world's people come online.

Figure 1: The World in 2030

By 2030, global networks will be:

More urban: seven out of ten people in the world will live in cities, with population growth accelerating fastest in ***Asia*** and ***Africa***.

Smarter: the "Internet of Things" will include 500 billion internet-connected devices.

Faster: networks could ***increase capacity*** by 125-fold and ***reduce latency*** by 200-fold.

Policymakers must start planning for this future today, with attention to:

The environment: ICT equipment could consume over ***one-fifth of global electricity***.

Investment: achieving universal internet access could cost ***$428 billion***.

Complexity: new systems require technical capacity and sound policies to maximize benefits.

Source: See endnotes 9, 35–37, and 62.

The Covid-19 pandemic has put those stakes into even starker relief. People with access to digital infrastructure have been able to continue working, learning, shopping, playing, and talking with family and friends. But nearly half of the world's population still does not have access to the internet, even as faster networks, cheaper sensors, and a proliferation of connected devices make connectivity more essential for modern economies. The suppliers that help close this digital divide will be positioned to thrive in the years ahead, rising with some of the world's fastest-growing economies.

China is already advancing a global vision for digital connectivity, the Digital Silk Road, which sits at the intersection of three major state-backed initiatives. It was first introduced in 2015 as part of Chinese leader Xi Jinping's signature foreign policy vision, the Belt and Road Initiative. It also advances "Made in China 2025" and "China Standards 2035," through which Beijing aspires to lead advanced manufacturing and standard setting, respectively.[4] There is plenty of hype in each of these efforts, but they signal serious ambitions. The Digital Silk Road advances China's bid for technological independence at home while moving it toward the center of global networks.

But the United States has much to offer and several advantages in this competition. The United States is home to seven of the world's top ten universities for research.[5] U.S. companies remain at the forefront of important areas, such as cloud computing, and they are piloting new technologies that could expand global access to communications while shifting the playing field in ways that favor the United States and its allies. The global popularity of U.S. content brings commercial advantages and enhances U.S. soft power. Unlike Beijing, Washington has a network of partners and allies, including many with deep historical and commercial ties in key emerging markets.

To help U.S. policymakers capitalize on those strengths and prepare for intensifying competition, this report provides a three-part examination of how global communications networks might develop through 2030. It begins by considering the larger role that developing economies will play in global communications networks over the coming decade. Next, it highlights the potential implications of several emerging communications systems: Open RAN, smart city systems, advanced photonics, low-Earth orbit (LEO) satellites, and high-altitude platforms. A final section includes recommendations for further research and policy options. The goal is not to predict the future, but to identify potential challenges and opportunities and better prepare for the possibilities it holds.

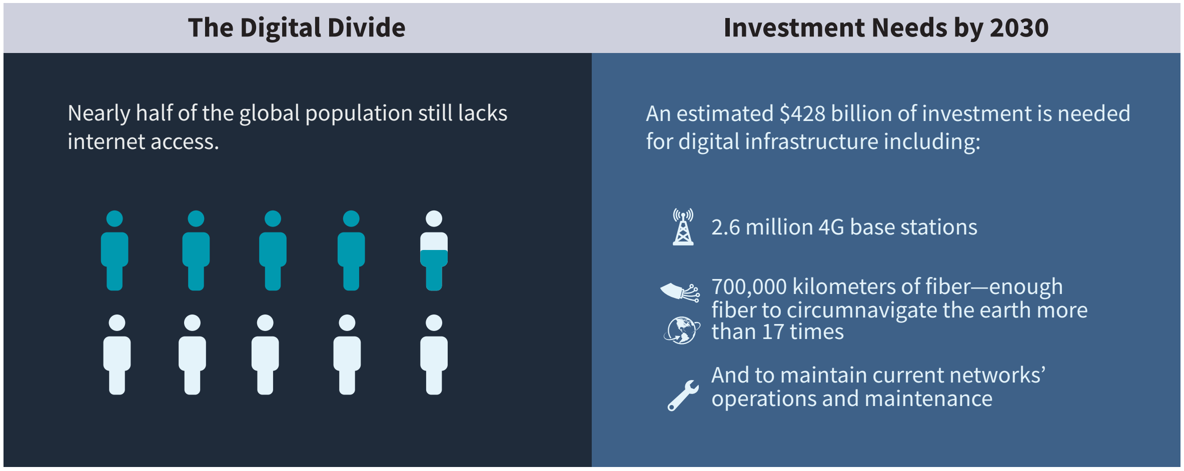
3

Developing Economies

One of the most important trends that will impact global networks during the next decade is the potential for more of the developing world to come online. More than half the world has limited or no access to the internet.[6] More than a third of countries still lack internet-exchange points, the facilities at which networks meet to exchange traffic.[7] More than a third of people live in countries where 1-GB mobile broadband plans are unaffordable.[8] Gaps in access will not vanish, but they will shrink as developing countries build more of the digital infrastructure that makes these connections possible. This section previews how the topology of global networks could evolve in the coming decade, with an emphasis on emerging markets in Asia, Africa, and Latin America.

"Achieving the target of connecting all of humanity to broadband internet by 2030 is, above all, an infrastructure investment challenge," notes the International Telecommunication Union (ITU).[9] It estimates that roughly 2.6 million 4G base stations and 700,000 kilometers of fiber are needed to expand access while maintaining existing infrastructure. Of the $428 billion in total costs, the largest expense is network operations and maintenance ($140 billion), underscoring the importance of countries using estimates that consider life cycle costs. Other estimates suggest that global investment needs could be even greater. The Asian Development Bank estimates that realizing the potential gains from the digital economy will require increasing investment by $701 billion every year through 2025.[10]

Figure 2: Closing the Digital Divide



Source: International Telecommunication Union, *Measuring Digital Development Facts and Figures 2020* (Geneva: International Telecommunication Union, 2020), 10, https://www.itu.int/en/ITU-D/Statistics/Documents/facts/FactsFigures2020.pdf; United Nations Conference on Trade and Development (UNCTAD), *Digital Economy Report 2019* (New York: United Nations, 2019), 12, https://unctad.org/system/files/official-document/der2019_en.pdf.

Of course, infrastructure investment is not the only challenge. The ITU estimates that $46 billion needs to be spent on ICT training, content, and policy reforms. Access to affordable devices is another key barrier. Nearly 2.5 billion people live in countries where the cost of a smartphone is a quarter or more of the average monthly income, according to the Alliance for Affordable Internet.[11] Devices in Africa are the least affordable (62.8 percent of the average monthly income), followed by those in the Asia-Pacific (16.2 percent when India is not included, 87.4 percent when it is included), and the Americas (11.7 percent). While manufacturing costs may continue to improve in the coming years, reforms such as reducing taxes on select low-cost devices would also expand access.

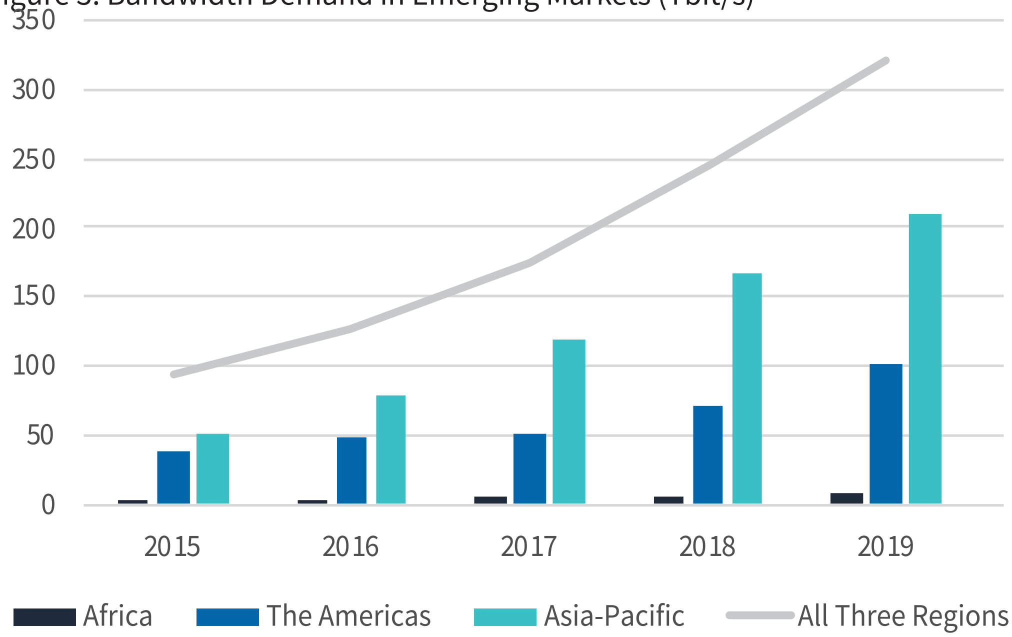
Urbanization will bring new opportunities to connect populations in all three regions. By 2030, the world will have 10 new megacities, defined as cities with more than 10 million people. Nine of these ten new megacities will be in Asia and Africa. The density of urban areas allows infrastructure investments to connect greater numbers of people, and capitalizing on that opportunity will require careful planning. The growth of urban areas, including many below the megacity level, will also drive demand for "smart city" technologies, examined in the next section, that offer to help improve traffic, public services, and safety.

The world's network of subsea cables, which carry the vast majority of international data, will continue expanding. Demand for international bandwidth is rising fastest in Asia and Africa. Between 2015 and 2019, Asia's international bandwidth grew by 42 percent annually.[12] Hong Kong has been a major beneficiary of this growth, ranking sixth globally in international bandwidth in 2019. But companies planning subsea cables are increasingly looking elsewhere in Asia after China imposed a sweeping national security law in June 2020. In the future, routes are more likely to land in Singapore, which is already the leading hub in Asia, as well as Japan, the Philippines, and Indonesia.

Connectivity in Southeast Asia has grown rapidly and is poised for further expansion. The Covid-19 pandemic accelerated the adoption of the internet and internet services, bringing 40 million new users online in 2020, according to a study by Google, Temasek, and Bain & Company.[13] The same study projects that e-commerce will reach $172 billion in value by 2025, four and a half times its total value in 2019. This increase in activity will contribute to demand for data centers, and Southeast Asia is projected to be the fastest-growing region for co-location data centers, which rent space to third parties, through 2024.[14]

India has significant growth potential, but also vast investment needs and policies that unintentionally inhibit access. Government surveys point to a considerable gap in access that is even more pronounced by gender: only 42 percent of Indian women have ever used the internet, compared with 62 percent of men.[15] Private sector interest from U.S. companies is strong, with several large tech firms, including Google, Amazon, and Facebook, announcing multi-billion dollar investments intended to complement the government's "Digital India" initiative. But additional public and private investment is needed. India tops the list of the countries with the greatest need for ICT infrastructure investment, requiring $95 billion by 2030, according to the ITU.

Figure 3: Bandwidth Demand in Emerging Markets (Tbit/s)



Source: International Telecommunication Union, *Measuring Digital Development Facts and Figures 2020* (Geneva: International Telecommunication Union, 2020), 10, https://www.itu.int/en/ITU-D/Statistics/Documents/facts/FactsFigures2020.pdf.

Africa's growth potential is massive. The continent is home to 17 percent of the world's population but only one percent of its data center capacity.[16] In sub-Saharan Africa, about a third of the population does not have mobile broadband coverage. Achieving universal access to broadband in Africa by 2030 would require building a quarter million new 4G base stations and laying at least a quarter million kilometers of terrestrial fiber, according to a UN study.[17] Access to affordable, reliable electricity is a major constraint. Even with those systems in place, satellites would need to deliver broadband to 100 million people living in remote areas. The UN estimates the cost of these investments at $100 billion.

While universal coverage by 2030 is a "moonshot," to use the United Nations' own words, growth is already occurring at an impressive clip. Between 2015 and 2019, Africa's international bandwidth grew by 45 percent annually, and several subsea cable projects are slated to come online in the coming years. South Africa is a leading hub, hosting 11 cables, while Egypt is a major hub to the north, hosting 17 cables.[18] Facebook's 2Africa Project, a collaborative effort among eight companies, is set to connect Nigeria and 22 other African countries, the Middle East, and Europe by 2024. Meanwhile, Google's planned Equiano subsea cable aims to connect Africa to Europe via South Africa and Portugal.[19] Africa's data center market is growing at more than 12 percent a year, with recent investments suggesting that Kenya and Nigeria could rise as regional hubs in the coming years.[20]

Urbanization rates in Africa are among the highest in the world. Africa's population is expected to double between 2020 and 2050, and two-thirds of that increase will happen in urban areas.[21] Smart city projects are already underway, including notable examples in Cape Town, Kigali, and Laos. The limited legacy of existing infrastructure in some cities could be an opportunity to build new systems that "leapfrog" ahead. But building megaprojects from scratch, such as Kenya's Konza Technopolis, which sits outside Nairobi, also carries risks. Convincing a critical mass of businesses to relocate from the city, the current hub of economic activity, may prove challenging.

Smart city solutions are also gaining momentum in the Middle East, which has the world's second fastest urbanization rate. Abu Dhabi, Dubai, and Riyadh all moved up in the rankings of the 2020 Smart Cities Index, which evaluates citizens' perceptions of the existing infrastructure and technology applications available to them in their city.[22] The first phase of Saudi Arabia's NEOM city, which aims to develop the first portion of the $500 billion megacity on the Red Sea coast, is scheduled for completion by 2025, as part of the country's Vision 2030 initiative. Bahrain Bay, a $2.5 billion commercial and residential waterfront development, is working to become a modern metropolis.[23] Kuwait was among the first Gulf Cooperation Council (GCC) countries to roll out 5G services, and its 2035 vision includes several digitization efforts in healthcare, renewable energy, and infrastructure.[24]

In Latin America, socioeconomic factors and gaps in digital skills have contributed to the slow adoption of digital technologies. According to the Inter-American Development Bank, nearly a third of the region's population is without internet access.[25] Most unconnected Latin Americans reside in urban areas, but high costs and a skills-gap have hindered mobile internet adoption.[26] Yet the region has significant potential. Internet user growth in Latin America outpaces that of the United States, and global venture capital (VC) tech investment is on the rise.[27] International funding is growing, but significant financial and human capital investments are still needed.

Brazil and Mexico are poised for growth. Brazil's eight planned research and development (R&D) facilities are focused on cybersecurity, healthcare, agribusiness, manufacturing, and smart city technology.[28] São Paulo hosts 60 percent of the country's start-up investments and headquarters 56 percent of the region's Fortune 500 companies.[29] Mexico has been attracting investments from Microsoft, Equinix, and other companies in data centers and encouraging digital transformations in Mexico City, Guadalajara, Monterrey, and other cities.[30] As the second largest economy and the largest fintech ecosystem in Latin America, Mexico is naturally positioned to bridge networks between North and South America.

Chile is emerging as a new hub. The country has attracted investment from major cloud and content providers due to its geography, climate, and business environment. The Chilean government estimates that there were 15 data centers being expanded or newly built in 2019.[31] In July 2020, Chile announced it had selected a Japanese proposal to build a cable to New Zealand and Australia, the first direct fiber-optic connection between South America and Asia.[32]

Developed markets will not remain static, of course. How the United States and European Union address questions about digital taxes, privacy, and data localization will impact how their robust network connections develop in the decade ahead. As several subsea cables connecting North America approach the end of their planned life cycles, cables will need to be replaced in a timely manner.[33] If the U.S. government cable approval process is not improved, Mexico and Canada could gain new landing points. It is also possible that a subsea cable connection through the Arctic, long proposed and only recently beginning to materialize, could emerge by the end of the decade.[34]

But the biggest changes in the global network topography are likely to come from developing economies. The decisions that developing economies make about what systems to use will impact the trajectory of the world's largest network providers. After adopting equipment, countries may be "locked-in" by high replacement costs. As these economies grow, the companies providing their technology will capture market share, which will underwrite their research and development investments and position them to set standards. Asia and Africa are expected to account for 90 percent of global population growth through 2050.[35]

The expansion of digital infrastructure globally, including in both developing and developed economies, also carries environmental implications. There could be as many as 500 billion internet-connected devices by 2030, according to Cisco.[36] The production and operation of ICT is projected to consume over a fifth of global electricity by 2030.[37] In a worst-case scenario, this rises to half of global electricity consumption. As the International Energy Agency points out, actual "energy use over the long run will continue to be a battle between data demand growth versus the continuation of efficiency improvements."[38] More optimistic developments include improvements in data center efficiency in recent years, and the energy-saving potential of photonic networks (examined in the next section).

For all three regions, the stakes are high, as is the need for investment. Digital technology impacts virtually all of the United Nations' 17 Sustainable Development Goals and 169 associated targets, which are intended to be achieved by 2030.[39] Progress in bringing people online has slowed in recent years, underscoring how significantly increasing investments in existing technology, and in the new technologies examined in the next section, will be essential to bridging the divide.

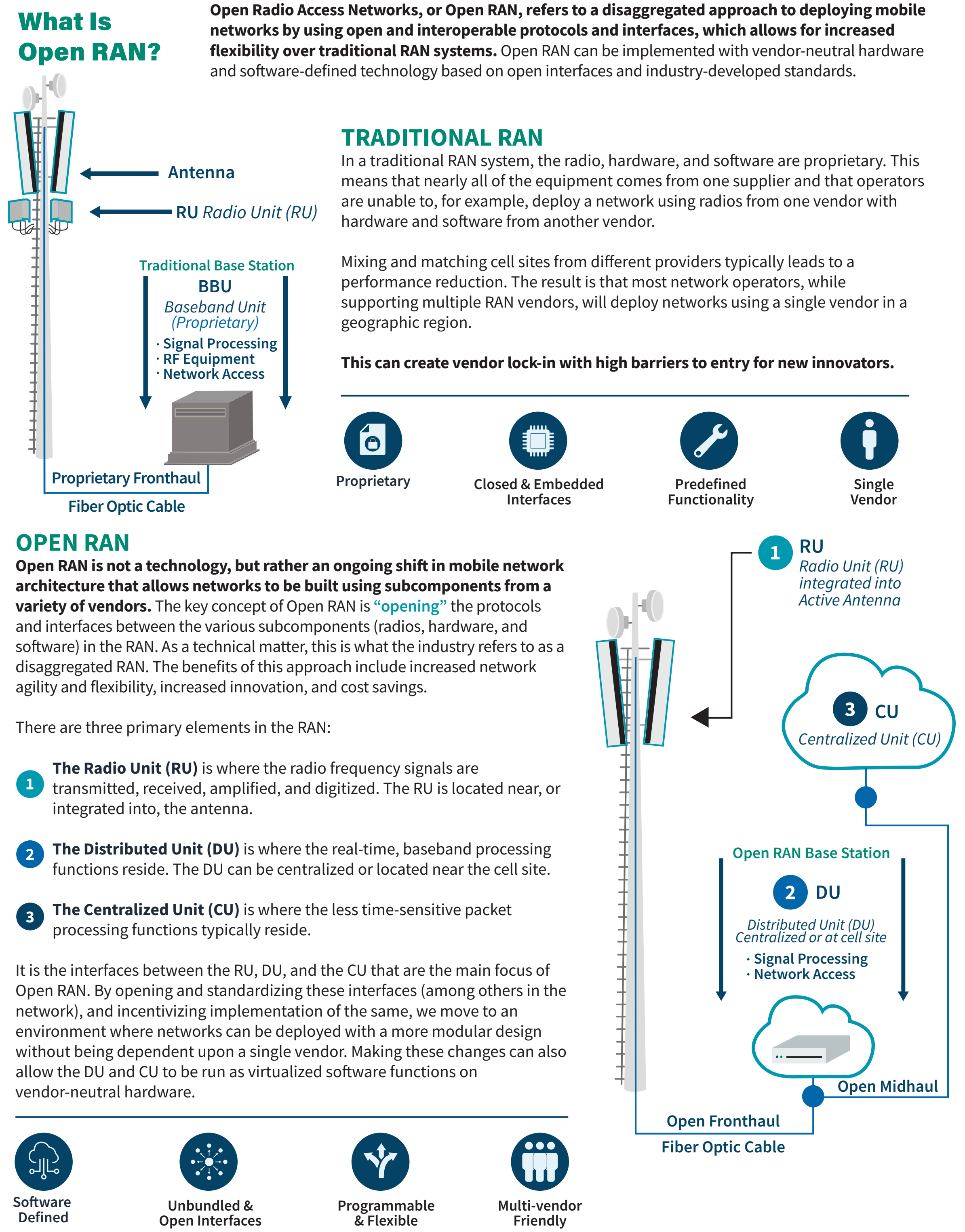
4

Emerging Technologies

New technologies for delivering communications, and new approaches to building networks, will gain traction in the coming years. This section focuses on five developments that are worth watching: Open RAN, smart city systems, advanced photonic networks, LEO satellites, and high-altitude platforms.

Open RAN

Figure 4: What Is Open RAN?



Source: "Infographic: What Is Open RAN?" Open RAN Policy Coalition, November 12, 2020, https://www.openranpolicy.org/wp-content/uploads/2020/11/Open-RAN-Infographic-FINAL.pdf.

Open RAN is an alternative way of building communications networks. The “RAN” stands for Radio Access Network, a wireless system that consists of radio frequency spectrum, towers, base stations, and mobile devices—the basic building blocks for using radio waves to deliver mobile connectivity. Currently, the largest suppliers of this equipment sell proprietary software and hardware that does not allow operators to mix and match from multiple vendors. By running virtualized software on open interface hardware, Open RAN aims to reduce costs and support interoperability among vendors.[40]

Open RAN could benefit the United States economically and strategically by creating a more diverse and innovative ecosystem for wireless networks, from 2G to 5G and beyond. Greater vendor diversity would disrupt the current commercial landscape, which is dominated by a handful of suppliers, the largest of which, Huawei, controlled 28 percent of the overall telecom market in 2020.[41] Companies in the United States, Japan, and Korea are at the cutting-edge of these developments, have advantages in developing the hardware and software for Open RAN, and could benefit from this shift.

Globally, network operators stand to benefit from greater choice. The choice to use a single vendor for a network can have longer-than-intended consequences. Many 5G networks, for example, are being built on top of existing 4G networks rather than from scratch. Network operators making these upgrades are incentivized to stick with their existing supplier. The move to Open RAN would make it less likely that operators would be locked into using a single supplier. Early trials also suggest operators could benefit from lower capital expenditures and operating costs.[42]

Open RAN is gaining momentum with high-profile deployments and investments in R&D. In 2020, Japan’s Rakuten deployed the world’s first 5G Open RAN network in Tokyo, a commercial mobile network using radios from different 4G and 5G vendors.[43] Parallel Wireless has built 2G, 3G, 4G, and 5G Open RAN systems across six continents.[44] NEC Corporation has established an Open RAN lab in India, focusing on post-deployment troubleshooting, life cycle management, and continuous integration and solution deployment.[45] During 2020, European operators announced Open RAN deployments in the United Kingdom, Germany, France, Spain, and Brazil.

In the United States, most large carriers are exploring Open RAN but are moving forward with traditional approaches for their 5G rollouts in the meantime. A notable exception is Dish Network, which plans to use Open RAN to deliver 5G services to 70 percent of the U.S. population by mid-2023. The short-term value proposition of Open RAN might appear more attractive for companies that are building new or “greenfield” networks than those that are upgrading or expanding existing networks.[46] In December 2020, Congress included the USA Telecommunications Act in the National Defense Authorization Act, making $750 million available for domestic 5G networks and Open RAN development.[47]

There is plenty of room for growth. In 2020, Open RAN made up less than 1 percent of the overall RAN market. That share is projected to grow to 1–2 percent during 2021 and 10 percent by 2025, according to Dell’Oro, an industry research firm.[48] More bullish estimates project that Open RAN could increase its market share to 58 percent by 2026 and 75 percent by 2030.[49] Government support and incentives for adopting Open RAN could tip the scales toward faster adoption. But the gap between these projections also reveals uncertainty about the challenges that Open RAN faces.

Successfully scaling Open RAN will require overcoming several challenges: complexity, policy coordination, market concentration, and cost. The security implications of Open RAN cut both ways.

On the one hand, Open RAN enhances security by giving operators choices and allowing them to avoid dependency on a single supplier and the security risks that a "monoculture" can present. It also enhances security by increasing the visibility that operators have into how their systems are functioning. Proprietary hardware that comes with closed approaches to RAN is less transparent and can make deeper preventative oversight more difficult.

But mixing and matching suppliers naturally adds complexity to networks. Open RAN interfaces can have as many as 14 or 15 different segments, from radio signal processing units to baseband units that transmit the signals to the core, to cloud computing platforms that host the network's virtualized functions. Industry opinions vary on the best approach to adoption. Deploying Open RAN can require additional specialized knowledge, which could pose an even greater challenge in markets with less local technical capacity. Additional trials will be important for developing best practices and equipment combinations that ensure system reliability and performance. These lessons could be shared with foreign markets through technical assistance and capacity building efforts.

How the United States addresses challenges in policy coordination and security standards will also influence Open RAN deployment. Currently, there is no single, centralized body for coordination. The O-RAN Alliance is one key body, a community of mobile network operators, vendors, and researchers focused on shaping and standardizing the Open RAN industry.[50] Several industry organizations, including the Open RAN Policy Coalition, the Telecom Infra Project, and the Open Networking Foundation are active as well.

Financing will be key. Emphasizing objective cost estimates, which take into account operations and maintenance costs, will help level the playing field. But state support allows Chinese firms to undercut their competitors by 20 to 30 percent, an offer that is often further sweetened by financing from the Export-Import Bank of China. In many developing markets, Huawei is the dominant incumbent supplier, and operators may be reluctant to incur the additional upfront costs of transitioning away from their current provider. The need for expanding financial support is discussed further in the final section of this report.

Smart City Systems

A growing suite of technologies behind "smart city" systems is another key trend. What these technologies have in common is that they "sense" the surrounding environment through connected devices.[51] These sensors—including anything from smartphones to smart meters to traffic signal systems—collect, analyze, and exchange real-time data. The goal is optimization. Solutions range from waste management (automatized waste bin collection), to crime prevention (surveillance and shorter response times), to traffic management (directing road traffic, lowering commute time). These applications all depend on systems that can rapidly and intelligently process large amounts of data to identify patterns, anomalies, and opportunities to improve efficiency.

Cities have been becoming "smarter" for years. In 2005, Cisco committed $25 million over five years to research what it dubbed "the connected Urban Development Program," working in tandem with San Francisco, Amsterdam, and Seoul on pilot projects.[52] In 2015, the Obama administration announced a Smart Cities Initiative aimed at supporting local communities and improving public city services.

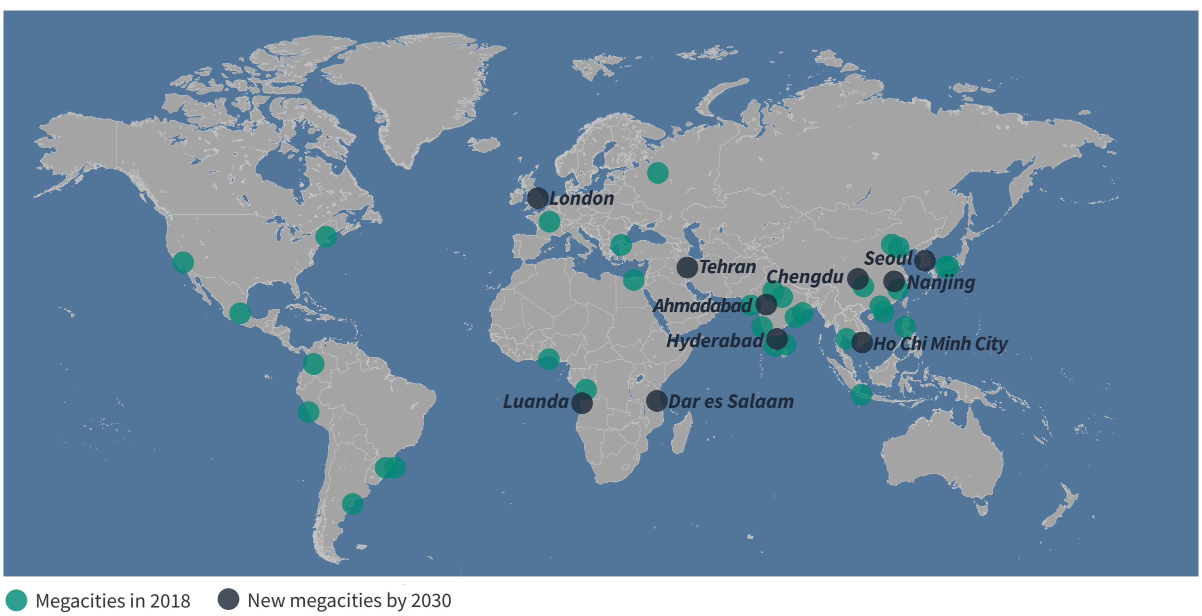
The arrival of even faster networks, cheaper sensors, and more sophisticated software is opening new opportunities for cities to increase economic growth, quality of life, and environmental sustainability.

For instance, governments and businesses with access to utility management systems can better allocate limited resources, or can utilize data to identify and better address energy inefficiencies.[53] Smart applications can also impact how agencies respond to global health crises, and can play an important role in epidemic prevention and control.[54] Nor are governments the only potential users of smart city data. Citizens can make better decisions about their commutes, energy usage, and other daily choices.

As more cities begin to adopt smart city technologies, and as these technologies advance, fashioning appropriate safeguards will be vital. Artificial intelligence (AI)-powered surveillance systems, for example, have already proved susceptible to racial and gender biases.[55] The challenge for policymakers is maximizing the social benefits that these new technologies can offer while minimizing the risks that could accompany wider use. In the United States, cities are experimenting with different approaches, with some banning AI surveillance outright, others taking a light-touch approach, and still others pursuing options in between. And while public safety applications understandably receive the most attention, data safeguards are also needed in more mundane applications.

Beyond harnessing safe city applications at home, the United States also has an opportunity to benefit from exporting these systems abroad. As the previous section detailed, urbanization is a megatrend that is increasing demand for smart city systems. By 2030, seven out of ten people in the world will live in cities, with urban populations growing fastest in Africa and Asia. Mayors and other local officials in developing economies are interested in deploying these systems for many of the same basic reasons as their counterparts in developed economies. As more smart city efforts are announced around the world, planners will need to decide which systems and safeguards to adopt.[56]

Figure 5: Tomorrow's Megacities Will Emerge in Developing Markets



Source: United Nations, *The World's Cities in 2018: Data Booklet* (New York: United Nations, 2018), 5, https://www.un.org/en/events/citiesday/assets/pdf/the_worlds_cities_in_2018_data_booklet.pdf.

Constraining adoption, however, are cost and complexity challenges. Many cities need to further invest in core infrastructure, especially fiber, wireless networks, and power systems, to make use of smart city systems. Some cities have an opportunity to "leapfrog" by adopting newer systems and avoiding older legacy systems. But the costs of all these investments still add up, even if they will boost growth and produce savings down the road. A challenge not unique to smart cities, but common to the Internet of Things (IoT) as a whole, is that having more connected devices naturally increases a network's attack surface. Cybersecurity practices will become even more important for mitigating these risks.

Developing countries also face a choice among competing models for smart cities. Chinese companies, which often refer to their offerings as "Safe Cities," emphasize public security applications. Chinese companies have exported smart city technologies to over 100 countries, according to a report prepared for the U.S.-China Economic and Security Review Commission.[57]

Several examples, including those involving Chinese surveillance equipment in Ecuador, Malaysia, and Serbia, have raised human rights and civil liberty concerns, in addition to highlighting abuses within China. In Pakistan and Kenya, the performance of these systems has raised questions about whether they deliver the benefits they promise.[58]

Figure 6: Huawei's Safe Cities

Source: Freedom House avg. combined political rights and civil liberties scores (2009-2018); World Bank World Development Indicators (Sept. 2019).

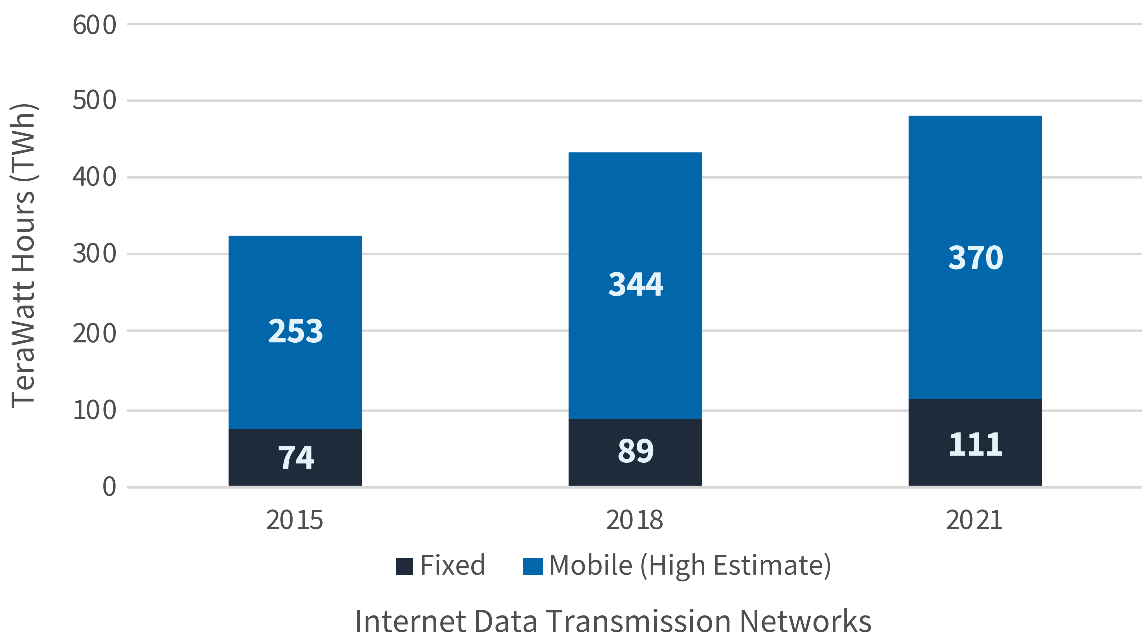
These shortcomings open the door for an allied approach to smart cities, examined in the final section of this report. U.S. and Japanese companies are already collaborating, including on a project in Las Vegas, where Dell and Nippon Telegraph and Telephone (NTT) are suppliers. The European Union is also investing in smart city applications with several efforts underway.[59] Some European cities, however, still use significant amounts of equipment from Chinese suppliers and need to decide whether, and when, to replace these systems.[60] Given the common aspirations driving the use of safe city systems, there is a massive commercial opportunity for companies that can navigate the common challenges these systems present.

Photonic Networks

Advances in photonics, which transmit information through optical signals rather than electronic signals, have the potential to increase network speed, energy efficiency, and security. Photonics have been widely used for decades (fiber optic cables, for example, date back to 1952), and current networks mix optical and electronic signals. The applications that photonics support are responsible for 11 percent of global GDP, according to one industry estimate.[61] Several cutting-edge technologies rely on photonics, including 5G networks, autonomous vehicles, and quantum computing.

Further advances could unlock speeds well beyond 5G. Current networks convert optical to electronic signals at several steps. Moving to a truly optical network, also called an all-photonics network, would entail using only light, rather than electrical currents, to transmit data at every step. Light is 10 times faster than electric currents and has other advantages related to capacity and security. To unlock these benefits, Intel, Sony, and NTT founded the Innovative Optical and Wireless Network (IOWN) Global Forum with the goal of achieving major network improvements by 2030: reducing power consumption by 100-fold, increasing transmission capacity by 125-fold, and lowering latency by 200-fold.[62]

Figure 7: The Internet's Rising Energy Demands



Source: International Energy Agency, "Electricity use by internet data transmission networks, 2015-2021," November 15, 2019, https://www.iea.org/data-and-statistics/charts/electricity-use-by-internet-data-transmission-networks-2015-2021.

These improvements could open the door to applications that currently seem like science fiction. For example, holograms and virtual reality applications are incredibly data-intensive. Making a realistic 3D hologram of a human face with expressions requires a download rate of 1 terabit per second.[63] For context, the peak download speed for 5G is 20 gigabits per second, which is 50 times slower than a terabit per second. Other potential use cases include telesurgery, large simulations that assist with disaster prevention, industrial manufacturing, as well as entertainment. The potential for photonics to hold quantum information will have future applications in quantum cryptography and network security.[64]

Photonic networks also have several potential use cases for smart cities.[65] Energy usage could become hyper-optimized with AI analysis. For example, a building's air conditioning system might automatically adjust based on the number of people in the building, their attributes, and other environmental factors. Streetlights could adjust based on weather, vehicle congestion, and foot traffic. These readings could inform the distribution of energy from solar panels and other renewable sources in the city. Autonomous vehicles, which need to recognize other vehicles, pedestrians, and other objects in real-time, could benefit from photonics.

Some use cases truly stretch the imagination, a valuable exercise when looking ahead a decade and beyond. Tapping into the power of photonic networks, researchers aspire to have the capability to build "digital twins" of not only physical objects for testing, but also exceedingly complex systems that include individual and group behaviors, economic activities, and the natural environment. These digital twins of society could be used to test policies for lowering carbon emissions, help people make decisions about where to live, and achieve other goals in the real world.

Photonics could change how people communicate with each other on an even more fundamental level. "Mind-to-Mind" communications, according to the Innovative Optical and Wireless Network (IOWN) Global Forum, "will overcome differences in language, culture, experience, values and sensibilities to gain a real and direct understanding of how the other people perceive and feel things in their minds through the transmission of expressed words and expressions."[66] As these hypothetical examples suggest, the possibilities are vast, and appropriate policies will need to be developed to avoid unintended consequences and misuse.

Creating an all-photonics network will require investing in research and development that leads to improvements in advanced materials, manufacturing processes, and devices.[67] Advances in fiber coupling, laser integration, and thermal management need to be developed. Chemicals added to photonic products will need to be reviewed and potentially improved, as some have been deemed hazardous and restricted through environmental regulations.[68] As the United States and its allies invest in R&D for these efforts, they must be vigilant about competitors using state-backed acquisitions and investments.[69] China is making significant investments in this area as well, and in 2017, it successfully tested the first integrated quantum communication network using optics technology.[70]

LEO Constellations

LEO satellites have a wide range of applications for remote sensing, global navigation and positioning, and communications. This section focuses in particular on the communications applications of LEO satellites, which have the potential to provide high-speed, low-latency global broadband. By helping to reach rural and underdeveloped areas, LEO constellations could play an important role in closing the digital divide. They could also allow U.S. companies to provide connectivity to rural markets and less developed countries where Chinese firms are the incumbent providers.

LEO satellites have several unique features. The prevailing approach to satellite communications uses geostationary (GEO) satellites, which orbit at 35,786 km above earth's surface and maintain their position by orbiting at the same rate that Earth turns, allowing a single GEO satellite to provide partial coverage of the Earth's surface. LEO satellites orbit at much lower altitudes, typically 500–2000 km, which allows them to provide lower latency. They change ground position quickly, passing into and out of a user's view in several minutes. To provide continuous coverage, LEO constellations are designed to include hundreds or thousands of smaller satellites. This also makes LEO constellations potentially more resilient, allowing the constellation to continue functioning even if several satellites fail.

A new wave of LEO constellations is emerging with better odds of success. The first wave of LEO constellations began in the 1990s, but ultimately failed due to financial and technical challenges. Today's LEO constellation proposals benefit from several advances since then: improvements in antenna development and processing, use of frequencies that allow higher data rates, predictive analytics and network optimization capabilities, and lower launch costs. Some constellations will use intersatellite laser links, which have the potential to lower latency rates, reduce the need for ground infrastructure, and help these systems outperform their competitors.[71]

Questions about commercial viability still persist. Building and maintaining LEO constellations is expensive. Deploying a fully operational system could cost anywhere from $5 billion to $10 billion, with operating costs upwards of $1 billion to $2 billion a year.[72] LEO satellites have lifespans of five years or less (compared to 15 years for a GEO satellite), making replacement relatively frequent, impacting costs as well as everything from supply chains to manufacturing to launch and operations.

Given these costs, LEO constellations are unlikely to significantly increase connectivity in low-income countries without government support. SpaceX, which is building the largest constellation, is currently charging beta testers $499 for equipment and $99 a month for service. Even if these costs decline significantly with improvements in scale and manufacturing experience, they will remain out of reach for many of the world's potential users. More immediate use cases for LEO constellations include wealthier users, governments, and businesses operating in remote areas, including maritime and aviation applications.

U.S. companies are at the forefront of these developments. SpaceX's Starlink constellation has a thousand satellites in orbit, including two dozen equipped with intersatellite links, as part of a much larger design that could include 12,000–40,000 satellites. It plans to achieve global coverage by the end of 2021, with subsequent additions to the constellation providing improvements in performance. Several other constellations could emerge in the years ahead, including Amazon's Project Kuiper, which has received approval to launch a constellation of 3,236 satellites. Facebook launched an experimental satellite last year and has released little information about its plans.[73]

Efforts are underway in Europe and Asia as well. After filing for bankruptcy in 2020, London-based OneWeb was acquired by the UK government and India's Bharti Group. OneWeb succeeded in recording an average latency of 32 milliseconds in 2019, and now plans to provide global commercial service by the end of 2021. The European Union is studying the feasibility of constructing a LEO constellation, although the effort remains at a very early stage with several competing goals being considered, including broadband, secure communications, and quantum cryptography.[74] Russia is developing an alternative system, but in terms of hardware, little has been seen.

China has been experimenting with several LEO projects to provide broadband in China and along the Belt and Road. The two main state-owned aerospace companies, CASIC and CASC, have both announced constellations, named Hongyun (with a planned 864 satellites) and Hongyan (with a planned 320 satellites), respectively. LinkSure and Galaxy Space, two private companies, are working on LEO broadband as well, but, like China's private aerospace sector writ large, lack the resources of their state-owned counterparts. In October 2020, China announced plans for a LEO constellation that includes 13,000 satellites, leading to speculation that it could merge the Hongyun and Hongyan projects.[75]

The LEO competition is much more complex than launching satellites and signing up customers. These constellations are all competing for priority spectrum rights, which the ITU grants, and they will need to gain market access in each of the countries they hope to serve. While there is an advantage in moving first to secure rights, profitability could be years away. The LEO race could turn into a marathon as companies pour resources into maintaining and operating systems. But the prize—low-latency, high-speed global broadband, with extra resiliency—could carry significant economic and strategic benefits.

High-Altitude Platforms

High-Altitude Platform Systems (HAPS) operate in the stratosphere (20 to 50 kilometers high) and have applications for broadband broadcasting, surveillance, remote sensing, and military-related services.[76] Consistent with the focus of this report, this section focuses on broadband applications. HAPS systems could fill gaps in connectivity, particularly in very remote or rugged terrain, by providing broadband to users and functioning as transmission links between users and networks. They have already demonstrated value in disaster relief and recovery situations, when ground networks are damaged or underdeveloped.

HAPS can potentially be used to provide both fixed broadband connectivity for end users and transmission links between the mobile and core networks for backhauling traffic. Both types of HAPS applications would enable wireless broadband deployment in remote areas, including in mountainous, coastal, and desert areas.

In some situations, HAPS may be rapidly deployed for disaster recovery communications, particularly because the use of inter-HAPS links allows for the provision of services with minimal ground network infrastructure.[77]

HAPS have been around for roughly two decades, mainly for military applications, and are becoming more sophisticated due to several advances in technology.[78] Composite materials are facilitating the production of lighter aircraft, while improvements in battery density and solar panel efficiency are extending their flights, and solar antennas are improving their range and performance. The most promising applications for HAPS involve integrating them with other connectivity sources, including both ground-based networks and satellites, to complement those systems and fill gaps in coverage.

Commercial viability remains a challenge. Alphabet's Loon project, for example, was designed to provide internet access using lightweight, high-altitude balloons. The balloons themselves were relatively inexpensive, and Alphabet logged significant amounts of flight and testing time, refining the technology and even contributing to disaster relief efforts. Yet even this system was too expensive for many users in areas without broadband access, who ultimately could not afford 4G handsets. As the project's CEO explained in January when announcing that Loon was being terminated, "While we've found a number of willing partners along the way, we haven't found a way to get the costs low enough to build a long-term, sustainable business."[79]

Other companies are hoping to avoid a similar fate. HAPSMobile, a joint venture between SoftBank and AeroVironment, has been experimenting with an autonomous glider that has solar panels on its wings and conducted a successful test flight last year.[80] Their service is being designed to supplement existing networks rather than directly serve individual consumers.[81] Thales, BAE Systems, and Prismatic are all working on similar solutions.[82] China's CASIC is working on a solar-powered drone network called Project Feiyun and a stratospheric aircraft to provide emergency service called Project Kuaiyun.[83]

HAPS face some challenges similar to those of LEO systems. HAPS require a large number of aircraft in the sky, and as such need sufficient mechanisms for autonomous flight control. In order to be deployed globally, they also require individual country approval for landing rights and regulation compliance. The HAPS Alliance, which includes companies from the telecommunications, technology, and aerospace industries, is working to promote HAPS and develop standard product specifications and interoperability.[84]

5

Recommendations

The economic and technological trends discussed above point toward several priority areas for action. As the United States looks toward 2030, it should articulate a vision for global connectivity, scale promising technologies, and compete in tomorrow's markets. Bridging the domestic and international dimensions of this competition will be critical. With that overarching goal in mind, the efforts described below include actions at home, with allies, and in developing markets.

Articulate a Vision for Global Connectivity in 2030

The United States should put forward its own long-term vision for global connectivity, one that benefits middle class Americans, aligns with key allies, and appeals to developing countries. These audiences have more in common than often realized, with citizens and communities around the world using technology to pursue shared aspirations. They can also face common barriers to access, meaning that solutions to expand access in the rural United States, for example, may also find applications to expand access in rural markets overseas. Similarly, smart city systems, a key area discussed further below, offers benefits with broad appeal.

As the United States formulates its own vision, it can draw inspiration from allied efforts already underway. The European Union, for example, has put forward digital targets for 2030 that include an emphasis on secure and sustainable digital infrastructure.[85] Japan's Beyond 5G initiative also looks ahead to 2030 and considers how digital infrastructure can contribute to an inclusive, sustainable, and dependable society.[86] Both visions include areas of common interest, and reflect common values, offering an opportunity for deeper cooperation.

The United States can also build on its own recent efforts. Two important principles, "free" and "open," are already being emphasized in the United States' approach to the Indo-Pacific region, a key area for growth. These principles have been echoed in statements by key U.S. allies, providing a basis for further cooperation, which will be critical given finite resources. These principles could be expanded to include an emphasis on "resiliency" or "sustainability," to include environmental, social, and financial dimensions. That emphasis advances U.S. interests, aligns with key allies, and draws a contrast with competing alternatives.

Scale Promising Technologies

Leverage domestic investments. There are several immediate opportunities to leverage domestic investments, including a domestic infrastructure package, efforts to "rip and replace" Huawei equipment in rural networks, and using proceeds from the Federal Communications Commission's spectrum auctions. Providing incentives for U.S. operators to accelerate 5G deployment and adopt Open RAN, for example, would provide a strong domestic base to support exports to foreign markets. U.S. government procurement decisions, especially Defense Department investments in future communications networks such as LEO constellations, could also produce broader positive spillovers. Increasing federal support for R&D would also help over the longer term.

Create an allied "accelerator" fund. As part of broader allied cooperation on technology, a dedicated "accelerator" fund could help navigate technological and operational challenges that naturally come with deploying new technologies. This fund would not replace the need for basic and applied R&D or incubators, all of which focus on earlier stage concepts, and should be pursued as well. But it would help scale systems that have already demonstrated potential. Because the focus is on later-stage development and deployment, some challenges that earlier R&D faces, such as those around intellectual property rights, might be easier to address. The accelerator could also support pilot projects that allow allied companies to build habits of cooperation and demonstrate the value of their systems in key developing markets.

Partner with regional anchor markets. The United States and its allies should approach large regional markets as partners rather than customers, giving them a tangible stake in the development and production of emerging communications technologies. This approach can be extended to other countries as well, of course, but could begin by focusing on larger markets. Promising examples include NEC's Open RAN lab in India and the Telecom Infra Project's Community Lab in Indonesia. In addition to helping remove barriers to market access, this approach could over time lead to more resilient supply chains and build support for the adoption of preferred standards.

Compete in Tomorrow's Markets

Expand financing for third markets. The United States and its allies should expand their financial support for networks in third markets. The challenge of expanding access to global networks is, at its core, a financial challenge. The sheer need for investment, as underscored by the ITU and other estimates referenced above, exceeds what any single country is likely to provide. The U.S. Export-Import Bank has taken encouraging steps by lowering domestic content requirements, and the U.S. Development Finance Corporation has been working more closely with Australia and Japan. Bringing European partners on board could expand the potential pool of resources. The United States and its allies should also work together at the World Bank, regional development banks, and other international financial institutions to mobilize more resources toward digital infrastructure.

Increase technical assistance. If the United States and its allies want other countries to embrace new ways of building networks—like Open RAN—and new systems, providing financial support and hardware is necessary but not sufficient. Technical assistance is critical to realizing the benefits of these systems and minimizing risks. The complexity that comes naturally with adopting new systems requires that this assistance become a default part of the "allied technical package," rather than an occasional add-on. Assistance should be concentrated on early-stage support to decisionmakers in foreign markets as they are planning systems, conducting cost-benefit assessments, and making procurement decisions. The United States and its allies should also connect stakeholders in developing countries with each other, forming a mutual support network for sharing experiences and expertise.

Promote a high-standard "smart city" model. Several economic and technological trendlines highlighted above converge in cities. Seizing the opportunity that the world's urban growth presents, the United States and its allies should put forward a higher-standard model for smart cities. For example, they could offer a "Sustainable City" certification, along with financial support, that emphasizes commercial viability, energy efficiency, social safeguards, and data security. This is another area where U.S. domestic and international efforts strongly align. More cutting-edge examples of U.S. smart cities will position domestic companies to succeed abroad.

Start Today

The actions above are only a start. They focus primarily on emerging communications technologies and developing economies, the two areas examined in this report. Other important areas include, for example, adopting a national data privacy framework, reducing foreign barriers to data flows, encouraging immigration to strengthen the human capital that makes innovation possible, preventing unwanted tech transfer, and global standard setting. Other promising communications technologies not examined above are likely to emerge in the coming decade as well. But if the United States wants to occupy a position of strength in global networks in 2030, it must start building that future today.

6

About the Authors

Jonathan E. Hillman is a senior fellow with the CSIS Economics Program and director of the Reconnecting Asia Project, one of the most extensive open-source databases tracking China's Belt and Road Initiative (BRI). Hillman has testified before Congress, briefed government officials and Fortune 500 executives, and written on economics, national security, and foreign policy issues for the *Financial Times, Wall Street Journal, Washington Post*, and other outlets. He is the author of *The Emperor's New Road: China and the Project of the Century* (Yale University Press, 2020) and *The Digital Silk Road: China's Quest to Wire the World and Win the Future* (HarperCollins, forthcoming).

Laura Rivas is a researcher with the Reconnecting Asia Project. She holds an M.A in security studies from the War Studies Department at King's College London.

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