FIVE THINGS TO CONSIDER WHEN ASSESSING THE IMPACT OF PRC DIGITAL INFRASTRUCTURE

Kathy Szot and Nancy Ross

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Introduction

Assessing the many factors propelling the increasingly automated, hyperconnected, smart environments deployed around the world can be challenging. Analyzing these aspects of Digital Silk Road initiatives can help inform and guide actions to counter the People's Republic of China's strategy for global digital dominance.

The ICT Technical Stack

A "Tech Stack" approach can be used to frame and organize the wealth of rich, dynamic, and diverse information and communications technology (ICT) to help analyze and identify potential areas of risk and opportunity. This approach integrates aspects of systems engineering, intelligence collection and analysis, and development of relevant socio-technical context. The goal is to generate actionable risk analysis to help identify, prioritize, and guide the development of courses of action for U.S. government stakeholders, allies, and partners.

We highlight five considerations related to studying the Tech Stack, and explore examples where the Tech Stack approach was used to assess the People's Republic of China (PRC) digital infrastructure in Africa.

The Tech Stack's basic composition can be oriented around common components found in many ICT environments, aligned generally with the traditional layers of the internet model (e.g., connectivity, internetworking, services). Examples of components may include facilities (e.g., data center, SATCOM) and service-related elements (e.g., cloud, wireless, internet service provider [ISP]) found within an end-to-end ICT environment (see **Figure 1**). In addition to these components, end user devices and platforms should also be included.

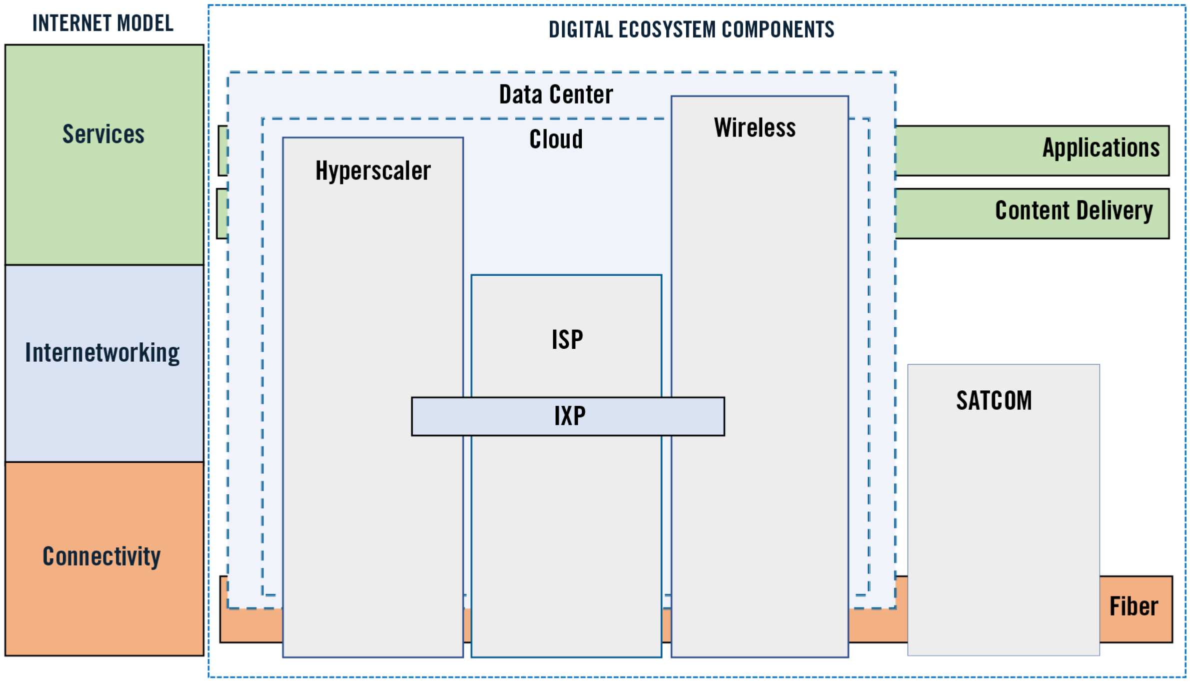

FIGURE 1. SAMPLE ICT ENVIRONMENT

Consideration 1: Start with Systems Thinking

View the environment under study as a system. The system can be decomposed into constituent parts, starting with identification of the relevant digital ecosystem elements.

Viewing the Tech Stack from a systems engineering perspective encourages examination of not only the technology but also the people and processes involved in the system of interest. Actors that provide value in the ecosystem may be aligned not only with the ecosystem components and internet layer functionality, but also with overarching systems aspects such as operations, administration, management, and provisioning, and relevant ICT-based services and applications. **Developing socio-technical context for this data is valuable and can be guided by established best practices in analytic tradecraft and all-source analysis (i.e., capturing details on sourcing, identifying areas of uncertainty, exploring, and presenting alternatives), providing useful, relevant information beyond what is generally known.**

A brief recap and relevant points about some of the highlighted component parts:

“TECH STACKS” FACILITATE THE CREATION OF A STRUCTURED VIEW OF THE INFORMATION AND COMMUNICATIONS TECHNOLOGY EMBODIED BY THE PRODUCTS, SERVICES, AND CAPABILITIES THAT COMPRISE CHINA’S DIGITAL SILK ROAD

- **Data centers:** As facilities that typically house ICT equipment enabling connectivity, internetworking, and services, including data (content) storage, data centers need to be resilient, scalable, and increasingly software-defined. Sustainable and economical energy and cooling solutions are critical, as is overall operational efficiency. Different data center models exist, and identifying stakeholders with financial interests in the facility may be of use in developing socio-technical context. PRC influence with data centers in Africa may be readily identifiable or may only be visible after following an investment trail or analyzing partnerships and collaborations. Wingu.africa is the data center owner and operator of the Djibouti Data Center (DDC) and is building two data centers in Ethiopia; controlling interests in Wingu.africa are not fully known [1], [2].[1]
- **Clouds:** Consistent with the definition captured by NIST, cloud computing includes many different types of services that can be public, private, or some combination thereof. Cloud capabilities are foundational to many ICT solutions, even in developing countries. National data sovereignty concerns may focus on cloud service provider data handling and data storage location(s). Some innovative cloud services may also fuse different ICT components, such as with satellite ground station-as-a-service offerings.[2]
- **ISPs:** Internet service providers are companies that provide access to the internet through broadband services. Connectivity methods (sometimes referred to as “last mile”) can be through a variety of means, such as fiber, digital

[1]It is not known whether the international investors for wingu.africa include PRC entities; Wingu.africa entered the market in partnership with an internationally owned company with local shareholders.

[2]Examples include https://aws.amazon.com/ground-station/ and https://azure.microsoft.com/en-us/blog/introducing-azure-orbital-process-satellite-data-at-cloudscale/

subscriber line (DSL), ethernet, wireless (e.g., mobile or WiFi), or satellite. Non-broadband methods include dial-up services via phone lines, although many developing countries in Africa "leap frog" older methods (e.g., dial-up, DSL) and skip to newer methods (e.g., 4G/5G, fiber).

- **IXPs:** Internet exchange points facilitate the interconnection of networks and exchange of internet traffic, ensuring data can be more efficiently and resiliently routed between senders and recipients. IXPs are viewed as a "fundamental bootstrapping step in the development of a region's communication infrastructure" [3]. The number of IXPs in Africa has more than doubled in the last ten years, aided in part by the Africa 80/20 initiatve sponsored by the Internet Society [4]. Being able to route traffic locally results in several gains, including lower latency and costs, and is also linked to data sovereignty interests and maintaining national data residency.
- **Hyperscalers:** These are companies focused on extremely large-scale, efficient, and cost-optimized delivery and management of compute, storage, and networking capabilities. Hyperscaler facilities may include IXPs and content delivery network nodes. Some hyperscaler companies are categorized as operators (e.g., Amazon, Google, Facebook, Microsoft, Alibaba) and others as platform companies (e.g., Oracle, Baidu, China Telecom) [5]. Real estate investment trust companies (e.g., Equinix, Digital Realty) that lease space are also important stakeholders in this category [6].
- **Wireless:** These providers offer mobile and WiFi services. Many developing countries have used wireless to leap frog legacy telecom technologies, such as using 2G/3G/4G-based mobile technologies to provide voice and data services instead of copper cable-based infrastructure. As a result, developing countries may have a different set of mobile network evolution issues. Focus currently is on deployment of 5G-based capabilties in many parts of the world; the PRC has been working to establish a leadership role with 5G, with active roles in industry standards as well as application of 5G in targeted vertical industries, such as transportation and logistics.
- **SATCOM:** Satellite communications (SATCOM) refers to the use of satellite technology in the field of communications. Common SATCOM services are voice and video calling, internet, fax, television, and radio channels. SATCOM provides communication capabilities spanning long distances and operates under conditions that are either infeasible or impractical for other forms of communication [7]. SATCOM is used by commercial, private, military/defense, and disaster relief operations. In addition to SATCOM satellites, there are navigational satellites (e.g., GPS, Beidou) and military satellites that connect into the ICT ecosystem.

While the discussion on systems thinking began with a decomposition effort, an understanding of the integrated, holistic environment should not be set aside, especially as it concerns critical aspects such as systems integration activities and identification of systems integration stakeholders. Understanding the value chain may help focus that effort. Additionally, some ICT environments may be viewed as part of a larger system; for example, smart environments are often linked together, such as with the PRC "Shekou" model [8] that binds together ports, parks, and cities into an interrelated and ultimately integrated system.

Consideration 2: Maintain Data Awareness and Protection

Along with the focus on components and functional layers of the internet model, the data that is associated with the system requires attention. **ICT environments are inherently data rich and continuing to increase in data volume, both in terms of data transmitted and received (i.e., bandwidth) and in the quantity and type of data created and consumed by interconnected devices.** Data-driven technologies such as artificial intelligence (AI) and digital twins benefit from access to "big data" datasets, and evolving software-defined infrastructure can use data to improve adaptability, defenses, and performance. The integrity, privacy, and availability of data are essential.

To improve data assurance, an awareness of the types of data in an environment is required; once awareness is achieved, then the associated data governance, protection, and sharing considerations can be included in Tech Stack–related analyses. Following the path of service chains and workflows can help reveal the nature and types of data within the system. These are some data examples: (1) data submitted by users as part of a service (e.g., user credentials); (2) data about system users, gathered by system operators (e.g., user account information, tracking of data usage); (3) management data (e.g., operational status of equipment, traffic statistics, error logs); (4) enabling data (e.g., location data used by mobile apps, video used by automated vehicles); and (5) data from sensors embedded within the system (e.g., position, movement of smart containers).

Hyperscalers are increasingly building data residency functionality into their data storage solutions, as well as establishing new data centers in a growing number of geographies. While Huawei initially leased data center capacity[3] to provide cloud service offerings such as in South Africa in 2019 [9], it has since expanded its strategy by financing and constructing new data centers in partnership with countries, such as Senegal, that are seeking to repatriate their state data and platforms in-country [10].

PRC-related companies creating intelligent ports solutions (e.g., CMG, IZP) appear to be establishing them predicated upon creation and exploitation of big data analytics. Furthermore, while some data analysis and use may occur nearby the data sources (e.g., within the port), the proximity of seaports to high bandwidth undersea connections (e.g., the PEACE cable project) facilitates the secure transport of large volumes of port data (and related port-park-city data) to distant data centers (e.g., the One Belt One Road big data centers based in China) [11]. This is of particular concern when indications of potential dual use (i.e., civilian and military) with ICT have been identified with PRC activities in locations such as Djibouti [12].

There is a need for secure, trusted, interoperable solutions to share data within and across ICT environments, especially those that include multiple stakeholders. Smart ports are a prime example of this and encompass seaports and airports. There is industry recognition of this need; however, efforts to address it are still nascent. The European Union DataPorts project was funded in 2020 to explore creation of an integrated data platform with associated data governance, to enable sharing of data among seaport stakeholders in a secure, private, and trusted

[3]Huawei noted that it "…is leasing a data centre in Johannesburg from a partner from where it is deploying localised public cloud services based on local industry policies, customer requirements and partner conditions."

manner [13]. Traxens, one of the firms involved in the DataPorts project, has a smart container solution that provides data on position, movement, ambient temperature, door opening, and shocks [14]. Traxens' first investor was CMA CGM [15], a company closely aligned with China Merchants Holding Group and an investor in the Djibouti International Container Terminal [16].

Consideration 3: Who is in Control?

Control and influence are important dimensions to the discussion of the ICT Tech Stack. **After decomposing the end-to-end ICT system of interest, and identifying the data that flows within it, consider which entities are managing and controlling the infrastructure and data.** This consideration focuses on the ICT digital ecosystem as much as it does on the actors and their objectives and incorporates insights from accompanying socio-technical analysis. Some aspects of interest to highlight encompass a) open platforms and industry standards; b) partners and collaborators; and c) effects and impacts.

Some of the ICT components of interest may be labeled as open or vendor neutral, or may be identified as compliant with industry standards or agreements. While these attributes may be viewed as positives, adherence to these principles and references requires further examination to gain insights into their primary influencers. The type and nature of industry standards leadership positions and technical contributions for ICT domains may indicate where standards have been impacted by strong influencers, such as those who have been identified with PRC activities [17].

Industry groups such as the International Port Community Systems Association (IPCSA) need this type of scrutiny as well. Consideration of influence also applies to contributors to open-source software, and to partnerships and collaborations. Identifying the operators of ICT systems is important, as is being aware of the suppliers of management, business, and operational support systems that will be used. Systems integrators also have a potentially influential role in how components are incorporated and managed in the overall system.

A detailed understanding of the ICT supply chain may also yield important knowledge; aspects of supply chain risk management may be applicable, helping to identify all the firms that may impact system operation. The potential concern for backdoors inserted within the manufacturing process has been raised, for example with undersea cable systems [18] that carry data and connect to the ICT.

Some governments may impose blocking or control measures (e.g., filtering, censorship) on content in ICT systems at the national level for content entering and/or leaving a country; this is sometimes referred to as a "digital iron curtain" or "great firewall." While the PRC and Russia provide well-known examples of countries establishing control boundaries between their national networks and the global internet, there are concerns that other countries will implement and exercise such capabilities following these examples. As an illustration, control over social media platform content is the focus of the recent Twitter block imposed by the government of Nigeria [19].

Consideration 4: Evolving Technology

There are many dimensions to the rapidly changing and evolving ICT technology space. The increased transformation and shift to software-defined functions and infrastructure as code is an important trend within the ICT industry. One result of this trend is that the digital ecosystem component definitions and locations are more dynamic than with prior traditional networks. For example, the 5G Core service-based architecture has a modular, cloud-native based structure that allows for virtualized functions to be specified individually and to have interaction between functions using service-based application programming interfaces. This approach can be coupled with software-defined networking and network functions virtualization concepts and use of centralized control and orchestration capability. **The software-defined infrastructure trend has benefits from the perspectives of agility, resiliency, efficiency, and potential cost-effectiveness, but it also presents new challenges when assessing where PRC-related products may be in use or where PRC entities may have control or influence within ICT systems.**

Smart ports are environments where many technologies are combined and integrated in different ways to achieve specific goals, such as reducing labor costs, improving security and safety, and increasing work efficiency. AI, internet of things (IoT), cloud computing, big data, edge computing, and security were noted as integral to the 5G-based smart port solutions that China Mobile has been developing with Huawei and ZPMC [20]. The 5G domain can serve as a valuable focal point for identifying where impactful PRC technology-related actions are occurring and potentially posing risks [21]. Specific 5G use cases noted for smart ports include smart tallying/inventory, remote control of rubber tyre gantry cranes, and unmanned container trucks [22]. Specific applications running on the multi access edge computing platform include a machine vision application, augmented reality assistance application, autonomous driving application, and remote-control application. BeiDou's GNSS system supports port operation vehicles, ships, and port operation equipment for positioning, monitoring, and collision avoidance [23]. The integration of these technologies in the context of port workflows can offer value to port stakeholders, but these technologies also pose potential risk regarding data collection, analysis, and exploitation, in addition to being potential points of control and manipulation with port-related data.

Two other PRC areas of interest are Huawei's development of their Harmony mobile operating system (OS) and application of AI. HarmonyOS is intended to compete with Android, and some predict that Huawei may target African countries as markets for mobile and IoT devices based on this operating system [24]. Applications of AI within smart environments are another area to keep in focus; while the technology may offer solutions to help address challenges such as traffic congestion within cities, there are already significant privacy and surveillance-related concerns [25] being raised with projects such as Alibaba's ET Brain for smart cities (called City Brain) [26]. ET Brain is also being applied to the aviation, industrial, and agricultural sectors. These Alibaba examples, like Huawei's "safe cities" [27][4] examples, highlight complex systems in which there is integration of multiple ICT technologies, and potentially significant risk with PRC implementations.

[4]Note: Huawei "Safe Cities" have been identified in Ghana, South Africa, Mauritius, Botswana, Nigeria, Ivory Coast, Uganda, Madagascar, Kenya, Ethiopia, Angola, and Cameroon.

Consideration 5: Identify Areas of Potential Risk

Identification of risk is dependent on threats and vulnerabilities, probabilities, and impact, along with definition of potential countermeasures or mitigations. Tech Stacks may be useful to high-level risk identification, helping to guide associated information collection and organization for further analysis, which may reveal general patterns or trends that had not been uncovered previously. As one example, an analysis of smart and intelligent port solutions identified PRC entities that are known to be actively developing and deploying solutions. However, more in-depth study revealed that the PRC's influence and presence are more pervasive than previously realized, specifically in areas such as port operating systems, logistics, and big data analytics [12].

Tech Stack–guided analyses may reveal the potential risk of vendor lock with ICT solutions, especially when coupled with socio-technical context. Use of this approach with the Digital Silk Road (DSR) project helped to identify a pattern of influence that the PRC has in specific parts of the digital ecosystem (e.g., data centers, cable landing stations) and with certain ICT environments (e.g., intelligent ports). This type of analysis may also highlight where a more open framework (e.g., for smart ports) may enable increased competition and innovative solutions, such as are being pursued with 5G O-RAN efforts [28].

With the global reliance on connectivity, risks related to internet disruptions are also of concern. Studies on internet disruptions have revealed that several categories of events occur, and different approaches are used when those disruptions are intentional (i.e., not an environmental or accidental outage) [29]. Content blocking, throttling, and sub-national and national shutdowns are different categories of intentional disruptions. The risk of intentional disruptions is a greater concern with authoritarian governments that seek to control their citizens' use of the internet. By understanding how intentional disruptions are enabled (e.g., DNS blocking, IP blocking, URL blocking) [30], and specifically with which portions of the ICT digital ecosystem (e.g., cloud provider, ISP) these are accomplished, we can better assess these risks. While this type of risk is well-known with countries like Russia, which has publicly announced testing the separation of Russia's networks from the global internet [31], in developing countries in Africa this risk may not be well-understood and may benefit from identification of the actors controlling the relevant ICT components and network operator roles.

Finally, the potential risk posed by the PRC's ability to collect, mine, and use data flowing through the eastern Africa Tech Stacks needs to be considered. Ensuring development of more open Tech Stacks and operational transparency may reduce the risk of surreptitious collection of sensitive data.

Tech Stack Examples

Tech Stack views can be oriented, framed, and filtered to assist with analyzing various aspects of technical competition and to provide a basis for comparative analysis. For instance, a smart city or smart port Tech Stack view can provide an overall ICT context, including data producers and consumers embedded within that specific ecosystem. Alternatively, Tech Stack views can provide an in-depth focus on technology advances or research and development efforts for technologies such as software-defined networking, automation and use of AI, etc. Tech Stacks also provide the basis for temporal analysis about the evolution of ICT capabilities over time.

The following Tech Stack examples illustrate some approaches we used to highlight and analyze risk related to PRC digital dominance.

Djibouti Tech Stack

Limited information is available regarding the Djibouti ICT environment; however, based on insights gained from press releases and industry articles, Djibouti's Vision 2035 document, think tank analyses, and other public sources, we developed a Tech Stack view specific to Djibouti. While not meant to be exhaustive, it reflects notable actors in their relative space in the ecosystem (see **Figure 2**).

Djibouti's Tech Stack is dominated by Djibouti Telecom, currently the monopoly provider serving as ISP, wireless provider, and application provider for their mobile payment service, D-money. Djibouti announced plans to sell a minority stake in Djibouti Telecom, however details about the privitization effort are limited [32]. Identified PRC entities in the Djibouti Tech Stack include Huawei Marine Networks, ChinaNetCenter (also known as Quantil Networks), Hengtong LightHash, China Telecom Global, PCCW, and Altai Super WiFi, in addition to port-specific firms such as China Merchants Group, IZP, and Sinotrans.

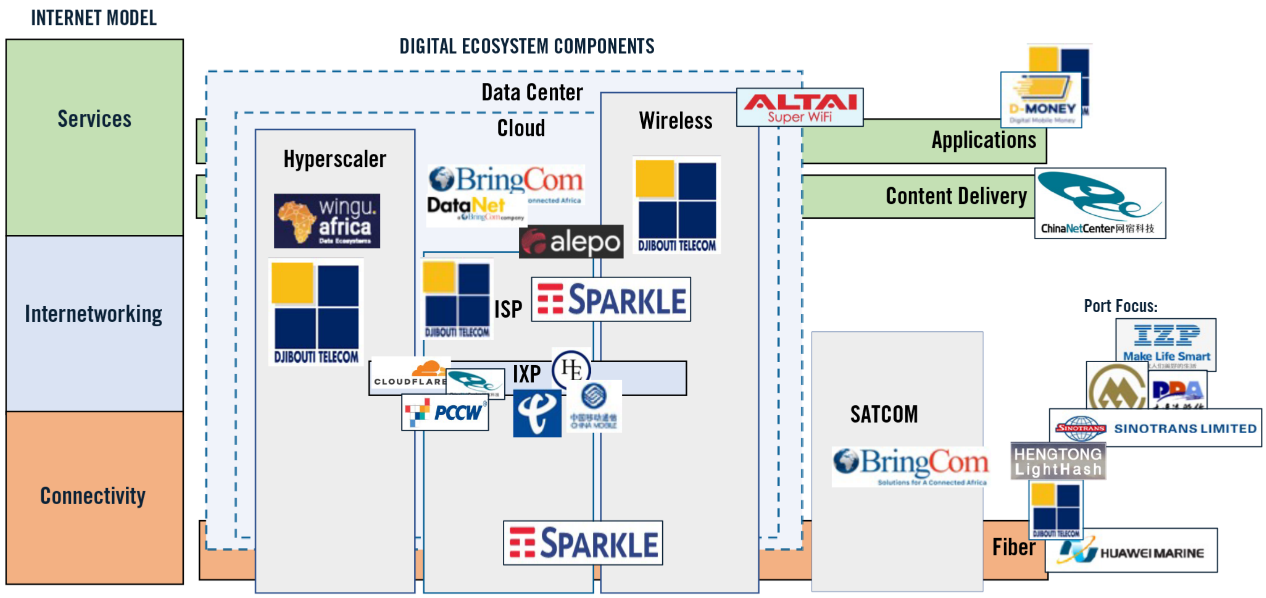

FIGURE 2. DJIBOUTI TECH STACK. JULY 2021: DJIBOUTI ANNOUNCED IT WILL BE SELLING A 'SIGNIFICANT MINORITY STAKE' IN DJIBOUTI TELECOM. NOTE: COMPANY LOGOS INCLUDED ABOVE ARE REPRESENTATIVE AND POSITIONED BASED ON KEY PRODUCTS, SERVICES, AND KNOWN CAPABILITIES.

[5] Alepo described Djibouti Telecom (DT) as "its long standing client" in 2015 when it was announced that DT would be upgrading to the latest version of Alepo's Service Enabler platform, which is considered "a complete carrier-grade BSS/OSS framework." While it is not known if Alepo is working with DT on 5G, they claim to be "…one of the industry's leading 5G Core vendors" and that they have "tactfully designed a 5GC solution comprising cloud-native 3GPP standards-compliant 5GC network functions (NFs) responsible for implementing subscription services, providing secured connectivity to subscribers, and handling charging and policy management."

While much focus has been on PRC engagement, there is also a western dimension to the Djibouti Tech Stack. BringCom and Alepo are two of the U.S. firms that have been identified.[5] BringCom provides satellite teleport services, has recently completed fiber deployment and acquisition of a Ugandan ISP, and is offering cloud and enterprise services in Djibouti and several other African countries [33]. Alepo is a provider of operational support system (OSS) and business support system (BSS) platforms that aid telcom providers with the efficient operation of their networks and delivery of customer services.[6] Alepo's partners include Altai Super WiFi, a Hong Kong–based firm whose Super Wifi A8 series–based station solution is currently deployed in Djibouti's Doraleh Container terminal ports, providing wireless coverage for daily port operations [34].

Power is an important facet of ICT infrastructure and bears mention here. The "DDC's main power supply is generated from renewable hydro sources located in Ethiopia" and is served by the same substation power distribution facility as the two cable landing stations in Djibouti [35].[7] In the 2020 announcement of their Cape Town Region opening, AWS noted that their offering is "comprised of three availability zones, each zone with one or more separate data centers each with independent power, networking, and connectivity" [36], highlighting the importance of power to data center resiliency.

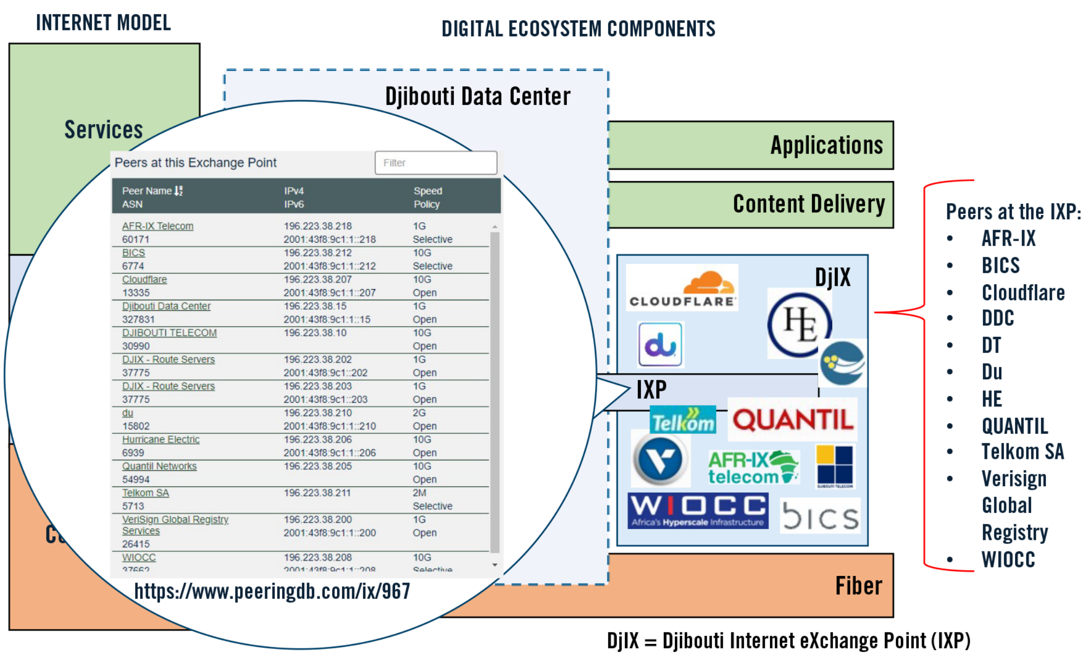

FIGURE 3. DDC AND DJIX: AN IXP VIEW

[6]A related PRC note: Alibaba's WhaleCloud company (based on an acquisition of ZTESoft) also offers cloud and OSS/BSS services specifcally targeted to African telecom providers; MTN Rwanda is using Whale Cloud's digital BSS suite to transform legacy systems, including billing and customer relations management platforms. To date we have found no indication of WhaleCloud use in Djibouti.

[7]In this 2018 interview, DDC Chairman John Melick III notes that the Djiboutian cable landing stations are both operated by Djibouti Telecom.

Internet eXchange Point (IXP) Component View

We took a deeper look at the IXP component of the Djibouti Tech Stack in an effort to gain additional insights into the technical capabilities and actors within the Djibouti ICT landscape. The Djibouti Internet Exchange Point (DjIX) is housed as a separate facility within the DDC (see **Figure 3**). DjIX, launched in 2016, is reported to have 14 connected networks with a combined peak traffic rate of 11Gbps [37]. By examining the publicly available peering information for DjIX we can learn more about the providers and networks that are interconnected in Djibouti. Most of this connectivity is transit traffic due to the significant cable landing activity in Djibouti and their strategic geographical position in eastern Africa. This is consistent with socio-technical observations regarding the "digital paradox" in Djibouti [16], where international data traffic uses Djibouti as a transit point and significantly less traffic is originated or destined for users within Djibouti.

Through examination of DDC peering information, we observe the presence of Quantil Networks, also known as Wangsu S&T or ChinaNetCenter, a PRC content delivery provider. WIOCC, jointly owned by 14 major African telcos, including Djibouti Telecom, is also present. Attributes found in this peering information may offer some insight into other facets of the ICT environment, such as the capacity of the interconnections and whether they are IPv6 and/or IPv4 capable. Multiple sites[8] offer peering information, and there may be value in comparing data from several reliable sources. On the DDC's website, both China Mobile International (AS 58453) and China Telecom (AS 4134) are listed as networks that peer directly with the DDC, with both operating at 10G port speeds and both IPv4 and IPv6 capable. In 2016, China Telecom announced that DDC was chosen as an expansion, colocation, and interconnection location [38]. Peering information for Djibouti Telecom reflects other public peering exchange points (e.g., DE-CIX, DjIX, France-IX) in addition to private peering arrangements, including Interxion in Marseille. MRS2 is the Marseille data center where the Pakistan East Africa Connecting Europe (PEACE) cable landing station resides; Djibouti Telecom is peered at both Marseille data centers: MRS2 and MRS1. The connection with DE-CIX in Marseilles is 20G, with both supporting IPv6 and IPv4.

Tech Stack Extensions

Another way we explored PRC ICT influence and activity was via "extensions" to the ICT Tech Stack. In other words, specific portions of the end-to-end ICT environment were examined more closely, such as the undersea cable and satellite connectivity into the ICT Tech Stack. For example, the DSR task studied the PEACE cable system due to its PRC ownership, with particular focus on the landings in Djibouti and Marseille. Connections from undersea cable systems into the Tech Stack occur in the connectivity layer via terrestrial cable after it has transitioned from the submarine segment. Undersea cables connect via cable landing stations that convert optical signals to digital signals. When satellite system connections are via a teleport, it converts satellite signals to digital signals. Please see the companion whitepapers [39], [7], on these topics for further technical details and identification of potential areas of risk and mitigations.

[8]Examples of sites include: peeringdb.com (note: historical data from this site has been used to analyze trends over time with IXP expansions and associated impacts, ref: https://arxiv.org/pdf/1810.10963.pdf), Looking Glass Data (providing insight into routing tables, useful with troubleshooting routing issues, ref: https://bgp4.as/looking-glasses), and location-specific data such as found at http://www.djiboutidatacenter.com/en/page/peering-networks.

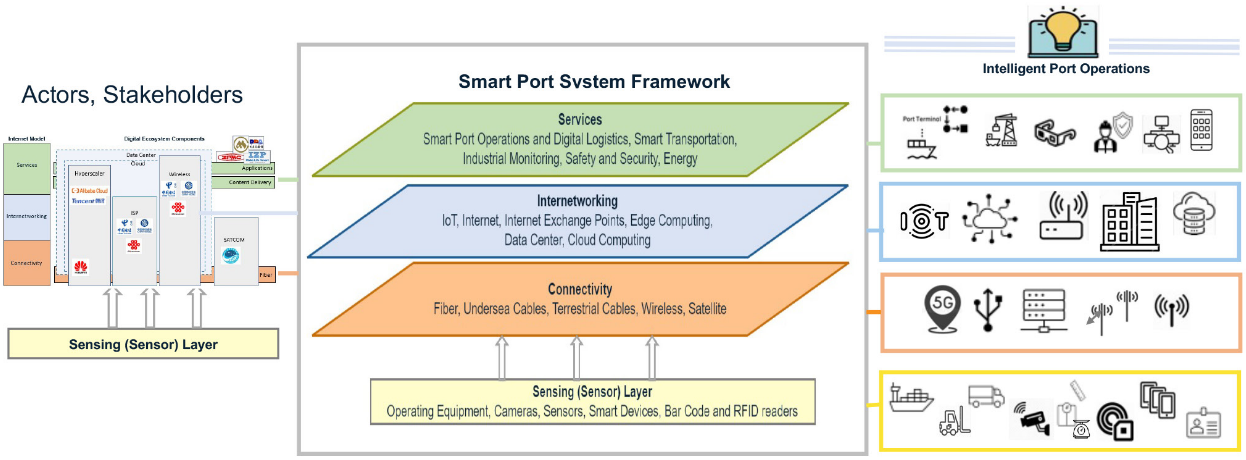

FIGURE 4. SMART PORT SYSTEM FRAMEWORK. A SMART PORT INTEGRATES SENSING AND ICT CAPABILITIES TO ENABLE EFFICIENT INFORMATION MANAGEMENT AND AUTOMATED OPERATIONS.

Smart Port System Framework

The Smart Port System Framework, our final example of Tech Stack usage, was compiled to help us better understand and organize facets of seaports for further analysis. The framework as depicted in **Figure 4** was inspired by elements of leading smart ports and smart cities projects. This ICT-centric framework aided in the data collection and analysis of the ports, especially where the PRC is actively involved. The analysis included PRC activities in the IPCSA industry group, oriented around development of port community systems that encompass both seaports and airports.

In building upon the Tech Stack foundation, a sensor layer was added to the Smart Port System Framework illustration for emphasis. Through this addition, we take a more focused approach to the devices that are interconnected within this environment. A sensor is a connected device whose primary or ancillary functions include collecting information and acting, potentially autonomously, based on its instantiation of connectivity, internetworking, and services and applications that it contains.

The final addition to the framework was considering the intelligent operations within the port. This effectively positions the various use cases of interest alongside the relevant sensors/devices, digital ecosystem components, and layers of the internet model. While **Figure 4** doesn't provide a precise positioning of some of these elements, it does draw attention to the multitude of connected devices and the workflows in which they are involved, and ideally highlights the various points of value to port stakeholders.

The PRC is actively leading intelligent port development, bringing together PRC state-owned entities, firms, and partners to research, trial, and implement advanced capabilities that will enable ports to meet their goals of improved efficiency, safety, and labor/cost savings. These advancements help the PRC move closer to its goals of leading the global supply chain. Please refer to the Smart Ports paper [11] for further details, observations, and recommendations.

Final Observations on DSR Tech Stacks

We found value in using the DSR Tech Stacks to organize, investigate, and assess implications from various points of view, such as for a country (e.g., Djibouti), an ecosystem component (e.g., IXP), a technology domain (e.g., 5G), and an environment (e.g., smart port). High-level Tech Stack views are notional and should be viewed as a guide to be adapted to the specific ICT area under study. Tech Stack content may only be current for a limited period, requiring a refresh of dynamic aspects such as emerging or evolving technologies (including new vulnerabilities or mitigations), ICT regulatory or policy positions, changes impacting actors (e.g., elections, new product releases, company acquisitions, partnerships, investments), and updates from industry organizations (e.g., standards development).

The DSR Tech Stack activities were based entirely on information from public sources. Much like software development approaches that "code low, deploy high" [40], there may be value for some stakeholders to use this approach in an unclassified environment and then port the results for use in other, secure settings.

Findings from associated analyses can be valuable input to the development of courses of action, modeling, or serious games. Patterns of interest may be revealed through study of these environments, helping to identify areas for further study. Early indications of trends may also be revealed. For example, some recently identified evidence of PRC activity in and around Mombasa may reflect an expansion or shift of PRC investment and focus from Djibouti to adjacent areas of strategic interest.

Working through the five considerations can prove valuable for identifying the most significant technologies, architectures, actors, partnerships, and government and commercial activities that are relevant to ICT environments under study.

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ABOUT THE AUTHORS

Nancy Ross is an Infrastructure Engineer at MITRE Labs providing technical and leadership expertise on enterprise architecture, cloud, and IoT in support of the Digital Silk Road. Prior to joining MITRE, Nancy served as Senior Vice President, Service Operations at Avaya Government Solutions leading government, commercial, and international telecommunications operations.

Kathy Szot is a Cybersecurity Engineer in the Cloud, Network, and Digital Service Engineering department of MITRE Labs. Kathy is a Group Leader and provides technical and leadership expertise pertaining to communications infrastructure, cybersecurity, and network engineering. Prior to joining MITRE, Kathy held multiple positions within Verizon including Director of IP Services Infrastructure, Director of Broadband Network Product Technology and Strategy, and Director of IP Network Architecture and Design.

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