IT UNIVERSITY OF COPENHAGEN

Emerging Technologies: The Case of Edge Computing

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Contents

1. Introduction

The following report arose as part of "Edge Platforms: Reimagining Digital Infrastructures", a research project developed at the IT University of Copenhagen and funded by Infinit (Innovationsnetværk for IT).

The aim of this report is to generate knowledge on the uses and limitations of edge technologies, as well as to design a business case for GI Networks, one of the project's industry partners. The first section grounds the notion of 'edge' and associated concepts by giving an overview of the current edge computing landscape. Following this is an analysis of the promises of edge computing as well as its drivers and consumers.. The final section is dedicated to the case company GI Networks, where we make a set of recommendations based on five use cases.

The empirical work and analysis presented in this report are based on a mixed methodology. This includes the design of, and participation in, two workshops with project partners, as well as interviews with same. We have also analysed multiple sectoral reports, including the Danish Data Centre Market 2020 report and the State of the Edge 2020 report.

This resource will be disseminated to project participants, academic staff and industry partners.

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2. EDGE COMPUTING

Understanding & Status

Edge Glossary

Edge Computing - The delivery of computing capabilities to the logical extremes of a network in order to improve the performance, operating costs, and reliability of applications and services. By shortening the distance between devices and the cloud resources that serve them, and by also reducing network hops, edge computing mitigates the latency and bandwidth constraints of today's Internet, ushering in new classes of applications. In practical terms, this means distributing new resources and software stacks along the path between today's centralized data centers and the increasingly large number of devices in the field.

Last Mile - The segment of a telecommunications network that connects the service provider to the customer. The last mile is part of the access network and is also the network segment closest to the user that is within the control of the service provider. An example of this is the wireless connection between a customer's mobile device and a cellular network site.

*extracted from the Open Glossary of Edge Computing V2

The initial stage of the internet was one where web browsers connected to servers by routing packets through a shared network system with the aim of getting data from one point to another. With rapid growth came the demand for instant page loads, high-fidelity websites, and even, today, movie streaming. These needs paved the way for content distribution networks and cloud technologies—materialized through hyperscale data centers. The 'cloud' has further segmented into four markets. Public cloud is the market most consumers and small to medium size organizations subscribe to, operating a pay-as-you-go pricing model typical of companies such as Amazon and IBM. Private clouds are more usual for large organizations concerned with having more control over their data's privacy and configurability. Community clouds are used by a community of users (usually quite small companies) and the infrastructure is shared by these organizations without relying on a major cloud vendor. And finally, hybrid clouds which are a combination of the other three types.[1]

Analogous to how 2010 heralded the "cloud revolution"—despite a lack of proof of value at that point—edge computing is now beginning to establish new business models and possible applications. If the transition to the cloud meant centralization of computing power and storage capabilities in the form of hyperscale data centers, the diversification of our digital infrastructure is pushing the industry towards partial decentralization, not as a replacement to existing topographies but as complementary to them. The notion of edge, in its most basic sense, refers to something that exists at the far-out periphery relative to something else. In computing, the same notion signifies the physical presence of processing and storage capabilities in close proximity to where those capabilities are needed.

Edge Glossary

Device Edge - is comprised of devices and servers located on the last-mile network towards the end-user side. These edge devices can take various forms: self contained end-point devices such as smart-phones, wearables and automobiles; gateway devices such as IoT aggregators; switching and routing devices, for example a network router or on-premise server platforms. For internet connection, these devices use wireless cellular or the cable system.

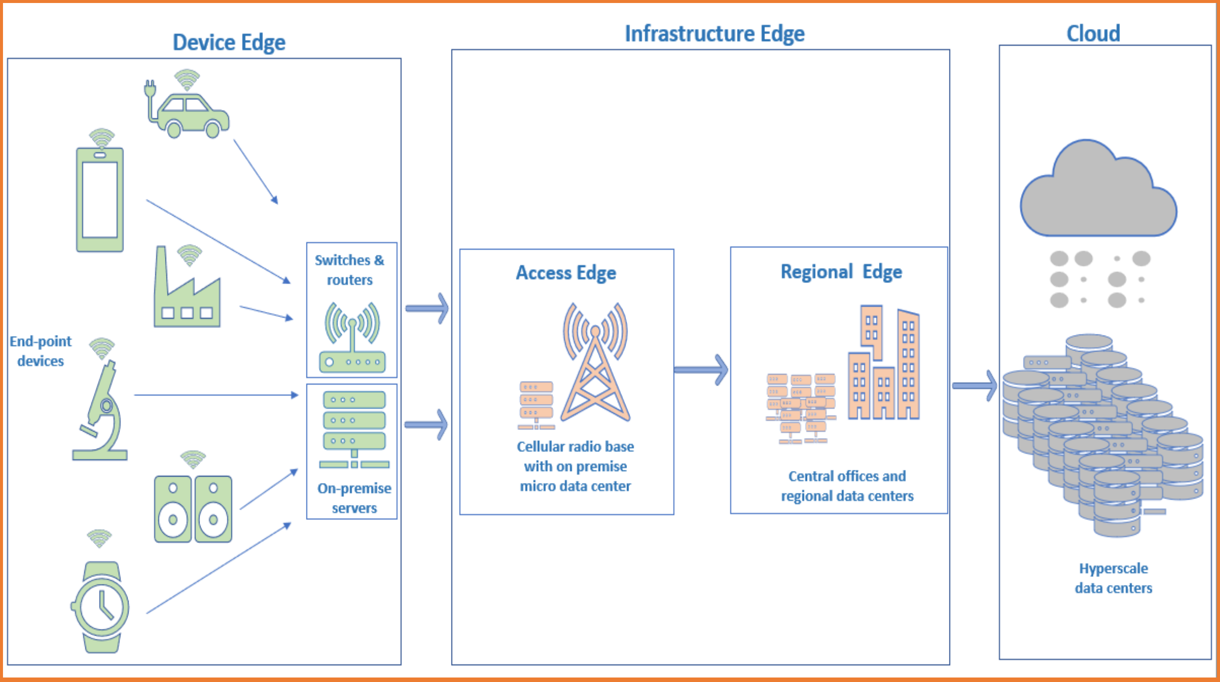
Infrastructure Edge - is situated on the "upstream" section of the last-mile network, between the device edge and the cloud. It consists of Access Edge, as compute platforms collocated with cellular radio base stations, access sites or aggregation hubs and Regional Edge made ofregional data centres and central offices. The distinction between device edge and infrastructure edge is made based on the physical location on the last mile network, the proximity to the centralized facility and the scale of computing capabilities and power consumption. An edge infrastructure can service multiple edge devices and numerically speaking, edge devices are in the range of billions whereas edge infrastructures in range of millions and hyperscale data centers are thousands. Both types of edges work in concert with each other and with the central cloud to form a complete edge to cloud architecture.

The current topography of digital infrastructures—where centralized cloud resources are the norm for accessing computing and storage power—suggests that "the edge" in computing terms is closer to the end-user, but at the periphery of hyper-scale data centers. Both cloud and edge computing paradigms use data centers, but they are of different sizes and positioned differently in relation to the end user. Understanding the difference between hyperscale and edge data centers is easier to grasp if one considers their consumption of electricity. The energy consumption of hyper-scale data centers depends on the computing needs of the public and private organizations that use them. The electricity use of a regional data center used for the public cloud, for example, ranges from 10's to 100's of megawatts, whereas a data center at the edge of the network uses somewhere in the range of 10's to 100's of kilowatts.

According to industry figures, edge computing—by decentralizing some parts of current infrastructural design—has several benefits. In terms of performance, lower latency enables real-time processing and brings with it the possibility of applications such as, for example, remote surgery and drone-based transport. When computing power is closer to the user, a large number of requests remain local, saving time and money, while also improving user experience. However, the effort to reduce latency for computation in the form of physical proximity represents only half the challenge. Although there might be a server next to a user, this does not mean that the data will follow this short path. Most current networks employ a topology which assumes a long route from departure to destination. The common procedure for current 4G LTE networks is for data to first be routed to a centralized facility before being sent for processing. This roundtrip would defeat the purpose of locally processing data as the data would have to travel both ways, thus adding more processing time. In the current setup, even though locally produced data is relevant for local use—traffic data, health records—it is, problematically, still being transported to, and owned by, the centralized cloud provider.

Placing computational power closer to the end-user has been driven by the rapid evolution of digital technologies. Increased automation has led to faster processing speeds as machine-to-machine transactions have grown.

The exponential growth rate in internet device connectivity has also meant more storage and processing capabilities, and accelerated data transmission. Automated infrastructures and the desire for multidimensional experiences require lower latency to provide safe and seamless encounters. The current trend towards continuous-delivery models and automated cloud infrastructure will accelerate the edge in ways similar to the growth of content delivery networks. The main obstacle is that many of the edge applications envisioned by experts are too expensive or impossible to deliver within our current data infrastructure configuration.



Edge Computing Architecture

It is only very recently that the private sector, research bodies, and academia have come together to establish a shared understanding and common definition of edge computing. *State of the Edge (SOTE)* is one of these initiatives; a 'vendor-neutral' white paper aiming to promote a commonly shared definition of edge computing. This white paper has put forward four assertions in an effort to define edge: "1) The edge is a location, not a thing. 2) There are lots of edges, but the edge we care about is the edge of the last-mile network. 3) This edge has two sides: an Infrastructure Edge and a Device Edge. 4) Compute will exist on both sides, working in coordination with the centralized cloud"[2]. Besides offering some form of definitional meaning, these assertions also provide an understanding of implementation opportunities in the digital chain.

[1] E. Yigitoglu, M. Mohamed, L. Liu and H. Ludwig, "Foggy: A Framework for Continuous Automated IoT Application Deployment in Fog Computing," 2017 IEEE International Conference on AI & Mobile Services (AIMS), Honolulu, HI, 2017, pp. 38-45, doi: 10.1109/AIMS.2017.14.

[2] State Of The Edge 2020: A market and ecosystem report for edge computing

3. EDGE COMPUTING

Expectations and Applications

The following section is dedicated to an overview of edge computing's current situation, future expectations, and upcoming applications, with a particular focus on the trends within Denmark. The section is comprised of two parts. The first, *the promises of Edge* gives an overview of what is driving edge developments, and how this new computing paradigm promises to respond to the challenges signaled through these developments. The second, *who drives and consumes edge services* gives an overview of the main industry players within edge computing. The purpose of this is to set the context for how SMEs can tap into the emerging digital infrastructure market. SMEs need the ability to fluidly navigate the market and be agile enough to pivot their strategies from technology trials into commercial operations. Current data infrastructure investments are based on user-specific applications, but the expectations for edge infrastructure development gravitate around platform-centric architecture.

3.1 The Promise of Edge

Edge promises to catalyze large investments in network upgrades, including optical fiber networks which are essential for the 5th generation of cellular wireless infrastructure (5G). Antennas capable of very fast connections need speed-matching underground fiber optic cables. These network upgrades have become even more relevant due to Covid-19's impact on work practices.

The need for fiber-based fixed networks has been made more visible during the pandemic as many employees have begun to work from home, increasing the demand for faster and more stable connectivity that local data arrangements are struggling to provide. These network upgrades could serve as a base for incremental edge deployments such as, neighborhood data centers and street-side cabinets, that in turn, can deliver real-time data analysis with decreased latency and more bandwidth.

The desire to develop wireless augmented reality, autonomous vehicles, videogame streaming, and a more seamless work-from-home experience pushes the need for edge processing and storage capabilities. As an emerging paradigm, there are currently only provisional solutions on offer. But these trends continue to repurpose existing sites, such as central offices, through the establishment of micro modular data centers.

Edge Glossary

Access Edge Layer - The sub-layer of infrastructure edge closest to the end user or device, zero or one hop from the last mile network. For example, an edge data center deployed at a cellular network site. The Access Edge Layer functions as the front line of the infrastructure edge and may connect to an aggregation edge layer higher in the hierarchy.

Aggregation Edge Layer - The layer of infrastructure edge one hop away from the access edge layer. Can exist as either a medium-scale data center in a single location or may be formed from multiple interconnected micro data centers to form a hierarchical topology with the access edge to allow for greater collaboration, workload failover and scalability than access edge alone.

Central Office - An aggregation point for telecommunications infrastructure within a defined geographical area where telephone companies historically located their switching equipment. Physically designed to house telecommunications infrastructure equipment but typically not suitable to house compute, data storage and network resources on the scale of an edge data center due to their inadequate flooring, heating, cooling, ventilation, fire suppression and power delivery systems.

*Extracted from the Open Glossary of Edge Computing V2

Resembling the form of shipping containers, these data centers can be deployed in various locations, such as factories or office parking lots, or even at the base of cell towers. Some of the envisioned benefits of edge solutions are, therefore, ease of use and cost reduction for application deployment. Latency-sensitive IoT applications cannot be supported by the traditional cloud model and one solution envisioned by computer scientists is to use the compute and storage power of network elements [3]. This way, data can be processed closer to where it is generated. It is important to mention that most of these applications will require constant internet connectivity but there are also uses that can function without it. Cruise ships, remote oil derricks, and military bases that are equipped with edge devices can function independently with low or intermittent internet connectivity, sending and receiving updates whenever the connection is available. The same would not be possible with cloud computing as it requires a stable connection while the cloud service is in progress.

Such promise has a range of possibilities for Danish technical infrastructure companies such as GI Networks. In particular, assessing the opportunities that exist within the various layers of the edge computing architecture is what could pay high dividends. From the Device Edge, the focus is on the server-side of the architecture made of on-premise servers. In the Infrastructure Edge, it is central offices and aggregation sites of communication networks where most current deployments are taking shape [4].

According to the DDCMR 2020, there is a trend for data centers to be located closer to where they are needed in the Capital Region, and to have custom sizes with energy consumption below 3MW. A survey from the same report shows that edge computing is the third most likely type of data center to be established in Denmark in the next 5 years. With the demand and needs already here, it becomes easier to identify which industries will drive edge innovation as well as the edge consumers [5].

[3] E. Yigitoglu, M. Mohamed, L. Liu and H. Ludwig, "Foggy: A Framework for Continuous Automated IoT Application Deployment in Fog Computing," 2017 IEEE International Conference on AI & Mobile Services (AIMS), Honolulu, HI, 2017, pp. 38-45, doi: 10.1109/AIMS.2017.14.
[4] State Of The Edge 2020: A market and ecosystem report for edge computing
[5] Danish Data Centre Market Report 2020

3.2 Who drives and consumes Edge services?

Communication services

Communication services are currently the main driver and consumer of edge computing. In Western Europe, multinational communication network operators (CNOs) are the largest consumer of edge computing equipment as part of their network upgrade efforts[6]. In this report, CNO is an umbrella term used to refer to a varied array of organizations that provide carrier services, both wired and wireless, such as, Internet Service Providers, mobile network carriers, and telephone companies As a reference point, in Denmark some of the largest CNOs are: Telenor, a mobile telephone operator; HI3G Denmark ApS, commonly known as 3 and a provider of mobile broadband only; Kemp & Lauritzen A/S service provider of telephony solutions to business customers[7]; and TDC, owner of the entire Danish last mile infrastructure and largest telecommunication company in Denmark[8].

CNOs are looking to upgrade their networks to meet the ever-growing demand for increased speed and reliability that private and public consumers exert. The fiber-optic cables that sustain 5G networks are expected to accelerate demand for edge solutions since they natively support service capabilities such as ultra-low latency, bandwidth management, and ultra-reliability. In this context, we suggest that there are two distinct types of consumers and drivers of edge capabilities. First, there are the CNOs who are driving innovation in this area, as well as consuming edge equipment, and second, there are both public and private communications service consumers who drive the CNOs' network upgrades.

It is these network upgrades that are making CNOs central players in the evolution of edge infrastructures. In order to assess this role, let us look at the energy consumption levels of CNOs (it is important to note that energy consumption is the main metric used by the data center industry to assess the size of future data center markets).

In 2019, the global edge energy consumption of CNOs was 22% and the majority of this (94%) was deployed in central offices (Regional Edge)[9]. What this suggests is that the repurposing of existing buildings and equipment has been the central focus of their operations, while opportunities to innovate into, for example, micro data center markets have not been seized (Access Edge). Therefore, opportunities for the business development of technical infrastructure companies, such as GI networks, may come from designing micro data centers and further repurposing of existing buildings to meet the needs for flooring, cooling and power delivery of edge data centers.

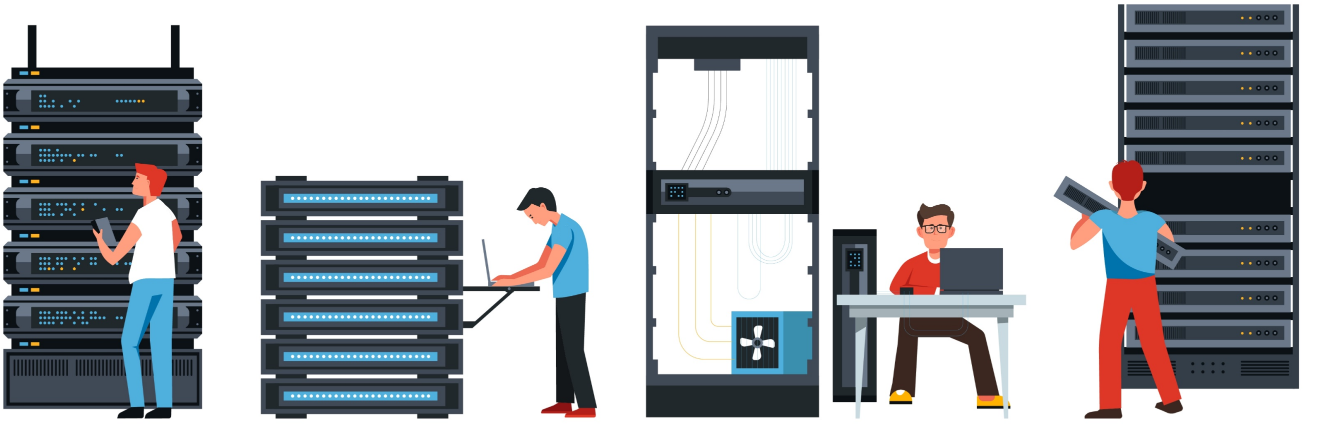
Enterprise trend: For public cloud providers to make their products available for Infrastructure Edge implementation, it is more likely that they will collaborate with CNOs and regional data centre providers that already have edge infrastructure facilities.

Mobile consumer services

As CNOs expand and improve their infrastructure, they will continue to provide mobile consumer services that require advanced new features. Integrated sensor-based technology, virtual and augmented reality, and real-time artificial intelligence are expected to transform mobile consumer services in the coming years. As a result, many consumers will require edge computing to provide reduced latency and real-time data analysis.

Besides mobile consumer services, future edge applications are taking over the automotive industry and digital services for smart homes. There are already smart appliances and digital services that are implemented on the Device Edge with support from centralized cloud functionality. End-point devices such as smart-lightbulbs, smart digital locks or smart speakers are digital services for smart homes deployed on the Device Edge. The sophistication of digital services for smart homes is driven by the demand for enhanced residential consumer experiences which will require Infrastructure Edge as well. Micro data centers and on-premise servers, as part of the Infrastructure Edge, will be needed to support the data storage and processing demands of future smart home applications. The frontrunners for digital service innovations for Infrastructure Edge will be, security, energy management, and assisted living.

[6, 9] State Of The Edge 2020: A market and ecosystem report for edge computing
[7] https://www.statista.com/statistics/554473/denmark-top-20-telecommunication-companies-by-turnover
[8] https://en.wikipedia.org/wiki/TDC_A/S



GI Networks

This business report considers the case of GI Networks as an enterprise that is currently learning to navigate the shifts produced by the new paradigm as centralized and decentralized computing begin to work more in tandem. It requires ongoing innovation for a company like GI Networks to remain relevant and stay competitive in this fast-changing industry. But it is clear there are a range of opportunities for technical infrastructure companies, provided they stay updated on current trends and market possibilities.

GI Networks is an infrastructure provider that has been operating in the data center business in Denmark for the past ten years. The Danish Data Center Industry categorizes GI Networks as a technical infrastructure company. Specifically, the company deals with the physical elements of digital infrastructures: building the data centers. Brian Møllerskov, the Data Center Manager at the company, says their strategy is to focus on the Infrastructure Edge component of the edge ecosystem, that is, the rack units and the technical equipment that make up an edge data center. In terms of future edge deployments, the organization recognizes the need to switch from building data infrastructures based on the coverage needs of corporations to infrastructures covering the needs of localities and geographical areas. This is known as a platform-centric approach, which, by focusing on creating the 'edge grid', allows a given platform to serve many future applications.

In what follows, we will lay out the specific edge use cases for GI Networks. Based on the main takeaways of the previous analysis, we have identified five areas of opportunity for edge implementation: the effects of the Covid-19 pandemic, advances in manufacturing and healthcare, future retail needs, and smart city evolution. For the use-case centric approach, we recommend practical applications following a three-step process. First, we look at the current situation in each area, followed by an identification of edge opportunities. Lastly, we recommend a solution to address the identified opportunities.

Global Pandemic

Current situation:

Inhabitants of Denmark are no strangers to working from home. Even before the global pandemic, the past ten years have seen 20% of Danes working from home on average at least once a month[10]. Under the pandemic, the numbers have changed significantly, and it is estimated that one in three Danish employees worked from home under the lockdown in March 2020. That is approximatively 650k people[11]. This situation will continue as employers have recognized the benefits of this type of work-setting in terms of cost reduction. Additionally, employee productivity has not decreased. In terms of computing needs, the current pandemic has brought various scenarios to light that have even further accelerated the need for increased digitalization. The normalization of working from home has meant that more computation and network capabilities are needed closer to the residential areas where most of the work is being done under lockdown, or near lockdown, conditions.

Opportunity:

For this particular use case, edge implementation can be a multilateral win that gives home users data sovereignty to satisfy privacy concerns, allows packet control in condensed networks, while also decreasing latency for a more seamless work experience. Because the user base is situated largely at home this means more focus on converged networks and fiber-only edge[12]. For example, if a company is located in Copenhagen and its employees work from home, it would not make sense to host a conference call on a data center located hundreds of kilometers away.

Recommendation:

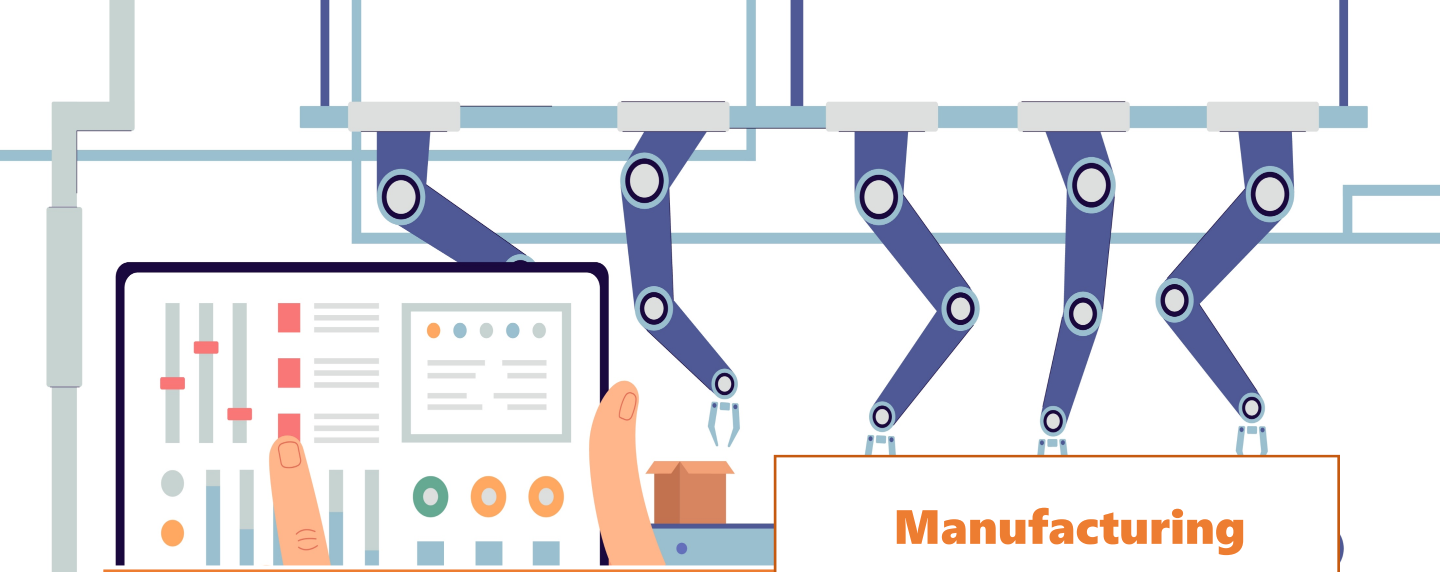
One way to address this challenge would be through various forms of public digital infrastructure investment that could be earmarked for SMEs as a post-Covid economic recovery strategy. Such investment could operate at various scales—state, regional, municipal—or through various constellations of public-private partnerships. Fostering an edge infrastructure ecosystem as a public utility—along the lines of existing public utilities, such as water, electricity, and sewerage—would enable technical infrastructure companies such as GI Networks to compete through the local activation of dark fiber networks[13]. For GI Networks this would mean, in practical terms, the provisioning of technical equipment, micro data centers, cooling and energy management solutions for eventual dark fiber customers.

[10] https://www.statista.com/statistics/878822/employees-who-had-worked-from-home-in-the-last-month-in-denmark/

[11] https://www.danskindustri.dk/arkiv/analyser/2020/3/hjemmearbejde-under-coronakrisen/

[12] Edge Supplement (Vertiv) 2020, Data Center Dynamics

[13] A dark fiber or unlit fiber is an unused optical fiber, available for use in fiber-optic communication. Dark fiber originally referred to the potential network capacity of telecommunication infrastructure, and can be leased from a network service provider.”



Manufacturing

Current situation:

Cyber-physical systems using artificial intelligence are becoming increasingly more common. For example, factories are now starting to use the two-step machine learning process. In the initial phase machines are trained with large amounts of data in order to learn the rules of the tasks to be performed. In the second phase, with the introduction of new data the machines make an inference. However, both steps do not need to happen on-premises. The training phase—the most resource intensive—can take place in the cloud, while the inference phase can happen locally in the factories, without having the outward bandwidth to deal with the huge data volume.

Opportunity:

For the manufacturing industry the current approach of selling data center build-outs to corporations is losing ground because a wide array of operations are moving to the cloud. As such, elements of edge computing are becoming an integral part of the enterprise data operations cycle. If AI and IoT are to be implemented successfully in smart factories, on-premise computation and a reliable network are needed. Compared to the evolution of telecommunication companies, where the industry adopted the virtualization of standardized hardware functions that run on commodity servers and cloud software, the manufacturing industry has not followed the same path of standardization in terms of the shape and size of the equipment used[14].

Recommendation:

As automated production becomes increasingly common in many industries, applications for smart factories are beginning to take off. Deploying infrastructure for smart factories is a real opportunity for a company like GI Networks given that such deployments are very similar to building small data centers (in terms of rack cabinets, cables and emergency power). What the manufacturing industry lacks is a common model that would permit faster implementation and reduce the effort of finding solutions for individual factories. GI Networks could capitalize on this by developing standardized deployment models where server racks, fiber cables, and emergency power supplies are bundled up in pre-made packages. Common models of deployment for smart factories could potentially become projects where hardware and infrastructure providers collaborate on edge opportunities.

[14] State Of The Edge 2020: A market and ecosystem report for edge computing

Healthcare

Current situation:

The concentration of network usage in residential areas during the pandemic has meant that it has become harder to guarantee the delivery of data packets from, for example, an IoT sensor to a hospital. Local edge infrastructure and device infrastructure have the potential to support the critical welfare infrastructures of public authorities by guaranteeing the delivery of critical data, on time. There are numerous applications within healthcare involving IoT sensors, edge nodes and cloud computing. The blueprint for a generalist application could be: 1) an IoT device used to run tests on premises, 2) this data is processed locally on edge systems and 3) the individual result is uploaded to the cloud for storage and trend identification. The role of the cloud is to store analysis results and aggregate them with other types of data, while also sharing them securely amongst authorized users.

Opportunity:

Currently, Denmark's Center for Regional Development—based in Copenhagen—supports a software program called "Safe Appointment" which intends to automate data sharing between ambulances and emergency-physician vehicles (akutlægebilen)[15] as and when they meet. This supports the pre-hospital efforts of medical staff to provide immediate treatment to critical patients and also ensures a safe trip to the meeting spot. This application uses a GPS software program integrated with the existing emergency systems both at the emergency center and in the cars.

Recommendation:

There are various pilot programs that are currently being tested in the Danish health care system that can make use of edge computing. For infrastructure operators and hardware providers such as GI Networks, this is an opportunity for developing edge devices to be a part of this new ecosystem. More concretely this would mean designing machinery for the Device Edge

[15] https://www.regionh.dk/forskning-og-innovation/eksempler-paa-forsknings-og-innovationsprojekter/Sider/Nyt-GPS-program-sikrer-patienter-hurtigere-akutbehandling.aspx

Retail

Current:

RaaS (retail as a service) is gaining ground in both the USA and China. In the US, Microsoft has partnered with the American grocer Kroger to use Azure AI in the grocery industry. Similarly, Alibaba is implementing smart mirrors with augmented reality in department stores in China. One such RaaS application is a digitalized fitting room experience where the mirror functions as a giant smartphone[16]. The technology makes use of augmented reality by giving users several options. Whether it is the ability to see a garment in a different size, or color, to pair it with other garments in the shop, or to see the available stock, the options are plentiful.

Opportunity:

The challenge with this technology is that all the information needs to be processed locally and implemented for in-store applications, and this means that local edge servers have to deal with high usage demands while having limited bandwidth. A good internet connection does not guarantee the ability to handle hundreds of simultaneous requests. The gap which needs to be filled, is the infrastructure required to deliver the processing and physical computing. Most commercial zones have not been designed to work in parallel with technology at scale and the hardware to meet edge demands for local stores has not arrived at the marketplace yet.

Recommendation:

Be it a smart mirror or an in-store tracking system, the common denominator and challenge here is to retro fit computational infrastructures into spaces not designed for them. Also, following the aforementioned tendency in the Copenhagen area for bespoke-small-sized data centers, GI Networks is well positioned to set-up a modular design system for edge deployments to address future retail needs.

[16] Edge Supplement (Schneider), Data Center Dynamics 2020

Smart cities

Current situation:

As an innovation forerunner, Denmark has been a central figure within smart city thinking and design for some time now. The popular image of a smart city is one of futuristic architecture with alien-shaped glass buildings, levitating public transport, sky-scrapper gardens, and remotely-controlled machines that oversee and regulate many facets of life. Theoretically, it would make sense to build a smart city from the ground up rather than implement these technologies within old city infrastructures. However, it is hard to imagine a ground-up smart development in a city with medieval, baroque and contemporary architecture such as Copenhagen. The exercise here, is to reconfigure our understanding of what building a smart city means. Copenhagen has already implemented adaptive traffic lights backed up by GPS that regulate traffic based on how many cars are on the road. These adaptive traffic lights are but one small element within a smart city infrastructure. At the same time, they are a form of edge application that would only require a few new hardware deployments. Other projects in Copenhagen include free parking space detection, chip-based cost-effective bike theft prevention, and optimized route-planning based on real-time traffic information[17].

Opportunity:

What is challenging about smart cities' reliance on the Edge is infrastructure ownership. The entire ecosystem could be constructed with SME's in mind so that they have a competitive advantage against tech giants. At the moment, there are two models of developing smart cities: 1) the corporate model (or building from scratch), and 2) the IES-City model. An example of the corporate model is Toyota's Woven City, a smart city built from scratch and owned by the company. This is a living laboratory with research-subject residents where everything from infrastructure to the data are company-owned. The IES-City framework created by NIST (USA's National Institute of Standards and Technology) offers a blueprint of possibilities with the option for city authorities to take control by building and owning the infrastructure of the smart city[18].

[17] https://www.opendata.dk/city-of-copenhagen
[18] IES City Framework

Smart cities

Generating business opportunities for small technical infrastructure companies is dependent on whichever smart city development model is selected. This option would mean following the steps of any other public investment. In order to build the infrastructure, governmental agencies would need to assemble the requirements and advertise the contracts that private contractors would bid on. The government pays for the construction and installation of the IoT network and has full ownership over it. The advantages of this model are lower operating costs, reduced government network constraints, and ease in deploying new services. On the other hand, this solution would mean huge public sector investment at a granular level comprised of capital costs, on-going operational costs, as well as a skilled workforce to operate and maintain the network. In a Danish context, considering the emphasis on IT education, advancement in public digitalization and overall technological investment, the knowledge foundation is already present if such an initiative were to be considered.

Recommendation:

There are a few strong smart city initiatives in Denmark that are experimenting with multiple use cases. EnergyLab Nordhavn [19] and Copenhagen Solutions Lab [20] are two of the projects that have developed and tested smart energy and city solutions. Here, as in the case of the Covid-19 pandemic recommendation, the idea of the digital infrastructure operated as public utility emerges. In this setup, infrastructure vendors such as GI Networks would function as service providers for the municipality. The core business of GI Networks is computer cabling and fiber. Collaborating on smart city projects to build local area infrastructure operated as Infrastructure Edge would result in multiple digital operating systems for the city infrastructure and would be on par with GI Networks platform-centric approach.

[19] http://www.energylabnordhavn.com/
[20] https://cphsolutionslab.dk/news/street-lab