Abstract

This article concentrates on the interconnected past, present and future of telecommunications and the environment in the Arctic. It brings together discussions on the natural environment, sustainable development, and connectivity in and through the Arctic and focuses on fixed-line infrastructure. This study builds on the theoretical literature on infrastructure, infrastructuring and pipeline ecologies and demonstrates how the peculiar features of the Arctic, such as coldness, snow and ice, ground frost and permafrost affect telecommunication lines, and how this infrastructure impacts the environment in which it is built. Similarly, the environmental conditions, paired with long distances, small populations and limited economic opportunities, affect the infrastructuring processes and the selection of technologies, as well as their spatial extent, quality, and the speed of their expansion. While the construction of telecommunication lines supports the exploitation of natural resources in and beyond the different parts of the circumpolar North, it also plays a role in the observation and protection of the Arctic.

Introduction

The questions concerning connectivity, telecommunication technology and infrastructure in the Arctic have attracted much attention in recent years. While the development of low and very low Earth orbit satellite systems (and, for example, fixed wireless solutions) has been included in these discussions, the importance of fixed-line solutions—mainly terrestrial and submarine fibre-optic cables—has been emphasised repeatedly. Besides shaping the digital environment, these modern-day information highways are present in the physical environment just like their predecessors were, ranging from the early telegraph wires to overhead phone lines and underground coaxial cables. These types of fixed telecommunication lines have a future full of expectations, but also a long history in the global North as technological solutions emplaced to connect people and communities in remote areas. However, infrastructural expansion in the Arctic has never been disconnected from the local natural features.

Themes that even more strongly than connectivity guide the discussion about the past, present and future of the Arctic include sustainable development and environmental concern. Yet, a missing analytical piece can be identified when the current scholarly debate over connectivity in the Arctic is reflected against these traditional schemes. Although there is a need for further studies on the social and economic sustainability of telecommunication technology and infrastructure in the Arctic, the lack of studies bringing connectivity and the environment together is striking.

When the environment and connectivity or digitalisation are mentioned together, the common argument is that digitalisation reduces the need to travel long distances, which contributes to the reduction of pollution, energy waste and loss of time in the Arctic (e.g. Arctic Economic Council Telecommunications Infrastructure Working Group (AEC TIWG), 2017; Arctic Council Task Force on Telecommunications Infrastructure in the Arctic (TFTIA), 2017; Salminen & Hossain, 2018; Zojer, 2019). The broader entanglement of cultural landscapes, livelihoods, climate change, natural resources, connectivity, and digitalisation remains largely underexamined. Yet, for example, National Geographic published an article entitled "The Internet Is Drowning" in 2018. According to it, the global sea level rise forms a threat to the fibre-optic cables and other parts of internet infrastructure deployed near the cost (Borunda, 2018). However, these effects are only one example of the complexities of the relationship between the telecommunication infrastructure and the environment.

This research combines elements from Arctic studies, environmental history (defined as an interdisciplinary approach to understanding human-nature interactions in the past), and infrastructure studies. It helps to understand how the Arctic environment has affected the past development and impacts the current condition of telecommunication lines. Moreover, it elaborates how the development of telecommunication lines affects the Arctic environment. It contributes to improve planning and management of future infrastructure and infrastructuring processes by elaborating the demands of the Arctic environment and the need to hear and incorporate local actors in order to generate sustainable solutions for the future.

In this article, connectivity is understood as a quality, state, or capability of being connective or connected in reference to telecommunications. The article concentrates on fixed-line infrastructure, that is, telegraph wires, telephone lines, and coaxial and fibre-optic cables, albeit radio and satellite communications have clearly played and will continue to play an important role in the Arctic (e.g. AEC TIWG, 2017; TFTIA, 2017). Aside from the immense importance of fixed lines to global data traffic (modern submarine fibre-optic cables transmit 99 per cent of international data traffic [Saunavaara & Salminen, in press]), the chosen focus is justified by the interpretation of the historical development from telegraph wires to fibre-optic cables as a continuum. The continuum consists of the of types of communication transmission infrastructure that have obvious physical similarities as linear infrastructures despite their great technological differences.

The environment, again, refers primarily to the natural environment or nature, encompassing all inartificial living and non-living ‘things’ and the interaction of these ‘things’. There is no Arctic environment but Arctic environments that are not static. The climate change is modifying the Arctic in an unforeseen magnitude and pace. For example, the already detected rise of the average temperature has increased precipitation, lessened ice cover, fed to thawing permafrost and generated challenges to a number of animals and people living in the area. These changes will affect both the telecommunication infrastructure and the societies depending on this evolving infrastructure.

The way this research approaches the Arctic environment may differ from the views of the Arctic indigenous peoples who see land as a part of their day to day existence and source of life. The fact that we have not conducted any telecommunication infrastructure-related field studies in the context of indigenous communities limits our analysis. The development of telecommunication infrastructure is often guided by national or corporate interests. However, critical analysis concerning the sustainability of this development in the Arctic can be carried out with multiple premises. We hope that further research building, for example, on the studies conducted by Olsén-Ljetoff & Hokkanen (2020) will follow.

Many factors can be identified as potential reasons explaining the lack of research focusing on the Arctic, connectivity and the environment. The Arctic may have been too remote and atypical context to draw the attention of those interested in telecommunications. The direct impact telecommunication infrastructure has on the environment is smaller than in the case of transport infrastructure which is much better researched subject. One explanation can also be found from the general way of imagining and describing the telecommunication infrastructure. As Starosielski (2015) pointed out, typical cable maps depict cables as vectors indicating connectivity between territorial and administrative entities such as cities or countries. Here, the environments that cables are laid through are represented (misleadingly) as friction-free surfaces across which force is easily exerted. This study is inspired by Starosielski's (2016) research on pipeline ecologies and Agar's (2018) ideas on the interplay and interconnection between the environment and technology. It answers to the following questions: How do the wires, lines and cables as constellations of engineered natural resources supplement the natural environment in which they are laid? How do harsh northern environmental conditions affect their design, route, installation, and maintenance? What kind of direct and indirect environmental impacts do telecommunication lines have? Finally, how can telecommunication lines be used to observe, record, study and protect the environment they are becoming a part of?

This study is based on public reports and declarations, media sources (newspaper and magazine articles) and memoirs. It introduces both historical and contemporary developments in different parts of the Arctic (referring roughly to the waters and lands north of 60°N) in a holistic manner. The approach entails that neither the particular characteristics of local environments nor the diverse local voices can be analysed in detail and, thus, it leaves plenty of room for further research. The article consists of six sections. The first part, which describes the theoretical and conceptual framework, is followed by four chapters answering the aforementioned research questions. The discussion at the end of the article identifies the main findings and returns to the topics of sustainability as well as the relationship between infrastructure, environment, technology, and pipeline ecologies.

Relationship between the Arctic Environment and Telecommunication Infrastructure

Although the telegraph wire that connected Alaska with the rest of the United States in 1903 was celebrated with the message ‘Alaska is now open to civilization’ (Hansen, 2005, p. 2014) and although infrastructure has been described as an integral part of the architecture of modernity and nation-state formation (Niewöhner, 2015), the construction of telecommunication infrastructure should not be considered merely a human-centred story about modernisation. Nor should it be seen only as a relatively simple policy-based process which improves the quality of life of and brings greater business opportunities for the populations of areas hosting or located at the end-points of this new infrastructure (Salminen & Hossain, 2018). The environment shapes society, culture, and economy – and the various material manifestations thereof. This mutual constitution of society, its technology and infrastructure, and the environment in the Arctic deserves closer scrutiny.

Connectivity becomes easily abstracted as an end or a development taking place in a technological vacuum with little reference to the local time, space and physical infrastructure. We argue that connectivity is nether ahistorical nor unattached from environmental questions. Literature discussing infrastructure—especially its modes and effects—offers a fruitful starting point for the analysis of the interplay between telecommunication lines and the environment. In this study, infrastructure is conceptualised as a matter which enables the movement of other matters. In practice, these spaces of flow are built networks which facilitate the flow of goods, people, or ideas and allow for their exchange (Castells, 2010; Larkin, 2013). Even if infrastructure supports particular forms of work and social life and shapes social practices, it may escape the public awareness due to its invisibility. Reliability is another typical and expected feature for infrastructure. Therefore, infrastructure often draws attention and is experienced only when it fails and is unable to deliver what is usually taken for granted. (e.g. Airaksinen, 2003.) Furthermore, the disappearance of infrastructure itself also means that the technical, social, political, and ethical choices made during the planning, construction, and maintenance phases become easily forgotten (Niewöhner, 2015).

People have augmented their natural surroundings with infrastructure such as roads, water supplies, power grids, telephones, and buildings to the extent that they have become the ‘naturalised background of modernity’ (Blok et al., 2016). Yet, it is not necessarily the infrastructure itself but the practices, materials, and settings of infrastructuring that ought to be focused on. Besides emphasizing the need to unfold the choices made by different actors throughout the development of infrastructure, the shift from infrastructure to infrastructuring guides one to consider the relations between centres and peripheries. ‘Centre’ and ‘periphery’ are not unambiguous concepts without internal frictions. The attitudes, exchanges, collisions, and dependencies between them can be analysed to understand the process through which infrastructure comes into being (Niewöhner, 2015). In analysing the infrastructuring of the environment, attention must be paid to the practices used to manage this environment. At the same time, as Blok et al. (2016) pointed out, the environment should not be seen as a passive ‘receiver’ of infrastructuring attempts. Simultanously, infrastructure should not be conceived merely as a tool of human intentionality. Although infrastructuring may appear as an attempt to exercise control over the environment, natural conditions can prevent, postpone, or force unforeseen modifications of the original construction and maintenance plans. Furthermore, infrastructuring can turn societies more vulnerable to phenomena taking place in the often-uncontrollable environment.

Of the many attempts to bring the histories of technology and the environment together, we found Agar’s (2018, see also Ward, 2018) eightfold categorisation clarifying. He provides the following conceptualisations to the environment and to the relationship between the environment and infrastructure: 1) environment as input into a technological system; 2) environment as something naturally made into or a component of a technological system; 3) environment as something changed (usually damaged) by technological processes; 4) environment as something which exists alongside an artificial world; 5) environment as something untouched by artifice; 6) environment as something represented through technology; 7) environmental knowledge as something organised by being registered with technology; and 8) environment and technology as interconnected cultural imaginaries. These eight categories remind us that the materials used in the construction and maintenance of infrastructure are parts of at least two environments: the environment they are extracted from (often outside the Arctic) and the environment they are added to. Technology, again, consists of both physical and informational components. The concept relates not only to the products embodying it but also to the information and knowledge concerning its use and to the process through which it comes into being (Wahab et al., 2012). While Agar's (2018) categorisation helped us in formulating the research questions, the discussion on 'pipeline ecologies', where pipelines are understood as a form of distribution connecting individual nodes via linear routes insulated from the environment (Starosielski, 2016), affected the basic premises of our project.

In this study we abstain from taking a stance on the question of whether the concept of pipelines could or should be broadened beyond the narrow metal conduits used to transport, for example, gas and oil. However, Starosielski's (2016) argument that (pipe)lines—that attempt to disentangle whatever they are carrying from the environment they move through—do not develop in isolation, but are connected to the surrounding elements, including the growth of trees, wind, and heavy winter snow, as well as to the local and regional entanglements of distribution, is found highly relevant. Based on her studies of rural New York State, Starosielski paid attention to the temporal dimension of infrastructure and argued that the expansion of fibre-optic cables is not a process through which a new technology is introduced. Rather it is a renewal of spatial organisation and a set of ecological practices established over the preceding decades. A new network is thus not simply an overlay onto existing infrastructure but an entangled part of the same spatial and ecological organisation of the land (and the sea). While Starosielski analysed how fibre-optic networks are enmeshed with electrical grids and take on their ecological underpinnings because of the similarities in their forms of distribution, our research focuses on the different types of telecommunication infrastructure—telegraph wires, phone lines and coaxial and fibre-optic cables—and the ways in which the development of newer telecommunication lines has connected with their predecessors and the ecological forces they all have confronted at different times.

Telecommunication Lines as Adjusted Additions to the Arctic Environment

The Development from Telegraph Wires to High-speed Internet

The era of the electric telegraph began in 1844. The new technology was first adopted in the United States, but by 1850 thousands of kilometres of telegraph wires had been installed in various countries. The British Empire eventually spread the technology around the world and the need to control railway operations, for example, accelerated the expansion of telegraph networks into rural areas as well. The usefulness of the new technology in governing a global empire became even greater after submarine telegraph cables were invented. The first submarine cables connecting the United Kingdom with continental Europe were installed in 1851 and the first functional transatlantic cable in 1866. The telegraph network continued to expand despite the invention of the telephone in 1876. The number of telephones in use globally reached 250 000 in 10 years, but it did not become an ordinary device in private households until the mid-twentieth century (Gere, 2008; McNeill & McNeill, 2003; Wheen, 2011).

Telegraph and phone lines also spread in many parts of the Northern hemisphere and in some parts of the Arctic relatively quickly; especially, in areas with significant economic activity. The first electric telegraph line in southern Norway was built in 1855 and a 170 km telegraph line was constructed in Lofoten in 1861 (Røde, 1996). In Sweden, the first telegraph station in the north, Haparanda, was opened in 1860. The Stockholm-Haparanda link was also connected to the Turku-Tornio line in Finland (Finland being an autonomous part of the Russian Empire until 1917) (Beckman & McKay, 2003/2005; Hallenberg & Linnarsson, 2017; Huurdeman, 2003; Turpeinen, 1996a). In Finland, the first telephone companies were established in the early 1880s, but the number of phones remained small and the networks expanded slowly from cities to rural areas. The entire Finnish Lapland was without phones in the early 1910s; the telephone network was eventually built—despite the small number of subscribers and opposition by some Sámi residents (indigenous people traditionally living in the northernmost part of Finland, Norway, Sweden, and northwestern Russia)—to the northernmost municipality of Finland from the mid-1920s onwards. The local (indigenous) opposition against telecommunication lines was unexceptional, as similar resistance was visible with regard to road development (Kylli & Saunavaara, in press; Turpeinen, 1996a). These examples support the argument that infrastructure is commonly designed in the centres and may deliver services nobody in the periphery wants or needs (Niewöhner, 2015). However, at the end of 1938, there were still fewer than 1 200 telephones connected to the network in northern Finland and connections were poor when compared with Norway and Sweden (Petsamon Nikkeli Oy, 1938; Turpeinen, 1996a).

The first electrical telegraph line between St. Petersburg and Moscow was established in 1851 and the Russian state telegraph network, with a total length of 11 000 km, was constructed from 1853 to 1855. In 1869, three Scandinavian telegraph companies merged to form the Great Northern Telegraph Company. Besides laying submarine cables between Great Britain, Norway, Sweden and Denmark, as well as between Finland and Russia, the company was entrusted with constructing a trans-Siberian telegraph line from St. Petersburg to Vladivostok. This intercontinental telegraph link, extended to Japan and China via submarine cables, became operational in 1871 (Huurdeman, 2003; Turpeinen, 1996b).

After the first transcontinental telegraph line in 1861, the rapid expansion of the telegraph network in North America was also directed toward the north. Following several failures to install a submarine telegraph cable through the Atlantic, the Western Union Telegraph Company initiated an ambitious plan to connect North America and Europe by running a telegraph line through British Columbia and Yukon Territory, Alaska (known as ‘Russian America’ until 1867), across the Bering Strait and through Siberia to Nikolaevsk on the Sea of Okhotsk. This project was pursued in the mid-1860s but abandoned in 1867 after the first submarine telegraph cable connected the two continents (Hudson, 2015; Huurdeman, 2003; Watson, 2005; Wheen, 2011). When the Russian-American Division received their cease work order, they learned simultaneously about the sale of Alaska to the United States. Eventually, the telegraph link to Alaska was constructed by the US Army Signal Corps, who finally linked army posts together and to the rest of the United States between 1900 and 1905. The newly organised Washington-Alaska Military Cable and Telegraph System laid the foundation for the regional telecommunications network and for the federal government's dominant role in the development of Alaskan infrastructure. Voice communication and radio telephone transmitters came to Alaska in the 1930s (Hudson, 2015; Huurdeman, 2003; Jessup, 2007).

Throughout history, the harsh environment has been a major factor contributing to the small overall population and low population density in the Arctic. This kind of surrounding is ill-suited to fixed-line infrastructure. The great distances that challenged the physical constructions and economic feasibility of different telegraph and telephone projects in the Arctic in the late nineteenth and early twentieth centuries have remained typical features in the twenty-first century (Hudson, 2015; Ramirez, 2015; Turpeinen, 1996a). The societal structure has thus supported experiments with various wireless solutions. In southern Finland, for example, buried coaxial copper cables succeeded open-wires and led to the modernisation of telecommunications from the early 1950s onwards. However, due to the high costs and small number of users in the northern part of the country, the automatization of telephone networks was delayed and based on radio links (Turpeinen, 1996a). Similarly, Alaska has served as a testbed of wireless solutions since the continual breakages in the submarine telegraph cable across the Norton Sound inspired the construction of one of the world's longest (in its own time) wireless section of any commercial telegraph system, which connected Safety and St. Michael in 1903. Since then, in order to meet its peculiar communications requirements, Alaska has pioneered various wireless communication technologies, ranging from troposcatter antennas and microwave relay towers to satellite communication. Furthermore, interest in cellular phones was also sparked early in Alaska (Hudson, 2015).

Today's global communication is based on fibre-optic cable networks. The first telecommunication applications based on fibre-optics were developed in the late 1970s.-The first submarine fibre-optic cables were developed in the mid-1980s and the first trans-Atlantic submarine fibre-optic cable became operational in 1988 (Montgomery, 2002; Wheen, 2011). The deployment schedule of this new technology varied greatly between different Arctic regions. While the first fibre-optic cable connections in Finland were built in the mid-1980s, the development of the fibre-optic network in Lapland gained speed only at the beginning of the new millennium, when the state began subsidising its construction. Meanwhile, the early internet usage in Russia was concentrated in big cities and the shift from copper cable wires to fibre-optic cables in the domestic communication network happened later there than in Scandinavia (Lapin liitto, 2007; Turpeinen, 1996b; Warf, 2011). Although the submarine fibre-optic cable connecting Svalbard and mainland Norway was constructed in 2014 (McGwin, 2019), the Arctic Ocean has only recently received attention as a potential shortcut between East Asia, North America, and Europe due to its offering lower network latency as well as resilience and diversity to the highly concentrated submarine cable network. Quintillion's project, which has already completed a regional network in Alaska consisting of both submarine and terrestrial fibre-optic cables, plans to connect these continents through the Northwest Passage; Arctic Connect and the cable initiative of Russian military authorities envision a new route through the Northeast Passage. However, the Arctic continues to be seen as an environment where fixed wireless and new types of satellite-based solutions are needed. Therefore, companies planning to create low Earth orbit satellite installations have considered the Arctic as a potential market (Saunavaara, 2018; Saunavaara & Salminen, in press).

All of the different methods of providing connectivity are eventually connected to the fibre-optic backhaul infrastructure now expanding in the Arctic which offers possibilities, for example, for the construction of new satellite ground stations. (For further details on the cooperation between Quintillion and ATLAS Space Operations, see Quintillion, 2019.) While today's policymakers recognise what Canada's Rural Economic Development Minister Bernadette Jordan has called 'topography challenges', huge Arctic countries such as Russia and Canada have set a target to connect 100 per cent of households to high-speed internet. In order to reach these targets, the majority of areas in Russia with a population of more than 250 people should have a fibre-optic connection by 2024, and installations of new submarine fibre-optic cables—for example, from Iqaluit, Canada, to Greenland—are planned (McGwin, 2018; President of Russia, 2018; Shekar, 2019a, 2019b). Although these plans could be understood as indicators pointing toward the victory of modern technology over the extreme environmental conditions in the Arctic, the past, current and future development of the telecommunication lines in the region can only be understood if the unique material and spatial context is taken into consideration.

Adapting to the Arctic Environment

Hansen (2005) concluded that the introduction of different generations of telecommunications in the Arctic happened early, but with limited capacity, due for the most part to the harsh climate and geography. While the issues related to economic feasibility (tested or presumed lack of chances for making profit, e.g. Hudson, 2015) and geopolitics have played an important role as well, the coldness, especially when coupled with winds, has always caused problems for both the workers who build and maintain the telecommunication lines and to the infrastructure itself. The workers have struggled with frostbites, icy working conditions and even the risk of actually freezing to death. Furthermore, throughout the decades, the workers and the infrastructure have also tried to adapt to seasonal variations, which take the form, for example, of floods in the spring and hordes of mosquitoes in the summer (A. K. 1918; Hudson, 2015; Kennan, 1873). Meanwhile, the need to use heavier telegraph wires in the Arctic than in warmer environments was recognised already in the 1860s. Despite the advances in telecommunication technology, new materials and imaginative methods developed to remove frost from open wires, these problems persisted into the twentieth century in different parts of the Arctic (Bush, 1871; Hudson, 2015; Stuhl, 2016; Suurin työ kuluvana, 1929; Telegraph to the Klondike, 1889; Turpeinen, 1996a).

Similarly, heavy snowfall, snowstorms, and avalanches have threatened telecommunication lines throughout the decades. The snow has slowed down construction processes and increased maintenance costs. Wires have been buried in snowbanks and been broken—and they are difficult to repair. In Alaska, it was assumed that telegraph stations would be snowed in for weeks every year, so it was necessary to store a sufficient quantity of provisions in each station to ensure the workers did not starve (Bush, 1871; Kennan, 1873; Turpeinen, 1996a, 201; Very First Wire, 1898). Due to the difficulties of maintaining traditional telegraph lines in the Arctic environment, the public authorities in Yukon even used Central Africa as a model and substituted the poles and wires with an insulated cable laid on the surface of the ground in 1903 (Dominion Line, 1901; Harsti 1929; Overland Cable, 1903). The frozen ground and permafrost made even the simple process of digging holes for telegraph poles difficult. These circumstances inspired new innovations: In North America, timber poles were occasionally replaced with iron masts set in and firmly cemented by simply pouring water around them, which quickly froze them tightly in place (A. K. 1918; Hudson, 2015; Huurdeman, 2003; Whymper, 1869). Coldness also slowed the decaying of organic material—it is still possible today to find wooden structures built in the Arctic during the early twentieth century (Stuhl, 2016).

In principle, the modern fibre-optic cables fit well into the Arctic environment, as they provide stable operation even when exposed to extreme and changing temperatures (Thomes et al., 2008). In practice, however, the submarine cables installed and planned in the Arctic Ocean face the same challenges with sea-ice and icebergs as those witnessed 150 years ago (Hansen, 2005; Hudson, 2015; cf. Whymper, 1869).Yet, problems related to installation and maintenance—especially in the case of submarine cable breaks during the winter months—are accompanied by the protection that ice-covered waters offer to submarine cables. Most submarine cable damage is caused by human activity, especially (bottom contact) fishing, which is responsible for more than 60 per cent of all external aggression faults. The ice cover preventing shipping and fishing activities can also be seen as the environment's own addition to traditional protective measures—consisting, for example, of burial and armouring (Bannerman 2018; Wargo & Davenport, 2014).

The great distances and lack of infrastructure supporting the construction and maintenance of telecommunication installations have remained typical problems for the Arctic. While modern technology may have helped with transport infrastructure-related problems and reduced the amounts of time and energy used to travel or to transport necessary supplies to construction sites (A. K. 1918; Alaskan Telegraph, 1901; Kennan, 1873), old challenges have also taken new forms. For example, when Arctic submarine fibre-optic cable systems are planned, the small number of cable ships capable of installing and repairing the cables must be considered. The existing few cable ships are usually located in areas where various submarine cable paths meet and the probability of failures is higher. Therefore, the time required to transfer a cable ship to the Arctic waters in the event of immediate repair needs is relatively long.

In her extensive study on the development of telecommunications in Alaska, Hudson (2015) mentioned the effects of and hardships caused by the brutal Arctic climate as a recurring theme in the history of communication networks, ranging from the emergence of the earliest telegraphs to ongoing fibre-optic cable projects. Based on the cases introduced above, Hudson's conclusion can be extended to cover the entire Arctic area. Furthermore, the longevity of the knowhow challenges—that is, the people living in the Arctic areas—are usually not the ones constructing, repairing, re-constructing, and updating the technology (AEC TIWG, 2017). Those skills are generally brought from the outside, leading to delayed reactions caused by the need to travel to the area and different forms of prioritisation.

New Materials Supplementing the Northern Environment

The interconnection between the Arctic environment and telecommunication lines can also be approached through the materiality of technology and infrastructure. Technological constellations are made from materials extracted from the environment and modified (Agar, 2018). Historically, telecommunication lines have played an interesting role as end products of the engineered environment, because they have also paved the way for more efficient global exploitation and control of nature and natural resources. The sites hosting telecommunication lines in the Arctic have often been locations where the local landscape has been supplemented with artifacts and materials carried from the south. In other words, infrastructure in the northern environments has been built using elements originating from totally different environmental settings.

Although telegraph and telephone lines have occasionally been attached to living trees (Turpeinen, 1996a), utility poles have been the dominant means of supporting open overhead wires. While the northern forests have often provided suitable material for wooden poles, even this part of the telecommunication infrastructure has occasionally been imported (Hamilton, 1964; Huurdeman, 2003). Besides the basically treeless Greenland, raising telephone poles in the northernmost part of Norway, for example, was very laborious because the trees intended for poles had to be brought from far away by sea and then pulled by horses through the barren fell region (J. A-la., 1926). In other parts of the Arctic, poles were floated hundreds of kilometres by river (A. K. 1918; Itkonen 1933; Kennan, 1873). If no suitable trees were available, iron poles made from pipes were utilised (Hudson, 2015).

Galvanised iron, together with copper, was also used in wires. Although iron is a relatively poor conductor of electricity, it was cheaper than copper, which was also problematic due to its mechanical strength. While both materials were used in the North American and Eurasian Arctic, deciding upon the material was not easy. According to the calculations made in Finland in the mid-1920s, a copper line was twice as expensive as an iron wire and, therefore, it was decided that certain parts of the Finnish Lapland would do with iron (Huuderman, 2003; Neitiniemi 1926; Peräpohjolassa, 1929; Turpeinen, 1996a; Wheen, 2011). Although it is impossible to trace the origin of the materials used in the wires installed in the Arctic, it is clear that neither iron nor copper were new products brought from the South; they were also extracted in the North (Avango et al. 2019; Weihed, 2016).

Gutta percha, a natural latex from tropical trees, solved various problems for the first submarine cable projects during the second half of the nineteenth century. This new material insulated the wires against salt water and did not lose its plasticity over time; nor did it degrade under the high pressure and low temperature of the seafloor. This milky sap from the Malaysian peninsula first helped to connect England and France and then enabled the submarine cable connection through the North Atlantic (Huurdeman, 2003; Ramirez, 2015; Wenzlhuemer, 2012). Although gutta percha became the global standard, other solutions were also seen in the Arctic. When the submarine cable connection between Alaska and Washington state was installed in 1904 in order to create an all-American connection independent of the Canadian lines, gutta percha and the British equipment used by the army to date were replaced with seamless American-made rubber-clad cables.

However, even the American cables were manufactured in New Jersey and shipped 12,000 miles around Cape Horn, that is, they were still southern additions to the Arctic environment (Hudson, 2015). The expansion of the modern submarine fibre-optic cable network, which currently includes approximately 450 submarine cable systems and 1.2 million kilometres of submarine cable, is a new addition of southern technology. These cables, consisting of glass fibre-optics encased in an electrical conductor, an internal steel core and a protective sheath of high-grade marine polypropylene, are mainly produced outside of the Arctic (Davenport, 2018; Saunavaara & Salminen, in press; ThomasNet, 2020).

The Direct Environmental Impacts of Telecommunication Lines

Although the construction period of telecommunication lines that causes the most significant changes in the environment is relatively short, the lines' direct environmental impact is long-lasting. Even telecommunication lines that are never completed or no longer used for their original purpose leave traceable signs and affect the surroundings they are attached to. For example, Walter R. Hamilton (1872–1964), who participated in the Klondike Gold Rush in 1898, found old green glass insulators and galvanised wires, which had been used by the constructors of the planned route from North America to Europe in the 1860s (Hamilton, 1964). Many of the impacts caused by the telecommunication lines in the Arctic seem to be global. Trees have been cut down in order to prepare a passage for telegraph and telephone lines, the surface of the ground or seafloor has been broken in order to bury cables, and local flora and fauna have had to adapt to the appearance, continuous presence, and repairs of the man-made infrastructure.

In different parts of the world, telecommunication lines have been built alongside transport corridors, including roads and railways. Although these decisions have been based on economic and functional rationales, the concentration of infrastructure has helped to limit the area of natural environment directly affected. Even if time has passed and technologies have evolved, the old spatial organisations have remained. Thus, for anyone who knows how the fibre-optic cable routes followed the routes of the telegraphic wires which followed the railway routes, it is easier to understand why Council Bluffs, the mid-sized town in Iowa where the first transcontinental railway began, is today the location of many large-scale data centres in need of good connectivity (Burrington, 2015). This kind of transport corridor, where humans, cargo and information travel side by side, is also present in the Arctic. The corridor idea has been mentioned, for example, when the projects envisioning both fibre-optic cable and train connections between Kirkenes in Norway and northern Finland have been bundled together (Saunavaara 2018; Turpeinen, 1996a). If the lack of roads and railways, a typical situation for many parts of the Arctic, has prevented the formation of such a corridor, the telecommunication lines may have been paired, for example, with power lines (Dall, 1870; Troianovski 2019).

The erection of telecommunication infrastructure has historically been part of the expansion of the non-indigenous lifestyle to the Arctic. The arrival of newcomers from the South has been a feature typical of the construction, maintenance, and operation of infrastructure. Although the locals, many of whom were indigenous, cooperated and worked for the telegraph companies, they sometimes lacked the necessary skills or interest to join these projects. (Dall, 1870; Electricity for Yukon, 1901; Huurdeman, 2003; Kennan, 1873; Very First Wire, 1898; Watson, 2005). The men from the South needed local natural resources to survive and bought those from the locals. The first ‘civilized men’—to borrow George Kennan’s (an employee of the Russo-American Telegraph Company) expression from 1873—who visited desolate territories in Canada, Alaska and Russia left behind plenty of new types of garbage (Bush, 1871; Hamilton, 1964; Kennan, 1873). The prepared poles were abandoned when the work was suddenly interrupted in 1867, but the locals used them as firewood (An Old-time Project, 1897).

Animals have both helped to construct the telecommunication lines and been forced to adapt to their presence. Descriptions of horses, reindeer, and dogs used to transport supplies to the telegraph and telephone line sites in different parts of the Arctic exist, but the reactions of wild animals to the new features of the environment have also been recorded (Bush, 1871; Dall, 1870). According to an article published in a Finnish magazine in 1912, animals severely damaged the telegraph lines before they got used to them. Telegraph lines had a buzzing sound and, according to the article, bears in Norway thought there were bee nests on the poles. The utility poles were also damaged by woodpeckers and small birds built nests in them (Eläimet ja sähkölennätin, 1912; -hm 1873). Encounters with human-made infrastructure have also damaged animals. Human presence and the material signs of it have disturbed the wildlife by causing physiological stress and behavioural changes (such as avoiding certain areas). (e.g. Coppes et al., 2017).

The Arctic environment has influenced the livelihoods which have been similar (hunting, fishing, reindeer husbandry) in different parts of the Arctic. Historically, the survival of the indigenous peoples has depended on animals they have lived in close connection with (Kylli & Enbuske, in press). The local people who had never seen telegraph lines had many kinds of fears when facing the line constructors. According to Richard J. Bush's reminiscences from the early 1870s, indigenous people in Siberia worried whether there would still be enough room for them and the deer once the line was completed, and wanted to know how apart the poles would be from each other and whether the line would frighten wild deer and prevent their migration (Bush, 1871). Besides illuminating the differences in the needs and desires between the local people and the infrastructure developers, this example testifies that the people living in the areas through which telecommunication lines were built have always seen the connection between the new infrastructure and the natural elements they were familiar with.

Although the direct environmental impact of the fibre-optic cables is relatively small and the installation process should not cause a major strain to the environment, the circumstances in the Arctic have recently challenged these assumptions in Alaska. Two companies dug trenches for their fibre-optic cables alongside the Dalton Highway, which is the only haul road to the oil fields at Prudhoe Bay. The road sits atop permafrost and its foundations remain stable as long as permafrost stays frozen. However, the removal of the insulating topsoil and vegetation as a part of the trench digging process accelerated the melting of permafrost which now threatens the foundations of the road. While there are examples of the thawing permafrost causing problems with roads even when fibre-optic projects are not involved, this particular cable installation is recognised as a threat to local streams and creeks, which could be polluted with the runoff of water and dirt from the trenches (Bernton, 2019; Grove, 2018; Herz, 2018; Quinn, 2016).

The interest in extending submarine fibre-optic cables in the Arctic Ocean also prompts questions regarding this infrastructure's environmental impact. Even if cables and cable operations are said to have a minor negative impact on the marine environment (Davenport, 2018), interactions between the environment and submarine cables are inevitable. In depths deeper than 2 000 m, that is, in areas where bottom trawl fishing does not take place, the physical footprint is the smallest because the fibre-optic cables are laid directly on the seabed and their diameter is only around 20 mm. Cables in shallower waters can be up to 50 mm in diameter, and although they can be surface-laid in areas with high ecological sensitivity, they are often buried below the seabed in order to protect them against shipping and fishing activities. The cable burial involving mechanical ploughing and high-pressure water injection disturbs the benthic environment, but it differs, for example, from bottom trawling in a few important points. While fishing activities are repetitive and affect wide areas, cable burial (assuming the normal situation where no maintenance is needed during the average operation time of 25 years) is a one-off operation which affects only the designated cable route (Carter et al., 2014; Davenport, 2018).

The tightening of regulations related to the environment, coordinated by the International Seabed Authority, is reportedly making the route planning for new submarine cables more difficult (Stafford, 2019). However, the issues related to cable landings are the most common reasons for conflicts between telecommunication companies and environmentalists, who usually worry about the flora, fauna, and landscapes in sensitive coastal areas. Although the Arctic hosts only a handful of cable landing stations and

Quintillion has managed to land in six new locations in Alaska—the cable comes ashore inside a steel conduit installed 60–80 ft deep and stretching up to a mile offshore (Quintillion, 2020a)—and there are no reports of major local opposition, some historical cases demonstrate conflicts in the North. For example, a dispute between the Canadian Overseas Telecommunications Corporation and environmentalists took place in 1963 when the company cleared forest for cables connecting to another cable system (Starosielski, 2015).

The relationship between submarine coaxial and fibre-optic cables and marine animals has received much attention. For example, the claim that sharks are a threat to submarine cables has been described as the biggest myth cited in the press. It is true that surface-laid cables are exposed to fish and marine mammals and that 16 cable faults recorded between 1877 and 1955 were attributed to whale entanglements, but when the submarine telegraph cables were replaced by the coaxial cables in the 1950s these problems ceased. However, a study conducted in the 1950s concerning whale entanglements in cables, which was based on telegraphic era findings, has been used to inform decisions about coaxial and fibre-optic cable development. The best-known case of conflicts between marine animals and fibre-optic cables dates back to the mid-1980s, when a deep-dwelling crocodile shark attacked one of the earliest deep-ocean submarine cables. It was speculated that sharks were attracted by electromagnetic fields or cable vibrations, which they confused for prey. While attempts to confirm this assumption were inconclusive, the cable industry reacted to the problem by adding insulating layers. No animal-related cable faults have been reported in recent years, but attention has been paid to the acoustic instruments used during cable route surveys. (Carter et al., 2014; Starosielski, 2015; TeleGeography, n.d.). This overall situation, coupled with the small number of submarine cables in the Arctic waters, explains why no marine-animal-related problems have been reported in the Arctic.

The Indirect Environmental Impacts of Telecommunication Lines

The construction of telecommunication lines has always been connected with different political, social, and economic processes, just like infrastructuring in general. The first telegraph lines built in Alaska connected local military garrisons with their regional headquarters, and the local telegraph network in northern Finland was expanded during World War I when the strategic importance of the area increased. Eventually, the new terrestrial line to Petsamo (Pechenga) and Aleksandrovski was connected to the submarine cable to Peterhead and it hence connected the United Kingdom and Russia during the war. The outbreak of World War II initiated the upgrading of communications in Alaska and prompted the decision to build the longest open-wire communication line in the world, stretching from Edmonton, Canada, to Fairbanks, Alaska. The US Army was concerned that the Japanese would be able to intercept communication based on the wireless radio technology. However, the Arctic telecommunication stations and networks that served the military carried also civilian traffic. For example, the rationale behind the so-called White Alice project in Alaska in the mid-1950s was to provide communication facilities needed for the defence against air attack from the North, but it also became the backbone of the state’s civilian communications (Hansen, 2005; Hudson, 2015; Turpeinen, 1996a). The recent evolution of Quintillion's submarine fibre-optic cable project shows that this kind of connection has not disappeared. Even if launched as a commercial project planning connect East Asia and the United Kingdom through Alaska and the Northwest Passage, the company has recently hired several former high-ranking military officers and refers openly in its communication to national security needs and the project's role as a part of the Arctic defence infrastructure (Quintillion, 2020b; Quintillion, 2020c).

When the Norwegian parliament discussed the routes and financing of the country's first telegraph lines, it paid attention to the connections between the southern cities and to the neighbouring countries. The connectivity needs of the most important fishing villages, both in the southern and northern parts of the country, were also prioritised (28de Juli, 1896; Storthinget, 1863). The early construction of telecommunication lines in northernmost Norway, the Lofoten line built in 1861, was backed by a calculation that the telegraph line would increase the fish catch by 25 per cent. This increase was assumed to result from improved exchange of information between fishermen working west and east of Lofoten (Røde, 1996).

In northern Finland, the expansion of telegraph and telephone network was closely related to the development of forest industry. When increased demand made logging activities economically feasible in Finnish Lapland at the end of the nineteenth century, timber companies began to promote the establishment of a telegraph station in Rovaniemi. The businessmen who applied for a permission to build a telephone line from Tornio to Haparanda in 1900 argued that a line crossing the national border was needed because the Swedish companies were interested in buying timber from northern Finland. Norwegian companies were actually already collecting timber from northern Finland in the 1870s, and the need for a telephone line to Sweden became soon obvious. Approximately 30 per cent of the timber used in the Norrbotten sawmills at the beginning of the twentieth century came from Finnish Lapland. However, the first wires north of Rovaniemi were built only after promising mineral deposits were found (Elenius et al. 2005; Turpeinen, 1996a).

The significant and long-lasting role of extractive industries in the infrastructuring of the Arctic must be emphasised. The opening or presence of a mine has often been the impetus not only for the development of housing, electric power networks, and transport infrastructure (Avango et al. 2019; Kylli & Saunavaara, in press; McCannon, 2012; Warde, 2019), but also for the construction or improvement of telecommunication lines. Just as Norilsk Nickel’s desire to modernise its business practices led to the construction of a 600-mile-long fibre-optic cable connection through the tundra in 2017 (Troianovski, 2019), the construction of telegraph and telephone lines alongside the so-called Iron Ore Line (*malmbanan*) between the Gulf of Bothnia and the Atlantic Ocean in northernmost Sweden was connected to the opening of the iron mine in Kiruna more than a century ago (Elenius et al., 2015; McCannon, 2012). The development of telecommunication infrastructure in Yukon and Alaska was also associated with gold discoveries. The telegraph line to Yukon not only provided a way to communicate but it was also used as a landmark to guide new miners coming from the South through the wilderness (Electricity for Yukon, 1900; Hudson, 2015; Jessup 2007; Lennätinlaitos Suomessa, 1899; Siwistyksen, 1927).

As the decades have passed, both the telecommunication lines and the businesses depending on them have developed. Telegraph wires have evolved into fibre-optic cables and the industry relying on connectivity has at least partially changed from gold mining into energy-hungry bitcoin mining. Obviously the record-keeping services related to cryptocurrency, which takes place at least in Iceland, northern Norway and Russia (Adalbjornsson, 2019; Baydakova, 2019; Fedorinova & Atkinson, 2019; Smolaks, 2018), are not the only digital-age industrial activity in the circumpolar North of which development is interwoven with that of the fibre-optic cable network. The data centre industry is recognised as a potential growth industry in regional development strategies in different parts from the Arctic (Saunavaara, 2018). As fibre-optic cable connectivity is identified as one of the prerequisites for the expansion of the industry, there are great hopes for Arctic submarine fibre-optic cable projects, for example, in Alaska, northern Finland, and Norway. The Arctic Connect project, aiming for a new submarine fibre-optic cable connection through the Northeast Passage, entails also a plan to create landings in the Russian Arctic in places of significant industrial activity. Therefore, if it materialises, the project could contribute to the future of areas already undergoing great transformations due to large-scale hydrocarbon developments (Saunavaara, 2018; Saunavaara & Salminen, in press). In general, the quickly advancing digitalisation of societies requires constantly new digital equipment and machines, new technical solutions and applications, new connections, transformed infrastructures, and new users, which all increase the demand for electricity. The life cycle of consumer goods has become relatively short, which means that energy is constantly used for replacing outdated equipment with newer versions. While the conventional wisdom remains that digitalisation decreases humanity's environmental footprint, the scale of the ongoing digital transformation is gradually challenging this claim.

Tourism has also been connected with the development of telecommunication lines in the Arctic. While the early Finnish tourists used the first telephone lines as guideposts when visiting the Sámi area of northernmost Finland (Kesäisiä, 1929), the demands of hikers were also taken into consideration when the telephone services in the extremely sparsely populated wilderness areas were developed in the 1960s and 1970s. The great distances and high expenses had postponed these projects in earlier decades. In the early 1980s, it was already clear that the services based on radio-telephones were not profitable. Eventually, the lack of profitability led to the elimination of these services in the 1990s (Turpeinen, 1996a, 1996b). In the past three decades, internet has become potentially the most important means of communication for tourists and service providers. At the same time, the expectations and demands of tourists and service providers regarding available high-quality internet connections have risen. It is thus unsurprising that improved connectivity is considered a factor supporting the growing tourism industry in the Arctic (Arctic Council Task Force on Telecommunications Infrastructure in the Arctic, 2017; Warf, 2011).

However, local networks, which are often planned to fulfil the needs of local populations, may face problems when the demand for bandwidth increases during the tourism season. In some extreme cases, such as the small communities hosting cruise ships (or cruise ships just passing by, see YLE, 2020), the demand for bandwidth may drastically change according to the time of the day. In many places in the North, teleoperators consider network construction unprofitable, so the states must subsidise the infrastructure construction and renewals through different financial schemes. On top of state support, the local residents may have been paying part of the costs of, for example, a village's fibre-optic network build-up or connecting the last mile. Commercial interest in network construction, however, does exist in regional centres and in the biggest tourism centres, although many rural areas will continue to depend on mobile connections in the future (e.g. Salminen, 2018)

As these examples show, the development of telecommunication lines has been a factor contributing to who and how many people live or visit in the Arctic and what kind of social and economic practices they initiate and sustain. It can be debated, case-by-case, whether the construction of telecommunication infrastructure actually triggers these changes or whether the construction of a telegraph wire, a telephone line or a fibre-optic cable demonstrates that some kind of change has already taken place. However, it is clear that telecommunication lines have, at least partially, enabled the technical, economic and social processes which have often had much greater impact on the environment than the physical infrastructure itself. The fact that all modern-day business activities need proper connectivity and people around the world rely on web-based services and leisure suggests that the indirect environmental impacts of telecommunication lines will expand.

Utilization of Telecommunication Lines to Observe, Record and Protect the Arctic Environment

The relationship between communication technology, infrastructure and the environment can also be approached from the perspective of the capability to register, record, and analyse the environment as well as to disseminate knowledge and information about the environment. Although the telegraph and phone lines and fibre-optic cables differ, for example, from cameras, tape recorders and weather satellites, which are technological devices designed to capture and store information, they can still be analysed from this perspective as well. This approach, echoing the conception that pipelines are not isolated but connected to the environments they pass through, challenges one to consider whether telecommunication lines have only harmful and destructive impacts on the natural environment they are attached to or whether they can be used to learn about and protect the environment.

Early telegraph line workers, who sometimes had side interests related to the possible exploitation of local natural resources, were also explorers who collected scientific and geographical information about the Arctic and made corrections to the maps then used (Dall, 1870). However, it is not only the people constructing and maintaining the infrastructure, but also the infrastructure itself that has had a role to play. Forest fires can have devastating effects on various businesses and communities in the Arctic. Although satellites may be the type of modern-day communication infrastructure that comes to one's mind when the struggle to prevent forest fires is mentioned (Arctic Wildfires, 2019), forest fire prevention was also one of the arguments used on behalf of the telegraph and phone line development in the 1920s in the northernmost part of Finland. Means of communication were needed to pass on information concerning the occurrence of fires rapidly and to deploy firefighters with minimal delay (Kulotorjunta, 1935; Peräpohjolassa, 1929).

While the telecommunication infrastructure has provided ways to share important information, for example, concerning weather conditions (Hansen, 2005), it has also helped us to understand life at the bottom of the ocean. Historically, organisms encrusted on recovered submarine communication cables have increased our knowledge of the marine biota; especially that of the deep ocean (Carter et al., 2014). While this kind of collection of data has been more or less unplanned and occurred only once, the future may be different if the Sensor Enabled Scientific Monitoring and Reliable Telecommunications (SMART) or dual-purpose cable initiatives are carried out. The basic idea of dual-purpose cables is to integrate different types of environmental sensors, designed to measure temperature, salinity, ocean circulation, sea level rise, and so forth, into commercial submarine fibre-optic cables. Such cables could also monitor seismic activity and tsunamis. While repeaters capable of regenerating fibre-optic signals every 50–100 km are often envisioned as the part of the cable system which could host these sensors, recent studies have proposed that the fibre itself could be used as the sensing element to detect earthquakes and other such phenomena (Marra et al., 2018; Starosielski, 2015; Webster & Dawe, 2019).

The basic idea behind dual-purpose submarine cables is not new, but its implementation has turned out to be challenging. However, the suggested industry-academia cooperation enabling the establishment of affordable large-scale research infrastructure (academic institutions would cover part of the total cost of the commercial cable system, but still pay less than the price of a purely academic installation) is particularly appealing in the Arctic. The Arctic Ocean is one of the marine areas we know least about and it is a very challenging environment for the development and maintenance of research infrastructure. (Saunavaara & Salminen, in press).

Discussion

This article demonstrates how the features of the natural environment in the Arctic affect telecommunication lines and how this infrastructure impacts the environment it is becoming a part of. Similarly, the environmental conditions paired with long distances, small populations, and limited economic opportunities have always affected the different phases of infrastructuring processes. Besides the planning, construction and maintenance of telecommunication infrastructure, the Arctic environment has had a major impact on the selection of the applied technologies as well as on their spatial extent, quality, and speed of expansion. In practise, technical solutions which have worked in the southern latitudes may not have met the Arctic demands, and the cost-performance analyses have led to delays and underdevelopment of the infrastructure. The construction of telecommunication lines has supported the exploitation of natural resources in different parts of the circumpolar North (and outside of it), but it has also played a role in the observation and protection of the environment. Even if technological advancement has changed the ways in which telecommunication lines and the natural environment interact, it has not abolished the strong linkage between them. Two characteristics are typical of the Arctic telecommunication lines: the connection between natural elements and man-made pipelines as theorized, for example, in the concept of pipeline ecologies and the complexity of the relationship between technology and environment as in Agar's eightfold categorisation.

The Arctic is undergoing rapid environmental and social transformations triggered by the global climate change. The existing or planned telecommunication have to consider these changes. While higher temperatures may ease some trouble related to the cold climate, increased rain fall and extreme weather events might bring along new challenges. The thawing permafrost has already caused significant problems to telecommunication lines, which impacts the reliability of communication in the Arctic. This reliability, again, become a crucial question for land and sea transportation, search and rescue, as well as for reaction and response in extreme weather events. As the ongoing digitalisation makes societies evermore dependent on the flawless functioning of telecommunications, potential infrastructure failures originating from living and non-living environmental forces can have devastating effects on social and economic sustainability.

The telecommunication infrastructure itself may have a relatively small direct impact on climate change, but its indirect effects through the development and location of industry and communities may be broader. Improved connectivity has effects that are considered positive, such as decreased travel to, from and within the Arctic; improved collection and dissemination of information concerning the Arctic; and eased communication within and between the Arctic communities and with their ‘expatriates’. Furthermore, the improved access to communication means such as social media provides people and communities across the Arctic with new possibilities to initiate and participate in activities arising from environmental concerns or climate change-related issues (Klein and Hossain, 2020). Yet, as explained above, telecommunication infrastructure has a long history as an artificial addition to the environment that has been developed regardless of or against the will of the Arctic (often indigenous) peoples.

While recognizing the existence of recent studies, based on the interviews of Sámi informants, which have identified several desirable impacts that improved connectivity can bring to the life of indigenous persons (ranging from improved possibility to stay in touch with family, relatives, friends, and the Sámi communities to opportunities to use the Sámi languages and maintain contact with culture via the internet where traditional knowledge and expertise can be saved, shared, and even commercialized, see e.g. Olsén-Ljetoff & Hokkanen, 2020), we do not want to oversimplify the complex and potentially conflict-prone relationship between telecommunication infrastructure and indigenous communities in the contemporary context.

Rather, we argue that ongoing and future projects should be based on the recognition that: 1) the environmental conditions have always affected telecommunication infrastructure development in the Arctic and they will do that also in the future; 2) tailor-made regional solutions may be needed instead of nationwide or pan-Arctic infrastructure policies; and 3) local knowledge concerning the Arctic environment should be utilized in the planning, construction and maintenance of telecommunication lines. The need for creative solutions capable of responding to the particular challenges posed by the Arctic environment is not disappearing and the incorporation of local voices and expertise can make future infrastructure projects both socially and environmentally sustainable.

Financial Support

This work was supported by the University of Oulu Arctic Interactions (ArcI) Visit Grant Programme.

Conflicts of Interest

None.

References

28de Juli [28 July]. (1896). *Tromsøposten*, 29 July 1896.

Adalbjornsson, T. (2019, 18 June). Iceland's data centers are booming—Here's why that's a problem. *MIT Technology Review*. https://www.technologyreview.com/s/613779/icelands-data-centers-are-booming-heres-why-thats-a-problem

Agar, J. (2018). Technology, environment and modern Britain: Historiography and intersections. In J. Agar & J. Ward (Eds.), *Histories of technology, the environment and modern Britain* (pp. 1–21). London: UCL Press.

Airaksinen, T. (2003). *Tekniikan suuret kertomukset. Filosofinen raportti*. [The grand narratives of technology. A philosophical report.] Helsinki: Otava.

A. K. (1918, September). Lennätinlinjan rakennus Lapissa talvella v. 1916–17 [The construction of a telegraph line in Lapland during the winter 1916–17]. *Lennättäjä*.

Alaskan telegraph. (1901, 22 May). *The Daily Morning Alaskan.*

An old-time project: Telegraph connection with Russia via Alaska. (1897, 1 October). *The Seattle Post-Intelligencer*.

Arctic Council Task Force on Telecommunications Infrastructure in the Arctic (TFTIA). (2017). Telecommunications infrastructure in the Arctic: A circumpolar assessment. https://oaarchive.arctic-council.org/bitstream/handle/11374/1924/2017-04-28-ACSTelecomsREPORTWEB-2.pdf?sequence=1

Arctic Economic Council Telecommunications Infrastructure Working Group (AEC TIWG). (2017). Arctic Broadband. Recommendations for Interconnected Arctic. https://arcticeconomiccouncil.com/wp-content/uploads/2017/03/AEC-Report_Final-

LR.pdf

Arctic wildfires: How bad are they and what caused them? (2019, 2 August). *BBC* Website. https://www.bbc.com/news/world-europe-49125391

Avango, D., Kunnas, J., Petterson M., Petterson Ö., Roberts, P., Solbär, L., … Wråkberg, U. (2019). Constructing northern Fennoscandia as a mining region. In E. C. H. Keskitalo (Ed.), *The politics of Arctic resources: Change and continuity in the "old north" of Northern Europe* (pp. 78–98). London and New York: Routledge.

Bannerman, N. (2018, 28 August). Connecting beneath the ice. *Capacity Media*, https://www.capacitymedia.com/articles/3822263/connecting-beneath-the-ice

Baydakova, A. (2020). Bitcoin mining farms are flourishing on the ruins of Soviet industry in Siberia. *CoinDesk*, https://www.coindesk.com/bitcoin-mining-farms-are-flourishing-on-the-ruins-of-soviet-industry-in-siberia

Beckman, B., & McKay, C. G. (2003/2005). *Swedish Signal Intelligence 1900–1945*. London: Frank Cass.

Bernton, H. (2019, 17 December). As Alaska permafrost melts, roads sink, bridges tilt and greenhouse gases escape. *Anchorage Daily News*. https://www.adn.com/alaska-news/weather/2019/12/17/as-alaska-permafrost-melts-roads-sink-bridges-tilt-and-greenhouse-gases-escape/

Blok, A., Nakazora, M., & Winthereik, B. R. (2016). Introduction: Infrastructuring environments. *Science as Culture*, *25*(1), 1–22.

Borunda, A. (2018, 16 July). The Internet Is Drowning. *National Geographic*, https://www.nationalgeographic.com/science/2018/07/news-internet-underwatersea-level-rise/

Burrington, I. (2015, 24 November). How railroad history shaped internet history. *The Atlantic*, https://www.theatlantic.com/technology/archive/2015/11/how-railroad-history-shaped-internet-history/417414/

Bush, R. J. (1871). *Reindeer, dogs and snowshoes: A journal of Siberian travel and explorations made in the years 1865, 1866 and 1867.* New York: Harper & Brothers.

Carter, L., Burnett D., & Davenport, T. (2014). The relationship between submarine cables and the marine environment. In D. R. Burnett, R. C. Beckman, & T. M. Davenport (Eds.), *Submarine cables: The handbook of law and policy* (pp. 179–212). Leiden and Boston: Martinus Nijhoff Publishers.

Castells, M. (2010/2000). *The rise of the network society.* (2nd ed.) The Information Age: Economy, Society, and Culture, Volume I. Chichester: Wiley-Blackwell.

Coppes, J., Burghardt, F., Hagen, R., Suchant, R., & Braunisch, V. (2017). Human recreation affects spatio-temporal habitat use patterns in red deer (Cervus elaphus). *PloS One* 12(5), 1–19.

Dall, W. H. (1870). *Alaska and its resources.* Boston: Lee and Shepard.

Davenport, T. (2018). The high seas freedom to lay submarine cables and the protection of the marine environment: Challenges in high seas governance. *American Journal of International Law Unbound*, 112, 139–143. https://doi.org/10.1017/aju.2018.48

Dominion line late in getting started. (1901, 11 August). *The Daily Morning Alaskan*.

Eläimet ja sähkölennätin [Animals and electric telegraph]. (1912). *Helsingin kaiun* *kuukauskuvalehti*, 10(October), 164–165.

Electricity for Yukon. (1900, 3 August). *The Lewiston Daily Sun*.

Elenius, L., Tjelmeland, H., Lähteenmäki, M., Golubev, A., Niemi, E., & Salo, M. (2015). *The Barents region: A transnational history of subarctic northern Europe*. Oslo: Pax Forlag.

Fedorinova Y., & Atkinson G. (2019, 29 November). Russia's largest bitcoin mine turns water into cash. *Bloomberg.* https://www.bloomberg.com/news/features/2019-11-24/seo-inside-russia-s-largest-bitcoin-mine

Gere, C. (2008). *Digital culture*. (2nd ed.) London: Reaktion Books.

Grove, C. (2018, 20 June). State: Permafrost thaw from Arctic broadband projects violated permits. *Alaska Public Media* https://www.alaskapublic.org/2018/06/20/state-permafrost-melt-from-arctic-broadband-projects-violated-permits/

Hallenberg, M., & Linnarsson, M. (2017). The quest for publicness: Political conflict about the organisation of tramways and telecommunication in Sweden, c. 1900–1920. *Scandinavian Economic History Review*, *65*(1), 70–87.

Hamilton, W. R. (1964). *The Yukon story: A sourdough's record of goldrush days and Yukon progress from earliest times to the present day*. Vancouver: Mitchell Press.

Hansen, K. G. (2005). Telecommunications. In M. Nuttall (ed.), *Encyclopedia of the Arctic: Volume 3, O–Z, index* (pp. 2013–2016). New York: Routledge.

Harsti, R. A. (1929, 26 January). Tammikuista Petsamoa [January in Petsamo]. *Suomen Kuvalehti* (Helsinki), 4.

Herz, N. (2018, 21 June). Alaska regulators assess damage to tundra and permafrost after

240-mile fiber-optic installation. *Anchorage Daily News*. https://www.adn.com/business-economy/2018/06/21/alaska-regulators-assess-damage-to-tundra-and-permafrost-after-240-mile-fiber-optic-installation/

-hm. (1873, 20 September). Bref från Lappmarken [Letter from Lapland]. *Hufvudstadsbladet*.

Hudson, H. E. (2015). *Connecting Alaskans: Telecommunications in Alaska from telegraph to broadband*. Fairbanks: University of Alaska Press.

Huurdeman, A. A. (2003). *The worldwide history of telecommunications*. New York: John Wiley & Sons.

Itkonen, T. (1933, 18 August). Puhelinpylväs [Telephone pole]. *Kansan Kuvalehti*, 34.

J. A-la. (1926, 17 November). Keskustelua Utsjoen asiasta [Discussion of the Utsjoki issue]. *Iltalehti*.

Jessup, D. E. (2007). Connecting Alaska: The Washington-Alaska military cable and telegraph system. *Journal of the Gilded Age and Progressive Era*, *6*(4), 385–408.

Kennan, G. (1873). *Tent life in Siberia and adventures among the Koraks and other tribes in Kamtchatka and Northern Asia*. New York: G. P. Putnam's Sons.

Kesäisiä matkasuunnitteluja [Travel plans for the summer]. (1929, 20 April). *Nuori Voima*.

Klein, J., & Hossain, K. (2020). Conceptualizing human-centric cyber security in the Arctic in light of digitalisation and climate change. *Arctic Review on Law and Politics*, 11, 1–18.

Kulotorjunta Peräpohjolassa ja Lapissa [Forest fire control in North Bothnia and Lapland]. (1935, 3 April). *Pohjolan Sanomat*.

Kylli, R., & Saunavaara, J. (in press). Debate concerning the early transport infrastructure in the Sámi area of Finnish Lapland. *Barents Studies: Peoples, Economies and Politics.*

Kylli, R. & Enbuske, M. (in press) Arktisen ympäristön muutos [Arctic environment in change]. In E. Ruuskanen, P. Schönach & Kari Väyrynen (eds.), *Suomen ympäristöhistoria*. Tampere: Vastapaino.

Lapin liitto [the Regional Council of Lapland] (2007). Lapin tietoyhteiskuntastrategia 2007–2010. Kilpailukyky—arjen tietoyhteiskunta—osallisuuden lisääminen. [Information Society Strategy of Lapland 2007–2010 Competitiveness—Everyday information society—Improved inclusiveness]. http://www.lappi.fi/lapinliitto/c/document_library/get_file?folderId=22575&name=DLFE-1086.pdf

Larkin, B. (2013). The politics and poetics of infrastructure. *The Annual Review of Anthropology*, 42, 327–343.

Lennätinlaitos Suomessa [Telegraph agency in Finland]. (1889, 28 May). *Uusi Suometar*, 123.

Marra, G., Clivati, C., Luckett, R., Tampellini, A., Kronjäger, J., Wright, L., … Calonico, D. (2018). Ultrastable laser interferometry for earthquake detection with terrestrial and submarine cables. *Science, 361*(6401), 486–490.

McCannon, J. (2012). *A history of the Arctic: Nature, exploration and exploitation*. London: Reaktion.

McGwin, K. (2018, 13 November). No matter where you live in Greenland, you can now get a 4G signal. *Arctic Today*. https://www.arctictoday.com/no-matter-live-greenland-can-now-get-4g-signal/

McGwin, K. (2019, 8 November). On Norway's internet frontier, the future is here—Again. *Arctic Today*. https://www.arctictoday.com/on-norways-internet-frontier-the-future-is-here-again/

McNeil, J. R., & McNeill, W. H. (2003). *The human web: A bird's eye view of world history*. New York, NY: W. W. Norton & Company.

Montgomery, J. D. (2002). History of fiber optics. In C. DeCusatis (ed.), *Fiber optic data communication: Technological trends and advances* (pp. 3–31). San Diego, CA: Academic Press.

Neitiniemi, A. A. (1926, 12 October). Valtakuntamme pohjoisiin rajoihin enemmän huomiota [Greater attention to the northern borders of our country]. *Kaiku*.

Niewöhner, J. (2015). Infrastructures of Society, Anthropology of. In J. D. Wright (ed.), *International Encyclopedia of the social & Behavioral Sciences, 2nd edition* (pp. 119–125, Volume 12). Elsevier. DOI: 10.1016/B978-0-08-097086-8.12201-9

Olsén-Ljetoff, L., & Hokkanen, L. (2020). The Interconnection Between Digitalisation and Human Security in the Lives of Sámi with Disabilities. In M. Salminen, G. Zojer, & K. Hossain (Eds.), *Digitalisation and Human Security. A Multi-Disciplinary Approach to Cybersecurity in the European High North* (pp. 295–322). Cham: Palgrave Macmillan.

Overland cable. (1903 19 February). *The Alaska Prospector*.

Peräpohjolassa ja Lapissa [In North Bothnia and Lapland]. (1929, 20 April). *Rovaniemi: Pohjolan ja Lapin ääni*.

Petsamon Nikkeli Oy [Petsamo Nickel Company]. (1938, 1 September). *Lapin Kansa*.

President of Russia. (2018, 1 March). Presidential address to the Federal Assembly. Kremlin website. http://en.kremlin.ru/events/president/news/56957

Quinn, G. (2016, 2 August). Climate change is hell on Alaska's formerly frozen highways. *Bloomberg*. https://www.bloomberg.com/news/features/2016-08-02/the-alaskan-highway-is-literally-melting

Quintillion (2019, 17 October). Quintillion and ATLAS space operations expand strategic data infrastructure in the Arctic. Quintillion website. http://qexpressnet.com/uncategorized/quintillion-and-atlas-space-operations-expand-strategic-data-infrastructure-in-the-arctic/

Quintillion (2020a). System specifications. Quintillion website. http://qexpressnet.com/system/

Quintillion (2020b). Quintillion Stands Ready to Close the Arctic Security Gap. http://qexpressnet.com/wp-content/uploads/2020/09/Quintillion-Press-Release_Jacoby-1.pdf

Quintillion (2020c). Quintillion Names Lance Dubsky Chief Security Officer, Delivering on its Commitment to Maintaining the Security of U.S.-Based Telecommunications. http://qexpressnet.com/wp-content/uploads/2020/09/Lance-Dubsky-Press-Release.pdf

Ramirez, A. (2015). A wire across the ocean. *American Scientist*, *103*(3), 180–183. https://doi.org.10.1511/2015.114.180

Røde, G., ed. (1996). *Guide to the history of Lofoten*. Lofoten Public Museums/Lofoten

Regional Council. http://www.lofoten-info.no/history.htm#10

Salminen, M. (2018). Digital security in the Barents region. In K. Hossain & D. Cambou (eds.), *Society, environment and human security in the Arctic Barents region.* Routledge Explorations in Environmental Studies. Abingdon: Routledge, 187-204.

Salminen, M., & Hossain, K. (2018). Digitalization and human security dimensions in cybersecurity: An appraisal for the European High North. *Polar Record*, 53(2), 1–11.

Saunavaara, J. (2018). Arctic subsea communications cables and the regional development of northern peripheries. *Arctic and North*, 32, 51–67. https://doi.org.10.17238/2221-2698.2018.32.6

Saunavaara, J., & Salminen, M. (in press). Geography of the global submarine fiber-optic cable network: The case for Arctic Ocean solutions. *Geographical Review*.

Shekar S. (2019a, 27 June). Rural economic minister unveils strategy to connect all Canadians to the internet. *Mobilesurup*, https://mobilesyrup.com/2019/06/27/rural-economic-minister-connectivity-strategy/

Shekar S. (2019b, 19 August). Canada invests over $151 million to build fibre optic cable between Iqaluit and Greenland. *Mobilesurup*, https://mobilesyrup.com/2019/08/19/fibre-optic-cable-greenland-iqaluit-broadband-services/

Siwistyksen etuwartijat [The outpost guards of civilisation]. (1927, 2 October). *Satakunnan kansa*.

Smolaks M. (2018, 28 March). Kolos data center park in Norway is being acquired by cryptocurrency miners. *Data Centre Dynamic*, https://www.datacenterdynamics.com/en/news/kolos-data-center-park-in-norway-is-being-acquired-by-cryptocurrency-miners/

Stafford, E. (2019, March). PTC'19 submarine cable workshop recap: 'We connect the internet!' *Submarine Telecoms Forum*, 105, 16–19. https://issuu.com/subtelforum/docs/subtel_forum_105_highres

Starosielski, N. (2015). *The undersea network*. Durham, NC: Duke University Press.

Starosielski, N. (2016). Pipeline ecologies: Rural entanglements of fiber-optic cables. In N. Starosielski & J. Walker (eds.), *Sustainable media—Critical approaches to media and environment* (pp. 38–55). New York and London: Routledge.

Storthinget [Storting]. (1863, 26 January). *Aftenbladet*.

Stuhl, A. (2016). Cold places: Movement, knowledge, and time. *Journal of Environmental Studies and Sciences*, *6*(4), 779–782.

Suurin työ kuluvana kesänä maakunnan puhelinoloissa [Main work related to the region's telephone situation during the summer]. (1929, 28 September). *Rovaniemi: Pohjolan ja Lapin ääni*.

TeleGeography. (n.d.). Submarine cable frequently asked questions. TeleGeography website. https://www2.telegeography.com/submarine-cable-faqs-frequently-asked-questions

Telegraph to the Klondike. (1899, 9 March). *The Dalles Daily Chronicle*.

ThomasNet. (2020). Top 10 US and international fiber optics suppliers. https://www.thomasnet.com/articles/top-suppliers/fiber-optics-manufacturers-suppliers/

Thomes, W. J., Chuska, R. F., Ott, M. N., LaRocca, F. V., Switzer, R. C., & Macmurphy, S. L. (2008). Fiber optic cable thermal preparation to ensure stable operation.

Proceedings of SPIE—The International Society for Optical Engineering, 7070. https://doi.org.10.1117/12.796977

Troianovski, A. (2019, 20 October). On ‘island’ in Russian Arctic, arrival of fast internet shakes political calm. *The New York Times*, https://www.nytimes.com/2019/10/20/world/europe/russia-internet-norilsk-youtube-arctic.html

Turpeinen, O. (1996a). *Yhdistämme: 200 vuotta historiaa—Haasteena tulevaisuus: Lennätinlaitoksesta Telecom Finland Oy:ksi. Osa 1* [We connect: 200 years of history—Future as a challenge: From a telegraph agency to Telecom Finland Oy. Part 1]. Helsinki: Edita.

Turpeinen, O. (1996b). *Yhdistämme: 200 Vuotta historiaa—Haasteena tulevaisuus: Lennätinlaitoksesta Telecom Finland Oy:ksi. Osa 2* [We connect: 200 years of history—Future as a challenge: From a telegraph agency to Telecom Finland Oy. Part 2]. Helsinki: Edita.

Utsjoen eristäytymispyrkimykset. [The Isolationist Aspirations of Utsjoki]. (1926, 11 May). *Rovaniemi: Pohjolan ja Lapin ääni*.

Very first wire to the Klondyke. (1898 9 January). *The Times* (Richmond, Va.).

Wahab, S.A., Rose, R. C., & Osman, S. I. W. (2012). Defining the concepts of technology and technology transfer: A literature analysis. *International Business Research*, *5*(1), 61–71. https://doi.org.10.5539/ibr.v5n1p61

Ward, J. (2018). Oceanscapes and spacescapes in North Atlantic communications. In J. Agar & J. Ward (eds.), *Histories of technology, the environment and modern Britain* (pp. 186–205). London: UCL Press.

Warde, P. (2019). Energy regimes in the Fennoscandian north, c. 1900–2015. In E. C. H. Keskitalo (ed.), *The politics of Arctic resources: Change and continuity in the "old north" of northern Europe* (pp. 140–160). London: Routledge.

Warf, B. (2011). Contours, contrasts, and contradictions of the Arctic internet. *Polar Geography*, *34*(3), 193–208. https://doi.org.10.1080/1088937X.2011.589012

Wargo, R., & Davenport, T. (2014). Protecting submarine cables from competing uses. In D. R. Burnett, R. C. Beckman, & T. M. Davenport (eds.), *Submarine cables: The handbook of law and policy* (pp. 255–280). Leiden: Martinus Nijhoff Publishers.

Watson, A. (2005). Western telegraph expedition. In M. Nuttall (ed.), *Encyclopedia of the Arctic. Volume 3, O–Z, index* (pp. 2168–2169). New York, NY: Routledge.

Webster, S., & Dawe, S. (2019, 9 April). Smart cables: A specification to enable informed investment [paper presentation). SubOptic 2019, New Orleans, LA, United States. https://suboptic2019.com/suboptic-2019-papers-archive/

Weihed, P. (2016). Mineral resources and mining. In M. Olsson, F. Backman, A. Golubev, B. Norlin, L. Ohlsson & L. Elenius (eds.), *Encyclopedia of the Barents region: Vol. 1, A–M* (pp. 482–488). Oslo: Pax.

Wenzlhuemer, R. (2012). *Connecting the nineteenth-century world: The telegraph and globalization*. Cambridge: Cambridge University Press.

Wheen, A. (2011). *Dot-dash to dot.com: How modern telecommunications evolved from the telegraph to the internet.* New York, NY: Springer-Praxis Books.

Whymper, F. (1869). *Travel and adventure in the territory of Alaska, formerly Russian America—now ceded to the United States—and in various other parts of the North*

Pacific. New York, NY: Harper & Brothers.

YLE. (2020, 25 January). 4G-yhteydet ovat hitaampia kuin muutama vuosi sitten ja paikalliset erot ovat valtavia [4G connections are slower than a few years ago and differences between regions are great]. *YLE*, https://yle.fi/uutiset/3-11174191

Zojer, G. (2019). The interconnectedness of digitalisation and human security in the European high north: Cybersecurity conceptualised through the human security lens. *The yearbook of polar law X*. Leiden: Brill Nijhoff, 297–320.