Satellite Communication Development in Arctic Region

M. Sivaranjani
UG scholar,
Department of Aeronautical Engineering,
Parisutham Institute of Technology and Science, Tanjavur.
Tamil nadu- india

D. Shalini
UG scholar,
Department of Aeronautical Engineering,
Parisutham Institute of Technology and Science, Tanjavur.
Tamil nadu- india

Abstract: This article surveys the unsatisfying communication capabilities in the harsh Arctic regions. By melting of the ice caps, the undergoing change of the north polar area opens new opportunities and, therefore, increases the need for human and machine-to-machine communications. The emerging demands and challenges are reviewed. New satellite systems, architectures, and technologies being deemed as key enablers are highlighted. As also addressed in this article, satellite links could additionally backhaul terrestrial networks for local communications.

***Keywords: satellite communication, arctic region, GPS, GNSS*.**

I. INTRODUCTION

Most commonly, scientists define the Arctic as the region above the Arctic circle , an imaginary line that circles the globe at 66° 32" N. The Arctic is currently experiencing a warmer climate, which is slowly reducing the permanent floating ice cover and making the area more accessible to shipping and other activities. Currently, fishing fleets, cruise ships, and cargo ships are operating already above 80°N, and oil/gas explorations are extending above 75°N. Therefore, the number of stakeholders in these areas will further increase. Communication infrastructure and associated equipment face a very harsh environment in the Arctic. Because of this rough environment, communication is an essential part for safety of life. However, availability of communication is very limited. The vast geographic areas of the sea and ice do not allow a dense terrestrial communication infrastructure. Geostationary (GEO) satellites can theoretically provide coverage up to 81°N, but the practical limit is typically assumed to be around 76°N. However, polar-orbiting satellites could serve the whole Arctic by using a low earth orbit (LEO) or high elliptical orbit (HEO), e.g., the “Molniya” orbit. In this article, the current situation and the existing communication possibilities for the Arctic are reviewed. A detailed outline of the communication challenges in Norwegian waters and territories can be found in [1]. A glance at potential high frequency (HF) terrestrial communication in the polar region is also given in [2]. The initial part of this article is addressing the change of this unique region regarding climate and its resulting potentials. The existing and future user needs in communication will be reflected. The main focus of this survey is the requirements for any kind of communication as well as the details on satellite communications. Finally, new architectures and technologies for satellite communications in the Arctic are discussed.

II. IRIDIUM

Iridium Communications LLC is a company offering several planet-wide satellite communications services spanning from voice to low-rate data transfer. Through Iridium it is possible to transfer both one-way sensor/tracking data through the Short Data Burst service as well as higher two-way data rates from 2.4 kbps to 132 kbps in today’s system. Iridium plans to launch a new rangeofsatellitesfrom2015. ThisnewconstellationwillbecalledIridiumNEXT,andisplanned to be operational from 2017 [18]. A short comparison over the legacy Iridium services and the new services is shown in Table 1. Today,Iridiumis the only open, planet-wide communications solution enabling voice and data services in the Arctic area.

Fig 1. LEO /GEO locations

II. CHANGES OF THE ARCTIC ENVIRONMENT

During the last decades, the Arctic Ocean has experienced a drastic change in the extension of its floating ice coverage. As shown in Fig. 1, the size of the ice cap has decreased significantly; this trend is being predicted to continue by several scientists. Increased shipping activities are experienced during the last years in the Arctic Ocean, where new routes are also feasible. Mainly, the Northern Sea Route (NSR) along the Russian Arctic Coast is of high interest and already in use by 40-50 transits per year. Scheduled to start in 2017, the northeast of the Yamal Peninsula, Russia at Sabetta, a new liquefied natural gas

plant (Yamal LNG) will operate, including 16 new built ice-class tankers. Nevertheless, the melting of the ice cap does not mean a permanent ice-free Arctic Ocean. Even according to the most extreme prognosis for 2050, the North Pole will only be so-called "ice-free", that is, less than 10% of
the water surface is ice covered, during a few months per year. Ships will still be slowed down by icebergs and drifting ice. The current average speed in the NSR is 7–13 knots [3] compared with 21–25 knots in open waters. Furthermore, sailing in these waters require a different class of ships compared with open waters. Moreover, all routes have political difficulties as the respective countries claim parts of them as territorial waters and not as international straits. Anyhow, the reduced ice cap has already allowed shipping in the NSR during the last years by support of ice breakers, not only in case of emergency caused by lack of communication capabilities but also because of areas with still permanent ice coverage (e.g., in the Laptev Sea).

III. NEW MISSIONS TOWARDS THE ARCTIC

Since there is an increasing interest for activities in the Arctic, several parties have plans for missions aiming to fill the communication gap identified by bodies like ESA. From the ESA study for Future Arctic Communications Needs we can read: "demand for broadband communications could extend over 100 Mbps in 2020. Maritime activities are considered one of the main drivers of the demand. The supply is virtually non-existent, i.e. there is an considerable capability gap." [11]. For Europe, it is also an important fact that the operational/planned systems for Arctic coverage so far are non-European projects. The following sections present assume-up of planned systems. The exact status for each project is not easily accounted for, but they serve as examples on envisioned systems.

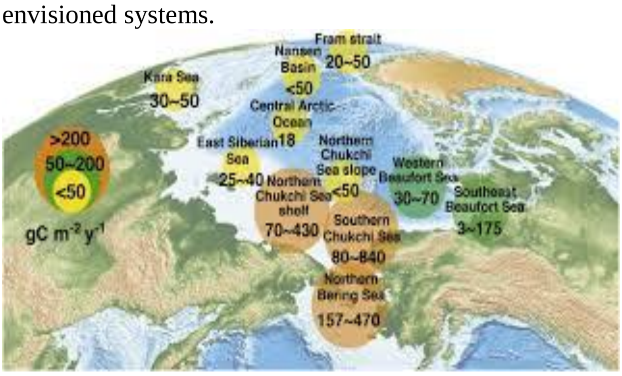

Fig.2 .signal covering arctic areas.

III. NEEDS OF CURRENT AND POTENTIAL USERS

Current fishing activities are even more up north than decades before. The same evolves in new areas of eco-tourism and leisure sailing. Additionally, the areas for drilling are explored in the High North, and research activities are permanently running. Finally, cargo shipping as transit or local traffic exists. Since the usage of satellites for collecting ship data via the automatic identification system (AIS), these new developments could be monitored [6]. Independent of the climate change and its consequences, the polar region experiences continuous air traffic since the mid of last century. The number of flights simultaneously present in the Arctic airspace (latitudes above 70°N) during peak period conditions are predicted to steadily increase from 55 at present to more than 160 in 2030 [7]. Not only airliners and cargo flights are taken into account but also general aviation, helicopter flights, nonscheduled flights (e.g., search and rescue (SAR), ambulance, etc.), and military flights. Many different groups have diverse communication requirements. Offshore oil and gas exploitations, including safeguarding of operations, installations, transportation, and associated ports are looking toward high data rates until the platforms are operational and linked via fiber cables to the main land. Also, crew welfare is a rising issue toward an attractive employment, not only on ships but also on explorations and for people living in these remote areas. Permanent monitoring of fish farms, aquaculture installations, and their associate activities request continuous flow of information, for example, machine-to-machine (M2M) communications for "health" monitoring of the systems. Within the maritime area, traffic and environmental safety monitoring is needed, including the distribution of navigational data, for example, navigational warnings, maritime safety information, and position reporting. Another source of information would be weather and ice information to be distributed over a vast geographic area toward the mariners, fishers, and others. Moreover, authorities (coast guards and homeland security) need reliable and robust communication solutions for defense operations, territorial control, law enforcement of illegal activities, and environmental crime. Also, a robust communication infrastructure is required for aircraft in the polar region [7]. Finally, research activities such as ice studies and meteorological and hydrological research require communication systems for monitoring and controlling. In Table II, the demands on data throughput for different applications in the maritime [8] and aeronautical domain are illustrated.

IV. EXISTING AND PLANNED COMMUNICATIONS SYSTEMS

Broadband communication is currently unavailable in the Arctic. The GEO Inmarsat satellite and very small aperture terminal (VSAT) satellites provide a theoretical coverage up to 81°N. Although the practical limit is assumed to be around 76°N. Attempts to optimize signal reception of the Ka-Sat by Eutelsat at the shelf of the Arctic Ocean in North-Western regions of Russia prove the practical difficulties of GEO satellites for polar areas [9]. Because of an inclination of 52° of the LEO orbits by the Globalstar satellite system, the Arctic is not fully covered. Also, the second generation of Globalstar satellites is using the same orbits. The only notable LEO satellite communications system constellation covering the Arctic is Iridium, comprising 66 satellites in six polar LEO planes at altitudes of approximately 780 km, providing a maximum voice and data service of 130 kbit/s. Nevertheless, because of the multi-hop architecture for reaching one of the four Earth stations via feeder links, high latencies exist in the system up to 500 ms for voice and 20 s for data [10]. Furthermore, the non-commercial US tactical satellite communications system MUOS (Mobile User Objective System) covers in a geosynchronous earth orbit the Arctic by up to 384 kbit/s. Based on a Russian Federal Space Agency program of the early 1990s, the Gonets system has been commercially operational since 2000, using a LEO orbit altitude of 1400 km with an inclination of 82.5°. In total, 5 satellites are in orbit today. The two Gonets-D-1 support a data rate of 2.7 kbit/s, and the three Gonets-D1M satellites, up to 64 kbit/s. A distress alert detection satellite system for SAR is provided by the Cospas-Sarsat program. Six LEO satellites are operational for collecting distress signals at 406 MHz in an orbit at an altitude of approximately 850 km and with emphasis on the polar regions. Since May 2011, SAR responsibilities in the Arctic are governed by the Arctic Search and Rescue Agreement [11]. Terrestrial systems also exist in the Arctic, although very limited in coverage. The current voice communications for maritime applications (ship-to-ship or ship-to-shore) is based on analog technologies in the very high frequency (VHF) band, mainly Channel 16 at 156.8 MHz but also Channels 6 and 13 with a range of up to 60 nautical miles (NM). Other communication systems are operating in the medium-frequency (MF) and high-frequency (HF) band with analog and a few evolving narrowband digital services, such as digital selective calling (DSC), Navigational Telex (Navtex), Maritime Safety Information (MSI), Narrowband Direct Printing (NBDP), and other HF digital data services. However, the dependence on signal reflection from the ionosphere is rendering MF/HF communications unreliable, although the coverage distances may be very large during favorable ionospheric conditions. A future MF/HF digital data service for MSI would include Navigational Data (NAVDAT). The NAVDAT operates in the 500-kHz band (MF) for digital broadcasting of maritime safety and security-related information from shore to ship with 10kHz bandwidth using OFDM modulation, providing a data rate of about 15 to 25 kbit/s. The coverage is approximately 250/350 NM from the coast station [12]. An overview of the coverage limitations of communication systems in the Arctic.

V. ARCTIC COMMUNICATIONS SYSTEMS' CHALLENGES

A.GNSS augmentation systems (SBAS/GBAS)

Precise satellite navigation positioning relies on correction signals obtained from fixed stations at known positions (socalled differential satellite navigation). Augmentation of global navigation satellite system (GNSS) is a method of improving the system’s attributes, such as accuracy, reliability, and availability, through the integration of external information from such reference stations into the receiver’s calculation process. Because of the vast open sea areas in the Arctic, adequate ground-based augmentation systems (GBAS) are hardly realizable. Satellite-based augmentation systems (SBAS) utilizing GEO satellites suffer from their coverage shortcoming in the Arctic, for example, the devised European Geostationary Navigation Overlay Service (EGNOS) system for future Galileo applications. Consequently, novel SBAS/GBAS solutions need careful attention to accommodate user requirements on accurate and reliable GNSS positioning in the High North [1].

A. Weather and Icing

The harsh, unpredictable, and rapidly changing weather conditions in the Arctic frequently cause icing on outdoor equipment, both so-called atmospheric icing due to precipitation and icing created by sea spray (salty ice). Antennas enable any radio system contact with the outside world and, thus, represent the most crucial elements regarding system performance. Icing is one of the most serious problems for numerous antenna installations. Ice buildup not only increases antenna wind load and weight but also often deteriorates the antenna’s performance to a point where it is no longer usable for any radio system. It is often experienced in maritime environments by ice first forming on an antenna that it is usually wet and conductive, particularly if it is the result of saltwater spray. This is the most destructive condition for electrically detuning and deterioration of antenna performance. Subsequently, ice buildup increases and will eventually freeze solid, causing the antenna wind load to escalate to a level where it may be stressed to its breaking point. Both the ice buildup and (subsequent) melting occur most frequently in an asymmetrical fashion, so one side of the antenna may be more affected than the other. Antennas can also be damaged by flying ice from nearby structures often found on ships and offshore installations. This can often cause catastrophic failures because heavy and large ice sheets often break loose with wind or melting. Consequently, novel robust antenna designs are required for reliable operations of radio systems under adverse weather conditions in the Arctic [1].

C. Vessel Movements

Stabilized antennas must lock into the intended satellite for proper operation, but several conditions, including the vessel’s unpredictable gyrations, can instigate a stabilized antenna to drift away from the intended satellite and cause signal blackout and/or harmful interference to adjacent satellites. Because of rather severe roll, pitch, and yaw movements of a vessel during adverse weather conditions, larger nominal elevation angles than 5° are required, and thus, practical problems with less advanced satellite communication terminals may be expected to arise.

VI. NEW ARCHITECTURES AND TECHNOLOGIES FOR ARCTIC

As outlined above, the state-of-the art in Arctic communications demand obviously new architectures and technologies to fulfill user requirements. This section addresses several topics that need be emphasized in paving the road toward novel innovative solutions and further associated research. The major goal should be to close today’s existing communication gap until adequate broadband coverage is obtained by utilizing new satellite systems and other spacebased assets in combination with advanced terrestrial systems.

A. Hybrid Architecture

The lack of land infrastructure in the Arctic is a limiting factor for fast emerging new communication systems. Therefore, a multitier approach using satellites, unmanned aerial systems (UASs), and extended coverage by terrestrial infrastructure could become a solution for the Arctic environment. Fig. 3 shows a possible architecture of such an approach. The high altitude platforms (HAPs) and/or UAVs could serve as relay stations between the satellite platform (GEO, LEO, MEO or HEO, whichever being the most appropriate) and the user terminals or terrestrial base stations embraced by the 'grey cone' [1]. Further, this infrastructure could vary between a standalone HAP system and an integrated terrestrial HAP satellite system. To achieve a large coverage area of about 400–500 km footprint diameter, and simultaneously remain in relatively calm tropospheric wind conditions, the HAPs/UASs should preferably fly at a height of about 20 km. Larger areas could be covered by several crosslinked HAPs/UAVs. Hence, they could also be visible from a GEO satellite due south up to approximately 85.8°N, which could provide a reliable data link with a GEO satellite up to approximately 83°N. From 83°N latitude, the longitudinal distance to the North Pole is only about 800 km, which is the same distance from 83°N down to 76°N, where communication between vessels and GEO satellites is normally of acceptable quality-of-service (QoS).

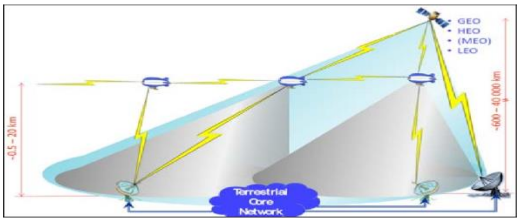

Fig .3.Heterogeneous satellite HAPs/UASs-terrestrial Systems.

HAP/UAV payloads could comprise radio-relaying equipment for all applicable kinds of communication services in the appropriate satellite frequency bands. However, to simplify the onboard equipment for a majority of the vessels, and because of the detriment of bandwidth, the use of VHF is recommended as a part of the frequency allotment scheme. Anyhow, as a network topology subset of any satellite solution, hybrid space-borne/terrestrial (HST) configurations should be developed, particularly for minor communities and in coastal areas, as well as on vessels and offshore installations; being a consequential means to any of the above referenced solutions in providing for a more convenient end-to-end connectivity over the corresponding heterogeneous link. Additionally, carefully devised HST solutions might also be utilized to extend the coverage of the lower Arctic region from GEO satellites, if larger and more powerful land station antenna constellations are deemed economically viable. The major advantages of such heterogeneous systems are that they might be made ad hoc–adaptively tailored to their mission–and deployed much faster and with less efforts and costs than a HEO satellite system, offering among others the following benefits: Easy to deploy; incremental deployments; Flexibility and reconfigurable; Low operational costs (compared to satellites); High elevation; Wide area coverage; Broadcast/Multicast; Mobility. The frequently mentioned challenges are suggested to be: Regulations; Sense and avoid systems; ATM (Air Traffic Management) integration; Safety and security; Airworthiness – the aircraft suitability for safe flights; Type certification; Availability of radio spectrum resources (frequencies and bandwidth); Human factors and autonomy; Public perception. Reliable communications links are crucial for search and rescues (SAR) activities. In the Arctic, remotely piloted aircraft systems (RPAS) would be of significant benefit for a fast and large-area SAR. Nevertheless, using any kind of aerial vehicle is regulated by the International Civil Aviation Organization (ICAO), the domestic aviation administrations, and also particularly dedicated regulations for UAV applications. Because of the geographical sectorial interests toward the North Pole, domestic regulations merge in these areas, and flying or operating aerial vehicles there might be practically unmanageable. Furthermore, neither the ICAO regions nor the Arctic SAR boundaries fit the regions regulated by the International Maritime Organization (IMO) in the Arctic.

B. VHF Data Exchange System (VDES)

New potential digital VHF satellite services are envisioned. Driven by the modernization of the global maritime distress safety system (GMDSS) and IMO's maritime e-Navigation strategy, request for new spectrum allocations in the VHF band for satellite usage will be discussed at the upcoming world radio conference (WRC) in 2015 under Agenda 1.16 in accordance with Resolution 360 of WRC 12. The initial approaches are looking at a system with possible data rates of about 300 kbit/s, the main goal being to protect the already defined satellite AIS bands. In this way the AIS system can be offloaded from all the additional services exploiting its payload. Furthermore, broadcasting services for the satellite-toship links are envisioned and can be particularly important for safety related information.

C. Usage of Existing Scheduled Aircraft

The collection of measurement data, AIS signals, or other M2M telemetry information could also be done by airliners. These scheduled aircraft fully cover the Arctic because of their polar routes with at least 5–10 contacts per day [18]. However, they would have to be fitted with appropriate radio receiver(s) and signal storage devices. After landing or after reentering satellite or terrestrial communications infrastructure, the data could be fed into the pertinent data base.

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