ICE-PPR Communications Workshop Report

14-15 December 2023

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Abbreviations

AI	Artificial Intelligence
AUV	Autonomous Underwater Vehicles
BICES	Battlefield Information Collection and Exploitation Systems
DDG	Guided Missile Destroyers
DHS S&T	Department of Homeland Security Science and Technology Directorate
DOD	United States Department of Defense
HF	High Frequency
ICE-PPR	International Cooperative Engagement Program for Polar Research
IP	Internet Protocol
ISR	Intelligence, Surveillance, and Reconnaissance
LEO	Low-Earth Orbit
MOU	Memorandum of Understanding
MUOS	Mobile User Objective System
NAACW	North Atlantic Arctic Crisis Workshop
NATO	North Atlantic Treaty Organization
NAVSEA	Naval Sea Systems Command
NORTHCOM	United States Northern Command
NSF	National Science Foundation
ONR	Office of Naval Research
OUSD	Office of the Under Secretary of Defense
PA	Project Arrangements
pLEO	Proliferated Low-Earth Orbit
PNT	Position, Navigation, and Timing
RDC	Research and Development Center
RDT&E	Research Development Test & Evaluation
RF	Radio Frequency
RFT	Resonant Frequency Transducer
SAWG	Situational Awareness Working Group
SOD	Segregation of Duty
SWaP	Size, Weight, and Power
TSC	Ted Stevens Center for Arctic Security Studies
TTX	Tabletop Exercise

UAS	Unpiloted Aerial Systems
UHF	Ultra High Frequency
UNH	University of New Hampshire
USCGC	United States Coast Guard Cutter
USSAWG	U.S. Situational Awareness Working Group
VHF	Very High Frequency

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Executive Summary

The ICE-PPR Communications Workshop, held at the University of New Hampshire in December 2023, brought together participants representing military branches, government agencies, academic institutions, industry partners, and Indigenous communities to address critical communications challenges in the Arctic region. The workshop built upon the North Atlantic/Arctic Crisis Workshop's tabletop exercise scenarios involving environmental emergencies and hostile adversary presence in the Arctic, with a specific focus on identifying communications-related gaps and potential collaborative research activities under the International Cooperative Engagement Program for Polar Research (ICE-PPR). This multinational agreement between the United States, Canada, Denmark, Norway, Sweden, Finland, and New Zealand aims to advance safety and security at high latitudes through sharing scientific knowledge and planning coordinated experiments.

Subject matter experts provided comprehensive briefings highlighting the changing Arctic landscape, where traditional Arctic exceptionalism is giving way to increased geopolitical competition from Russia and China amid challenging Arctic environments. Presentations covered a wide spectrum of communications technologies and challenges specific to high latitudes, including commercial satellite communications, radio frequency propagation issues, quantum communications, free-space optical communications, Arctic safety information distribution, disaster relief communications, and subsea asset protection. Experts emphasized the need for enhanced interoperability, resilient networks capable of withstanding environmental disruptions, and secure systems that can function in contested environments. A recurring theme was the balance between leveraging rapidly advancing commercial technologies and developing specialized military-grade systems for Arctic operations, with emphasis on information management rather than simply increasing bandwidth.

Workshop breakout groups analyzed communications requirements for three crisis scenarios. These discussions revealed several critical needs: (i) adaptable and resilient networks capable of prioritizing traffic during disruptions; (ii) enhanced space weather monitoring and prediction; (iii) underwater communication capabilities for infrastructure protection; (iv) secure but interoperable systems across alliance partners; (v) user-friendly emergency communications suitable for high-stress situations; and (vi) engagement with local communities as vital stakeholders in Arctic response. The plenary session synthesized these findings into four focus areas: Transport Mechanisms, Networks, Information Management, and Security, creating a framework for identifying gaps and organizing research programs directly relevant to Arctic security concerns. Progress on these issues involves improving multinational communication interoperability, leveraging industry advancements, enhancing space weather utilization, and improving data sharing across military and civilian entities, with specific action items including classified follow-up discussions and budget assessments to advance the ICE-PPR's goal of enhancing preparedness in the increasingly complex Arctic operational environment.

Introduction

This Arctic Communications Shortfalls and Gaps Workshop is a research and technology and stakeholder-oriented event hosted by the Ted Stevens Center (TSC) at the University of New Hampshire (UNH) 14-15 December 2023 at the UNH campus in Durham, NH. This workshop is aimed at (i) participants in the preceding North Atlantic/Arctic Crisis Workshop (NAACW), including mid to senior level security practitioners, decisionmakers, and regional leaders from the US interagency, Arctic Allies, and the Arctic Indigenous communities, and (ii) stakeholders involved with high-latitude communications, including program managers, researchers, service branches, government laboratories, and academic and industry partners. The workshop identified communications-related topics of interest and practical issues of greatest concern, with the goal of developing and fleshing out near-term RDT&E collaborative activities, including, but not limited to, field campaigns, model intercomparisons, technology interoperability exercises, and systems engineering requirements development, with the prospect of global applications.

This workshop is under the auspices of the International Cooperative Engagement Program for Polar Research (ICE-PPR). Since its inception ICE-PPR has successfully fostered and developed international collaboration within several topic areas vital to Arctic security.

TSC Director, Randy "Church" Kee, Maj Gen (Ret) USAF opens the conference with a welcome presentation. Photo by M. Schell.

ICE-PPR Overview

ICE-PPR is a multilateral agreement between the defense departments and related government agencies of seven allied high-latitude stakeholder nations: the United States, Canada, Denmark, Norway, Sweden, Finland, and New Zealand. ICE-PPR partner nations share emerging scientific and technological knowledge and assets, and plan and execute experiments to advance safety and security at high latitudes. The ICE-PPR Memorandum of Understanding (MOU), which was recently renewed in 2020, has a duration of 25 years so that substantive and lasting collaborations can be developed and executed. The US component of ICE-PPR is led by the Office of Naval Research (ONR). ICE-PPR is organized into several topical working groups including Environmental, Human Performance, Energy, Platforms, and Situational Awareness. This workshop falls under the Situational Awareness Working Group (SAWG). The SAWG is led by Randy “Church” Kee, Maj Gen (Ret) USAF, who serves as both the Principal for the US component (USSAWG) and International Chair.

As an immediate precursor to this Communications Workshop, the USSAWG organized a meeting of subject matter experts at the TSC Campus at Joint Base Elmendorf-Richardson, in April 2023. In this meeting, participants from TSC, University of Alaska, US Coast Guard, US Air Force and ONR identified seven high latitude communications priorities suitable for ICE-PPR collaboration. These seven priorities, which were used to organize this Communications Workshop, are:

(i) *Commercial Satellite Communications*. At high latitudes there are many challenges with commercial systems (Starlink, Starshield, OneWeb) that are normally robust at lower latitudes, including latency issues involving orbital paths and dropouts, adaptation to low size, weight and power (SWaP) terminals, adaptation to unpiloted aerial systems (UAS), access by local communities, coordinating resources among international partners, and the potential for adversary jamming.

(ii) *Phenomenology or Radio Frequency Propagation*. Challenges at high latitudes include ducting events, Arctic Ocean (sea ice) effects, and solar activity and space weather events. Several government laboratories and research groups develop models for propagation forecasting. Concerns include availability of adequate space-time data at high latitudes for model validation and improvement, harnessing the latest advances in Machine Learning and Artificial Intelligence, and organizing international partnerships.

(iii) *Quantum Communications*. This is a field with rapid technological advancements, including by adversaries. In the Arctic, underwater applications may be an important topic, particularly for securing infrastructure.

(iv) *Free-Space Optical Communications*. This can include surface-to-satellite, ground-to-ground or ship-to-ship. At high latitudes technical issues include atmospheric effects, and delay and disruption tolerance.

(v) *Arctic Safety Information*. Concerns include capabilities and interoperability when getting information out to remote units, vessels, aircraft or travelers. Concerns may also include Search and Rescue, particularly involving international collaboration. With the extreme remoteness of much of the high Arctic, UAS or other autonomous systems may be increasingly necessary.

(vi) *Communications Involving Natural Disaster Relief*. Concerns include re-establishing communications after a disaster, and the related need to coordinate international efforts. This topic can also include major human-caused disasters such as oil spills.

(vii) *Subsea Asset Protection*. There is current concern over the security of major assets such as the Quintillion fiberoptic cable, in the context of both natural variability (sea ice motion) and adversaries meddling with these assets. One issue involves effective technologies for protecting these assets, including acoustic versus optical communications, and persistent surface patrol vehicles such as SailDrones.

Contents of the ICE-PPR Communications Workshop Report

This report will: 1) detail the structure of the workshop, speaker presentations, and breakout groups and 2) compile the key insights, highlighting identified gaps and outlining questions for future SAWG constituent research. The appendices contain the agenda, participant lists, presentations, and summary notes from the breakout groups and plenary sessions.

Structure of the Workshop

The ICE-PPR Communications Workshop, hosted at the University of New Hampshire by the TSC, was a structured, two-day event focused on identifying practical research and development pathways to address communication challenges in high-latitude Arctic environments.

TSC hosted the Communications Workshop as a follow on to the NAACW, held on 12-13 December, thus encouraging the maximum number of attendees to participate in both events. NAACW brought together U.S. and international Arctic crisis response professionals (e.g., government, Indigenous, military, commercial) for a multifaceted Arctic crisis exercise. The Communications Workshop followed with a narrower group of attendees to tackle specific issues around high latitude communications gaps and concerns, and aligned to the seven priorities outlined by the April 2023 SAWG workshop. The twenty-one Workshop participants included subject matter experts, TSC, UNH faculty, ONR, and representatives from Indigenous communities, the Canadian Coast Guard, the Royal Danish Navy, and the Danish Ministry of Defence Acquisition and Logistics Organisation (DALO).

The first day began with opening remarks from TSC and ICE-PPR leadership, establishing the strategic relevance of the workshop within national and international security frameworks. Subject Matter Experts from academia, government agencies, FFRDCs, DOD, and industry provided in-depth technical briefings. Mr. Paul Dodge acted as the senior policy keynote speaker and Dr. Phil McGillivary as the research keynote speaker.

Following speaker presentations, participants engaged in lightning talks, allowing for a broad exchange of expertise and ongoing research activities, followed by breakout groups. Participants were divided into three breakout groups, each assigned to analyze specific crises modeled from the previous NAACW tabletop exercises (TTX). Student rapporteurs documented group discussions, which were later synthesized during the final plenary session. Facilitators employed the Diamond Model of Participatory Decision Making, guiding groups from individual observations to collective action planning.

The workshop aimed to bring together participant priorities, stakeholder requirements, and ongoing efforts to shape actionable plans, such as field exercises, technology trials, model testing, or other tangible short-term initiatives. Ideally, these would take the form of formal Project Arrangements (PA) under the ICE-PPR framework, which require involvement from at least two international partners. Even in the absence of a PA, the workshop may also facilitate the development of interagency collaborations within the U.S., which could later evolve to include international partners. This report, compiled using session notes and breakout group summaries, serves as a gap analysis and planning document for the ICE-PPR research community.

Perspectives of Subject Matter Experts

The workshop began with a policy-oriented keynote address from Mr. Paul Dodge, and a research-specific keynote from Dr. Phil McGillivary before launching into presentations from subject matter experts, detailed below.

Keynote Speakers

Mr. Paul Dodge, *Deputy Director for Arctic and Oceans Policy, Office of the Under Secretary of Defense (OUSD) for Policy*, discussed Arctic policy and strategy from the perspective of the Global Resilience Office. He outlined the need for a refined Arctic strategy due to changing dynamics including Russian tensions, China's Arctic ambitions, and the end of "Arctic exceptionalism." He highlighted the need for a new U.S. Arctic strategy aligned with national defense objectives, focused on maintaining Arctic stability through monitoring, response capabilities, and partner engagement. He stressed investments to prioritize enhanced communication infrastructure, domain awareness, and Arctic-specific equipment, with collaborative efforts involving Canada and Denmark, alongside engagement with local communities. Additionally, Mr. Dodge advocated for the establishment of an international security forum to address the current gap in defense and policy discussions among Arctic nations.

Dr. Phil McGillivary, *Icebreaker Operations, US Coast Guard Pacific Area,* covered a range of key developments including military advancements, proposed communications research initiatives, space weather impacts, updates on polar fiber optic cable projects, progress in free-space optical communications, emerging commercial satellite plans, quantum communication technologies, and strategies for safeguarding subsea critical infrastructure. He highlighted developments in communications systems that enable control of unmanned assets between U.S. Navy and NATO ships, emphasizing the importance of unmanned systems in Arctic environments given the shortage of manned assets.

Subject Matter Expert Presentations

Robert Graham, *Technical Director, Requirements, Development, Program Management and Policy Division, Air Force Material Command,* presented high frequency (HF) communications in the Arctic, describing a desire to establish HF coverage, focusing on fixed HF site communications rather than mobile systems. He stressed the importance of collaboration and deconfliction in communication propagation.

Dr. Frank Rack, *Office of Polar Programs, US National Science Foundation (NSF),* discussed ongoing projects, including highlighting collaboration with the Coast Guard and DOD models for remote testing systems. He oversees NSF-funded field operations in northern Alaska and on vessels navigating the Arctic Ocean and nearby waters. He described NSF's myriad research activities throughout the high Arctic, spanning Alaska through Greenland, emphasizing the need for robust communication technologies. He mentioned parallel work happening in both Arctic and Antarctic regions and noted the interfaces between programs and the National Guard, emphasizing communication between programs.

Mr. Martin Marshall, *Senior Sales Engineer, OneWeb,* described the technology and operation of a major commercial satellite communication network, and discussed communication services that provide land, maritime, and air capabilities and discussed efforts to enhance aircraft communication services.

Along with his experience supporting broadband deployments in remote areas of Alaska, he mentioned his organization has established multiple relationships with governments, including in the U.S. and Europe, to provide services at various levels, and noting the disparity between government and commercial advancements in communications

Ms. Shalane Regan, *US Coast Guard Research & Development Center (RDC),* facilitates collaboration between federal agencies and civilian organizations to coordinate efforts in advancing capabilities for improved polar operations. She discussed the RDC's robust science programs on annual summer patrols aboard the Icebreaker USCGC Healey and examined multinational connections within Arctic focus groups. There was discussion about connecting the Research and Development Centers work to multinational Arctic focus groups and ICE-PPR.

Dr. Paul Sikora, *US Air Force Research Laboratory,* briefed the Air Force interest in HF communications modernization, in the context of the DOD Arctic Strategy and the Air Force's large footprint in DOD Arctic resourcing. He also discussed high-latitude network planning for POLARIS, describing equipment for 8 nodes. He emphasized making research broadly available, the importance of logistics alongside research, and the expandable design of their setup. He also discussed the challenge of cross-service collaboration.

CAPT Don Wilson, *Communications & Information Systems, US Fleet Forces Command,* discussed Navy communications capabilities, including proliferated low-Earth orbit (pLEO) systems, addressing bandwidth needs and costs of Arctic operations and the resilience of networks in contested environments. He emphasized the importance of information management and prioritization rather than simply increasing bandwidth and noted that competition might eventually lower costs for communications technologies.

Dr. Jonathan Chavanne, *TMB Inc., NAVSEA Team Ships S&T Directorate,* discussed NAVSEA's role in Arctic maritime policy and guidance, including the Arctic Integrated Product Team and its efforts to improve the capability of guided missile destroyers (DDGs) to operate at high latitudes with new technologies. He reviewed segregation of duty (SOD) technology for integrated tracking of sonar, radar, and target recognition. He also described the capabilities of DDG-class ships in marginal ice zones and stressed the importance of lessons learned from Coast Guard Arctic experiments.

Maj Michael Hampton*, U.S. Air Force, Arctic Policy Advisor for OUSD,* discussed a forthcoming Arctic Communication Workshop at the Secret and Top Secret levels in February 2024 by OUSD and NORTHCOM, and inquiring about ICE-PPR and other attendees' interest in participating.

Key Takeaways:

- The Arctic is a rapidly evolving strategic and security concern.
- There is a pressing need for improved, secure, and resilient communication infrastructure.
- Investments in advanced technologies, including artificial intelligence (AI), quantum communication, and unmanned systems, are critical.
- Government agencies need to work closely with commercial entities to leverage existing technologies.

- Collaborative efforts between military, industry, and Arctic nations are needed to develop robust, secure, and adaptive communication networks that can withstand environmental and geopolitical challenges.

Workshop Findings

Following the speaker presentations, TSC reviewed the scenarios posed at the NAACW TTX with the participants. These were three separate (hypothetical) emergencies in the Arctic region. Each scenario was caused, or exacerbated, by the challenging Arctic environment, disruptive weather conditions, and the presence of hostile adversaries. Compounding proposed response solutions was the presence of increasing solar storms, with significant solar flares disrupting high latitude communications. A summary of these scenarios is as follows:

(1) The Pituffik Space Force Base in Greenland is partly out of service due to surface flooding making the runways and health infrastructure inoperable. At the same time, contact is lost with a group of twenty college students, tribal nation students, and professors who were last located on Baffin Island.

(2) A small Arctic cruise ship has grounded and partially sunk by a landslide-caused tsunami, near the Kaiser Franz Joseph Fjord on the East coast of Greenland. Among the 120 passengers are two Members of Congress and celebrities. Deaths and numerous injuries are reported, and the ship is leaking fuel oil into the Fjord.

(3) The Svalbard Undersea Cable, a critical allied defense asset providing satellite downlink, is being menaced by Chinese and Russian warships that have turned off their Automated Identification Systems.

The twenty-one workshop participants were divided into three breakout groups to discuss specific communications issues relevant to the three scenarios. Participants discussed each crisis in terms of (a) current communication technologies including those in development, (b) technology needs, (c) research needs, and (d) considerations, including specific reactions to the crisis. These breakout group discussions were documented by UNH student rapporteurs to motivate final plenary discussion

Group A: Svalbard Undersea Cable

1. **Chat Surfer:** Requires heating elements for antennas to prevent frost buildup. Communication infrastructure is essential for research and operational effectiveness, particularly in developing quantum communication.
2. **Satellites (Low and Medium Earth Orbit):** A key limitation in the high North is the lack of infrastructure, affecting vast regions of Greenland, Finland, and Norway. Research is needed to enable communication between underwater systems and those on the surface or land.
3. **Intelligence, Surveillance, and Reconnaissance (ISR):** Requires expanded satellite coverage for Electro-Optical/Infrared imaging and both government and commercial satellite communication. Further research is necessary to determine whether quantum communication is less disruptive to marine ecosystems.
4. **Drones:** Must be capable of underwater communication to help secure critical infrastructure, addressing existing gaps in knowledge regarding this capability.

5. **Sonar for Underwater Explosion Detection:** A hybrid acoustic-optical system is needed, enabling two Autonomous Underwater Vehicles (AUVs) to track acoustic or light signals.
6. **NATO Cryptographic Systems:** Requires testing of quantum sensors that can detect 6-foot AUVs with minimal power consumption.
7. **Sting:** Needs a standardized framework to ensure interoperability.
8. **P-8 Aircraft:** Requires AI and machine learning integration, with an emphasis on collaboration with allied nations for effective implementation.
9. **Maritime Aircraft:** Needs advancements in subsea quantum and surface communication technologies.
10. **Naval Messaging:** A formal program of record must be established, along with identifying a resource sponsor for its development.
11. **BICES-to-NATO Secure Communication:** Must be integrated into a larger network without requiring fiber optic connections for restoration.
12. **Underwater Detection Capabilities:** The current architecture is insufficient and requires continued efforts.
13. **Voice Communications:** Security improvements necessitate the use of quantum sensors on fiber optic cables.
14. **Fly-Away Kit (Antenna, Router, Laptops, and Satellite Communication):** Likely to use MUOS (Mobile User Objective System), Starlink, or commercial satellite connections. While solar power does not interfere with Starlink, MUOS performance under space weather conditions needs further assessment.
15. **Unmanned Underwater and Surface Assets (Gliders & AUVs):** Communication between these assets is currently limited to underwater acoustics and constrained in horizontal and vertical transmission. The goal is to exchange images or videos at a minimum. Ideally, multiple vehicles should communicate via a single AUV as a hub to optimize bandwidth.

Additionally, this group noted potential concerns with restoring service after disruptions, particularly if a subsea cable is cut, as it requires immediate action, including deploying sensor systems to detect and confirm damage. Participants highlight the need to ensure area security, necessitating the installation of additional subsea sensors to enhance situational awareness. Questions remain about the type of data transmitted through these cables and who is responsible for assessing its security. Additional challenges include solar flares, which cause unpredictable communication disruptions, though Starlink remains unaffected due to its optical-based transmission.

Group B: Baffin Bay/West Coast Greenland

1. **Radio Frequency (RF):** Requires an adaptive network to function effectively in Arctic conditions. Researchers must determine optimal signal angles and assess the signal-to-noise ratio in challenging environments. HF communication is particularly unreliable near the magnetic poles, necessitating further study.
2. **UHF, VHF, Satellite, and HF Communications (Impact of Space Weather):** A universal translator is needed to facilitate seamless communication across different networks and bandwidths.

Research should focus on local space weather modeling, as existing models are global and lack resolution in northern latitudes. A sensor array network would enhance data collection, but funding is required for its development and maintenance.

3. **Current technologies for Space weather effects:** Vary in duration (minutes to hours), with some predictive capability through AI models for solar flares. Coronal mass ejections can be detected through solar imagery, offering limited warning.
4. **Adaptive Network Routing:** Data transmission must prioritize critical security related information first, with richer data sent once a stable connection is reestablished. Routing and frequency sensing across RF bands are essential for maintaining robust communication.
5. **Starlink on Ships (Coast Guard, Fishing Vessels, Villages):** Serves as a backup for communication and navigation during satellite or UHF/VHF disruptions due to space weather or jamming. Total Electron Content measurements can help model atmospheric disturbances across multiple frequencies. A flexible system should switch frequencies based on real-time space weather feedback. Research is needed to enhance wideband HF technologies and assess atmospheric disturbance impacts, including electromagnetic pulses.
6. **Community Communications:** Includes commercial internet, social media, commercial radio (e.g., K-BET), IP systems, fiber optics, VHF, and UHF. Fiber optics are vulnerable to broadband limitations, flooding, and weather-related integrity issues. Research is needed to assess readily available sensors and alternative data sources for monitoring and maintaining network resilience.
7. **Special Operations Communications:** Includes narrowband, Land Mobile Radios. Quantum-based Position, Navigation, and Timing (PNT) will be crucial in the near term, with the need for greater understanding on underwater cable vulnerabilities.
8. **Microwave Repeaters (Cellular and Infrastructure-Based Communications):** Requires a sensing and routing mesh while considering the full RF chain (antennas, couplers, power sources, and human-machine interfaces).
9. **Meteor Scatter Communications:** Long-term sustainability is a challenge due to battery limitations in extreme cold. Improved capabilities could reduce maintenance requirements. Research is needed into operational risks of commercial satellite systems (e.g., Starlink, LEO satellites) to assess vulnerabilities, including potential signal exposure and classification concerns.
10. **Data Casting via Unused Bandwidth:** Requires mobile nuclear power to support operations. Research should focus on utilizing existing signals of opportunity (e.g., repeatable transmission patterns) for atmospheric and space weather modeling while addressing privacy concerns related to signal monitoring.
11. **Alternative PNT (eLoran):** Needs Autonomous Underwater Vehicle (AUV) monitoring to detect and deter threats to undersea cables. Strengthening underwater infrastructure against tampering would be costly in operations and maintenance but necessary for long-term security.

Additional requirements mentioned by the group include: distributed acoustic sensing for real-time disturbance detection in subsea cables; secure communications, including potential military-classified use of Starlink with quantum encryption; quantum security measures to defend against real-time encryption key breaches from quantum computing; the ability to adjust security levels dynamically based on threat conditions; and the capability for widespread emergency broadcasting to mobile devices via satellite or UAV networks, particularly in Arctic regions where terrestrial networks may be unreliable.

Group C: Arctic Cruise Ship

1. **Iridium Phones:** Require consistent coverage from pole to pole, ensuring reliable voice and video communication without frequent drops or network saturation, especially in emergency situations when survivors may also need to make calls. Understanding how solar flares affect HF communications is crucial.
2. **Wireless Connection:** Needs shore-based and mobile communication capabilities, including HF repeaters and pop-up towers to extend signal range and provide sustained power. The system must support voice and video transmission while also incorporating universal translation for seamless communication across different groups.
3. **Cellular Networks:** Require the same infrastructure as wireless connections but with a focus on public access solutions like Arctic communication personal unlocking keys for general use.
4. **Local Cell Towers on Ships:** A mobile response kit should be available for rapid deployment without burdening emergency responders, allowing international coordination. Survivors should have access to a status-check system (e.g., a green button for safety, red for distress) with geofencing capabilities to collect and share location data through ship-based network coverage.
5. **Battery-Powered Communications:** Needs end-user-friendly interfaces that integrate with mobile devices. Gamification elements may improve usability in high-stress environments.
6. **Life Rafts:** Require weatherproofing and technical testing to ensure reliable performance in extreme Arctic maritime conditions.
7. **Distress Communications (406 MHz):** High-latitude communications need increased bandwidth capacity, ideally reaching gigabyte speeds for more effective emergency response.
8. **Global Maritime Distress & Safety System Iridium:** A low-power, low-bandwidth relay system should be developed, leveraging radio antennas along coastlines. Since existing infrastructure was built when satellite coverage was unreliable, a modernized energy-efficient alternative with limited device capacity could provide a cost-effective solution.
9. **DHS S&T VHF Channel 70 via Satellite:** This simplex communication system is designed for data transmission, not voice. A critical limitation is the lack of temporary power surges to charge devices.

The group expressed additional considerations. Language translation and voice inflection remain obstacles in effective communication, particularly for military and emergency operations, but advancements in AI and machine learning may help mitigate these issues. HAM radio and other traditional communication systems require expertise, making it essential to simplify technology for usability in high-stress situations. The high cost and logistical difficulties of deploying high-capacity satellite networks in the Arctic continue to be a barrier, requiring innovative solutions like optical communication and alternative power sources beyond solar, which is unreliable in long Arctic winters.

Breakout session participants discuss gaps and needs critical for enhanced Arctic response.
Photo by M. Schell.

Plenary Session

Following the breakout groups, participants convened a plenary session to discuss areas of focus. Participants debated structuring the report to encompass transmission mechanisms, network security, and command and control. They emphasized the need for secure communication in both military and civilian contexts and explored compatibility across alliances. The discussion highlighted the importance of architectural frameworks that facilitate interoperability while ensuring security at multiple levels, including U.S.-specific and multilateral networks.

The Arctic's unique communication challenges, such as weather-related disruptions and the marginal ice zone's impact on acoustic signals, motivated additional discussion. Participants proposed research into transport mechanisms, including satellite communications, free-space optical links, and quantum technology. They also debated whether specific concerns, such as space weather effects on communications, should be categorized under transport or broader network security.

Another key discussion centered on data management and network security, particularly in mission networks. Topics included ensuring quality of service, prioritizing traffic in disrupted environments, and leveraging emerging technologies like AI to process large-scale data. Participants acknowledged the need to balance open access to critical Arctic safety and disaster relief information with security measures to prevent unauthorized interference.

Lastly, the discussion addressed ongoing and future research needs, the necessity of a glossary to standardize terminology, and the importance of maintaining a forward-looking perspective on evolving communication technologies. Plans were set to hold a classified follow-up discussion to refine research priorities and explore project collaborations. These plenary session discussions generated four new Focus Areas with subheadings specifying topics and issues:

(i) Transport Mechanisms

a. Radio frequency propagation, phenomenology and RF systems
b. Commercial satellite communications
c. Free space optical communications
d. Quantum links
e. Undersea communications in the marginal ice zone.

(ii) Networks

a. Command and Control
b. Mesh networking
c. Quality of service across disparate networks
d. Prioritization
e. Link management
f. Restoration
g. Queuing

(iii) Information Management

a. Secure communications enclaves at high latitudes
b. Arctic safety information
c. Communications involving natural disaster relief

(iv) Security

a. Subsea asset protection
b. Quantum communications
c. Communications security
d. Transmission security
e. Zero trust architecture and authentication
f. Identity, Credential and Access Management

These Focus Areas are intentionally broad, so that additional topics and issues might be added as new subheadings. These focus areas provide a framework for identifying gaps and shortfalls, and for organizing communications-related research programs, technology transfer, test and evaluation, and requirements definition, in flexible ways directly relevant to Arctic security concerns.

Overarching Themes

Several Overarching themes emerged from the discussions at the ICE-PPR Communications Workshop:

1. The Arctic region faces unique communications challenges that require specialized solutions beyond those developed for lower latitudes, including issues with ducting events, sea ice effects, and significant disruptions from solar and space weather events.

2. There is an urgent need for enhanced interoperability between military, civilian, commercial, and multinational systems to enable effective crisis response in the Arctic, particularly as traditional "Arctic exceptionalism" gives way to increased geopolitical competition.
3. The protection of critical subsea infrastructure, particularly communication cables, requires new detection and monitoring technologies including hybrid acoustic-optical systems, underwater drone communications, and quantum sensors.
4. Commercial satellite communication systems like Starlink and OneWeb offer potential solutions for Arctic coverage, but face challenges including orbital path limitations, potential adversary jamming, and adaptation to low size, weight, and power requirements.
5. Information management and prioritization are more crucial than simply increasing bandwidth, requiring systems that can appropriately route critical information first during limited connectivity crisis scenarios.
6. Crisis communications require redundant, user-friendly systems that function in extreme weather conditions, with emphasis on weatherproofing, power efficiency, and intuitive interfaces suitable for high-stress environments.
7. Space weather effects represent a major area of concern for Arctic communications, with current models lacking sufficient resolution in northern latitudes and requiring expanded sensor networks for improved prediction and response.
8. Technological security concerns encompass multiple domains, from protecting physical infrastructure to ensuring transmission security and implementing quantum-resistant encryption as quantum computing advances.
9. The increasingly contested nature of the Arctic requires balance between open access to safety information and secure communications for military operations, with flexible architecture enabling different security enclaves.
10. Network resilience in the Arctic requires comprehensive approaches to restoration, mesh networking, and quality of service across disparate systems, with AI and machine learning potentially offering solutions for efficient routing and data management.
11. Unmanned systems (aerial, surface, and underwater) are increasingly vital for Arctic operations given the shortage of manned assets, requiring advanced communications systems to enable effective control and data transmission.
12. Cross-service and international collaboration faces significant coordination challenges despite shared objectives, with ICE-PPR offering a framework to develop practical research and technology-sharing initiatives.

Path Forward

The path forward involves addressing critical communication, interoperability, and situational awareness gaps in Arctic operations. A primary action item is improving secure and efficient communication between nations, ensuring that responders can coordinate effectively across various technologies and frequency bands. This includes developing a persistent network and conducting interoperability exercises to identify and address gaps in real-world scenarios. Testing current technologies in Arctic conditions will be essential to validate their reliability and functionality.

Another key action is leveraging industry advancements in AI, satellite communications, and networking to enhance Arctic capabilities. Rather than building entirely new systems, collaboration with industry can help adapt existing technologies for Arctic use. Additionally, increasing the use and accessibility of space weather information can support decision-making, particularly in high-latitude environments where such factors significantly impact communications.

Engagement with local and Indigenous communities is also crucial. These communities are often the first responders to emergencies, and their knowledge of the region can be invaluable. Ensuring collaboration, including language translation support, will enhance emergency response effectiveness. Furthermore, improving data sharing and situational awareness between military and civilian entities, particularly in crisis situations, will allow for a more coordinated response.

Upcoming steps include: (i) classified discussions on Arctic communications, (ii) a budget and capabilities assessment within the DOD, and (iii) continued synchronization efforts among stakeholders.

The participants of the 2023 ICE-PPR Communications Working Group conference attendees. Photo by M. Schell.

Appendix

The following conference items are available by request but not included in the workshop report. If you'd like to see the materials listed below, please email the TSC Deputy Associate Director for Research and Analysis, Matthew Shell, at matthew.schell.6@us.af.mil.

A. Agenda
B. Participant List
C. Speaker Presentations
D. Summary Notes: Breakout Groups
E. Summary Notes: Plenary Sessions