INSIGHTS INTO

VESSEL CONNECTIVITY

APRIL 2022

TABLE OF CONTENTS

1 INTRODUCTION 1

1.1 HISTORY OF VESSEL CONNECTIVITY 1

1.2 VESSEL CONNECTIVITY FOR SMART, AUTONOMOUS AND REMOTE-CONTROL FUNCTIONS. 1

1.3 GOALS AND SCOPE 1

2 REGULATIONS AND STANDARDS 2

2.1 GLOBAL MARITIME DISTRESS AND SAFETY SYSTEM (GMDSS) 2

2.2 INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO) 2

2.3 INTERNATIONAL ELECTROTECHNICAL COMMISSION (IEC). 3

3 CURRENT VESSEL-CONNECTIVITY TECHNOLOGIES 4

3.1 RADIO 4

3.2 SATELLITE COMMUNICATIONS 4

3.3 CELLULAR COMMUNICATIONS 7

4 APPLICATIONS 8

4.1 SMART, AUTONOMOUS AND REMOTE-CONTROL FUNCTIONS 8

4.2 UNMANNED SHIPS. 9

4.3 REMOTE SURVEY 9

5 FUTURE 10

5.1 TECHNOLOGY 10

5.2 CONNECTIVITY GAPS FOR SMART, AUTONOMOUS AND REMOTE-CONTROL FUNCTIONS IMPLEMENTATION 10

5.3 IMPACT ON VESSEL OPERATION 11

5.4 IMPACT ON CLASS ACTIVITIES 11

6 SUMMARY AND CHALLENGES 12

7 LIST OF ABBREVIATIONS 13

8 REFERENCES 14

1 INTRODUCTION

1.1 HISTORY OF VESSEL CONNECTIVITY

Communications between vessels and between vessels and shore are important for the safety of navigation and vessel operations. Throughout history, given the technology available at hand, the industry was able to find ways to communicate between vessels or between vessels and shore. A lighthouse, lit during the night, is one simple form of shore-to-vessel communication that marks dangerous coastlines for vessels in the vicinity. For early vessel-to-vessel communications, ships raised signal flags, or used flag semaphores performed by a sailor, to communicate with other ships. In the late 19th century, signal lamps were adopted, which allowed communications with ships further away and during the night. However, the amount of information that could be sent by flags or signal lamps was limited to only a few letters at a time, and the range was limited to the line of sight.

The invention of the radio at the end of the 19th century significantly extended the range of vessel transmission and allowed for an enhanced form of communication. The initial technology used radio to send telegraphs to vessels, a few sentences at a time, while later advancement allowed voice communications. Advancements in satellite technology since the 1970s allowed vessels to be connected anywhere on the globe, with increasing connection speed and capacity. Information such as navigation data and weather data could be updated with increasing frequency to enhance the safety of the vessel. Voice and video communications were enabled, and internet access has become possible in recent years. The development of cellular networks since the 2000s, with current technology such as LTE (Long-Term Evolution), 4G and 5G, allows even faster connections for vessels that are close to the shore.

1.2 VESSEL CONNECTIVITY FOR SMART, AUTONOMOUS AND REMOTE-CONTROL FUNCTIONS

Smart, autonomous, and remote-control functions are enabled by the ability of machines to collect and process data. Vessel connectivity plays a vital role in almost all aspects of these functions since they rely on a continuous, fast, reliable and secure transmission of a large volume of data communication between the vessel and a control or supervision center located onshore.

The essence of vessel connectivity comes down to addressing two issues: What information is being communicated, and how is the information being communicated? The increasing connection capacity and speed at a more reasonable cost has enabled the maritime industry to explore the implementation of various smart, autonomous and remote-control functions. Further development in these areas in turn requires higher speed data transmission and imposes higher connectivity requirements between the vessels and the onshore facilities.

1.3 GOALS AND SCOPE

This whitepaper aims to discuss the current demands for vessel connectivity, specifically driven by the smart, autonomous and remote-control functions and the available communication technology to address such demands. It is intended that this whitepaper will provide guidance to vessel owners, operators and system vendors in adopting suitable communication technologies to meet current and future demand.

This whitepaper reviews the relevant regulations and industrial standards on vessel connectivity, current communication technologies, applications, future technology development and challenges. Data security, while a significant concern for vessel connectivity, is beyond the scope of this paper.

2 REGULATIONS AND STANDARDS

2.1 GLOBAL MARITIME DISTRESS AND SAFETY SYSTEM (GMDSS)

The Global Maritime Distress and Safety System (GMDSS), as mandated by the International Convention of Safety of Life at Sea Convention (SOLAS), 1974, as amended in 1988, requires ships to carry specified equipment that can send or receive distress alerts, maritime safety information, as well as general communications [1]. GMDSS applies to passenger ships and cargo ships with over 300 gross tonnage on international voyages. The required equipment are terrestrial and satellite radio communication devices. GMDSS requirements came into full effect in 1999.

According to the International Maritime Organization (IMO), the GMDSS regulations are under review for modernization, in preparation for amendments to be adopted in 2024 [2].

2.2 INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO)

ISO TC8, the technical committee of ships and marine technology, has published standards related to ship data communications, namely;

- ISO 19847, Ships and marine technology – Shipboard data servers to share field data at sea [3]
- ISO 19848, Ships and marine technology – Standard data for shipboard machinery and equipment [4]
- ISO 16425, Ships and marine technology – Guidelines for the installation of ship communication networks for shipboard equipment and systems [5]

ISO 19847 defines requirements for onboard data servers that collect, store, and share data from other onboard sensors, machinery and systems. These standards are directly relevant to vessel communications and the implementation of smart, autonomous, and remote-control functions.

Another standard, "ISO 23807: Ships and marine technology – General requirements for the asynchronous time-insensitive ship-shore data transmission" is under development [6]. The standard intends to standardize the transmitting and receiving of a large amount of data between ships and shore asynchronously such that data can be communicated without being affected by the ship-shore communication status.

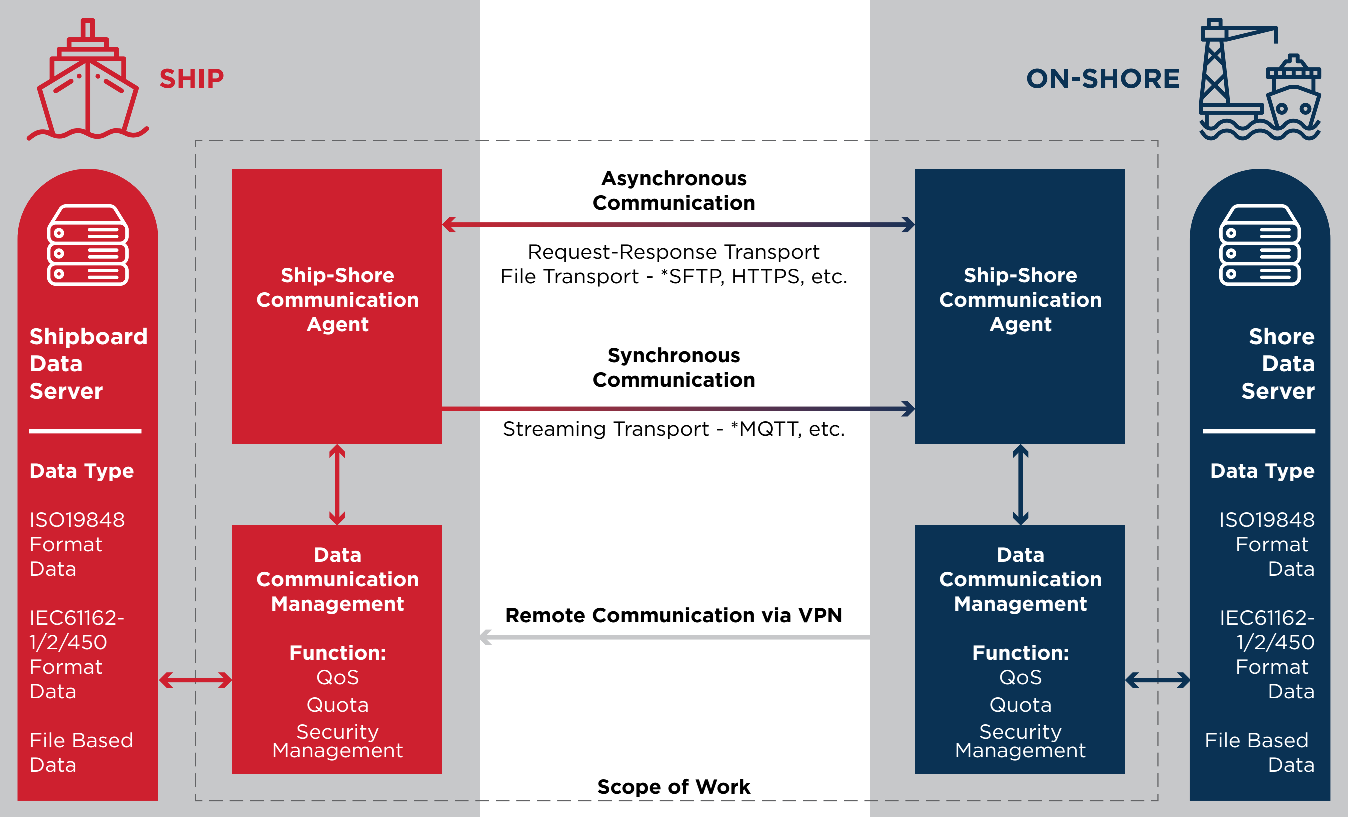


Figure 1: ISO/PWI 23807 Drafting Scope

2.3 INTERNATIONAL ELECTROTECHNICAL COMMISSION (IEC)

Navigation instruments may use the IEC 61162 series of standards to exchange data

- IEC 61162-1, Maritime navigation and radio communication equipment and systems – Digital interfaces – Part 1: Single talker and multiple listeners [7]
- IEC 61162-2, Maritime navigation and radio communication equipment and systems – Digital interfaces – Part 2: Single talker and multiple listeners, high-speed transmission [8]
- IEC 61162-3, Maritime navigation and radio communication equipment and systems – Digital interfaces – Part 3: Serial data instrument network [9]
- IEC 61162-450, Maritime navigation and radio communication equipment and systems – Digital interfaces – Part 450: Multiple talkers and multiple listeners – Ethernet interconnection [10]
- IEC 61162-460, Maritime navigation and radio communication equipment and systems – Digital interfaces – Part 460: Multiple talkers and multiple listeners – Ethernet interconnection – Safety and security [11]

3 CURRENT VESSEL-CONNECTIVITY TECHNOLOGIES

Wireless communications, regardless of radio, cellular, or satellite communications, rely on transmitting and receiving electromagnetic waves. Electromagnetic waves are created from periodic changes of electric and magnetic fields and can travel at the speed of light in vacuum.

Two important properties of electromagnetic waves are frequency and wavelength. The shorter the wavelength, the higher the frequency. The higher the frequency, the more information the waves can carry. In the order of descending wavelengths, electromagnetic waves can be categorized into a radio wave, microwave, infrared, visible light, ultraviolet, X-rays and gamma rays [12].

Wireless communications use mostly radio waves and microwaves, with frequency from 30 Hz to 300 GHz and the corresponding wavelengths from as long as 10000 km to as short as 1 mm.

The frequency bands are categorized differently by different associations. The following table shows the frequency bands defined by the Institute of Electrical and Electronics Engineers (IEEE) [13] and the International Telecommunication Union (ITU) [14].

STARTING FREQUENCY	IEEE	ITU
300 kHz		MF
3 MHz	HF	HF
30 MHz	VHF	VHF
250 MHz		
300 MHz	UHF	UHF
500 MHz		
1 GHz	L	
2 GHz	S	
3 GHz		SHF
4 GHz	C	
6 GHz		
8 GHz	X	
10 GHz		
12 GHz	Ku	
18 GHz	K	
20 GHz		
27 GHz	Ka	
30 GHz		EHF
40 GHz	V	
60 GHz		
75 GHz	W	
100 GHz		
110 GHz	mm	
300 GHz		THF
3 THz		

Table 1: Frequency Bands Designation

For marine wireless communications, there are three major types, namely radio, cellular, and satellite communications.

3.1 RADIO

Maritime radio communications use medium frequency (MF), high frequency (HF) and very-high frequency (VHF).

Marine VHF operates between 156 MHz and 174 MHz. It uses frequency modulation (FM) and is limited to 25 watts and can reach up to 100 km. For longer range, MF and HF are used. Marine MF and HF radios operate in the frequency range of 1.6 MHz to 30 MHz and can reach up to 6,000 km [15].

Marine radio equipment is crucial to the safety of vessels. The GMDSS requires a vessel to be equipped with radio equipment that can have radiotelephone coverage of at least one coast station in the sea area that the vessel is sailing. When a vessel travels close to the shore, VHF radio is sufficient. As the area gets farther from shore, MF radio is required. If the vessel travels even farther into the sea, the vessel should be equipped with HF radio, and complemented by satellite devices [16].

Apart from voice communications, another application is the automatic identification system (AIS), which transmits and receives vessel position data through the VHF band. Vessels can be tracked by AIS base stations located along the coast, or by satellite AIS if out of range of terrestrial stations.

Due to their long usage history and narrow frequency bands, marine radio communications are highly regulated, with most of the frequencies bands already allocated. Therefore, there is limited potential for future applications.

3.2 SATELLITE COMMUNICATIONS

3.2.1 ORBITS

Depending on the altitude, the orbits can be categorized into Low Earth Orbit (LEO), Medium Earth Orbit (MEO) and High Earth Orbit (HEO). The higher the orbit altitude, the longer it takes for the satellite to complete one orbit [17].

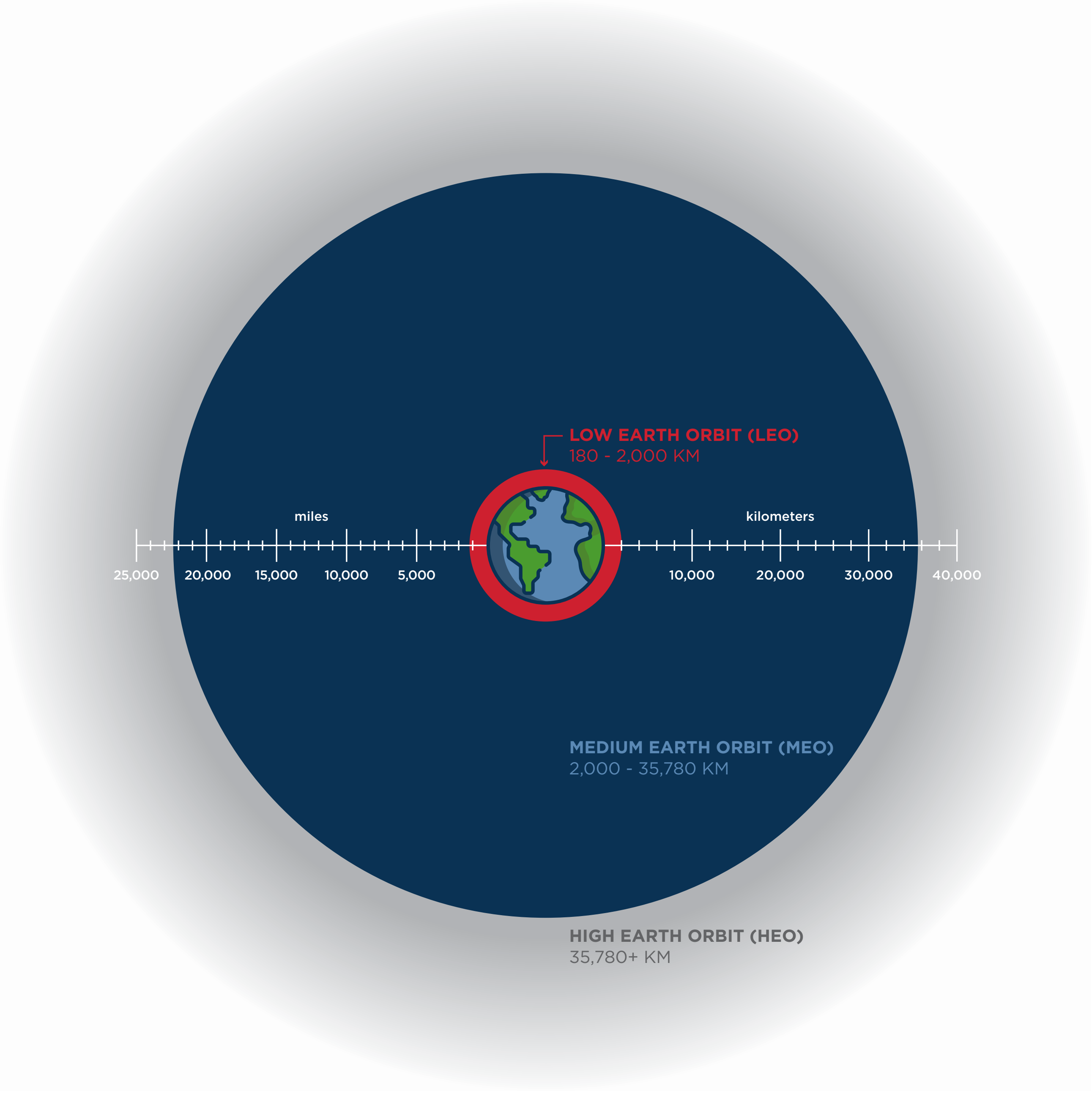


Figure 2. Satellite Orbits [17]

Geostationary orbit (GEO) is one type of HEO, with an altitude of 35,780 km and a period of 24 hours. Satellites in this orbit match Earth's rotation and appear stationary from the ground, which is ideal for communication satellites. However, communication signals provided by satellites on the geostationary orbit must travel a great distance, and therefore latency at this orbit is very high (more than 500 ms) [18]. Latency is also dependent on the frequency bands, with the Ka band at 700 ms and the L band at higher than 1,000 ms.

The MEO has an altitude range from 2,000 km to 35,780 km. The semi-synchronous orbit, at an altitude of around 20,000 km, and a period of 12 hours, enables the satellite to pass the same spot over the equator twice a day. Due to this characteristic, the orbit is used by navigation systems such as GPS [19], GLONASS [20], Galileo [21] and BeiDou [22]. There are also communication satellites on the MEO, with latency lower than those on the geostationary orbit.

Another MEO of interest is the Molniya orbit, which is a highly elliptical and highly inclined orbit. The satellite stays high over the hemisphere of its interest and stays low over the other hemisphere so that it can travel longer over the hemisphere of interest [17]. In this way, the satellites can provide coverage for high latitude areas.

The LEO has an altitude lower than 2,000 km. The orbit has a much shorter period, at two hours or less. Since the satellites pass over an area so fast, it requires a large number of satellites to provide global coverage. Due to the proximity to Earth, LEO satellites can offer lower latency (less than 30 ms) and higher speed (around 100 Mbps) [23]. Traditionally the LEO is for space stations and remote sensing, but satellite service providers are planning to expand their LEO constellations, utilize the Ku and Ka frequency bands to enhance the communication network.

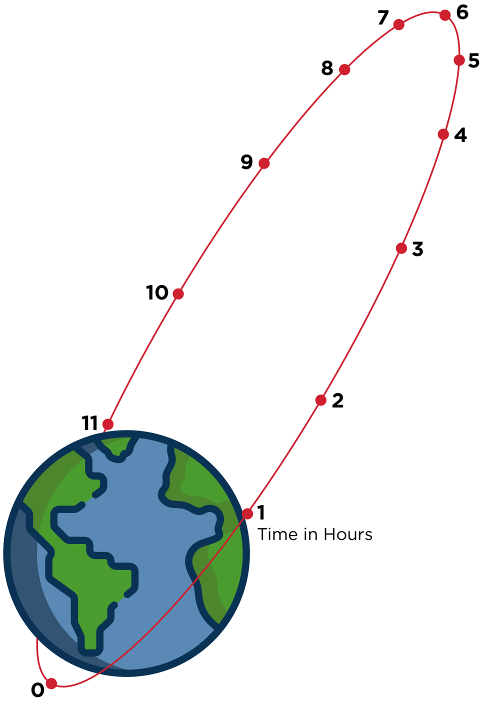


Figure 3. Molniya Orbit [17]

ORBIT	ALTITUDE	LATENCY	SPEED	APPLICATIONS
High Earth Orbit	> 35,780 km	> 500 ms	< 25 Mbps	Communication
Mid Earth Orbit	2,000 – 35,780 km	30 – 500 ms	50 Mbps	Navigation; Communication
Low Earth Orbit	180 – 2,000 km	< 30 ms	100 Mbps	Space Stations; Remote Sensing; Communication

Table 2: Satellite Orbit Types

3.2.2 FREQUENCY BANDS

The satellite frequency bands are listed in Table 3. These start with the L band, which is more robust against environmental factors such as clouds, rain, storms and vegetation. However, as the bands in the lower end of the spectrum are becoming more congested over the years, the frequency bands used by satellite are shifting to higher ranges. Currently, most of the commercial services are operating in the Ku and Ka bands. There are plans to even use the V band [24].

As the frequencies go over 11Ghz, the satellite signals are more susceptible to rain fade, a phenomenon where the signals are absorbed by rain, snow, or ice. This would result in degradation of signal quality or even loss of service. To compensate for rain fade, several options are available. Uplink power control (UPC) will boost the signal strength when rain fade is detected. The satellites can also increase the site diversity by connecting to multiple surface stations to have more redundancy when one of the stations is affected by rain fade. Another option is to use receiving antennas of a larger size. Finally, users can adopt adaptive coding and modulation (ACM), which will lower the modulation when rain fade occurs, and resume the modulation back to normal capacity when the weather improves [25].

BAND NAME	FREQUENCY RANGE	APPLICATIONS
L	1 - 2 GHz	GPS; satellite phones; satellite radio; communications
S	2 - 4 GHz	Weather radar; communications
C	4 - 8 GHz	Communications
X	8 - 12 GHz	Weather; marine traffic control
Ku	12 - 18 GHz	Communications
Ka	26 - 40 GHz	Communications
V	40 - 75 GHz	(Still in planning)

Table 3: Frequency Bands of Satellite Communications [26]

3.2.3 EQUIPMENT

Due to the shift to higher frequency bands, the size of equipment for satellite signals are much smaller now. The very-small-aperture terminal (VSAT), smaller than 4 m, has now been widely used in the marine industry. Since a ship is moving, the antenna of marine VSAT must be stabilized so that it can keep tracking the satellites with which it is communicating [27]. In 2021, one service provider launched a new generation of VSAT that supports the 5G network and the LEO and MEO satellite constellations [28].

3.3 CELLULAR COMMUNICATIONS

While satellite communications provide solutions to deep sea connections, cellular communications offer connectivity for vessels close to the shore. The IMT-Advanced (4G) technologies are widely in use for public mobile communications. It can reach 100 Mbps for users in motion and as fast as 1 Gbps for stationary users [29]. The frequency band is from 450 MHz to 5,000 MHz.

The 5G standard was developed by 3GPP. The 5G network provides higher throughput and lower latency. The peak speed can reach 10 Gbps. There are two frequency bands for 5G networks, the Frequency Range 1 (FR1) [30] from 410 MHz to 7125 MHz, and Frequency Range 2 (FR2) [31] from 24.25 GHz to 52.6 GHz.

GENERATION	DATA RATE	LATENCY	FREQUENCY BAND
4G	0.1 – 1 Gbps	< 100 ms	450 MHz – 5,000 MHz
5G	1 – 10 Gbps	< 1 ms	FR1: 410 MHz – 7,125 MHz; FR2: 24.25 GHz – 52.6 GHz

Table 4: Cellular Communications

4 APPLICATIONS

In addition to satisfying safety requirements and providing internet access for vessels, the advancement in communication technology enables data-intensive functions and applications.

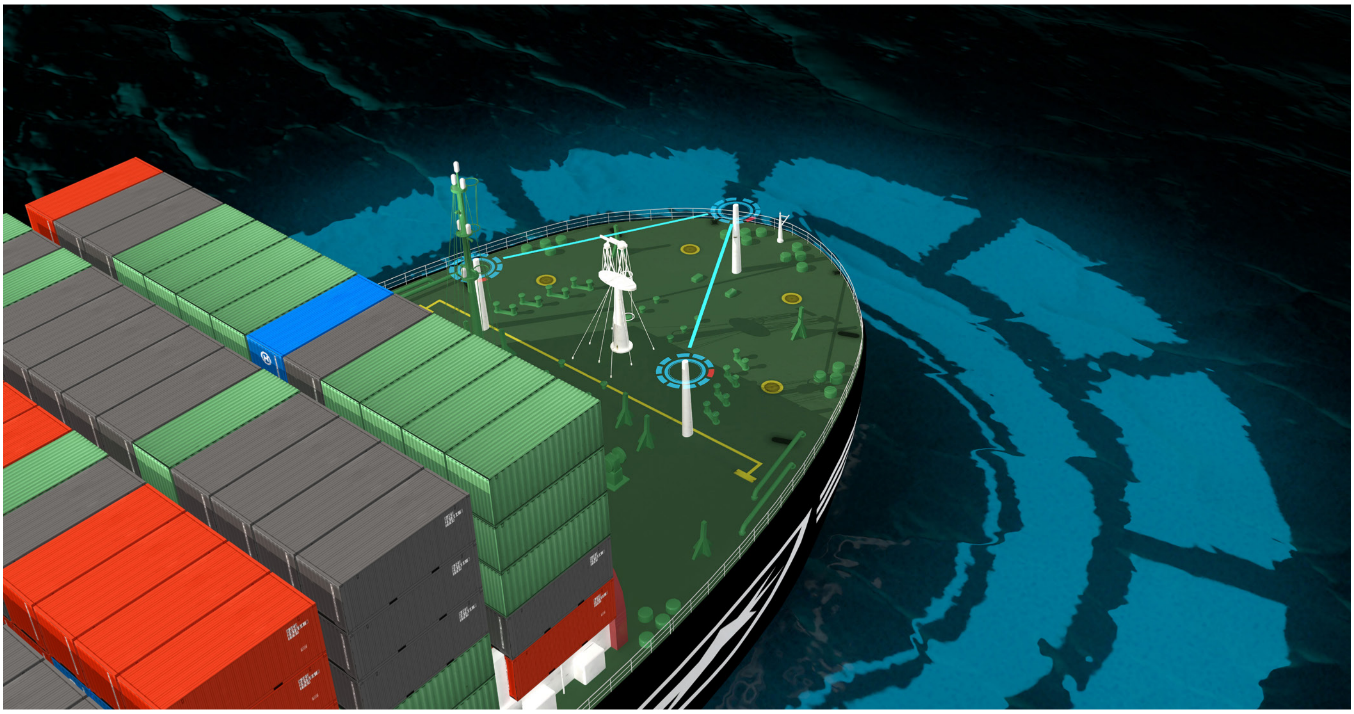
4.1 SMART, AUTONOMOUS AND REMOTE-CONTROL FUNCTIONS

As defined in ABS *Guide for Smart Functions for Marine Vessels and Offshore Units,* smart functions refer to systems installed and services deployed to continuously collect, transmit, manage, analyze, and report data for enhanced health, condition, and performance awareness, operational assistance, operational optimization, and decision-making support. Smart functions are often data-intensive for their algorithms to work reliably, and may also involve an onshore supporting facility connected with the vessel for providing advanced analytics and human in the loop support for machinery and structural condition or performance to support informed operational decisions, optimized inspection and maintenance, as well as a more condition-based asset life-cycle management strategy. Depending on their purpose and the risk impact on their integration and control capability with vessel control systems, all smart functions may not require real-time large data transmission between vessel and onshore facility. However, continuous, reliable and secure large data communication is important for functionality and performance. The ABS *Smart Guide* summarizes the vessel connectivity requirements for smart functions implementation based on the risk level [32].

As defined in the ABS *Guide for Autonomous and Remote-Control Functions*, autonomous functions are functions that allow machines to take operation actions of monitoring, analysis, decision, and action in a loop, without human intervention to achieve the system mission and perform tasks. Remote control functions allow a system or an operation to be monitored and controlled by a human operator who is not located at the system or where the operation takes place [33].

Unlike smart functions, autonomous and remote-control functions require real-time monitoring and control. Consequently, fast and reliable connectivity between the vessel and the remote station is considered essential even if the crews are onboard for monitoring and vessel operational functions. There are various factors and more rigorous requirements to be considered, such as bandwidth, data integrity, reliability, latency, and security. The connectivity requirements for autonomous and remote control functions are presented in the ABS *Guide for Autonomous and Remote-Control Functions*.

For smart, autonomous and remote control functions, data integrity should be verified, with corrupted or invalid data detected and addressed in a timely manner. Data connection to the vessel should be robust. For smart, autonomous or remote-control functions of higher risk, the functions are not to be compromised even with degradation of network or complete loss of connection. Network latency should satisfy the functional and performance needs of the specific smart, autonomous or remote-control function.



For smart, autonomous and remote-control functions, data exchange volumes much larger than for typical navigation needs are required for status and operational monitoring and operational purposes. The communication equipment for smart, autonomous or remote-control functions should also have enough data capacity to satisfy the functional and performance requirements. The amount of data that can be carried out depends on the frequency band of the network. The higher the frequency, the more data can be carried.

The low latency as set by the 5G standards, as well as the low latency offered by the LEO satellites, would have a better chance to satisfy the latency requirements, while the development in the Frequency Range 2 (FR2) of the 5G network, and the usage of Ka band and V band in satellites would satisfy the data volume requirements.

4.2 UNMANNED SHIPS

The successful operation of unmanned ships in a reliable manner depends on the correct and coordinated operation of multiple systems, such as navigation, collision sensors and AIS, all of which require robust and reliable connectivity to give the vessel the most up-to-date traffic and weather information. In addition, the vessel and system status should be continuously transmitted to the onshore facility and monitored for safe operations. Due to the absence of crews, an even more robust and reliable vessel connectivity is critical to safe vessel operations. The increasing speed, low latency, more reliable and high data volume of the new communication technologies, such as 5G network and LEO satellites, would satisfy such demands. In recent years, unmanned ship trials are mostly in the coastal areas where a cellular network can satisfy these communication requirements. When unmanned ships travel to deep seas, ensuring reliable satellite-based vessel connectivity is still a challenge.

4.3 REMOTE SURVEY

ABS, as a classification society, continues to pioneer new ways for smart, efficient, thorough and safe surveying experience to minimize operational interruptions. With ABS Remote Survey, clients can now have 24-hour worldwide coverage from our global network of surveyors.

The ABS Remote Survey program augments traditional surveys through the transfer of digital documentation such as reports, photos and videos for non-attendance-based verification of select surveys. However, in many instances, a live stream from the vessel may also be required to cover the full set of requirements remotely and such situations will demand robust and reliable communication capabilities. Adoption of this program improves scheduling efficiencies and reduces operational disruptions.

Vessel connections that are more reliable, faster, and have higher capacity would allow remote surveys to be performed more efficiently. For vessels in locations that are not accessible by surveyors, connections can be established to allow high-resolution streaming from the vessel to shore, enabling surveyors to inspect the ships to the best degree possible versus an in-person survey, without being on-site.

5 FUTURE

5.1 TECHNOLOGY

There are many promising technologies currently in development that will potentially further enhance vessel connectivity by providing reliable, fast, large volume and affordable communication options.

5.1.1 5G AND LOW-EARTH-ORBIT SATELLITES

With the reduction of launch cost, more LEO satellites will be launched, forming large constellations that can be integrated into the 5G network system [34], and provide uninterrupted global coverage to ships at sea. One company even plans to provide global maritime coverage [35], with more than 40,000 satellites being launched in the coming years [36] [37].

5.1.2 HIGH ALTITUDE PLATFORM STATIONS

High altitude platform stations (HAPS) are radio stations at an altitude of 20 to 50 kilometers [14]. These stations can be carried on solar-powered unmanned aerial vehicles (UAV). Similar to the LEO constellations, these stations can also act as relays for the 5G network and provide coverage for ships at sea.

5.1.3 THE 6TH GENERATION STANDARD FOR WIRELESS COMMUNICATIONS (6G)

The sixth-generation (6G) standard for wireless communications is still in the early research phase. 6G will venture into the terahertz frequency range, has a much higher speed than 5G and can utilize artificial intelligence to optimize the design and operation of the network [38].

5.1.4 WIRELESS OPTICAL COMMUNICATION

Wireless optical communication uses infrared (IR), visible, or ultraviolet light (UL) to carry a signal. Laser communications have been used by satellites since the early 2000s. However, the use of optical communication in the marine industry is still limited. The technology is still under development and continuing improvement and it can offer an alternative solution to marine vessel connectivity in the future [39].

5.2 CONNECTIVITY GAPS FOR SMART, AUTONOMOUS AND REMOTE-CONTROL FUNCTIONS IMPLEMENTATION

The smart, autonomous and remote control functions may require high connection speed, large data volume and low latency for some operational scenarios. It will take some time for the communication technology for these high data-intensive functions to mature and become affordable. The remote operating center, which may be considered as part of the vessel's smart, autonomous and remote-control operations by the flag States, could be subject to class requirements.

5.3 IMPACT ON VESSEL OPERATION

A highly connected vessel will have more operational possibilities. Apart from the autonomous functions and unmanned operations mentioned earlier, the vessel operational and environmental data and machinery and structural health status could be continuously synchronized to a data center onshore. Based on the received data and data analytics, such as digital twin, anomalies or defects can be detected at an earlier stage. The vessel can then receive remote diagnostic or decision support from the data center to avoid dangerous situations, potential system or structural failures, and to optimize operations. In addition, the continuous operational and condition data will lead to optimized inspection and maintenance to increase the vessel reliability and readiness for the whole fleet life-cycle management to enhance the fleet safety while reducing the overall OPEX.

5.4 IMPACT ON REGULATORY AND CLASS FRAMEWORK

Since vessel connectivity is becoming an integrated part of vessel operation and functions, it is foreseeable that new rules and industry standards will evolve to address the various safety and performance requirements on connectivity for data-centric vessel functions. Likewise, there will be an increased focus on remote control centers.

The development of vessel connectivity also enables implementation of technologies such as Digital Twins for operational decision-support and services such as structural and machinery health monitoring for condition-based maintenance.

6 SUMMARY AND CHALLENGES

While technology advancement on vessel connectivity enables data-intensive functions, such as smart, autonomous and remote-control functions in the marine industry, these more data-intensive functions require continuous, faster, more reliable and secure vessel connectivity. To fill the gaps between the functional and performance demands and available technology, there are a few challenges for marine vessel connectivity.

- The technology, with respect to widely available and reasonably priced communication capabilities to cover the demand of today's marine use cases for smart, remote-controlled and autonomous capabilities, is still developing.
- Regulations and standards are still evolving.
- Adoption of new technology by ship owners is driven by regulation change, commercial benefits or other sources such as social pressure. However, these driving factors are still weak.
- Connectivity infrastructure in ports and in space requires long-term investment.
- Communication cost is still high for data-intensive demands.

Connected vessels are the foundation for data-intensive functions, and are also changing the traditional business models for the marine industry, including classifications, for safer and more efficient operations and maintenance with potential reduced OPEX.

7 LIST OF ABBREVIATIONS

3GPP	The 3rd Generation Partnership Project
ABS	American Bureau of Shipping
ACM	Adaptive Coding and Modulation
EHF	Extremely High Frequency
Gbps	Gigabits per second
GMDSS	Global Maritime Distress and Safety System
GEO	Geostationary Orbit
HAPS	High Altitude Platform Stations
HEO	High Earth Orbit
HF	High Frequency
HTTPS	Hypertext Transfer Protocol Secure
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IMO	International Maritime Organization
IMT	International Mobile Telecommunications
ISO	International Organization for Standardization
ITU	International Telecommunication Union
LEO	Low Earth Orbit
LTE	Long-Term Evolution
Mbps	Megabits per second
MEO	Medium Earth Orbit
MF	Medium Frequency
MQTT	A messaging protocol that was designed to create a reliable standard for machine-to-machine (m2m) communication
QoS	Quality of Service
SFTP	Secure File Transfer Protocol
SHF	Super High Frequency
SOLAS	International Convention of Safety of Life at Sea Convention
THF	Tremendously High Frequency
UAV	Unmanned Aerial Vehicle
UHF	Ultra High Frequency
VHF	Very High Frequency
VPN	Virtual Private Network
VSAT	Very-Small-Aperture Terminal

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