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SHIP CONNECTIVITY

SAFER, SMARTER, GREENER

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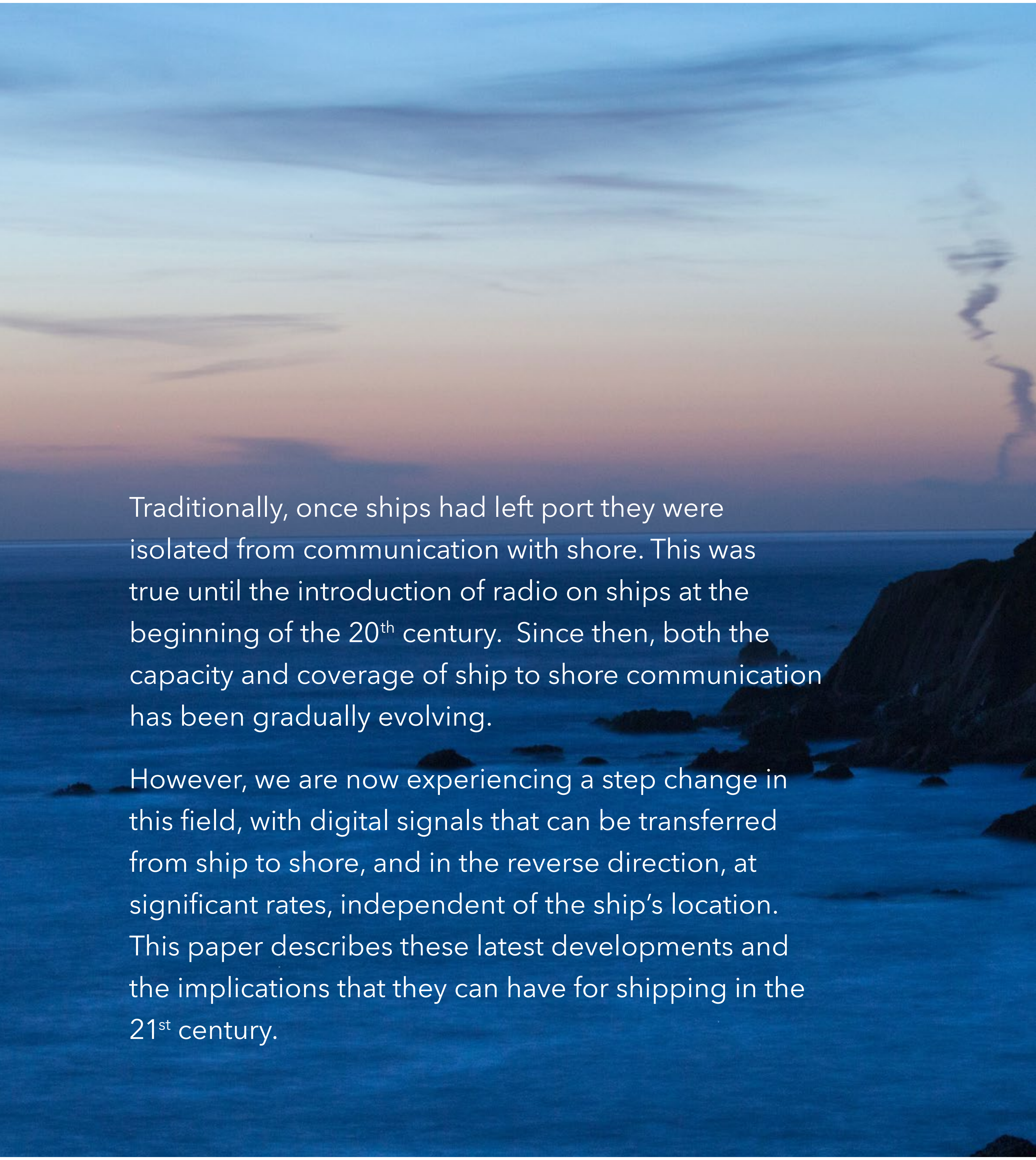
CONTENT



Traditionally, once ships had left port they were isolated from communication with shore. This was true until the introduction of radio on ships at the beginning of the 20th century. Since then, both the capacity and coverage of ship to shore communication has been gradually evolving.

However, we are now experiencing a step change in this field, with digital signals that can be transferred from ship to shore, and in the reverse direction, at significant rates, independent of the ship's location. This paper describes these latest developments and the implications that they can have for shipping in the 21st century.

INTRODUCTION

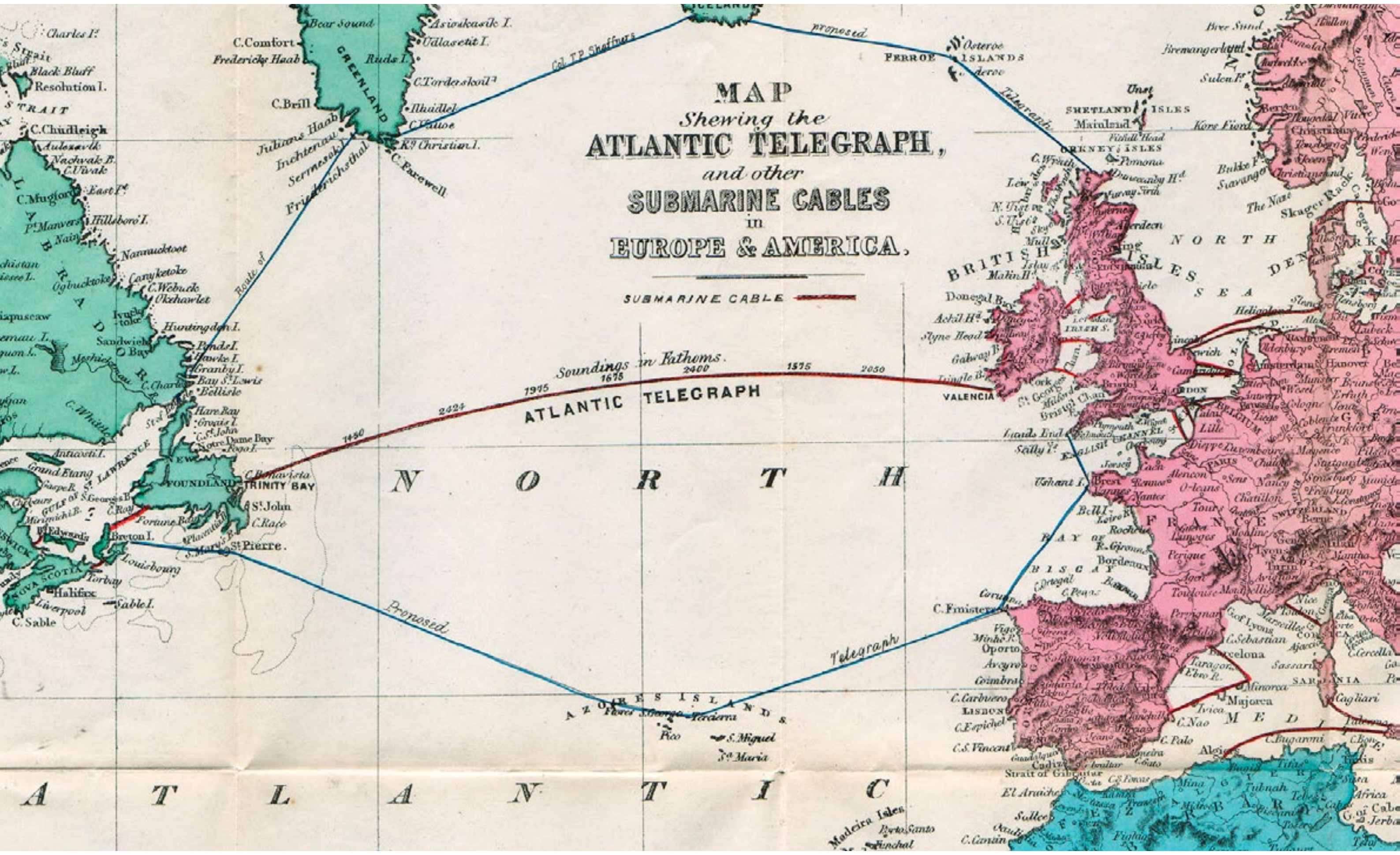


Figure 1. The transatlantic telegraph cable of 1865. Source: Atlantic-Cable.com

In 1865, the first successful transatlantic cable was installed. It had the capacity of 8 words per minute, which may seem absurd today, not to mention the price of $10 per word ($134 at current values). Within a decade, a network of cables linking major cities around the world was in place.

By 1897, there were 162,000 nautical miles of cable, with London at the centre of the network, being the hub of the Commonwealth. This communications network revolutionized shipping communications and transformed the shipping industry. Before then, vessels could lie idle in port for weeks waiting for orders on what to take on board as return cargo. As of mid-2012, the demonstrated design capacity of existing transatlantic systems was 49.5 Terabytes per second (Tbps).

The early capabilities of ship to shore communication were limited to voice, Morse, and telex for navigational and safety purposes. The capability and coverage of these systems gradually evolved during the 20th Century, and, in the 1990s, the Global Maritime Distress Safety System (GMDSS) brought the introduction of satellite communications and simple, yet effective, digital messaging to support distress alerting. The early capabilities of digital communications were limited, but there has recently been an unprecedented boost in communication capabilities due to completely different drivers emerging. Satellite broadband systems are increasingly used for a variety of operational commercial purposes, and also for leisure and entertainment.

Although “connectivity” is primarily to do with communication, the term is meaningless unless we also consider the data that is being communicated. There are now vast amounts of a wide variety of data on board a ship and these are generated from many different sources. Many of the onboard systems are designed for the purpose of collecting and presenting data to the crew as vital aids for decision-making during the ship’s daily operation.

As a result of the revolutions within sensors, communication, and data analytics, we now have “connected vessels”, with communication infrastructures that enable the implementation of a range of new applications based on the data now available on board. Ship connectivity will act as an enabler for these new applications by supporting the data analytics from shore through expertise and increased computational power. There is even the potential for control of ship functionality from shore. Applications may be capable of delivering key benefits, such as better performance, and improved reliability and safety, but these will also create new challenges.

The era of ship connectivity is upon us and will make a dramatic impact on ship operations as we know it today. This paper aims to explore ship connectivity in further detail, discuss the types of applications that may be enabled by ship connectivity, and finally present our view on how we, the maritime community, should utilize this great opportunity with the aim of making shipping safer, greener, and smarter.

HISTORIC AND CURRENT DRIVERS

Distress and safety

Historically, the primary driver for communication between ship and shore has been the safety of crew and passengers. Since the use of Morse telegraph on board ships in the early 1900s, the ability to send an alert message from a vessel in distress has saved thousands of lives at sea.

In 1988, GMDSS was established to increase safety and make it easier to rescue ships in distress. Chapter IV of SOLAS [/3/] was introduced to define required GMDSS functionalities and supporting communications equipment, and is applicable to all passenger vessels and cargo vessels above 300 gross tons that are engaged in international voyages.

GMDSS is mainly based on terrestrial radio systems (VHF, MF, and HF) with no data service, and the digital satellite communications systems used (Inmarsat-C and EPIRB) have highly limited data rates that are just suitable for supporting distress alerting and safety messaging.

Since its introduction, GMDSS regulations have remained relatively stable, and very little new technology has been introduced. The International Maritime Organization (IMO) is currently in the process of reviewing the GMDSS requirements with the aim of establishing an updated set of modernised GMDSS requirements by 2017. [/5/]

Navigational aid and reporting to authorities

Communication is also used as a navigational aid and for mandatory reporting to maritime authorities. Examples include:

- **Two-way voice communication (by radio or satellite):** this is, by itself, an essential navigational aid as it enables navigators on the bridge to exchange information with other vessels or shore-based parties about route choice, weather, or navigational hazards.
- **Automatic Identification System (AIS):** AIS messages containing vessel ID, position, course, and speed, are transmitted on dedicated channels in the VHF band for collision avoidance purposes. AIS messages are received by nearby vessels or AIS base stations, and, in recent years, a satellite overlay has been added (S-AIS) to increase coverage.
- **Long-range identification and tracking (LRIT):** this system requires vessels to report their ID position to their flag administration four times a day, typically done over satellite.
- **Vessel traffic service (VTS):** this is a marine traffic monitoring system established by harbour or port authorities, and is similar to air traffic control for aircrafts. Typical VTS systems use radar, CCTV, AIS,

and VHF for two-way radio communications, to keep track of vessel movements and to provide navigational safety in a limited geographical area.

- **Port arrival notifications (FAL requirements) and different ship reporting schemes for port states:** these are, e.g., related to dangerous goods and marine pollution.

As with GMDSS safety communications, the above applications are mandated by regulations, and do not require broadband data connections.

Operational applications

A different type of communication driver relates to the main operational purpose of the vessel. Unlike the drivers discussed already, this type of communications application is not driven by regulations, but rather deployed voluntarily in order to optimize operations, thereby saving costs to the shipowner or increasing service quality for the charterer. Such operational applications could be:

- Cargo logistics and monitoring applications
- Route planning and energy efficiency applications
- Administrative communication between the vessel and the shipowner's HQ.
- Upload of gathered data (e.g. seismic data or environmental data)

Operational applications are highly dependent on the type and purpose of the vessel and the applications' requirements for latency and bandwidth will vary. For example, the exchange of credit card transactions will be an important operational application for a cruise or passenger vessel. Although these transactions are time-critical, data volumes are relatively low and do not require much bandwidth.

Operational communications is a relatively modern driver that has emerged over the last decade through the age of digitization and satellite communications. Operational applications have been a key driver for shipowners to invest in new broadband communication capabilities on board their ships.

Welfare and entertainment

Welfare and entertainment for crew and passengers has been one of the strongest drivers for investment in advanced communications equipment in recent years. Shipowners have learnt that to attract the best crew, provision of TV and Internet is essential. Who wants to be stuck for weeks on an offshore vessel without being able to connect with friends and family on Facebook when off-duty? And who wants to spend the holiday on a cruise liner where it is not possible to check your emails or see your favourite team in the Champions League? Our modern digital habits have clearly influenced this development, and so have the falling costs and increased competition within satellite communication.

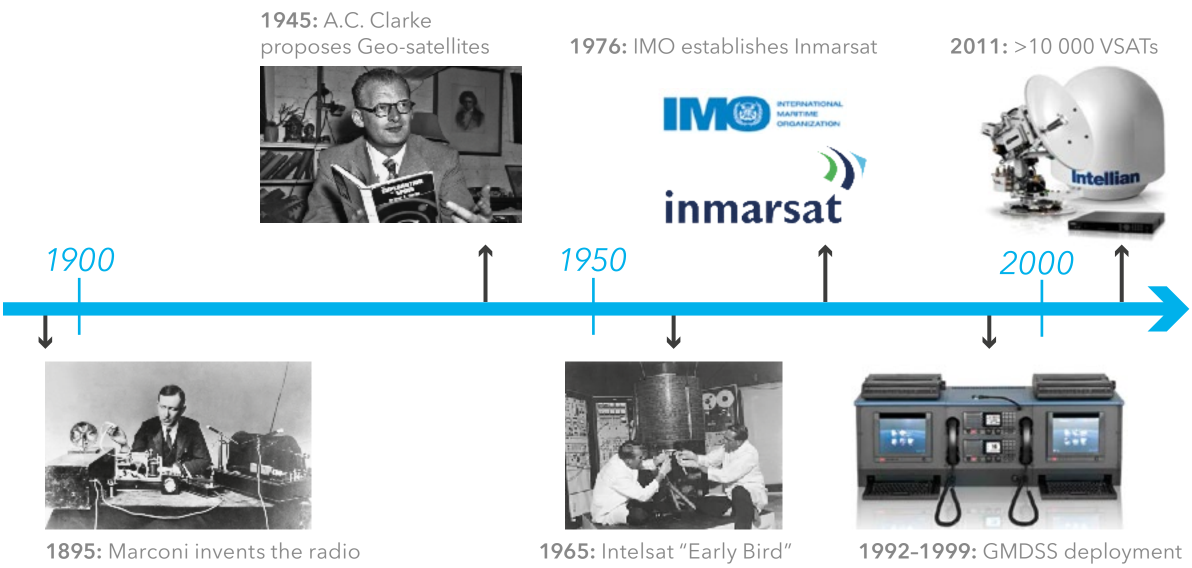


Figure 2. Maritime communication - key milestones

STATE OF THE ART COMMUNICATION AND FUTURE DEVELOPMENTS

Terrestrial radio

Existing systems

The terrestrial radio-systems VHF, MF, and HF are well known and established in the maritime community, and are cornerstones of the mandatory GMDSS requirements for SOLAS vessels. The services provided over these systems are quite similar;

- Duplex voice service, with digital selective calling (DSC) for automated call setup
- Distress alerting capability
- Telex with printing facilities

The differences between the systems relate to the frequency bands used and the coverage areas.

SYSTEM/BAND	TYPICAL COVERAGE FROM EARTH STATION
VHF	40 - 60 nautical miles
MF	150 - 200 nautical miles
HF	Worldwide (given appropriate conditions & frequency)

Table 1. Typical coverage of radio systems

These legacy radio systems are typically operated by maritime authorities on a non-commercial basis, and are offered to the maritime community as a free service.

Barriers

Although a free service is beneficial for mariners, the maritime authorities do not drive the development of maritime broadband communications. This lack of drive and "technology push" is a barrier, and probably a key reason for the lack of data services in the VHF, MF, and HF bands. The bandwidth available in these bands is severely limited anyway, so any new data-service will remain narrow-band compared with the alternatives (satellite and terrestrial mobile).

Other barriers include service coverage, which is limited to a distance from the shore base stations (VHF and MF), and the service quality, which is limited for long-range connections (HF).

New systems and innovations

Due to the barriers mentioned, technology development on the legacy radio-systems is generally limited. However VDES (VHF Data Exchange System) is a promising initiative to provide a digital data service based on the existing terrestrial VHF radio infrastructure. IALA (The International Association of Marine Aids to Navigation and Lighthouse Authorities) have proposed VDES, with

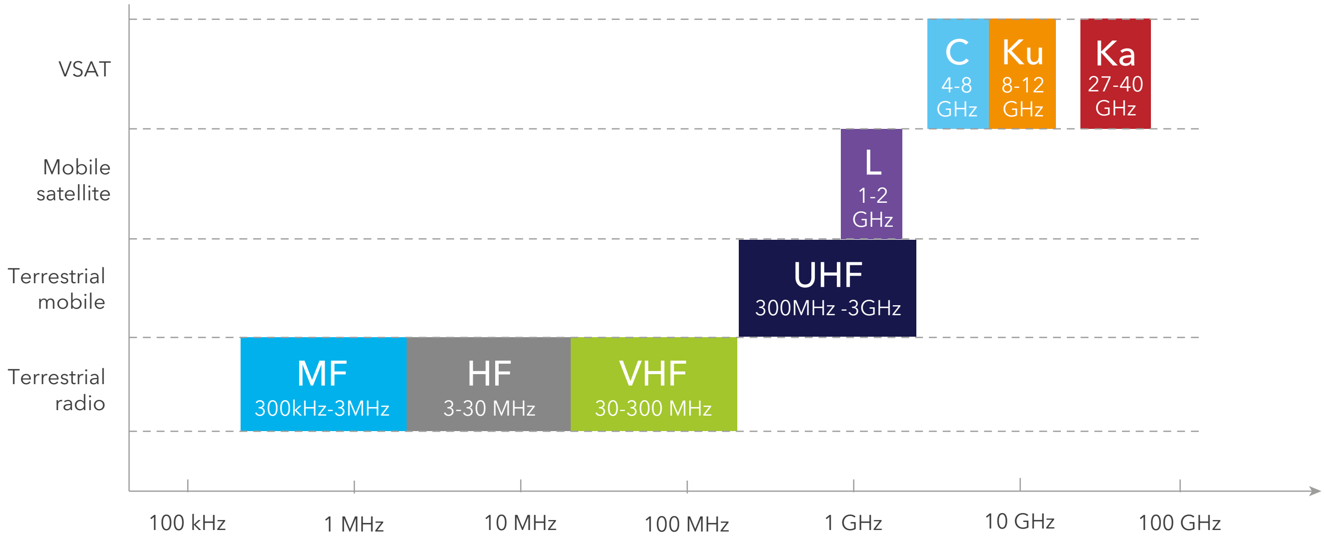


Figure 3. Frequency bands relevant for maritime communications

the aim of offloading the VHF Data Link (VDL) of AIS and creating a new channel for data exchange, to support new e-Navigation applications. [/43/] VDES is based on ITU-R M.1842-1. This defines more spectrum-efficient modem techniques and higher data rates (up to 307.2 kbps per 100 kHz), which is 32 times the speed and 8 times the efficiency of the existing AIS channels (9.6 kbps per 25 kHz).

There are several attractive aspects of VDES. Assuming that it will be built on the existing operational model and infrastructure of VHF, service coverage will be optimized towards maritime use, with a service that is free to use for mariners. With its limited data rates, VDES will not be a suitable alternative for commercial and bandwidth-hungry applications that are better served by satellite and 4G. However, VDES may become a viable solution for e-Navigation applications such as VTS (Vessel Traffic Service), distribution of MSI (Maritime Safety Information), and different types of narrow-band ship-to-shore reporting applications e.g. cargo indications and piracy reports.

Mobile Satellite Systems (MSS) on L-band

Existing systems

Since its founding in 1976, **Inmarsat** has been a reliable provider of satellite communications services to the maritime community. Inmarsat owns and operates a network of L-band satellites in Geo-

Figure 4. Inmarsat products; FleetBroadband (left) and Inmarsat-C (right). Source: Sailor/Cobham

stationary orbit (35,786 km altitude) and gateways connected to public networks. Inmarsat's system design has traditionally been in-house and they have created their own proprietary products, generating traffic on their satellites. Inmarsat takes an active role in operations, distribution, and sales, but still considers itself as a "wholesaler" based on a wide international network of distribution partners.

Inmarsat provides a wide range of maritime services over their L-band satellites. Inmarsat-C is a low-rate messaging product that was launched in 1992, and that typically forms part of the equipment set-up for GMDSS vessels. Fleet Broadband is a family of broadband products launched in 2007, designed

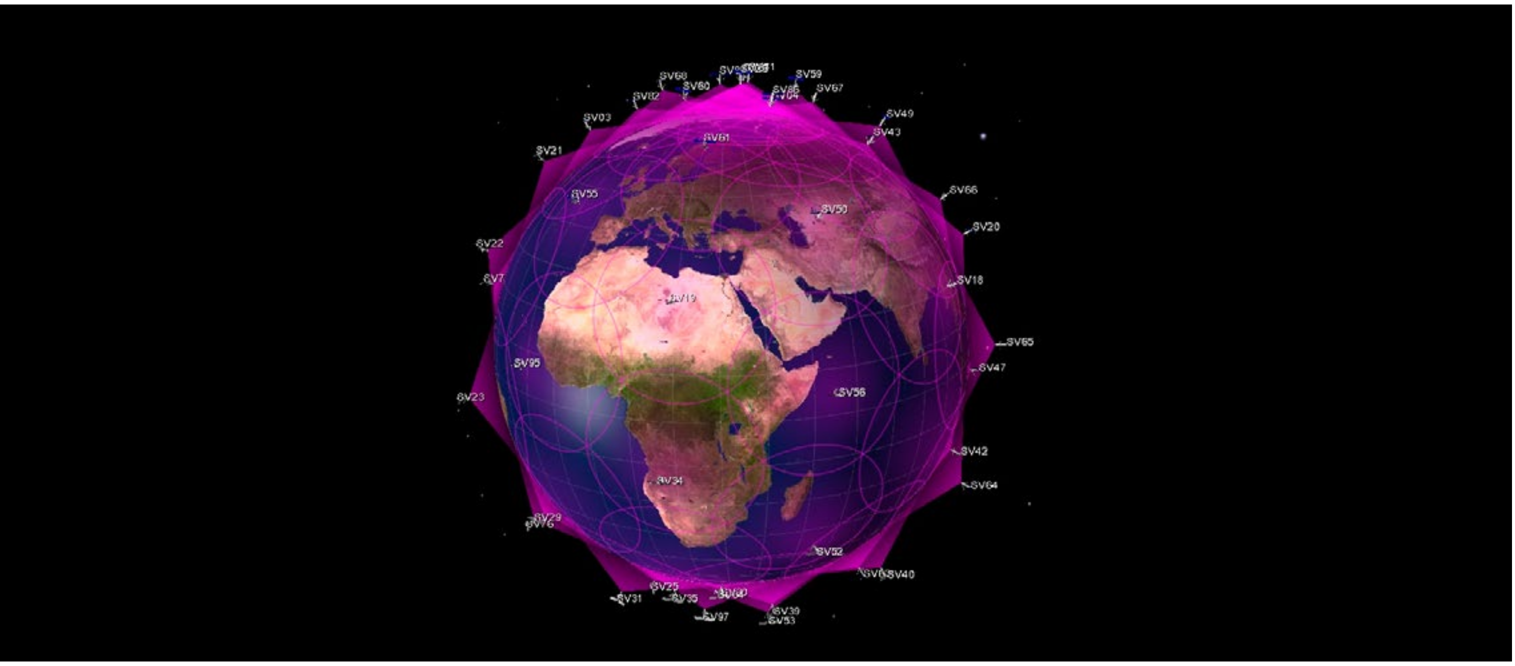


Figure 5. Iridium's constellation of 66 LEO satellites.
Source: Iridium Satellite LLC

for the Inmarsat-4 satellites and providing 3G-type services up to 500 kbps. [/9/, /76/]

The strengths of the current Inmarsat products are reliability, coverage, and a streamlined way of delivering services. Inmarsat is the dominant player, with ~90 % market share within mobile satellite systems (L-band). [/7/]

Like Inmarsat, **Iridium** is an L-band satellite operator, but Iridium's satellites are in Low Earth Orbit (LEO), at approximately 780 km altitude. Iridium became operational in 1998 with a constellation of 66 satellites. The Iridium satellites can communicate directly with neighbouring satellites via Inter-satellite links (ISL), thus reducing the need for gateways and on-ground switching. The satellites have an orbital speed of 27000 km/s, use 100 minutes to orbit the earth, and approximately 8 minutes to cross the horizon as seen from a fixed location on the ground. This creates system challenges such as Doppler effects, and satellite handovers during user sessions. Iridium's key strength is that the constellation of constantly moving LEO satellites provides continuous coverage over the entire surface of the Earth, including Polar regions. [/8/]

Thuraya is a regional L-band system using two Geo-satellites, providing maritime products such as OrionIP, with IP data capabilities that are similar to those of Inmarsat's Fleet-Broadband. [/27/]

OrbComm operates a satellite network of 29 LEO satellites at 775 km altitude, optimized to support M2M (machine-to-machine) applications. Unlike the other MSS providers operating in L-band, OrbComm is the only licensee operating in 137-150 MHz VHF band, which was allocated globally for "Little LEO" systems. [/4/]

Barriers
The MSS satellite communications market suffers from poor competition, with Inmarsat as the dominant player, partly based on its unique position in GMDSS.

Given the market situation and the relatively little bandwidth available for MSS systems on L-band, user data rates are relatively limited and prices are quite high. Inmarsat and Iridium have done a good job in making products that provide a few hundred of kbps, but at high charges and with comparatively limited throughputs compared with very small aperture terminal (VSAT) systems and terrestrial options.

Regulations and standards are trailing behind technological and commercial developments. The only MSS product with any substantial status within GMDSS is Inmarsat-C. This was launched in 1992 and is limited to messaging applications. Regulators have not yet utilized MSS products' broadband capabilities to enhance safety, navigation, and to protect the environment. Despite unique Polar coverage and success with voice and M2M tracking applications, Iridium has taken 17 years to become considered for inclusion as a GMDSS operator.

Finally, lack of available spectrum on L-band is a barrier that will constrain further growth of these systems and, as a result, MSS operators like Inmarsat and Iridium are moving to higher frequency bands for their new systems.

New systems and innovations
Due to the lack of spectrum, new large-scale investments or future deployments in broadband capabilities at L-band should not be expected. L-band MSS products will still have an important role in the future, but for any new developments the emphasis is likely to be on narrow-band messaging and tracking applications with smaller terminals, while higher frequency bands (VSAT Ku and Ka) will be the main arena for broadband developments.

Terrestrial mobile systems

Existing systems
Terrestrial-based mobile communications have enjoyed enormous growth for land users over the last two decades, and base stations along the coast also handle maritime traffic. The current 3G coverage extends out to around 10 nautical miles (nm), whilst 2G services reach out 20 nm and even further in some places. [/21/] Given appropriate power and antenna configuration and the use of 800-900 MHz band, 4G (LTE) services may reach 100 km (50 nm), although with reduced data rates. Whilst typical 3G data speeds are in the order of a few Mbps, new 4G technologies such as LTE can provide over 100Mbps. [/17/]

Although these coverage ranges are slightly shorter than VHF for plain voice communications, the cellular systems provide useful data connectivity for smaller vessels, such as yachts and fishing vessels, travelling along the shore. They are also a valuable alternative for deep-sea cargo vessels approaching or leaving port, should the VSAT be blocked from view of the satellite due to mountains, buildings, or other obstructions.

There are also other mobile broadband concepts at the national and regional levels. One example is ICE, a Scandinavian mobile broadband service using code division multiple access (CDMA) over 450 MHz, the band previously used for analogue mobile telephony. Due to the propagation characteristics of this band, maritime coverage may reach as far as 120 km from shore, with healthy data speeds in the Mbps range. [/26/]

Wi-Fi is another terrestrial mobile technology that plays a significant role, at least on a "hot spot"-basis. Wi-Fi is defined as wireless local area network (WLAN) products based on the IEEE 802.11 standards and use on non-regulated spectrum at 2.4GHz and 5GHz [/75/]. In recent years there have been several examples of Wi-Fi-network deployment in ports e.g. Vladivostok (Russia), Rotterdam (Netherlands) and Auckland (New Zealand). [/25/] Such IP zones are typically set up by flag states or port authorities to facilitate mandatory reporting, e.g. port clearance, or by telecom operators to provide Internet access as a paid service. As Wi-Fi is unlicensed, service offerings can be established very cost effectively, with low or no user charges. WiMAX (Worldwide Interoperability for Microwave Access) is another interoperable wireless communication standard (IEEE 802.16) that has been used by the Maritime and Port Authority of Singapore (MPA) to provide a subscriber service called WISEPORT in Singapore port, based on licensed spectrum on 2.3 GHz, providing 15 km coverage and download data rates in the range of 512 kbps-8 Mbps.[/23/,/24/]

Barriers
Terrestrial systems have some natural coverage limitations that mean that they are unable to support vessels during the "deep sea" part of their voyages, so for most vessels a terrestrial mobile communication capacity is only relevant as part of a communication mix, i.e. one out of several communication options.

Unlike operators of the legacy radio systems, terrestrial-based cellular operators are both commercially focused and technologically advanced. However, their primary focus is land-based users and applications, implying that the maritime segment is not prioritized regarding rollout strategies and applications development.

Another barrier is traffic costs. Although the user's investments in terminals are attractively low, the operator's investments in terrestrial base stations and licensed spectrum will require payback through the user's traffic bills. Anyone travelling abroad with a mobile phone has learnt to be cautious in order to avoid hefty international roaming charges.

The 3GPP standards are expected to drive future mobile terminal development, which means that terminal cost and availability will be experienced as a barrier for other variants of mobile technologies that deviate from the mainstream standards. With the global adoption of 3GPP-defined 4G/LTE technologies, this will be a challenge for technologies such as ICE and WiMAX as these require special modems.

Wi-Fi remains a highly capable and cost-effective option for "hot spots", but any unlicensed band brings with it quality of service related challenges. According to research by the Greenwich Maritime Institute, cybersecurity concerns are the main reason for the slow uptake of Wi-Fi and WiMAX networks in ports [/25/].

New systems and innovations
An interesting recent development is deployment of mobile picocells on board vessels. These concepts are based on establishing a 2G/3G base station (picocell) on board the vessel, enabling access to 2G/3G capable devices by standard roaming functionality. On-Waves (Iceland) [/29/] and Maritime Communications Partner (MCP) (Norway) [/30/] are two companies delivering such solutions, which have become quite popular within the passenger / cruise segment. The key advantage with these systems is that users can simply use their personal cellular devices, but usage is relatively expensive due to the use of VSAT backhaul and international roaming charges.

MCP are also involved in another interesting deployment of mobile technology in the maritime sector, as they are planning a rollout of a LTE (4G) network on the Norwegian continental shelf. [/22/] The main objective is to provide communication for people and systems on the platform, but with a service coverage radius of up to 30-40 nm of the surrounding sea areas, many passing vessels may also benefit from the service, which will be accessible by standard cellular equipment and roaming functionality. Such an offshore 4G-network will make it possible for offshore supply vessels to remain within 4G-coverage during offshore operation, as well as during much of the time in-transit to and from port.

It is not only telecom operators who recognize the 4G offshore opportunity; in a recent spectrum auction in Norway, the oil and gas operator, Statoil, acquired a license for 10 MHz of 4G spectrum in the 900 MHz band for the Norwegian continental shelf. [/50/]

Figure 6. MCP's planned 4G coverage on Norwegian shelf. Source: MCP

Innovations using unlicensed Wi-Fi technologies should also be expected. With solutions addressing cybersecurity and quality of service, the importance of IP zones in ports may increase in the maritime communication mix.

Ongoing research is investigating the deployment of Wi-Fi technologies in different ways. Hazra and Seah (2010) defined a mesh network concept in which Wi-Fi links were deployed as part of a wireless backbone infrastructure. Mesh nodes, consisting of a Wi-Fi base station and highly directive antennae, are mounted on buoys to provide connectivity by multi-hop to vessels approaching or departing port. [/51/]

Satellite VSAT

Existing systems

VSAT is a larger type of terminal operating towards geosynchronous satellites on C-, Ku- and Ka-bands. [/77/] The majority of VSAT antennae range from 60 cm to 1.2 m. Given the large amounts of available spectrum on these bands, data rates are considerably higher and traffic costs significantly lower than L-band systems like Inmarsat and Iridium. Due to the ship movements, a maritime VSAT antenna needs an accurate and reliable stabilization and tracking mechanism to ensure that the directive beam points continuously towards the satellite.

Typical VSAT offerings can provide data speeds of up to 6 Mbit/s, and the typical subscription will involve a monthly lease with a cap on a certain data volume. The subscription fee will depend on the satellite dish size, coverage, and bandwidth – and also whether the data rates are provided on a guaranteed or best effort basis. A typical VSAT subscription costs between $1000 and $5000, with incremental traffic costs at <$1/per MB. [/31/]

In contrast to MSS at L-band, the VSAT market is highly competitive and has been an active arena for many commercial and technological developments in recent years. VSAT service providers typically bundle packages with modem, antenna, and a satellite resource lease from a satellite operator such as Eutelsat, Intelsat, or Telenor. Satellites delivering VSAT services are typically in geostationary orbit, implying that service quality deteriorates beyond 70° latitude. However, with clever antenna installations and link budget margins, it is possible to offer acceptable service quality as far as 75-78° North.

Due to the lower antenna gain, VSAT services on C-band provide excellent deep-sea coverage due to wide beams covering large sea areas, but also require larger ship antennae. Over the last years Ku-band coverage has improved, and can now offer a very cost-effective alternative to C-Band. On Ka-band there are still only a few satellites, but due to the amount of bandwidth available, and the potential efficiency benefits from the higher antenna gain, the prices have the potential to drop below those of Ku in the longer term.

Barriers
The main barrier for the adoption of VSAT is the size and cost of the end-user equipment. Due to advanced terminal electronics and the large stabilized antenna platform, equipment and installation costs for a maritime VSAT installation are typically in the range $50-$100k, which is much higher than L-band products. So far only heavy data users have found this initial investment worthwhile, which explains why there are considerably fewer VSAT installations than smaller, cheaper, and more narrow-band L-band products.

Although VSAT is much better than MSS L-band in terms of cost per bit and available bandwidth, Ku-band allocations have been filling up, and there are many on-going regulatory fights for spectrum. So cost and bandwidth are still bottlenecks, making it expensive to accommodate bandwidth hungry applications in a maritime setting.

Regarding rules, regulations, and standards for functionality and performance related to VSAT, there is a vacuum; virtually nothing exists in the public domain. Statutory regulations concerning GMDSS and navigational safety simply do not recognize VSAT as a communication option. For emerging non-safety related connectivity applications there is also a need to document best practices and standardize interfaces to ensure effective, future-proof implementations and to achieve vendor competition and economies of scale.

Another challenge for VSAT is the susceptibility to rain fade due to the absorption of microwave radio frequency signals by atmospheric rain, snow, or ice. This effect is significant above 11 GHz, and hence especially challenging for Ka-band. Operators need to plan in link margins or other mitigations in order to avoid reduced service reliability.

Figure 7. The second Global Xpress satellite – Inmarsat-5 F2 – launched in Kazakhstan on February 1st 2015.
Source: International Launch Services/Inmarsat

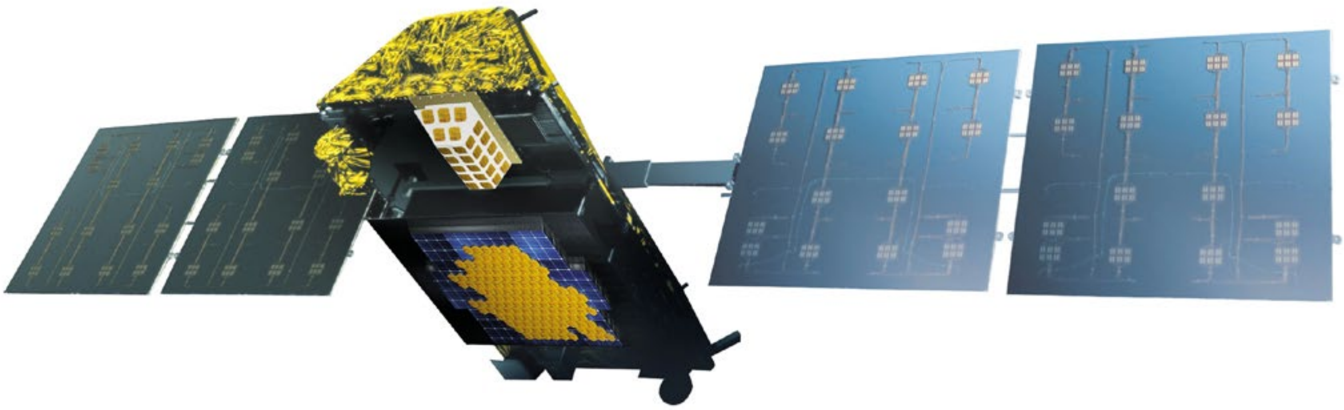


Figure 8. Iridium NEXT satellite. Source: Iridium Satellite LLC

New systems and innovations

Inmarsat Global Xpress: Inmarsat's 5th generation of satellites (three I-5 satellites launched in 2013-2015) will support a new network called Global Xpress (GX), with a global network entering commercial service early in the second half of 2015. [/49/]

With Ka-band satellites built by Boeing, Inmarsat are entering the VSAT world with a new maritime service called Fleet Xpress. The Fleet Xpress service includes a FleetBroadband terminal together with 1m or 60 cm GX Ka-band parabola, that, according to Inmarsat, is capable of delivering data rates of up to 5 Mbps/50 MBps (uplink/downlink) over all maritime trading routes. Inmarsat anticipates equipment pricing for GX to be in line with that for equivalent Ku-band VSAT devices. The system design has been delivered to Inmarsat by iDirect, who also delivers a "Core Module" that may be licensed to other manufacturers for incorporation in their products. Rain fading is a well-known problem for Ka-band, but the Fleet Xpress system has built-in adaptive code modulation so that the data rate can change with variable signal-to-noise levels. The GX system is designed for a target availability of 99 %, but the experienced availability should be higher as FleetBroadband (L-band) may be used as backup. [/76/,/80/]

Iridium Next: Iridium's current satellite segment is approaching end-of-life, and Iridium will be launching new satellites from mid-2015 onwards. Like Iridium's current satellite constellation, Iridium NEXT will deploy a cross-linked mesh architecture with 66 LEO satellites providing continuous global coverage, including the Polar regions. A new feature with the Iridium Next satellites is that in addition to L-band transponder to support existing products, it will also contain a Ka-Band transponder to support new broadband services. [/48/]

In February 2015, Iridium announced their plans to launch Certus, a new broadband service on the NEXT satellites delivering data rates of up to 1.4 Mbps, an impressive 10-fold increase on Iridium Openport. Iridium have partnered with experienced vendors, including Cobham Satcom and Rockwell Collins, to provide the new broadband offering, which is planned to be available towards the end of 2016.[/16/]

Intelsat Epic^{NG}: Intelsat's new high-throughput satellites initiative is called Intelsat Epic^{NG}. The new satellites will have C-, Ku-, and Ka-transponders, complementing their existing fleet of around 50 C- and Ku-band satellites. The two first Epic^{NG} satellites, Intelsat 29e and Intelsat 33e, are expected to be in-service in 2016. According to Intelsat, the new Epic^{NG} platform will provide 3-5 times more capacity per satellite than their traditional fleet. The expected throughput of the satellites will vary according to application and satellite, but is expected to be in the range of 25-60 Gbps, typically 10 times higher than the traditional fleet. [/10/]

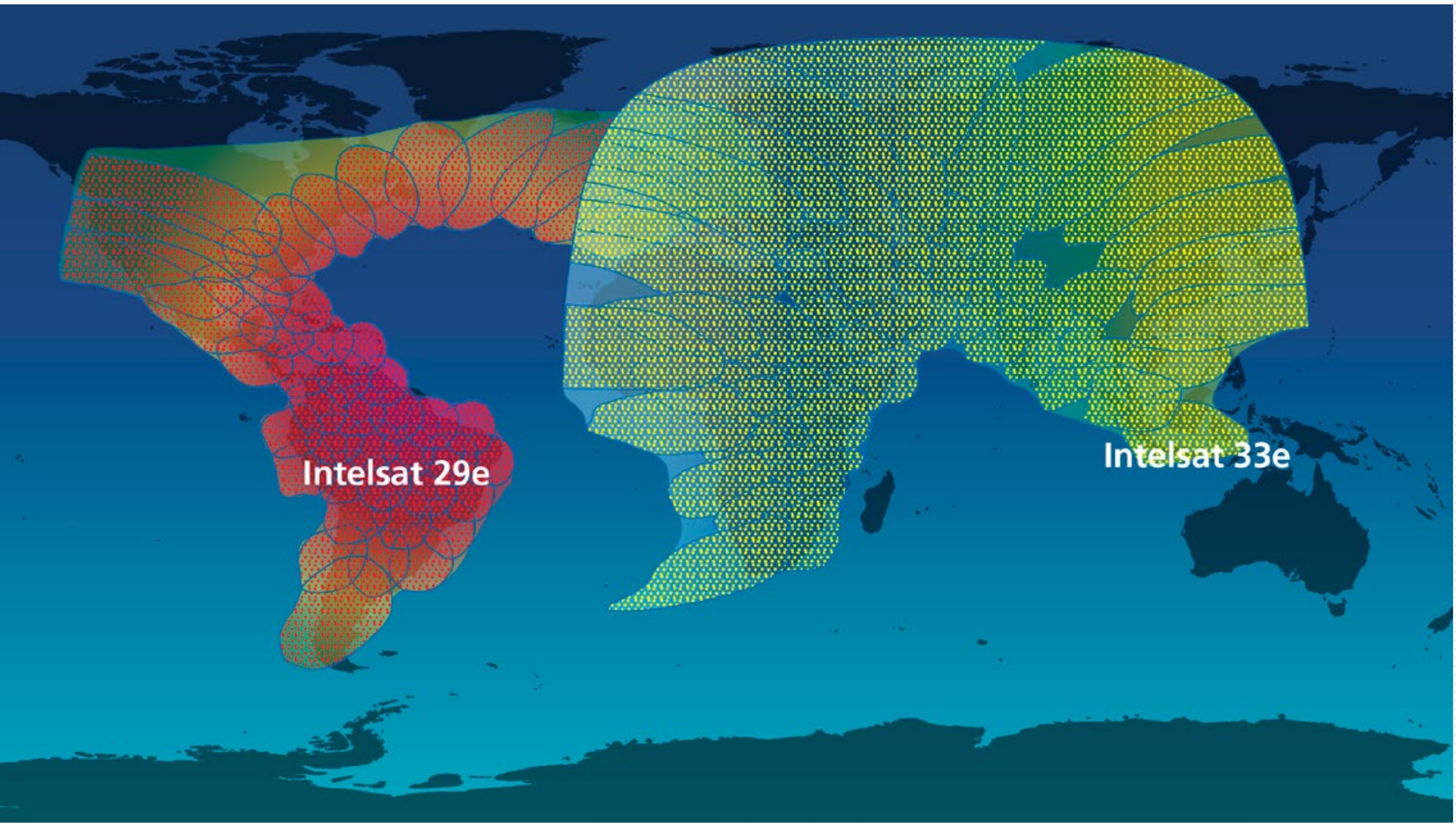
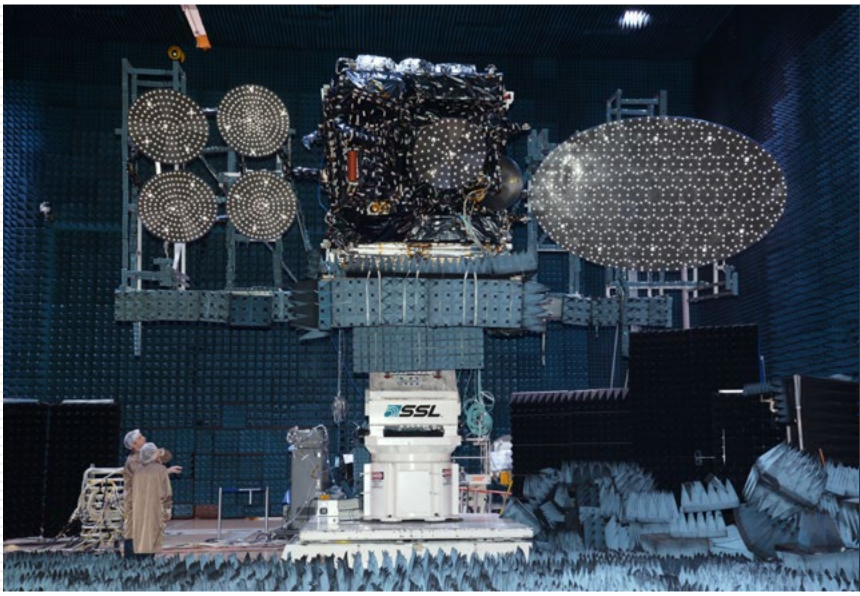


Figure 9. Intelsat Epic[NG] Coverage map. Source: Intelsat

As Intelsat is an existing VSAT satellite operator on C- and Ku-band, it is in the position to make complementary service offerings by combining C-, Ku- and Ka-band from existing and new satellites, in order to utilize the strengths and mitigate the weaknesses of each band. In many ways, Intelsat's investment in the new Epic[NG] satellites can be considered a low-risk, organic extension of their existing operations. While Inmarsat are designing their Fleet Xpress product with a closed group of partners under contract, Intelsat takes a more "open" and collaborative approach, allowing customers to design product offerings that exploit the new satellite capabilities, such as mesh networks, with guaranteed data rates and special service attributes.

The O3b Satellite Constellation is a new Ka-Band system that started operation in September 2014. [/11/] Eight satellites have been launched, and another four are scheduled for launch in 2015. The satellites are in Medium Earth Orbit (MEO) at 8063 km altitude, and each is equipped with 12 fully steerable Ka-band antennae, using a total of 4.3 GHz of spectrum corresponding to a throughput of 12 Gbps per satellite. According to O3b, their system is low-latency (130 ms round trip) and connectivity speeds are over 500 Mbit/s, making it a potent communication alternative. O3Bs approach for maritime is to track vessels with steerable spot beams, providing the tracked vessel with data rates up to 350 Mbps. The scalability of this approach has been questioned as O3B's satellites have only 12 steerable spot beams, but may prove viable for larger cruise vessels with huge communication needs. O3B's service coverage is limited beyond +/- 45° latitude, and there is no service beyond +/- 62°.

WorldVu Satellites Ltd recently secured regulatory approval for 2 GHz Ku-band spectrum for their new initiative, OneWeb, a proposed constellation of approximately 700 small LEO-satellites to provide global internet broadband to homes and mobile platforms. The satellites, each with a weight of 125 kg and data throughput of 8 Gbps, will orbit at 1200 km altitude. The system is estimated to require about $3bn by the time the full constellation becomes operational in 2019-2020. [/18/,/19/]



Thor VII

Telenor's new HTS "Thor VII" inspected in factory.

Source: Telenor Satellite Broadcasting

SpaceX: On a similar note, Elon Musk, CEO and founder of satellite launch provider SpaceX, recently announced on Twitter that SpaceX is in the early stages of developing "advanced micro-satellites operating in large formations". [/20/] In January 2015, the Seattle Times reported that SpaceX would be starting up a new satellite development facility in Seattle, with the initial focus on developing low-cost, high-performance satellites to be used by SpaceX in a new, space-based internet communication system supporting the backhaul communications and local internet traffic in high-density cities. The constellation is said to consist of 4000 satellites and the goal is to have the initial satellite constellation in orbit and operational in approximately 2020. [/55/, /56/]

There are a number of on-going HTS (High Throughput Satellites) initiatives, but many are focused on land-based markets and fixed installations for TV broadcast distribution. However, some HTS will also have return transponders to provide interactive services over maritime regions. One example is Telenor Satellite Broadcasting's new HTS "Thor VII" that will provide maritime VSAT connectivity across the North Sea, Red Sea, Baltic Sea, and the Mediterranean, as well as the North Atlantic.

Thor VII was launched in April 2015 and will offer 6-9 Gbps throughput, with up to 25 simultaneously active spot beams. According to Telenor, service offerings will include download speeds in the tens of Mbps and uplink speeds in the range 2-6 Mbps (depending upon antenna size). [/13/]

Other examples of new HTS systems providing maritime coverage include ViaSat2, covering large parts of the North Atlantic [/15/], and Telesat's Vantage 12 that was launched in late 2015 to provide coverage to high traffic maritime zones in the Mediterranean, North Sea, Caribbean, and South Atlantic. [/14/]

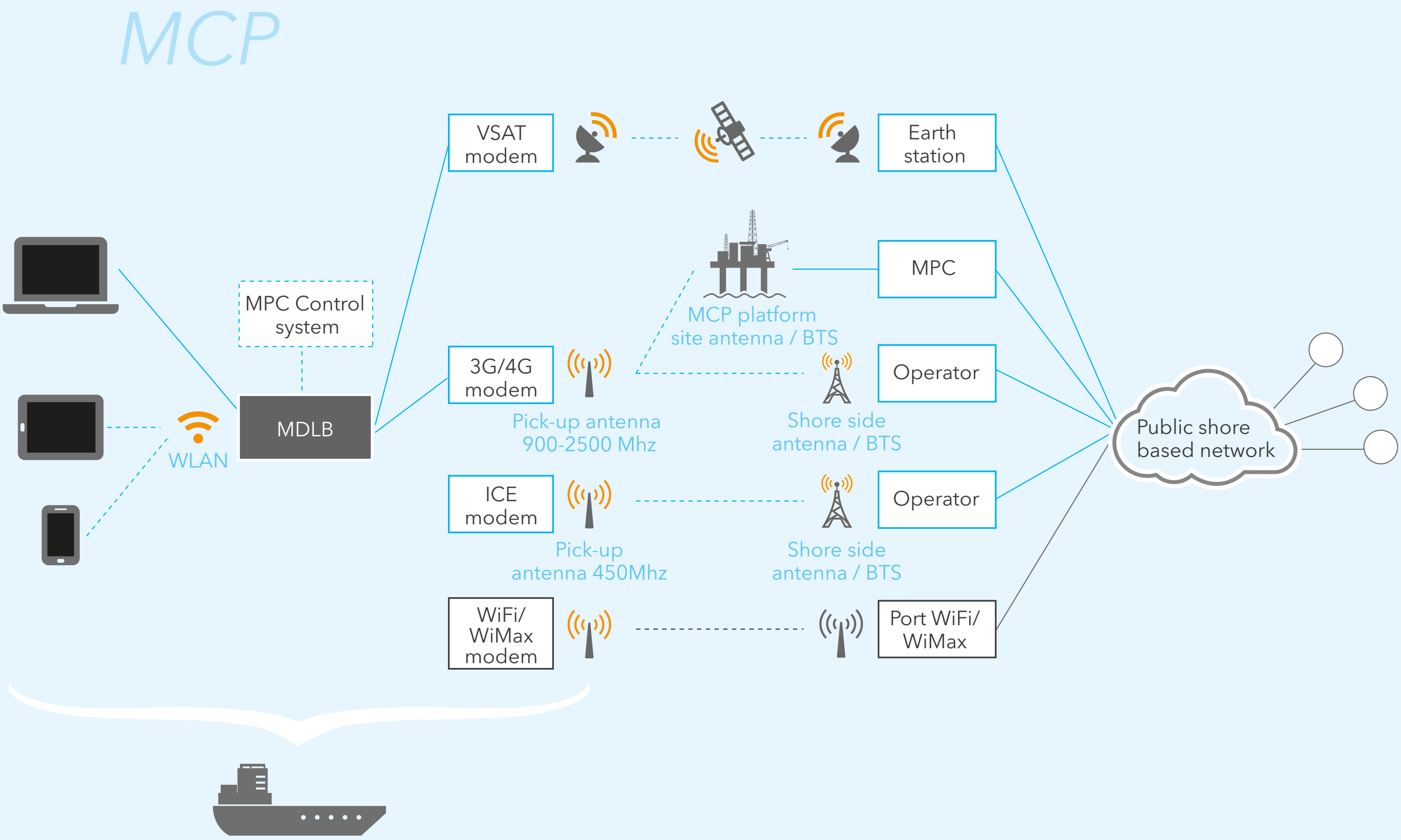


Figure 10. Communication broker solutions from MCP (left) and Inmarsat (right). Sources: MCP and Inmarsat Plc

Other innovations and trends

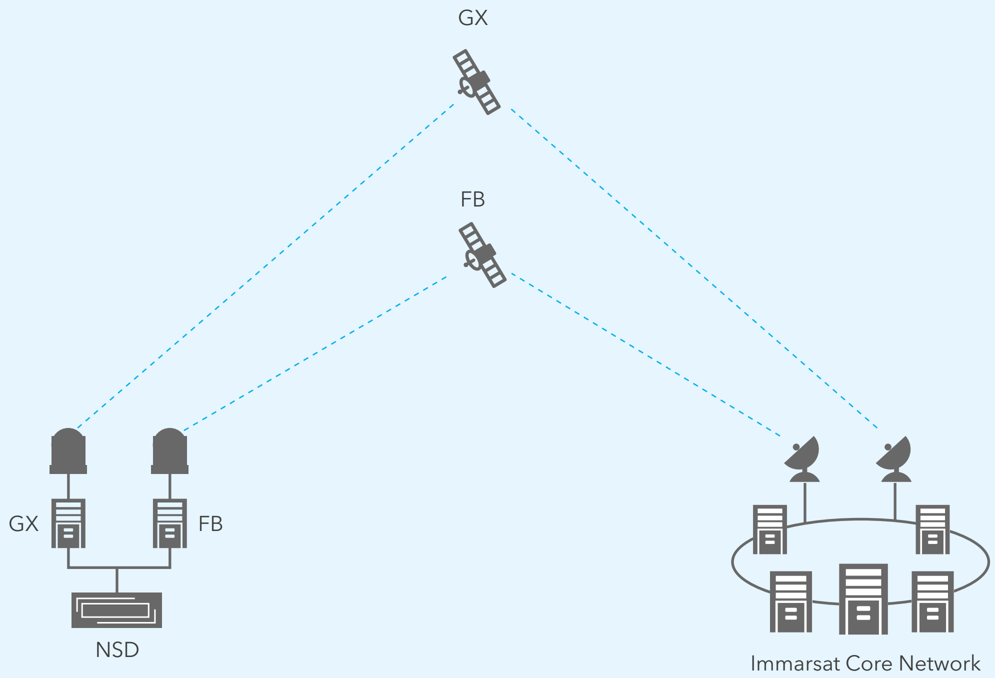
Communication broker

Given the diversity of communications options becoming available to the maritime market, further growth of communication broker applications, capable of working with several underlying communication bearers of different capabilities and characteristics, should be expected.

The communication broker selects which communication bearer to use according to predefined selection logic and selection criteria. Some of these criteria may be related to bearer capabilities, such as availability, cost, bandwidth, and latency. Others will be related to characteristics of the data to be transferred, such as data size, urgency, or priority. For example, a short, urgent data message will be sent immediately on any bearer available, whereas a non-urgent, voluminous transfer of raw data may be deferred until a cheap broadband alternative is available, e.g. 4G or Wi-Fi in port. The communication broker may also take responsibility for pre-processing of data, compression etc.

The broker functionality may also include resource management functions, such as reserving parts of the available broadband capacity for different applications. Critical applications related to safety could be given reserved slots of bandwidth, and the broker could use preemption logic to suppress or deny traffic from less critical applications (e.g. Facebook) in case the bandwidth is needed for urgent purposes.

Inmarsat



In this way, the communication broker will form an abstraction layer, leaving higher-level applications to remain agnostic about which underlying communication bearers to use. Furthermore, the user will have a seamless experience, allowing the focus to be on the application's intended purpose, without having to worry about switching systems, antenna pointing, and similar.

A communication broker solution from MCP, providing least-cost routing over multiple bearers ranging from Wi-Fi to VSAT, is shown in Figure 10 (left). The right part of Figure 10 shows how Inmarsat will integrate the existing FleetBroadband service on L-band to enhance and complement the GX Ka-band service in a hybrid configuration. Here, a shipboard network service device will monitor and route traffic between the Ka- and L-band services, and also provide functionality such as firewall, transmission control protocol (TCP)-acceleration, and VoIP (Voice over IP). [/49/,/80/]

These are two examples of communication brokers, and, given a future environment of multiple and diverse communication options, we can expect increasing use of similar solutions to improve cost-efficiency, ease-of-use and reliability of connectivity applications.

New antenna technologies
A major source of cost and complexity of maritime antenna platforms is the stabilization and steering mechanisms required to keep the antenna continuously pointed towards the satellite. Phased array antennae are composites (arrays) of antenna elements where the total gain and directivity can be changed by applying signals of different phases to the various elements. This concept allows electronic steering of the antenna lobe and removes the need for moving parts, making it very attractive for maritime use. One example is the new MTenna product developed by Kymeta Corporation, that uses new elctromagnetic metamaterials technology to steer beams from a thin and flat antenna the size of a large pizza box. [/45/]

Advances in antenna design techniques have enabled the creation of multi-band antennae, with the capability of operating on several different frequency bands. As an example, the new iPhone 6 models A1586 and A1524 support 20 LTE (4G) frequency bands ranging from 700 MHz to 2600 MHz, in addition to eight legacy 2G and 3G bands for backwards compatibility. [/46/]

New antenna concepts will not only result in user equipment being cheaper, neater and more capable, but we should also expect that new antenna technologies will be deployed in satellites and base stations in order to optimize coverage areas and focus the energy in small spots and cells. This will allow better spectrum reuse and result in increased traffic capacities and lower traffic costs.

Satellite imaging
Video surveillance is an ever-increasing and controversial application in large parts of society, and, with Google Earth and Street View, Google has demonstrated the information value of pictures. Satellites are already used for information gathering and intelligence, but companies like Satellogic intend to make imaging cheaper, more effective and accessible by using a network of small 50 kg nano-satellites. [/12/] Satellogic's vision is to image any spot on Earth every few minutes and to provide easy, low-cost access to the image data to enable a variety of monitoring applications.

Figure 11. mTenna – a phased array antenna based on metamaterials. Source: Kymeta Corp.

Another example is Skybox Imaging [/57/], which was bought by Google in August 2014. With small and low-cost satellites, Skybox provides high-resolution satellite images, and video and analytics services. The resolution of the company's images and videos is sufficiently high that objects that impact on the global economy, like terrain, cars, and shipping containers, can be observed. Skybox says that its satellites can capture video clips lasting up to 90 seconds at 30 frames per second. [/58/]

It is easy to envisage how systems like Satellogic and Skybox may be used for maritime applications such as vessel traffic monitoring, pirate tracking, or collision avoidance. For example, the existing AIS system relies solely on ship-initiated transmissions, but this could be enriched with, or replaced by, imaging data.

Another potential application is extraction of environmental information such as wind and waves from satellite images. There is ongoing research to retrieve Significant Wave Height (SWH) data from satellite-based altimeter measurements, and this may become a valuable complement or alternative to ship-based measurements. [/52/]

Figure 12. High resolution image of Liberty Island, New York. Source: Skybox Imaging, Inc.

SHIP CONNECTIVITY IN THE FUTURE

The ever-increasing communications capacity

An unseen, yet empirically unmistakable force, driving the cost and capacity of communications is the regular doubling in capacity of any information-related technology. This pattern was first identified by Gordon Moore, who, in 1965, formulated what is now known as Moore's law [/60/]; this law states that the density of transistors on a chip doubles roughly every 2 years. This has held true up until today, although it has been discussed when this would hit the limit and it is not physically possible to cram any more components into a given area. Such doubling patterns lead to an exponential development of any domain, technology, or industry that becomes information enabled. Communications is a technology that is highly information enabled, and there are several empirical 'laws' dictating the development in capacity:

- **Butters' Law of Photonics** says the amount of data coming out of a fibre doubles every nine months. [/60/]
- **Nielsen's Law of Internet Bandwidth** states that a high-end user's connection speed grows by 50 % per year. [/59/]
- **Cooper's Law of Spectral Efficiency** states that the maximum number of voice conversations or equivalent data transactions that can be conducted in all of the useful radio spectrum over a given area doubles every 30 months. [/62/]
- **Edholm's Law of Bandwidth** considers wireless, nomadic, and wireline internet connections and asserts that: "the three telecommunications categories march almost in lock step: their data rates increase on similar exponential curves, the slower rates trailing the faster ones by a predictable time lag." [/61/]

The growth rates of nomadic and wireless corresponds to annual growth rates of more than 60 %, and, extrapolating forwards, indicate a convergence of the rates of nomadic and wireless technologies in around 2030.

Martin Cooper, a mobile phone inventor and the man behind Cooper's Law, wrote the following in his position paper "The myth of spectrum scarcity" in 2010 [/64/]:

> *"When Guglielmo Marconi conducted the first radio transmissions in 1895, the energy from his spark-gap transmitter occupied the entire usable radio spectrum. In 1901, his first transatlantic transmission blanketed an area of more than 100 million square miles. Yet it sent only about one bit every six seconds–and the earth's surface could accommodate only few such transmissions at a time."*

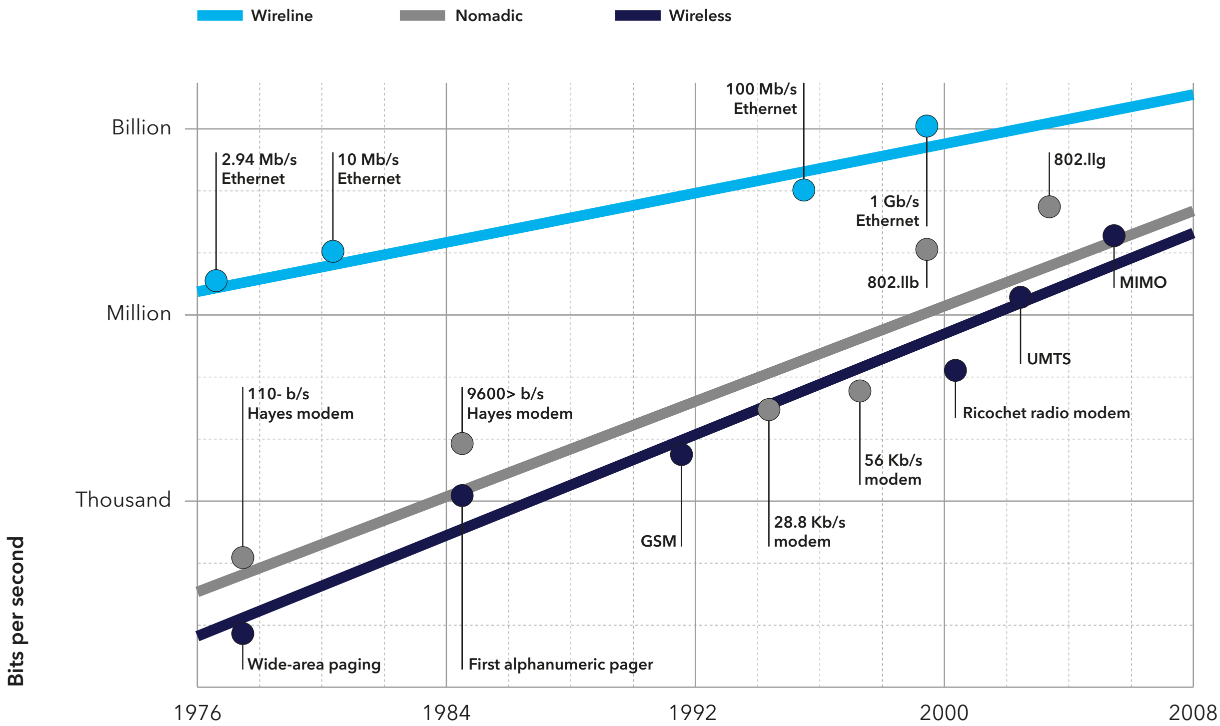


Figure 13. Edholm's law, the exponential development of three internet connection technologies marching in lock-step. Source: IEEE Spectrum [/63/]

> *"Since 1901, for instance, spectral efficiency in telephone communications has improved by a factor of about one trillion. Since 1948, it has improved a million times over. And when introduced in 1983, cellular communications immediately offered a ten-fold increase in spectrum capacity–by transmitting in 30 MHz of spectrum what would have taken 300 MHz to transmit with the previous generation of technology. Today's cellular systems are better than 100 times more efficient than the mobile telephones of the 1980s."*

Cooper's point is that history shows that mobile communications grow exponentially, and that this growth has always been accommodated by the introduction of smarter technologies that improve spectral efficiency and expand the practical useable frequency range. Examples of technological advances are smart antennae, smaller cells (allowing frequency re-use), more efficient modem and compression techniques, improved multiple access schemes etc. Cooper predicts that the usable spectrum will continue to scale to the demand due to continued technological innovations, and concludes that the spectrum should not be viewed as a scarce resource.

In the simplest terms, the above laws tell us that we should expect a continued exponential growth in the data transfer capacity available to ships and that current bandwidth limitations will disappear to allow the internet of things and broadband applications in terrestrial networks to expand into all sea-going activity.

The maritime VSAT boom

The exponential growth laws take a top-down approach and do not consider the physical limitations of any technology, and, although they deal with wireless shared-bandwidth systems, they do not consider maritime communications specifically. Therefore it is useful to take a bottom-up perspective by looking at numbers for maritime VSAT, the key communication bearer for ship connectivity.

In 2013, 95 % of the 350,000 active maritime satellite terminals were narrowband L-band terminals (Inmarsat and Iridium), used for safety and regulatory compliance. However, as the current growth is driven by broadband applications and increasing data usage, there is a strong increase in installations of maritime VSAT.

Figures from COMSYS show that the number of maritime VSAT installations in service increased from 6001 in 2008 to 21,922 in 2014, corresponding to an annual growth rate of 24 %. Forecasts for the next years indicate that the growth is set to continue, and that the number of maritime VSAT terminals will exceed 40,000 by 2018. [/66/]

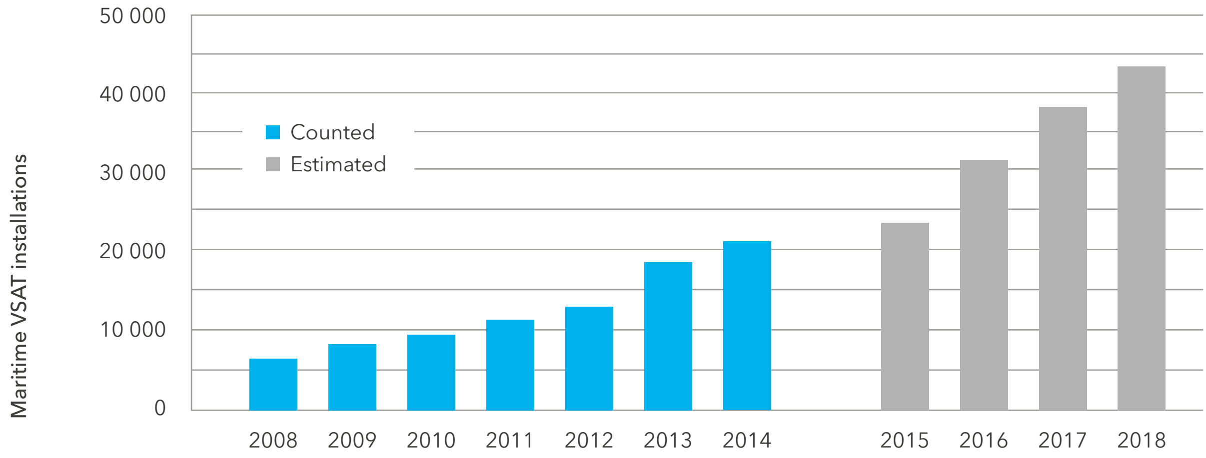


Figure 14. Maritime VSATs in service by year 2008-2018. Source: © COMSYS [/66/,/78/]

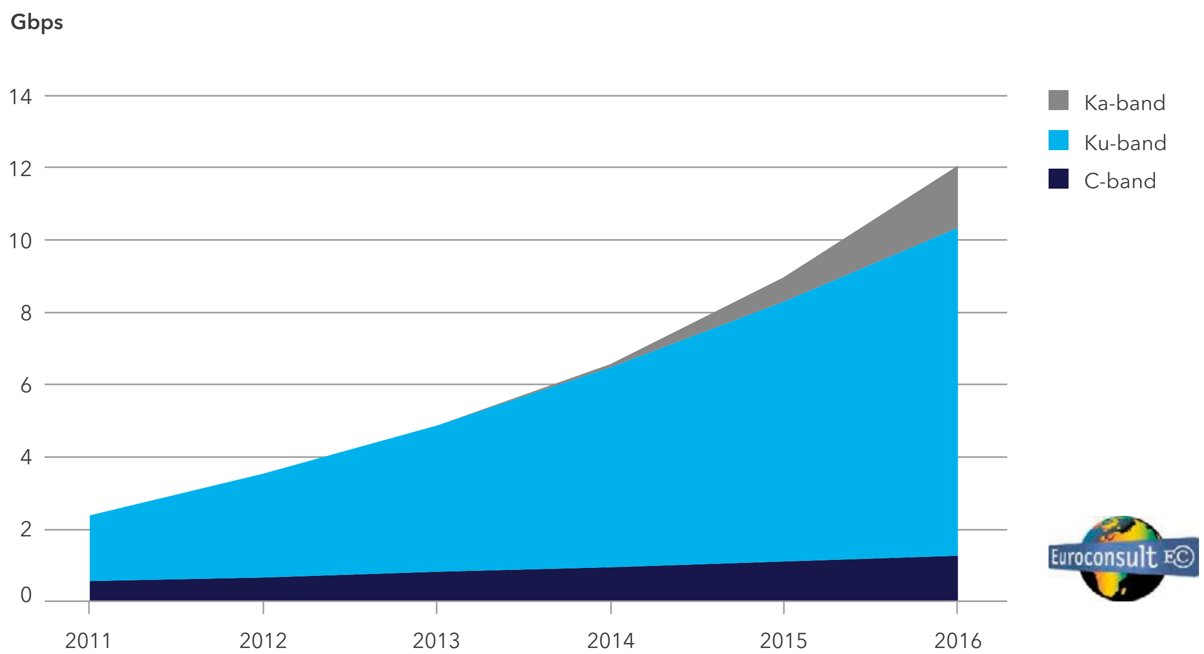


Figure 15. Maritime VSAT bandwidth utilization by frequency band. [/79/]

When it comes to capacity, Euroconsult expects that with the launch of currently announced HTS systems, the Ku/Ka-band HTS capacity available over ocean regions will increase from approximately 15GHz in 2013 to approximately 90GHz in 2016, a six-fold increase in raw capacity. Taking into account how the new capacity will be deployed and demand side effects, Euroconsult have calculated that the overall VSAT bandwidth utilization over maritime regions will increase from 2.4 Gbps in 2011 to 12 Gbps in 2016 [/65/, /79/]. An increase of a factor 5 in 5 years corresponds to a hefty annual growth rate of 38 %, which is in line with the exponential growth laws of Nielsen, Edholm, and Cooper.

In 2013, MSS operators (L-band) accounted for 67 % of maritime revenues at the satellite operator level, while FSS operators (VSAT) only had 33 %. Euroconsult predicts that the situation will be reversed by 2023 (70 % VSAT vs 30 % MSS), due to the emerging HTS systems and increased competition. [/7/]

The above figures demonstrate that the maritime sector is in the midst of a connectivity revolution, in which more and more vessels will become broadband capable and a massive increase in available capacity will lead to more competition and lower cost per transferred Megabyte.

New applications

The new communication capabilities and the increase in available bandwidth will be an enabler for the real-time transfer of significant amounts data from ship to shore and vice versa. In this section, the effects of improved coverage and data transfer rates on existing applications will be discussed, along with the introduction of new applications benefiting the maritime community.

Condition monitoring

Up until now, maritime maintenance practices have mainly been reactive and time-schedule based. A preventive maintenance scheme is based on the assumption that a component has a given lifetime, after which its failure rate increases. However, lifetime estimates are uncertain, and, in practice, failure rate patterns tend to be random rather age-related. This calls for a reliability-centred maintenance (RCM) framework, where the actual conditions of the components are monitored, and used as decision input for maintenance actions, thereby achieving more targeted and cost-efficient maintenance.

As discussed in /2/, condition monitoring has been widely and actively adopted in aviation in the last decades, and is a probably a key contributor to the improved safety over the last 20 years.

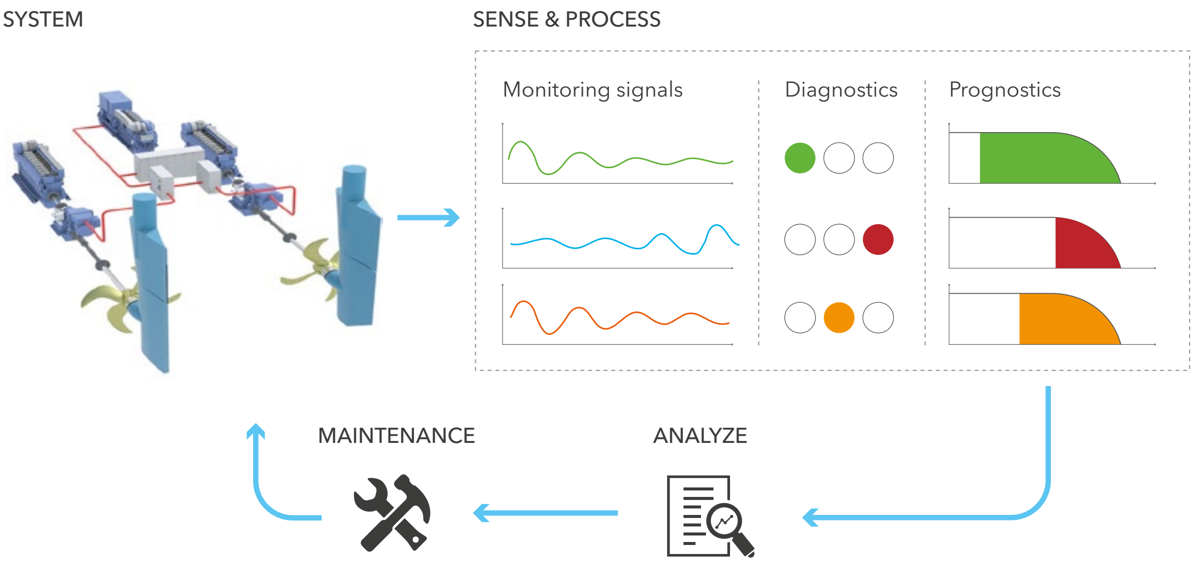


Figure 16. Condition monitoring process. [/2/]

A conditioning monitoring application is based on deploying sensors (temperature, vibration, pressure etc.) appropriate for detecting symptoms of the failure modes of selected components or systems. The sensor readings are collected and stored locally on board the ship, and then pre-processed before the data are sent to an onshore data centre for further analysis and long-term storage.

Some condition monitoring products have already been introduced in the maritime market, for example US-based ESRG with their OstiaEdge Monitoring suite. [/69/] Many of the vendors of machinery and automations systems in maritime are also establishing condition monitoring systems, e.g. Rolls Royce's Hemos [/70/], Wärtsila's Propulsion Condition Monitoring [/71/], and ABB's RDS system [/53/]. The vendors' motivation is not only to improve their maintenance proposition to shipowners, but also to learn more about their products' performance in an actual operational environment in order to improve future products.

The Japanese SSAP (Smart Ship Application Platform) project [/72/] and TNO's iShare@Sea [/73/] are research initiatives investigating data exchange, data models, and necessary standards for realizing condition monitoring in a maritime context.

Classification societies have also introduced class notations for condition monitoring to replace time-scheduled surveys. However, although condition-based monitoring has been proven to be more effective in other industries, implementation in the maritime industry has been slow. A major reason is that the communication link has been a bottleneck in terms of cost and bandwidth, because of the high data volumes resulting from aggregation of raw data from many sensors sampled at high frequency. Another challenge is the complexity of maintaining a well-functioning condition monitoring system. However, improved connectivity, providing increased bandwidth at reduced cost, will become an enabler for a bandwidth-hungry application like condition monitoring. Once the data have been transferred to shore, the complexity challenge can be overcome by facilitating shore support in terms of expertise, data feeds, analytics, and increased computational power, thereby accelerating the implementation of condition monitoring from ships.

Remote maintenance
Deployment of condition monitoring applications as decision support tools will enable smarter and more effective maintenance, but ship connectivity will also enable remote diagnostics and even remote maintenance of the different components and systems on board.

Carl Magne Rustand, product manager for Navigation products in Kongsberg Maritime Offshore says [/81/]:

> *"A significant part of the cost for a service trip is related to travel of service-personnel. KM has established local offices at strategic locations around the world to mitigate this, but still cost and time of service is a challenge to the industry. Remote diagnostics will significantly reduce the need for travel. Many services can be carried out remotely from Support Centers without physical presence on-board. Moreover, the efficiency of service trips can be improved by ensuring that the service engineer is prepared for the right task when he comes on-board. With improved connectivity and proper security measures, our vision is to avoid many service trips by diagnosing and fixing problems remotely and thereby reduce the service cost for our customers as well as warranty cost for the company."*

In addition to cost savings, remote maintenance will also reduce downtime and increase profitability for the ship operator. Service quality will also be improved, as problems will be diagnosed and resolved more quickly and effectively when the service personnel can log in and carry out the work from their home office.

Although some problems, e.g., broken hardware, may require manual actions on board, it is not difficult to envisage how, in the future, an expert service engineer will remotely guide a crew member to perform various manual tasks under close supervision in interactive video sessions using augmented reality technology. Google Glass [/67/] and DAQRI's smart helmet [/68/] are early examples of the types of products that the future may bring to support remote maintenance.

Risk-based classification and surveys
During a vessel's life cycle, classification societies and flag states perform surveys on board at regular intervals as a basis for renewal of certificates. The surveys conducted are typically based on fixed lists of items to be manually checked or visually inspected on board. Such surveys can be made smarter and more effective by using operational data from the vessel. Ship connectivity could be

Figure 17. DAQRI's smart helmet contains an integrated display, camera, and sensors.
Source: http://daqri.com/

used to transfer relevant operational data to shore (to the flag state or classification society) prior to the survey, allowing the surveyor to analyse the vessel's operational performance before going on board. This would enable a more risk-based survey to be conducted, where the attention could be focused on those items for which the recent operational data had indicated potential problems.

Such operational data could be the output of a condition monitoring system giving information about the health status of different components, but could also be the logs of operational data documenting how the vessel has been operated, e.g. alarm logs, load figures of different components etc.

In addition to the benefits from more purpose-fit, risk-based surveys, live reporting of operational data could also enable some verification items to be conducted entirely remotely, which, in turn, may decrease the scope of surveys or prolong the intervals between surveys, thereby increasing the availability of the ship.

Energy efficiency optimisation

A key concern of shipowners is keeping fuel costs down, as these are a major part of the operational cost picture. There are already a number of players offering solutions and advisory services to help shipowners save on fuel costs.

The class societies are also increasing their focus on energy efficiency:

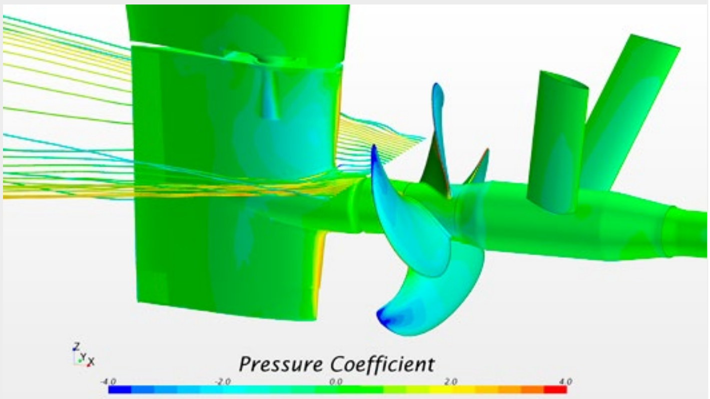
- Class NK and Napa's Green product portfolio includes fuel consumption optimization through speed profile, engine configuration, and route recommendations, as well as trim optimization system data from the onboard Loading Computer. [/32/]

- DNV GL recently launched its performance management portal, ECO Insight, providing dashboards for managing the performance of a fleet, including voyage, hull & propeller, engine & systems performance. [/33/]

Energy optimization services are also provided by engine manufacturers and system integrators, such as Rolls Royce and Wärtsila. In addition, many niche players are entering the market to provide different kinds of data analytics. One example is Marorka. Their onboard product is an energy monitoring system installed to log, track, and analyse more than 500 data sources, including fuel consumption, speed, weather, and draft. [/34/]

Rolls Royce's Promas Lite propeller/rudder system

The system integrates the propeller and the rudder into a single system. Behind a normal propeller hub there is a strong low pressure vortex (hub vortex) that acts on the propeller hub, increasing drag and reducing propeller thrust. A special hubcap fitted to the propeller streamlines the flow onto a bulb that is added to the rudder, effectively reducing flow separation immediately after the propeller. This results in an increase in propeller thrust, as previously wasted energy is recovered from the flow. According to Rolls Royce, fuel consumption reductions of 5-15 % are possible, depending on the vessel's operating profile.



Source: Rolls-Royce AB [/82/]

A commonality in all the applications above is that they rely on the regular transfer of status data from the vessel, thus relying on ship connectivity. Improvements in ship to shore connectivity will enable more advanced and accurate services related to energy efficiency optimization, based on higher data resolution with increased accuracy and more advanced analytics algorithms. Increased accuracy and resolution is required for determining whether operational or technical measures implemented for improving efficiency have been effective. For example, reliable verification of the effects of an energy saving device such as the Promas Lite system (see fact box) will require high resolution measurements, recorded at high sampling rates for all the relevant operational modes, thus driving data volumes and bandwidth requirements.

Environmental monitoring

The annual global emissions from shipping are 1 billion tonnes, accounting for 3 % of the world's total greenhouse gas emissions, and there is strong international pressure to reduce emissions of CO_2, NOx and SOx from maritime transportation. [/35/]

EU and IMO are currently working on establishing new regulations and guidelines for a Monitoring, Reporting and Verification (MRV) regime, and the European Commission has proposed that owners of all large ships (over 5 000 gross tons) using EU ports should report their verified emissions. IMO has also made a Ship Energy Efficiency Management Plan (SEEMP) that is mandatory for all ships, as well as guidelines for a standardized Energy Efficiency Operational Indicator (EEOI). [/36/,/37/] The US also has a strong focus on avoiding emissions, and additional domestic requirements are imposed for vessels entering US waters through legislation from US Coast Guard (USCG) and Environmental Protection Agency (EPA). [/6/]

The detailed reporting requirements are still under development, and the initial provisions are based on manual filling in of web-forms based on estimated consumption, and manual readings from gauges and logbooks. In order to increase data quality and reliability and to relieve the crew from unnecessary administrative burdens, we expect to see a push for mandatory automated measuring and reporting systems, using the vessel's communications system to transmit reliable emissions data to the relevant authorities in a timely manner. In order to ensure fair enforcement of legislation and to ensure that the correct decisions are reached in terms of implementation of effective measures and legislation for environmental purposes, the transparency of such data is also important.

Another potential environmental application would be using vessels as sailing weather stations. If an advanced weather station is fitted on a vessel, relevant data may be transmitted regularly to an onshore data centre, for further analysis or data sharing. If many vessels participate, a network with continuous feeds of weather data from many locations would be created. This could become a meteorological Big Data application in which the collated data could be used to calibrate weather models and improve weather forecasts.

Safety applications

The maritime community expends enormous effort in preserving safety in the design requirements for the vessels themselves (e.g. hull requirements) and their onboard systems required for various safety purposes (e.g. navigation systems or fire detection systems). These requirements are typically verified by flag states and classification societies during the new building process. Nevertheless, during operation the safety aspects are largely left to a vessel's captain and crew. However, systems can fail during operations and humans make errors. Given that human error is said to be the cause of up to 85 % of all maritime accidents, it is paradoxical that shipowners, classification societies, and authorities do not use operational data from vessels to monitor and improve safety.

Ship connectivity is an enabler for new safety applications based on operational data from vessels. Examples include:

- Live monitoring of safety systems: This could determine the integrity and status of various safety systems; perhaps some fire detectors are offline, some watertight doors are kept open too often, or maybe the Electronic Chart Display & Information System (ECDIS) uses an obsolete version of maps. Although bridge personnel already have access to these data, sending it to shore will enable the shore personnel to help the crew to discover problems early, and also provide an opportunity to analyse and learn from historical data.

- Emergency services: During emergencies and search & rescue operations considerable effort goes into communication in order to establish the status, so that the relevant shore parties can provide appropriate support and guidance. In such situations, the shore parties could benefit from additional data being transferred live from the vessel. For example, they could find it useful to know the status of the navigation system and safety systems (e.g. fire and flooding status), stability information from the vessel's loading computer, and possibly video streams from strategic positions on board the vessel.

- VDR-in-the-cloud; The VDR (Voyage Data Recorder) stores essential safety-related data in each vessel's black box, to be preserved for post-accident analysis. However, this data could be sent to shore on a regular basis, giving a network backup in the case the VDR is not found after an accident. Similar considerations are being made in the aviation sector.

We are already beginning to see new service offerings along these lines, especially in the cruise / passenger vessel segment, where safety is in focus. For example, NAPA's Emergency Computer offers live status information on watertight doors and flooding sensors as support for decision-making and recovery actions in different accident situations. [/38/]

e-Navigation and the Maritime Cloud

The concept of e-Navigation was initially introduced by IMO to increase safety and security in commercial shipping by improving data organization and also data exchange and communication between ship and shore. The scope of e-Navigation, as defined by the IMO and formulated by IALA, is *"the harmonized collection, integration, exchange, presentation and analysis of marine information on-board and ashore by electronic means to enhance berth to berth navigation and related services for safety and security at sea and for protection of the marine environment."* [/43/]

In the recently approved Strategy Implementation Plan (SIP), three of the five prioritized e-navigation solutions are directly related to communication:

- S2: means for standardized and automated reporting;

- S4: integration and presentation of available information in graphical displays received via communications equipment; and

- S9: improved communication of VTS Service Portfolio.

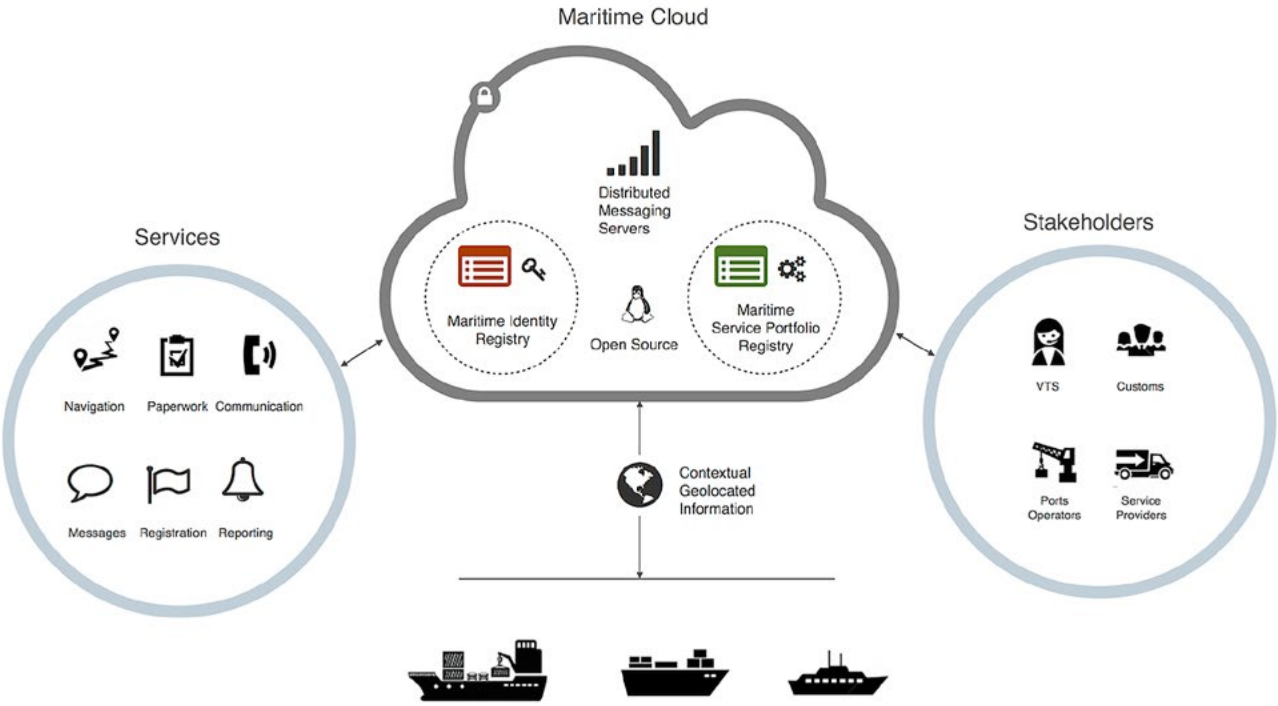


Figure 18. Maritime Cloud infrastructure. Source: DMA [/54/]

The SIP assumes that existing GMDSS systems, other commercially available systems e.g. VSAT, Iridium, and terrestrial alternatives, as well as future systems, e.g. VDES, could be used. [/44/]:

The Danish Maritime Authority (DMA) recently proposed the Maritime Cloud as a digital IT-framework of standards, infrastructure, and governance to facilitate secure interoperable information exchange between stakeholders in the maritime community. The Maritime Cloud consists of components such as the "Maritime Service Portfolio Registry" that holds information about service capabilities and associated providers and subscriptions, and the "Maritime Identity Registry" that holds *maritime identities* and provides basic methods for authentication, integrity, and confidentiality. A Maritime Messaging Service has also been defined to provide seamless and communication carrier agnostic messaging capability between ships, and between ships and shore. [/54/]

The Maritime Cloud has received considerable attention and support in e-Navigation forums, and may play an important role for future connectivity applications.

Another interesting e-Navigation initiative is CMDS (Common Maritime Data Structure) that is to be based on in the IHO S-100 format. S-100 is based on the ISO 19100 series of geographic information standards. While ISO 19100 is mainly intended for geospatial data, it is believed that S-100 will also be able to handle other types of data. [/47/]

Nevertheless, robust and reliable communication is essential for e-Navigation services, and thus these initiatives benefit from the current ship connectivity revolution.

Remote control and autonomy

Increased reliability and capacity of data transfer can enable applications related to flow of information, but may also have the potential for introducing capabilities for controlling ship functions from shore.

Remote control of vessel functions will have intensive requirements regarding the communication link to the vessel. Firstly, the connection needs broadband in order to be able to transfer sufficient amount of information to the onshore operator and back to the vessel. The bandwidth requirements for the forward link will be smaller as it will be mainly control commands

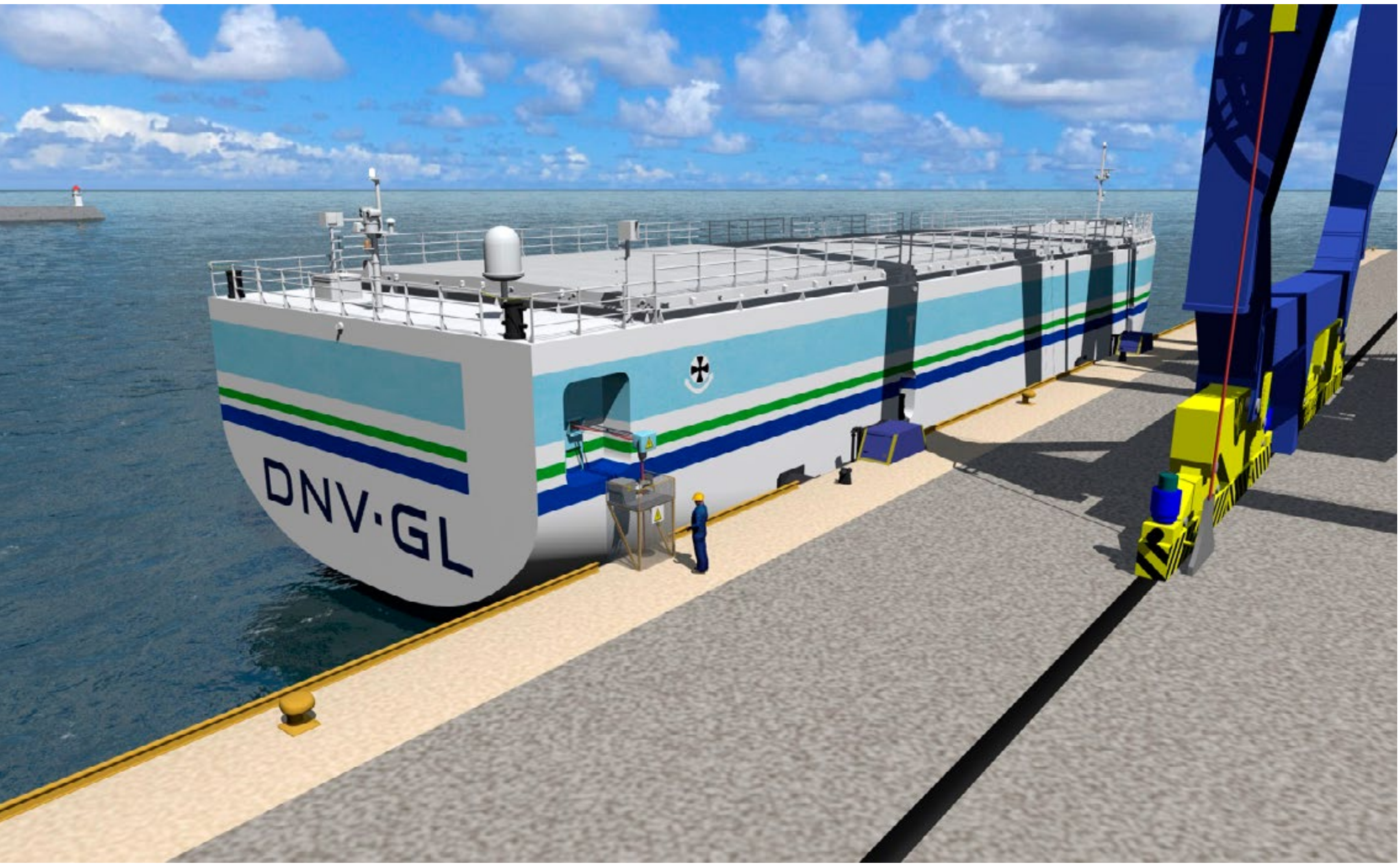


Figure 19. ReVolt – DNV GL's unmanned, battery-powered concept vessel.
Source: DNV GL © Toftenes Multivisjon AS

from pilot to vessel. Secondly, as loss of communication will result in loss of ability to control the vessel, the communication system must be highly reliable. Furthermore, the connection should have low latency to avoid an introduced lag impeding reaction times, which may be critical for adequate response times.

Autonomous onboard systems may, in principal, not need any control communication, but most concepts still include some level of monitoring and control, and typically the possibility for full manual override (i.e., remote control) from shore.

A key aspect of autonomy and remote control applications is reliance on a robust and dependable communication link. This could be solved by redundancy and diversity, e.g. by use of several independent communication systems in order to maximize the availability of communications. When communication is lost, a fail-safe logic could be applied, so that the autonomous system configures the vessel to the safest possible state until communication is restored.

The EC-funded project MUNIN (Maritime Unmanned Navigation through Intelligence in Networks) is a collaborative research project that aims at developing and verifying a concept for an autonomous ship, primarily guided by automated onboard decision systems, but controlled by a remote operator in a shoreside control station. [/39/] The consortium of eight partners, led by Fraunhofer CML, will consider operational, technical, and legal aspects in connection with the vision of an autonomous ship.

Other research initiatives include the Japan-based Eco Marine Power's Aquarius, a prototype of an unmanned surface vessel intended for lightweight tasks like surveys, surveillance, and data monitoring.[/40/].

DNV GLs "ReVolt" is an unmanned short sea shipping concept. This battery-powered concept vessel has increased loading capacity due to the removal of crew facilities and will use ECDIS, GPS, radar, Lidar, and cameras as sensor signals for its automated operation. [/41/]

Researchers at Munin-partner Marintek have estimated that a 3-4 Mbps broadband connection will ensure effective communication between the vessel and the control room, and believe that unmanned 200 m cargo vessels will be sailing the oceans within 10-20 years. [/42/] Even if unmanned ships in commercial use are still some years into the future, many projects testing out novel concepts for decision support, remote control, and autonomy should be expected in the coming years, and we anticipate a gradual adoption of autonomy as more and more functions become automated and/or shore-controlled, reducing the current necessary levels of crewing.

New challenges

Capacity limitations

Assuming that all the new systems and communication capacity become available, overall capacity and user data rates will keep rising, whilst costs continue to fall. However, maritime communication remains wireless and relies on sharing a limited physical resource; spectrum.

The exponential growth laws discussed earlier do not fulfil themselves, and, as Martin Cooper postulated, continued innovations and technological developments are necessary in order to grow the available bandwidth further. [/64/] Although smarter antennae, more powerful satellites, and novel modem techniques will gradually allow better utilization of the spectrum, the maritime offerings cannot be compared with terrestrial broadband, where fibre cables provide data rates in the Gbps range at low cost to enterprises and households. Also, considering the cost picture associated with launching and maintaining a satellite system or terrestrial system with maritime coverage, there are limits regarding how cheaply the operators are able to sell their airtime.

Thanks to the ship connectivity revolution and new HTS systems, the situation will be much better than in the past. However, at least in the short-term, we should expect communication to continue to be perceived as a bottleneck in terms of cost and capacity. The consequence is that maritime applications must be smart and bandwidth-efficient. Taking condition monitoring as an example, uploading data from all sensors on a continuous basis cannot be expected, as this will consume too much of a vessel's broadband capacity. Countermeasures may include compression, pre-processing, and smart transmission schedules, which could be provided by a communication broker as discussed earlier. For example, the application may send a short status messages on a live basis, and defer upload of the full set of raw data until triggered by a risk event or by availability of a cheap connection, e.g. Wi-Fi in port.

Availability and robustness

Ship connectivity will enable a range of new applications. As applications rely progressively on communication, it is clear that the criticality of communications equipment will increase. This elevated criticality will, in turn, call for tougher requirements regarding the availability and reliability of the communication systems used for the new applications. IMO has laid down stringent technical and performance requirements for the GMDSS safety communication bearers, but for so-called voluntary communication systems, such as VSAT, no requirements or type approval regimes exist, at least not in the statutory domain.

Until IMO, flag states, or classification societies decide to fill this "vacuum" by defining regulations and standards for new communication systems, shipowners, yards, and vendors are left to set their own requirements prior to purchase of communications systems.

Availability figures are typically high for satellite communication, for example Inmarsat has a stated target of 99.9 % for their legacy L-band network. The availability of satellite systems operating on Ku- and Ka-band will typically be lower due to rain fades. An availability figure of 99 % or 99.9 % will be acceptable for most applications, but for some applications, e.g. remote control or safety applications, loss of connectivity, even for short periods, will be critical. Availability may be increased by redundancy, e.g. parallel operation of two satellite terminals with similar capabilities; however, in order to avoid the satellite or the satellite gateway becoming single points of error this parallel operation should not go through the same satellite system. Backing up a satellite connection with a terrestrial connection, such as 3G or 4G, is another alternative providing diversity. Broker solutions handling different underlying communication bearers, as discussed earlier, may be used to realize the redundancy implementation.

Availability and reliability of communication will be even more important as new Arctic shipping routes are enabled due to melting of the Polar ice. With Geo-based L-band and VSATs struggling beyond 70-75° North, non-Geo systems will be needed to provide reliable connectivity along these routes. Iridium is an existing alternative, but in the future we may also see new systems using highly elliptical orbit (HEO) to provide satellite connectivity in Polar regions.

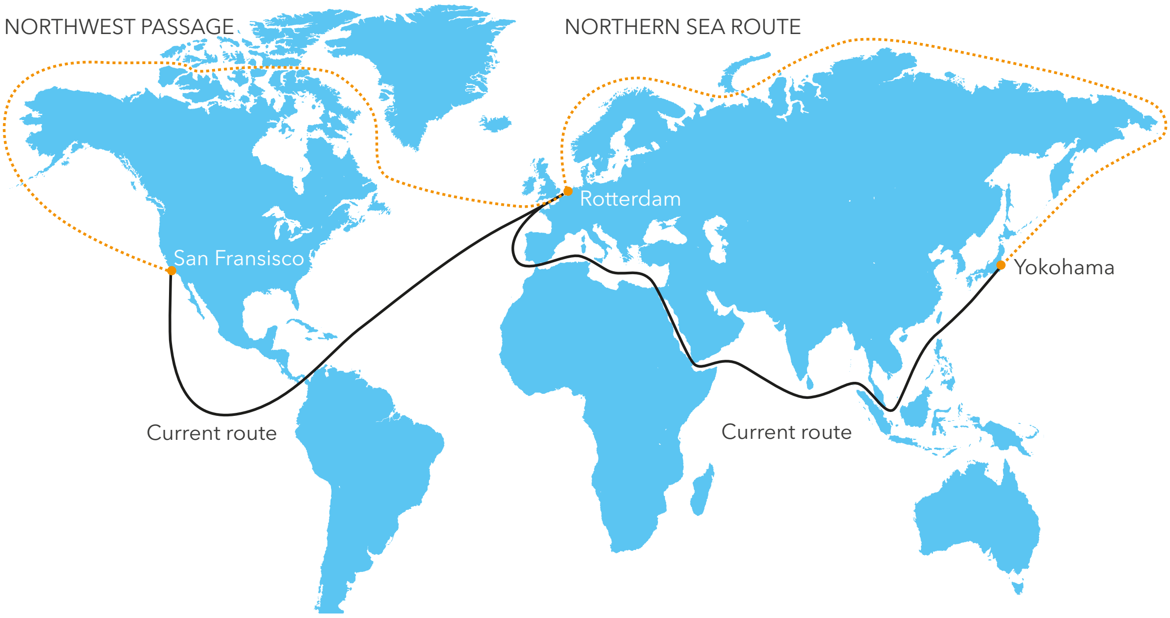


Figure 20. New shipping routes enabled by melting of the Polar ice.

The headaches of system integration
In the era of ship connectivity, systems on board a vessel will become increasingly integrated.

For navigational systems on the bridge, integration has already been going on for several years in order to allow more efficient implementation and to provide a more user-friendly environment for the navigator. The same trends are seen for control systems, automation systems, and safety systems, and the ship connectivity revolution will lead to communication systems becoming increasingly integrated with other systems on the bridge. For example, the ECDIS system depends on communication in order to obtain map downloads and updates on navigational hazards from shore.

System integration enables new service capabilities, but at the same time new challenges are created:

- **System interdependencies**; a failure in one system propagates to another, and one application in the network may affect other applications due to the use of shared resources.

- **Complexity in design**; due to the interdependencies, the requirements for an integrated system will typically include aspects such as redundancy, prioritization, resource allocation schemes, and handling of network and interface failures. This makes design and requirements definition more challenging.

- **Complexity in verification & testing**; when systems are integrated they cannot be tested in isolation, calling for more complex test infrastructure and methods.

- **Non-transparent black boxes**; given free hands, vendors combining many products into one integrated system may choose to implement proprietary protocols or hide the internal interfaces. This may prevent operators and testers having access to and interpreting essential operational data.

The challenges above all call for the definition of requirements and standard setting at the network level and the component level, as well as for the key interfaces.

A success story showing how this can be managed is the integration of navigation systems on the bridge. The maritime community has established effective IMO requirements and International Electrotechnical Commission (IEC) standards for INS (Integrated Navigation System), BAMS (Bridge Alarm System), and the interfaces between different systems (IEC 61162-family).

Big Data challenges
Ship connectivity is an enabler of the "Internet of Things" and "Big Data" for maritime, resulting in a number of "Big Data" related challenges [/1/];

- **"Data swamping":** A well-known Big Data problem is "swamping" with overwhelming amounts of raw data. 1000 sensors on board a vessel sampled at 1 Hz will produce 31,5 billion data points annually, and if each data point is 8 bytes and a fleet consists of 30 vessels, the shipowner will accumulate 7,6 TB of sensor data every year. In order to achieve efficient use of storage and communication capacity, smart pre-processing and compression schemes are needed.

- **ICT infrastructure design aspects:** Where to store the raw data – on the vessel or onshore? Different solutions may be needed for intermediate-term and long-term storage. Should there be multiple data collectors or one centralized data collection facility on the vessel? What is necessary regarding the design and functionality of an onshore data centre?

- **Data analytics:** Many of the new data-driven applications will require data analytics that are capable of converting large amounts of cryptic raw data into compact, actionable data that are suitable for automation or operational decision-making. In many cases the physical processes behind the data are not well-understood, so analytical methods are needed to derive patterns of behaviour and build a model from the data. Data mining and machine learning techniques may be used for this purpose.

- **Data quality:** Another challenge is ensuring the integrity and accuracy of the data. Several factors may contribute; sensor accuracy, compatibility of interfaces, the potential for communication outages causing loss of data and incomplete data sets, the requirement for the metadata necessary to interpret and process the raw data correctly, and the possibility of accidental data insertion, updating, or deletion by analysts or unauthorized individuals. Any new data-driven application must include protection against such data quality problems.

- **Access control and cybersecurity:** In an open and integrated data landscape, where data are expected to be easily accessible, it is important to ensure that only the intended users have access, and that the data are protected from eavesdropping and tampering. One particular fear is that critical vessel functions, such as engine controls or navigation systems, could become the targets for cyber-attacks from shore. According to research by the Greenwich Maritime Institute, cybersecurity concerns are a major reason for the slow uptake of Wi-Fi and WiMAX networks in ports [/25/]. Proper access control and security schemes must be in place for the Data Analysis Centres onshore, as well as the vessels themselves.

The above aspects need to be addressed by design requirements and operational measures, as well as by new standards.

Lack of standards
Regulators and standard setters have not yet made their entry to the game of "ship connectivity", and there is a currently a general lack of standards.

Rule setting and standardization may become effective countermeasures for many of the barriers identified above;

- New standards and regulations can define functional and performance requirements to ensure the availability and reliability of the new communication systems.

- System integration challenges can be tackled with well-defined network requirements and standardized interfaces.

- Big Data challenges, such as data quality and cybersecurity, can be effectively mitigated by documenting and spreading best practices as standards.

These are some specific areas where standards are currently missing:

- **Non-GMDSS communications standards:** Unlike GMDSS, where IMO and IEC have defined functional, performance, and test requirements, little or nothing exists for non-GMDSS systems to ensure that the communication component can support new applications, e.g. with respect to coverage, availability, and latency. It is also challenging to determine the right level of detail and approach to such standards. As new technologies and systems are introduced at an increasing pace, it is difficult for standard setters to keep up with making highly detailed and bearer-specific standards. A more flexible

approach in which over-arching standards are defined, focusing on high level performance and functional aspects, may be more future-proof.

- **Data-related standards:** Ship connectivity applications will benefit from:
  - Standardized data collection equipment to achieve a common infrastructure to be used for gathering different data from the various sources on board the ship.
  - Standards for data formats and interfaces to allow integration and interworking between systems from different vendors.
  - Standardized ontology and data models for maritime data (e.g., ship building and operational voyage data) to form a common language to support automated applications and data exchange between different parties.

Although standards for many aspects of the new ship connectivity applications are lacking, every module and function need not be subjected to standardization, as application designers and service operators need some freedom to differentiate their service offerings. Thus, this needs to be carefully balanced with the benefits associated with establishing common definitions and systematics.

E-Navigation is recognized as a promising arena for standard making, e.g. through initiatives like VDES, Maritime Cloud, and CMDS, but there presently remains a standard challenge which, if not dealt with, may result in fragmented and proprietary solutions, preventing economies of scale and inhibiting the uptake of ship connectivity applications.

Legal and commercial challenges
The new data-driven applications enabled by ship connectivity will create legal and commercial challenges:

- **Data ownership:** Who owns the data legally? As a starting point, shipowners will claim that they own any operational data that are produced by the systems that they have purchased and installed on board their vessels. However, shipowners may enter into agreements to share those data, e.g. to a vendor of machinery to provide better maintenance.

- **Responsibility:** Does access to data bring with it a responsibility regarding detection of problems? Who is liable if errors that are evident in the data are not detected? Leaving the legal aspects aside, there is also a cultural aspect; anyone providing data for analysis may feel less responsible and become more passive than if a monitoring arrangement was not in place. In order to avoid role confusion and misunderstandings, any data-sharing arrangement should contain clear definitions on roles, rights, and obligations in the use of the shared data.

- **Competence:** The era of ship connectivity and Big Data will require new data-related skills and competencies such as general IT expertise, data modelling, data analytics, data security, and data quality and communications technology. The traditional maritime disciplines and domain knowledge will still be needed, but the domain experts must also bear in mind how to utilize connectivity and data when defining new requirements or systems. For example, a machinery designer should consider sensor placement and sensor data flow as part of the design work, and a class surveyor should consider which operational data streams and analysis tools are appropriate to verify compliance with applicable rules. The key will be combining new data skills with legacy maritime domain expertise.

- **New business roles and models:** The novel data-driven applications will shape a new business landscape, with opportunities for fresh players as well as the incumbents. New companies specializing in data analytics or hosting Big Data reported from the ship or other sources should be expected to emerge. For example ESRG [/69/] specializes in data analytics and remote condition monitoring for maritime. Business models and roles will probably settle with time, but in the transition phase we may see a dynamic situation in which some emerging players will grow quickly and the incumbents who are unwilling to change will suffer

OPPORTUNITIES AHEAD

The era of ship connectivity will provide a range of new opportunities for all players in the maritime community;

- **Shipowners and operators:** to improve cost-efficiency and reduce downtime due to smarter vessels equipped with advanced ICT and sensor systems. Gain more insight and learn from how the onboard systems are performing, and how they are operated by the crew. Use operational data to undertake analyses and comparisons between vessels in order to deploy best practices across the fleet. Attract the best crew by offering Internet connectivity. Provide better support from shore offices to the vessel and crew. Deploy monitoring and automation to save crew costs and to provide a safer, more interesting workplace for the remaining crew.

- **Crew:** to enjoy improved welfare and a more interesting workplace. Internet access improves keeping in touch with those at home, reducing the barrier for long voyages. New safety applications and better onshore support make the vessel a safer workplace.

- **Yards and ship equipment vendors:** to design and sell smarter and more advanced vessels to owners, and offer better and more cost-efficient maintenance and value-adding services to owners. Gain more insights and learn more about the operational performance of own vessels (or systems) in order to improve design or manufacturing.

- **Marine authorities and regulators:** to update and modernize regulations and standards to gain better control and improve maritime safety and environmental performance. Deploy reliable and automatic reporting applications instead of manual, hand-written reports. Achieve more efficient and reliable operational communication with vessels.

- **Classification societies:** to upgrade rules, standards, and classification services to benefit from connectivity and operational data available, with the view to improving safety in ship design and operations. Should look for new ways to apply their maritime domain knowledge and risk management expertise.

- **Charterers and cargo owners:** to get better and more dynamic insights into the whereabouts and condition of their cargo. This transparency may help improve cargo conditions and assist in optimizing cargo logistics; it may also be used to verify compliance with charterer contracts.

- **Insurers:** to get better insights into the technical condition of vessels and how they are being operated, which, in turn, may be used to differentiate insurance pricing and incentivize safe sailing.

- **Communications operators and vendors:** to capture the potential of an increasing maritime market segment for communication.

- **Academia:** to develop and apply new methodologies to support maritime applications, e.g. data mining solutions and analytics methods. This opportunity is especially relevant for ICT disciplines, but other fields of research will also be relevant depending on the nature of the data made available from the ships.

- **New players:** to grasp the opportunity to perform onshore analytics, hosting of operational vessel data, and any new roles enabled by ship connectivity.

CONCLUSIONS

In this paper we have discussed ship connectivity, its drivers, benefits, and challenges.

Historically, safety has been the main driver for maritime communication with focus on voice and distress signalling, supported by narrow-band communication methods. The current drivers are more diverse. Shipowners today invest in advanced broadband satellite communications in order to offer welfare and entertainment to the crew and to gain commercial benefits, with operational applications requiring communications with shore.

Over the last decade, we have seen a remarkable growth in broadband satellite installations on board larger vessels, and several upcoming new HTS initiatives will fuel this growth by providing a massive increase in bandwidth available for maritime users. Within the next few years, a highly competitive marketplace will emerge, with a variety of products, different offerings, and lower prices.

This revolution in ship connectivity will reduce existing barriers and enable the implementation of many new applications for maritime users. These new applications will include condition monitoring, energy efficiency, and autonomy, making shipping smarter and more cost-efficient. Yards, maritime equipment vendors, classification societies, and new players will identify opportunities for improving maintenance schemes and developing new services based on operational data that will be transferred to shore on a live basis. As more and more vessels become "connected" via broadband, concepts such as "Big Data" and the "Internet of Things" will soon become a reality in the maritime business.

Ship connectivity also provides a unique opportunity for maritime authorities to upgrade existing regulations to improve safety and achieve environmental targets.

Although the future growth of maritime communications looks certain, these new initiatives and technologies may also cause problems and disruptions. Potential game changers may include satellite imaging, new antenna technologies, innovative applications of terrestrial technology such as Wi-Fi or 4G, or maybe a new speculative satellite initiative will succeed by doing things differently.

In order to realize the potential benefits to be obtained from ship connectivity some important challenges must be tackled. Regulators and standard setters should define requirements and standards to ensure that availability and reliability are sufficient, and define service architectures and interfaces to allow quality verifications and to stimulate a competitive vendor market.

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