Man Overboard detecting systems based on wireless technology

An evaluation of wireless tracking systems in Man Overboard situations for the cruising industry

Bachelor thesis in Nautical Science

EMIL ÖRTLUND
MALIN LARSSON

Department of Mechanics and Maritime Sciences
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2018

BACHELOR THESIS 2018:18

Man Overboard detecting systems based on wireless technology

An evaluation of wireless tracking systems in Man Overboard situations for the cruising industry

EMIL ÖRTLUND
MALIN LARSSON

Department of Mechanics and Maritime Sciences
Division of Maritime Studies
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2018

Man Overboard detecting systems based on wireless technology
An evaluation of wireless tracking systems in Man Overboard situations for the cruising industry
EMIL ÖRTLUND
MALIN LARSSON

Bachelor Thesis 2018:18

Department of Mechanics and Maritime Sciences
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone: + 46 (0)31-772 1000

Cover:
Man over Board / after E.Thiel. [Fine Art]. Retrieved from Encyclopædia Britannica ImageQuest. http://quest.eb.com/search/109_124998/1/109_124998/cite Reprinted with permission.

Printing /Department of Mechanics and Maritime Sciences
Gothenburg,

Abstract

The cruise industry is an industry on the rise, and the large amounts of passengers inevitably lead to an alarming number of man overboard situations. Most of the passengers and crew who have fallen overboard are never to be found again, a problem not only of the humanitarian sort but also something that brings negative publicity to the cruise industry.

This report investigates the possibility for more rapid notification of the crew if a person has fallen overboard, and increase the possibility of locating said person, using wireless radio transmitters. The decision of what wireless technology to use is based on a literature study and the chosen technology was then field tested in a maritime environment. The results were analysed and the possibility of using said technology in an automated man overboard system was further evaluated.

The technology selected after the initial literature study was LoRa, an LPWAN-technology. Two simple LoRa-transceivers were obtained and the performance were tested on board a passenger ferry. The attenuation caused by submersion in water were examined as well.

Based on the results of the literature study as well as the field tests a conclusion could be made that using wireless technology to detect and track a man overboard, on a large cruise ship, is difficult. This is mostly an effect of the physical limitations radio wave transmissions have in combination with water.

Keywords: Man Overboard, Tracking, LPWAN, LoRa, Wireless

Sammanfattning

Kryssningsindustrin är en industri på uppgång, och det stora passagerarantalet leder oundvikligen till en alarmerande mängd man-överbord-situationer. De flesta passagerare och besättningsmedlemmar som fallit överbord återfinns aldrig, ett problem som inte bara är en humanitär tragedi utan även något som ger kryssningsindustrin negativ publicitet.

Denna rapport undersöker möjligheten att med hjälp av trådlösa radiosändare snabbare uppmärksamma besättningen på att en person fallit överbord, samt förbättra möjligheten att finna denna person,. Valet av trådlös teknik har gjorts genom en utvärdering i form av en litteraturstudie och denna teknik har sedan undersökts i en fältstudie i en maritim miljö. Resultatet analyserades och möjligheten att använda tekniken i ett automatiserat man-överbord-detektionssystem utvärderades ytterligare.

Tekniken som valdes baserat på litteraturstudien var LoRa, ett LPWAN-system. Två LoRa-transceivrar införskaffades och deras prestanda testades ombord en passagerarfärja. Signalens attenuering, eller dämpning, vid nedsänkning i vatten testades också.

Baserat på både litteraturstudien och den utförda fältstudien drogs slutsatsen att trådlös detektion och spårning av man-överbord-situationer ombord på större kryssningsfartyg är svårt. Detta till stor del orsakat av de fysiska begränsningarna radiovågor har när de kommer i kontakt med vatten.

Nyckelord: Man Överbord, Spårning, LPWAN, LoRa, Trådlöst

Acknowledgements

The authors would like to thank supervisor Henrik Pahlm and examiner Monica Lundh, both at the Department of Mechanics and Maritime Sciences at Chalmers University of Technology

Table of contents

List of figures

List of tables

Glossary

AIS –	Automatic Identification System
ATD –	Active Tracking Device
BLE –	Bluetooth Low Energy
CCTV –	Closed Circuit Television
CLIA –	Cruise Lines International Association
CPU –	Central Processing Unit
CVSSA –	Cruise Vessel Security and Safety Act of 2010 (U.S.)
DSC –	Digital Selective Calling
GNSS –	Global Navigation Satellite System
GPS –	Global Positioning System
IoT –	Internet of Things
LoRa –	Long Range
LPWAN –	Low Powered Wide Area Network
MOB –	Man OverBoard
POB –	Persons On Board
RF –	Radio Frequency
RFID –	Radio Frequency Identification
RSSI –	Received Signal Strength Indication
Rx –	Receive, receiver or reception
SAR –	Search And Rescue
SF –	Spreading Factor
SNR –	Signal to Noise Ratio
SOLAS –	The International Convention for the Safety of Life at Sea
TDOA –	Time Difference of Arrival
Tx –	Transmission
UNB –	Ultra Narrow Band
VHF –	Very High Frequency

1 Introduction

The cruise industry makes up a large part of the maritime sector. In 2016 alone the industry had over a million employees directly involved in the ships and the supporting land organisation and transported almost 25 million passengers (CLIA, 2017). Over the last century vessels have increased in size from having the capacity to carry a few hundred passengers to the megaships of today, the largest vessel is presently capable of carrying 6780 passengers along with 2300 crew (Royal Caribbean, 2016).

The global interest for leisure cruises is large, the number of passengers rose by 63.7%, from 15.11 million to 24.73 million, between 2006-2016 (BREA, 2017) and it is still rising, according to the Cruise Lines International Association, CLIA. Even though the personal risk for each individual passenger is low, due to these large numbers, deaths and illnesses among passengers and crew are to be expected during a voyage, and precautions are taken to ensure safe and pleasant journeys for all onboard. Whenever an incident happens onboard the crew is trained to handle it, be it a fire, medical emergency or drunk and rowdy passengers. The vessel itself is equipped to facilitate these actions, with different safety and security systems, such as firefighting equipment, an onboard hospital cabin, and one or more “drunk tanks” or jail cells. It is also equipped with one or more Fast Rescue Boats (FRB), also called Man Overboard Boats (MOB boat), in order to be able to retrieve people from the water.

These MOB boats, however, are useless if the crew are unaware of individuals falling overboard. Few technological systems are presently available and in use that are both capable of detecting a falling person and alarming the crew about it, and even fewer can actively assist in the Search and Rescue operation by localizing the missing person. The few systems that are on the market are generally not adapted for large cruise liners but for vessels with up to approximately 15 persons on board (POB).

However, advancements in the wireless technology sector might prove beneficial. Today wireless technology can be found almost everywhere, from autonomous cars to small handheld devices such as cell phones. A normal smartphone today contains at least five different wireless technologies; Wi-Fi, Bluetooth, GSM (Global System for Mobile Communications), GPS (Global Positioning System) and often NFC (Near Field Communication). A sixth slightly different but neighbouring wireless technology commonly seen is wireless charging. The wireless devices are smaller, smarter and more power efficient than ever before, something that might be used to prevent an unnoticed Man Overboard (MOB) situation.

1.1 Purpose

The aim of this report is to investigate the possibility to develop a compact and inexpensive tracking system based on wireless communication networks on board larger cruise vessels. The system is intended to detect a possible Man Overboard (MOB) situation and help locating and tracking the missing person in the ensuing Search and Rescue (SAR) operation. The report will evaluate the technical challenges related to different systems, such as whether they work as intended on board the vessel and underwater. Trials of a selected wireless technology in different maritime environments are to be performed to further evaluate its performance and limits.

1.2 Questions

How could a functioning wireless technology-based tracking system be designed and developed that is capable of working in a larger passenger ship environment?

- Which wireless technology is best suited for Man Overboard tracking and why?
- What are the most prominent challenges?

1.3 Limitations

This report is directed towards the passenger ship industry with special regards to the global leisure cruise industry. The report focuses on the possible wireless communication systems and how it can be used in personal devices on board. The estimation and evaluation of the installation costs of said system has not been prioritized and little effort has been put into investigating the mechanical design of the personal tracking device or the ergonomic aspects.

2 Background

The cruise industry is an industry on the rise. The total number of passengers has increased from 17.8 million to 25.8 annually between 2009 and 2017 and is estimated to increase to approximately 27.2 million in 2018 (CLIA, 2017). During the same period there has been 194 cases of suspected or confirmed man overboard situations, causing 154 deaths (as of 2017-12-01, Klein, 2017). The vast majority of these are accidents or cases where the true cause of the fall is unknown (87.1%), some are suspected or confirmed suicides and attempted suicides (10.8%) and a small number are investigated as homicide or attempted homicide cases (2.1%).

While the likelihood of going missing on a leisure cruise is low, at around 20-25 persons per year or 0.00007%, many such cases are highly publicised in the media (Jainchill, 2010). Despite the fact that the numbers are low, the significant negative publicity from the media after any incident onboard puts pressure on the cruise industry to develop systems capable of quickly identifying and managing a Man Overboard (MOB) situation. Most present-day solutions are adapted for smaller vessels, such as hobby boats and fishing vessels, and are often too expensive and bulky to distribute among passengers and crew on a cruise ship where the number of people on board can exceed several thousand. Today the industry generally employs camera surveillance systems, sometimes with the capability of identifying larger objects falling from the ship. Regular CCTV systems cannot today automatically identify a possible MOB situation but needs to be reviewed by crew after being notified about a missing person to confirm whether the person is overboard and when and where it happened. More advanced infrared camera-based systems, such as the PureTech Systems' "System and method for man overboard incident detection" (see 2.2.2) are capable of identifying a falling human and alert the crew much faster than if a crew member has to be alerted by witnesses or passengers missing their travel companion and personally verify it.

2.1 Existing legislation regarding Man Overboard detection

Due to the international nature of most leisure cruises the vessel may be subjected to safety and security regulations from several different nations. This complicates crime investigations as investigators could be sent from the flag state, the nation claiming the territory within which the crime has occurred, the nation(s) of origin of the victim and/or the suspected perpetrator, etc. (Lewins & Gaskell, 2013).

Due to the lack of suitable technology and solutions most nations have no regulations regarding the detection of individuals falling into the water, the exception being the United States of America[1] (Selmy, 2017). In 2010 the United States Congress enacted the *Cruise Vessel Security and Safety Act of 2010* (CVSSA, 46 U.S.C. 3507) to regulate crime prevention, detection and investigation at sea. The act sets requirements regarding vessel design, equipment and construction such as minimum rail height, peep holes in passenger stateroom and crew cabin doors and the integration of "technology that can be used for capturing images of passengers or detecting passengers who have fallen overboard, to the extent that such technology is available" (CVSSA, 46 U.S.C. 3507(a)(1)(D)).

However, due to the formulation "to the extent that such technology is available" the industry does not have to implement these technologies until they are considered reliable under maritime conditions. As there presently are no solutions available on the market yet that are classed as such most cruise lines have equipped their vessels with camera-based systems as described below in 2.2.1 (USCG, 2015)

The bill applies to ships in the following circumstances (CVSSA, 46 U.S.C. 3507(g)(3)(B)):

I. "the vessel, regardless of registry, is owned, in whole or in part, by a United States person, regardless of the nationality of the victim or perpetrator, and the incident occurs when the vessel is within the admiralty and maritime jurisdiction of the United States and outside the jurisdiction of any State;
II. the incident concerns an offense by or against a United States national committed outside the jurisdiction of any nation;
III. the incident occurs in the Territorial Sea of the United States, regardless of the nationality of the vessel, the victim, or the perpetrator; or
IV. the incident concerns a victim or perpetrator who is a United States national on a vessel during a voyage that departed from or will arrive at a United States port."

This means there is no law specifically mentioning man overboard detection for vessels not owned in some part by a United States citizen or operating in the United States' territorial sea. The International Convention for the Safety of Life at Sea (SOLAS 1974) chapter III regarding life-saving appliances and arrangements contains the requirements for equipping and maintaining the ship in preparation for a possible emergency evacuation or retrieval of individuals in the water but fails to mention anything about how or how quickly a vessel should be able to react in case of a MOB situation.

[1] The article mentions "there are some local rules for cruise ships and fishing boats, such as U.S. and French rules for MOB detection" but the authors have been unable to ascertain whether the French rules applies to the cruise industry as no further references to such a rule has been found in a cruise context.

2.2 Existing Man Overboard systems

This section summarises a number of MOB detecting and tracking systems currently on the market. Many of these are developed for smaller leisure crafts and commercial vessels with few crew members and an elevated risk of a MOB case, such as fishing vessels, and are therefore not suitable on larger passenger ships due to cost, technical issues or impractical size.

2.2.1 Closed Circuit Television

The simplest camera based system, and the one commonly found on all cruise vessels, regardless of other systems, is the regular Closed Circuit Television surveillance system, CCTV. The CCTV technology is readily available and can be purchased off the shelf, however it lacks any automated detection or alerting capabilities but can be found throughout the vessel to deter possible criminals and criminal actions. The recorded video can be used as evidence of criminal activity but to identify an incident a crew member must go through the recording in order to find the event in question. This makes for a poor MOB system as crew first must be alerted to a missing person before they can conduct a search of the vessel and review the footage (PureTech Systems, 2017).

2.2.2 PureTech Camera based Man Overboard detection

One of the most advanced Man Overboard detection system today is the camera based system developed by PureTech (Maali, Barnes, 2017), a U.S. based company founded in 2005 that focuses on computer vision software to develop intelligent camera surveillance systems.

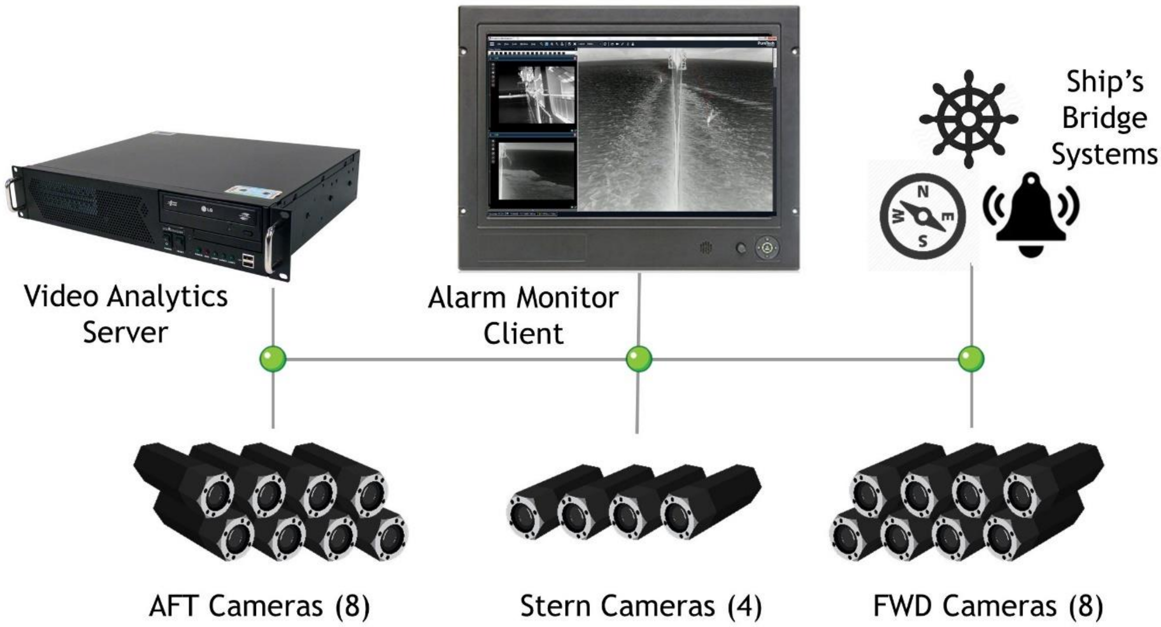


Figure 1. System Diagram - Superliner Class Ships (PureTech, 2018) Reprinted with permission

The PureTech system uses a series of infrared cameras capable of detecting heat sources. These cameras are installed along the sides of the ship as well in the stern. They are positioned below the passenger decks and are therefore capable of detecting objects falling from the decks above.

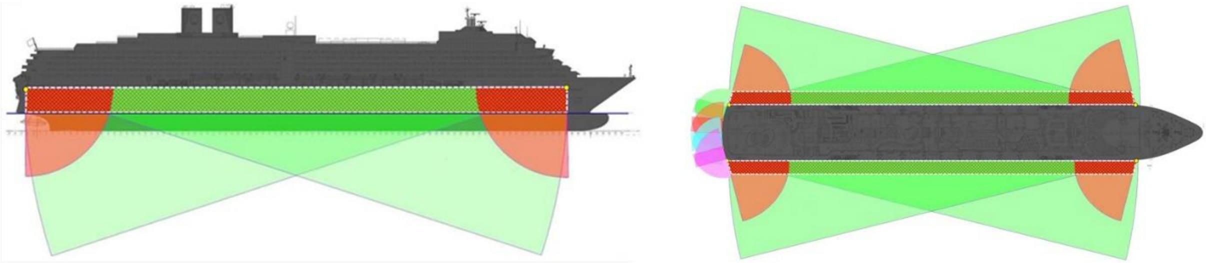


Figure 2. Camera Layout for Superliner Class Ships (PureTech, 2018) Reprinted with permission

Video capture combined with advanced data processing and geospatial video analysis it is possible for the system to both differentiate between falling debris and a person falling overboard and calculate the exact deck and area the person has fallen from. A downside of this system is that even though it can detect a MOB situation and can log the position of the vessel as someone falls and quickly alert the crew, it is incapable of positioning the victim once they are in the water as there is no tracker attached to the victim or other victim positioning means. The system does however log the ship's position at the time of the incident (PureTech Systems, 2017).

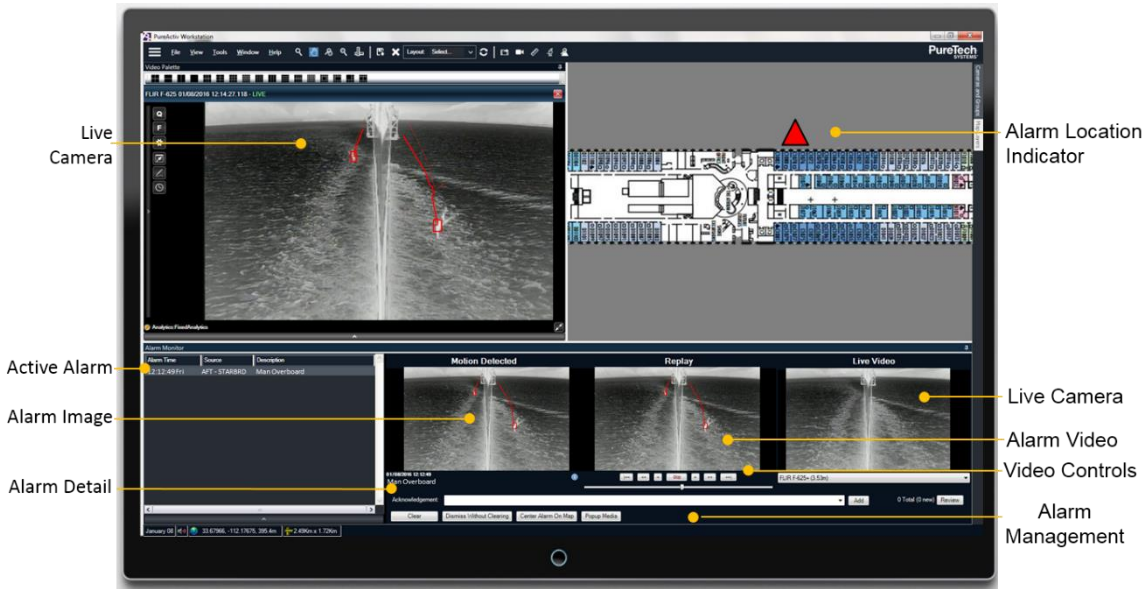


Figure 3. Man Overboard Detection User Interface (PureTech, 2018) Reprinted with permission.

2.2.3 Raymarine LifeTag

The Raymarine LifeTag is a system developed mainly for smaller leisure crafts and can manage up to 16 LifeTag tracking units per base station (Raymarine, 2018). The MOB alarm is activated by loss of contact for >10 seconds between the base station and the personal LifeTag module, caused either by water immersion or the device being out of range, or by manual activation from the victim or a witness by pressing on their LifeTag pendant for 5 seconds.

While the unit is reasonably compact compared to other similar devices with a size of 49 x 56.8 x 24.4 mm and an integrated antenna it is still too bulky for use on a cruise vessel. Due to its size and combined with the short range of 9 m and the lack of ability to track a person in the water once they drift outside of its range it is unsuitable for large vessels with many persons on board (POB). The cost aspects of the system makes it hard to implement on a cruise ship, one base station along with two LifeTag pendants cost £395 (ex VAT) and additional LifeTag pendants can be bought separately (Safety-Marine, 2018).

Figure 4. Raymarine LifeTag (Raymarine, 2018) Reprinted with permission.

2.2.4 Sea Marshall AU9

Marine Rescue technologies have developed a MOB system based on 121.5 MHz radio transmitters. This system has no maximum amount of transmitters per receiver and has a tracking range up to 12 kilometres between the victim and the ship. The distress transmission is initiated after immersion in water lasting 2-5 seconds which may be unsuitable on cruise ships equipped with pool facilities.

Due to it using an analogue radio transmitter transmitting on a relative low frequency it requires a relatively long antenna (1 m), which combined with a size of 76 x 78 x 35 mm (excluding antenna and strobe light) makes it too big and cumbersome to be comfortably worn by cruise passengers. The price per transmitter unit is approximately €300 which is a contributing factor to why it is unsuitable on larger passenger ships (MRT, Sea Marshall, 2016).

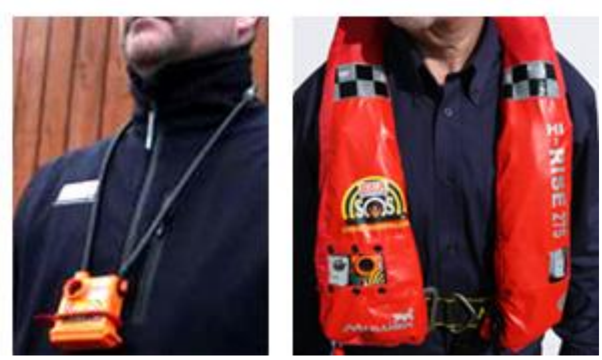


Figure 5. Sea Marshall AU9 (Sea Marshall, 2018) Reprinted with permission.

2.2.5 sMRT V100

Marine Rescue Technologies have also developed a VHF/DSC based personal MOB alarm combined with an AIS transmitter. This uses the already installed VHF and AIS that is mandatory on all SOLAS approved vessels, which cuts the installation process. The emergency transmission can be activated in three ways, which are; immersion in water, inflation of the life vest to which the beacon is attached, or through manual activation.

As cruise vessels as a rule do not carry inflatable life vests for emergency use, the device may be immersed in water as part of the recreational activities the ship has to offer, and since manual activation is unlikely to be considered by a person who has recently fallen from the ship, this device is unlikely to perform efficiently on a large cruise vessel.

Add to that the cost of around £300 (ex. VAT) for every transmitter, it is unlikely to ever be implemented on a large passenger ship. The size of 51 x 137 x 26 mm and weight of 168g also makes it impractical aboard said ships (MRT, sMRT, 2016).

Figure 6. sMRT v100 (MRT, 2018) Reprinted with permission

2.3 Limitations of wireless MOB-systems

Over the last decade numerous solutions using wireless communication to detect a possible MOB-situation have been developed. To detect a MOB-situation using wireless technology there are two main ways to do it; active systems and reactive systems (Schmidt, 2015). A common limitation for wireless MOB-systems is the attenuation of radio signals in water caused by the waters conductivity. Salt water in particular has a high conductivity caused by the salinity and is typically a bad medium for radio waves propagation. The radio waves frequency is also a factor affecting the attenuation where high frequencies causes the radio waves to fade sooner (Qureshi et al, 2016).

2.3.1 Active MOB-systems

An active system builds on the concept of tracking all passengers with the help of radio frequency (RF) transmitters at all times. The personal RF-transmitters continuously sends out a unique code which an on-board network detects. When the signal is lost it is assumed the corresponding transmitter is no longer in range of the network and therefore not on board the ship (Schmidt, 2015). An example of this technology is the Raymarine LifeTag (see 2.2.3). A limitation of an active system is, since it builds on the loss of signal from a transmitter, tracking of a person who have fallen overboard is not possible beyond logging the vessel's position at the loss of signal.

To be able to deploy an active MOB-system on board a large cruise ship the transmitters would need to be small and very power efficient in order to be worn by passengers. Good coverage would also be a preferable attribute since it would decrease the number of receivers needed on board. The receivers must be capable of detecting thousands of transmitters simultaneously. The power management of the personal devices will be a challenge since it is not likely possible to rely on the passengers to manage charging or similar tasks.

2.3.2 Reactive MOB-systems

A Reactive MOB-system only activates when the transmitter is submerged, or when it comes in contact with water, which would activate a distress signal. The alarm might also be triggered when device escapes its geofence (Schmidt, 2015). The Sea Marshall 1003 and sMRT100 are two examples of a reactive system. When using reactive systems there is a possibility that submersion in the pool/pools, which can be found on most cruise ships of today, could trigger a false alarm from the water activated devices.

To simplify a deployment of a reactive system on board a large cruise ship the transmitters would need to have the same attributes as needed for an active system, including long range, as well as a way to eliminate false alarms.

To position a MOB a positioning system would be necessary, such as an integrated GPS-receiver or similar. The coordinates received could then be transmitted with the distress signal (see 2.3.2.1). Another solution could be using the principles behind time-difference-of-arrival (TDoA) tracking (Xu et al, 2013) (see 2.3.2.2).

2.3.2.1 Global Positioning System

GPS, or the Global Positioning System, was developed by the U.S. military and launched in 1978 (Pace et al, 1995). Five years later it was decided it would be freely available for public use[2] and since then it has been implemented in many aspects of life. The GPS determines its position by measuring the distance to four or more GPS satellites. The satellites continually broadcast its position along with a time of transmission (TOT) which is picked up by the device which then calculates the time it took for the signal to reach it by comparing it to an internal clock. By combining the distances to three different satellites as well as controlling the internal clock's deviation from the satellite time with a fourth satellite the receiver can determine its position down to around 5 metres[3]. Currently 32 satellites are in use in orbit around the Earth and from any given point on the planet around nine of these should be visible at all times, providing redundancy to the system.

GPS uses radio waves moving with a known and constant speed, the speed of light (approximately 3×10^8 m/s), transmitted at 1575.42 MHz (L1) or 1227.60 MHz (L2). Attenuation, or fading, of the radio signal in water is unfortunately a significant issue and prevents GPS positioning underwater (Mankari & Navale, 2017).

There is a competing positioning system developed and maintained by the Russian federation, the "Globalnaya Navigatsionnaya Sputnikovaya Sistema" or GLONASS. This system is also satellite based, operating at about 1600 MHz and have thus similar performance and limitations as the GPS technology (Polischuk et al, 2002).

[2] Until May 2nd 2000 the public GPS systems were intentionally made more inaccurate to prevent enemies of the U.S. from using public GPS for precision guided weapons. This is called Selective Availability (SA) and lowered the accuracy by approximately 50 m horizontally and 100 m vertically (Grewal, 2006).

[3] The predicted accuracy for the most recent GPS system, L5, is 30 cm. L5 is due to launch in certain smartphones in 2018. It is unknown exactly which models are affected (Moore, 2017)

2.3.2.2 Time Difference of Arrival

A location system placed on the searching vessel could use the Time Difference of Arrival technology, TDOA. As the name suggest, TDOA can be used to position a transmitter by measuring the time-difference of reception of a signal between two or more receivers. Using a system with two receivers the transmitters position can be calculated as being somewhere along a 2-dimensional hyperbolic curve (as seen in **Fel! Hittar inte referenskälla.**). By equipping the ship with 3 or more receivers a more precise position can be acquired. (Gustafsson & Gunnarsson, 2003). One benefit with a TDOA system is that the requirements on the signal transmission quality is low and it can thus be used as a backup feature for a more intricate positioning communication system since it can utilize the carrier wave of the transmitter.

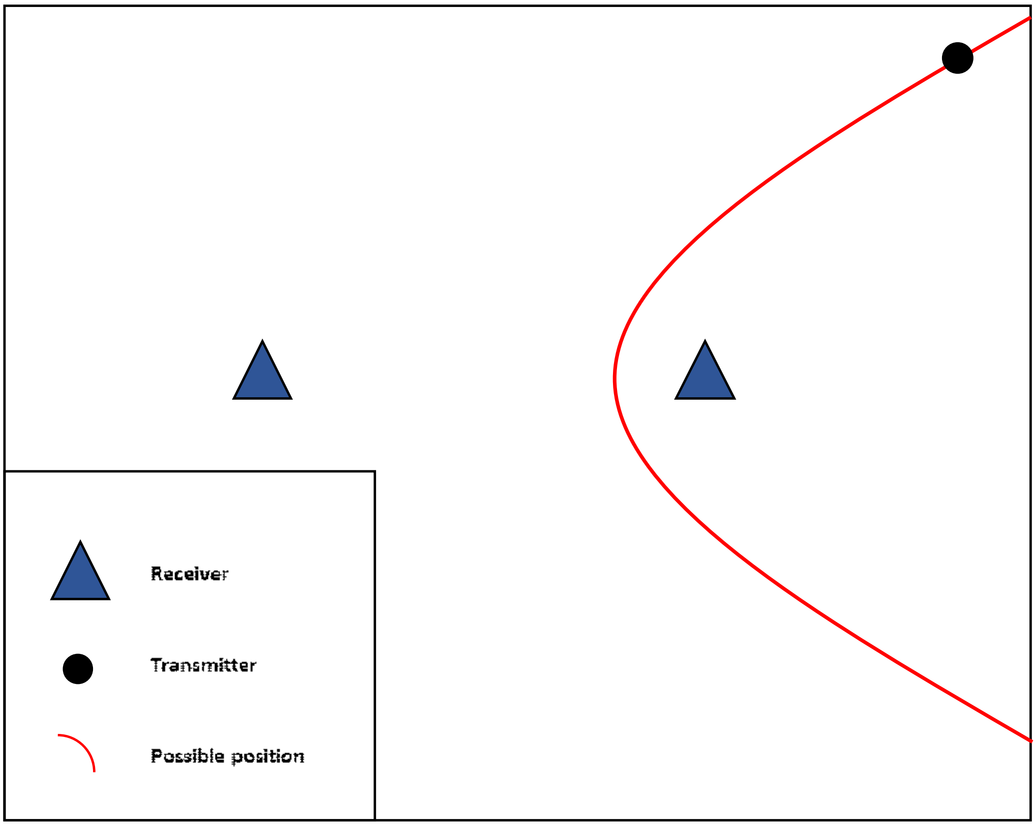


Figure 7. The possible positions for a transmitter located by two receivers form a hyperbolic curve. (Source: Authors)

2.4 Wireless communication technologies Theory

The first wireless network was developed in the early 1970s in Hawaii as a way to communicate between the islands and these networks has since then grown to be a large part of our everyday routines.

A number of cruise companies have started to implement wireless systems in their passenger experience, one notable example being Royal Caribbean's WOW band, an RFID, Radio Frequency Identification, tag bracelet that serves as both stateroom key and a way to record purchases made on board to a passenger's registered credit card.

Figure 8. Royal Caribbean WoW band (Royal Caribbean Blog, 2015) Reprinted with permission.

Wireless systems designed to allow for long range transfer of small data packages at a low energy cost are generally referred to as Low-Powered Wide Area Networks, or LPWAN and have found their main use is in the IoT area, where data from one or several sensors can be transmitted through a gateway to a network server from which the data can be presented in various programs and inputs sent back to the module. (LoRa Alliance, 2018)

Today there is a variety of wireless technologies on the market. However, to be suitable for a possible MOB-situation amongst cruise-passengers the technologies must pass the following criteria, as defined by the authors;

- Power-efficiency: The device has to be functional during the whole voyage without the need to charge or replace the battery.
- Range: The device should be able to track the passengers at all times while on board.
- Capacity: The system must have the capacity for thousands of transmitters on one network without causing interference.
- Size: The passengers must be able to comfortably wear the devices at all times, likely in the form of a bracelet or a necklace.
- Prize: The device is to be distributed amongst all passengers, and possibly the crew, and must be inexpensive.

This section compares four different wireless technologies and evaluates which would best fit these criteria. The selected systems are Bluetooth Low Energy (BLE), ZigBee, Sigfox and LoRa.

2.4.1 Bluetooth Low Energy (BLE)

Bluetooth Low energy, BLE or Blue Tooth SMART, uses a different protocol compared to "regular" Bluetooth. BLE works in the 2.4 GHz-spectrum and uses 40 band where each band is 2 MHz wide. Its Receive (Rx) sensitivity is down to -93 dB which gives BLE an effective range of approximately 100 metres in line-of-sight. According to calculations by Kamath & Lindh (2012) a BLE-node can last approximately 400 days while transmitting once every second running on a coin cell battery of 230 mAh. The topology of BLE is a so called Piconet with a calculated max number of 5917 transmitters per network under optimal conditions and a transmitting-interval of 4 seconds (Gomez et al, 2012). A BLE module can be bought for €4.34 and measures 12.9 mm x 15 mm (Mouser Electronics, ARTIK-020-AV2R, 2018).

2.4.2 ZigBee

ZigBee is an open-source modulation technique which operates on three different frequencies; 2450 MHz, 915 MHz and 868 MHz. Different frequencies results in different data rates. These frequencies are divided into a total of 27 channels. Out of the 27 channels ten are used in the American region and operate at 915 MHz at a speed of 40 kbps, one channel is used in the European region and operates at 868 MHz at a speed of 20 kbps and the remaining 16 channels operate at the worldwide unlicensed frequency of 2450 MHz at a speed of 250 kbps (Labiod et al, 2007). Zigbee's topology could be a mesh network or cluster-tree (Figure 9), with a capacity of up to 64.000 devices per network. The usage of a mesh/cluster tree network means ZigBee-nodes have the capability to forward messages from other nodes to the gateway. In a mesh network the nodes will find their own path to the server, while a cluster-tree will need to be set up and maintained by a technician. ZigBee-nodes have an effective range of 10 meters indoors and a range of up to 100 meters in line of sight.
Using the other nodes in a network a node can transmit a message 400 meters in line of sight between the nodes (Baker, 2005). With a coin cell battery at 120mAh Zigbee have an estimated battery life of 4 months under optimal conditions, based on a packet-size of 102 bytes and an interval of 10 seconds between transmissions (Casilari et al, 2010). A ZigBee-module, measuring 25mm x 19mm, can be purchased for €11 (Mouser Electronics, ETRX357, 2018)

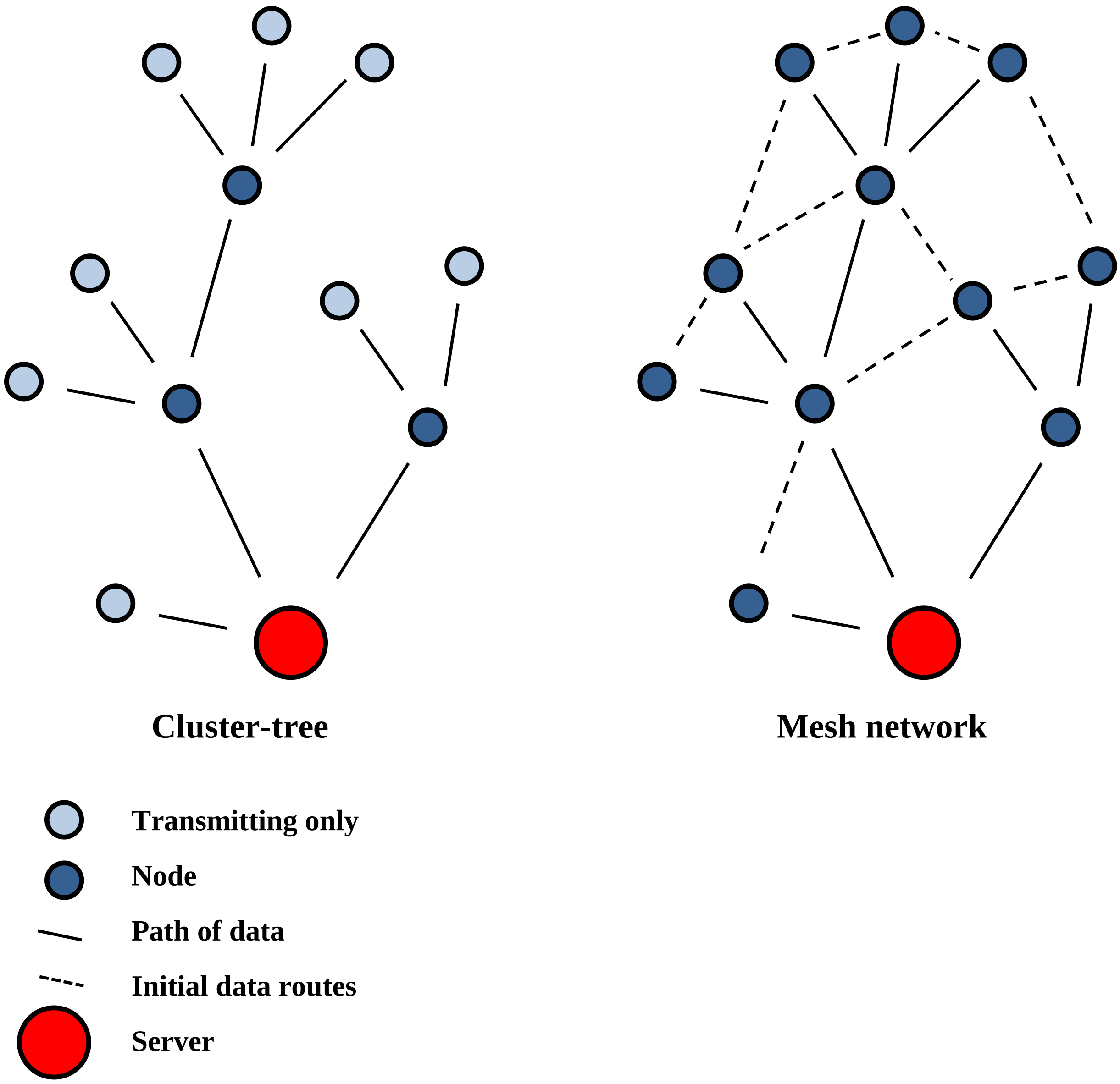


Figure 9. Cluster tree and Mesh network. (Source: Authors)

2.4.3 Sigfox

Sigfox is a French company founded in 2009 who have developed the so called Sigfox technology, which is a LPWAN technology. Sigfox operates on the 868 MHz spectrum in Europe and the 902 MHz spectrum in Asia (Sigfox, 2018). It uses an ultra-narrow-band technology to transmit data. While actively transmitting the Sigfox transmitter uses a peak power of 120-300 mA but while inactive it only consumes 5 µA. Sigfox have an expected battery life of 2.5 months with a duty cycle of 15 minutes running on a 200 mAh battery (Hernandez et al, 2017). Sigfox transmits with a rate of 100 bits/s and uses 26 bit to transmit. Sigfox has a link budget of 155 dB which gives it a range of up to 50 km in line of sight. Sigfox is limited to a maximum of 140 messages per day, which equals to less than 6 messages per hour, and with a maximum payload of 12 bytes per message (Sinha et al, 2017). A Sigfox module, of type RCZ1, measures 15mm x 13mm (Sigfox, 2018). Since the Sigfox technology is not open source, the user will have to both purchase the device, at a price from €1.63 (Sigfox, 2017), and subscribe each transmitter to the Sigfox company for a cost of between €1-12 per year per device[4].

2.4.4 LoRa

LoRa uses the same frequency spectrum as Sigfox, 868 or 902 MHz, but uses a different technology to modulate the information and is also a LPWAN technology. Instead of depending on a fixed number of data-transmissions LoRa have a maximum of 1% uptime in g1-areas and a 0.1% for g2-areas. This mean that if a transmission takes 50 milliseconds to transmit the node will have to wait 5 seconds before the next transmission in g1-areas and 50 seconds in g2-areas, which equals to a maximum of 17280 respectively 1728 messages per day. LoRa has a bitrate between 0.3 to 5.5 kbits and a link budget up to 154 dB depending on what bitrate to transmit, which gives it and effective range up to 15 km. While transmitting LoRa uses a peak power 32 mA and 1uA while sleeping. (LoRa Alliance, 2018). Assuming the LoRa chip consumes 32 mA at all times while transmitting, a LoRa transmitter has an estimated battery-life of up to 150 days with a transmitting interval of 1 minute and a payload of 30 bits. If the payload were 12 bits every 1.5 seconds the maximum transmitters per gateway would be 2560 (Bardyn at al, 2016).

The only producer of the LoRa-chipset5 is Semtech, a company specialized in building various types of semiconductors, which uses the HopeRF RFM95W wireless radio chip, which can be bought for €3.67 (Digi-Key Electronics, SX1276IMLTRTCT-ND, 2018). The entire module can be purchased for €5.86. The module measures 16 x 16 mm (see Figure 12) and is capable of operating in temperatures between -10°C - +70°C (Digi-Key Electronics, RFM95, 2018).

2.4.5 Wireless systems summary

Technology	Range (km)	Cost/module	Tx/day/device (max)	Max capacity (Tx interval)	Size (mm)
BLE	0.1	€4.34	21600	5917 (4 seconds)	12.9 x 15
ZigBee	0.1-0.4	€11	N/A	64’000 (N/A)	25 x 19
Sigfox	3-50	€1.63 module cost + €1-12/year subscription	140	N/A	13 x 15
LoRa	2-15	€5.8	17280	2560 (1 minute)	16 x 16

Table 1. Summary of the selected technologies

[4] Sigfox does not publish price lists, cost is approximated based on answers on Sigfox support web site; https://ask.sigfox.com/questions/574/subscription-price.html

[5] As of January 2018

[6] Price for a single module as no comparison prices for bulk purchases have been found

Based on the compiled data the LoRa technology was chosen for the field testing prototype due to its good range, low power consumption and because it is an open source technology capable of sending up to 17280 transmissions per day. It is also fairly resistant to interference and the doppler effect and therefore good for tracking mobile objects (Mikhaylov et al, 2016).

2.4.6 LoRa features

LoRa stands for Long Range. The technology belongs to the category LPWAN (Low Power Wide Area Network) and is a relatively new wireless technology capable of sending small packages of data over very long distances of up to 15 km in direct line-of-sight. There are 3 channels in the 868MHz-band used by LoRa, 868.1, 868.3 and 868.5MHz, each band covering 125KHz. LoRa uses chirp spread spectrum (CSS) modulation to transmit data. A chirp is a frequency modulated pulse, wherein the frequency is linearly shifted, which gives CSS a good resistance against interference (**Fel! Hittar inte referenskälla.**). While transmitting, the number 1, or ON, is represented by a chirp while the absence of a chirp represents the number 0, or OFF (Reynders & Pollin, 2016).

LoRa can use spreading factor (SF) 7-12 which impacts the data rate and the effective range of the transmitter. A lower spreading factor equals shorter chirp duration and higher data rates but shorter distance. For example, a SF of 7 gives a bit rate of 5.5 kb/s and a minimum sensitivity of -123 dB while a SF of 12 have a bit rate of 0.3 kb/s but a minimum sensitivity of -137 dB (see Table 1) (Bardyn et al, 2016). In conclusion, the factors affecting the maximum possible transmitters per gateway is the SF, the size of the payload and the transmitting interval. Another option is to transmit at all the different spreading factors simultaneously which enables sending 64 messages of 12 bytes every 1.5 seconds (or 2560 messages every minute) gateway station. LoRa's topology is usually a "star-of-star" layout (see Figure 11), with transmitters connected to gateways, and the gateways are in turn connected to a server (Bardyn et al, 2016).

SF	Bitrate (kb/s)	sensitivity (dBm)	payloads/1.5 sec (12 bytes)
12	0.3	-137	1
11	0.5	-134.5	2
10	1	-132	4
9	1.8	-129	8
8	3.1	-126	16
7	5.5	-118	32

Table 1. Properties of different Spreading Factors

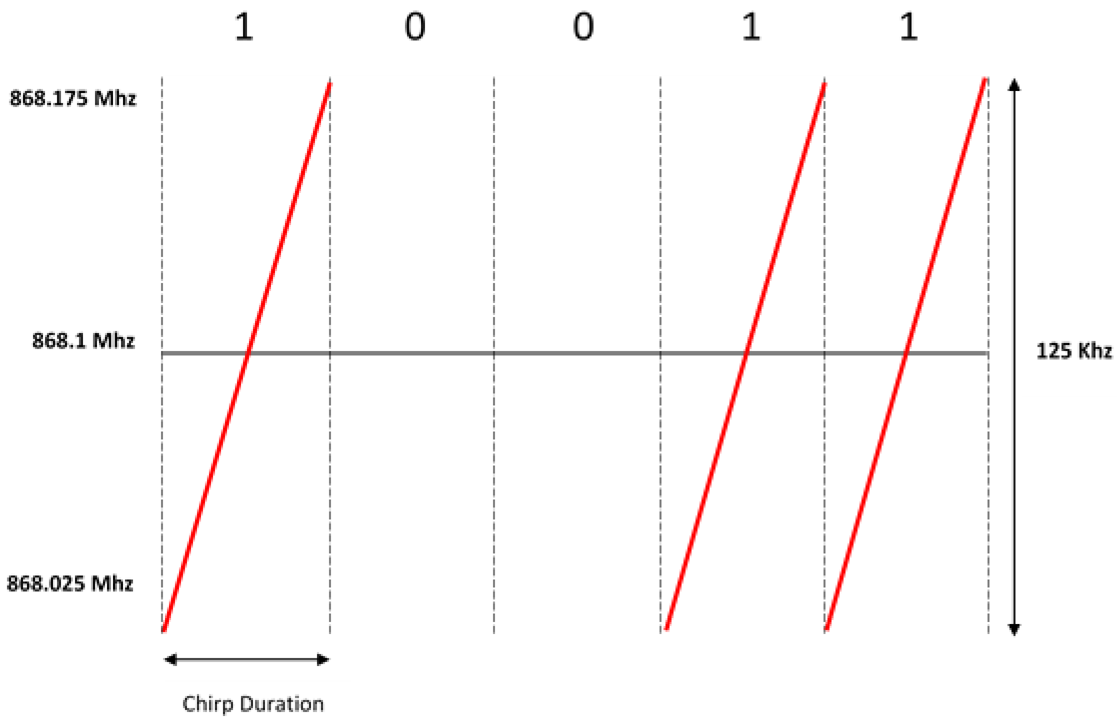


Figure 10. An example of Chirp Spread Spectrum (Source: Authors)

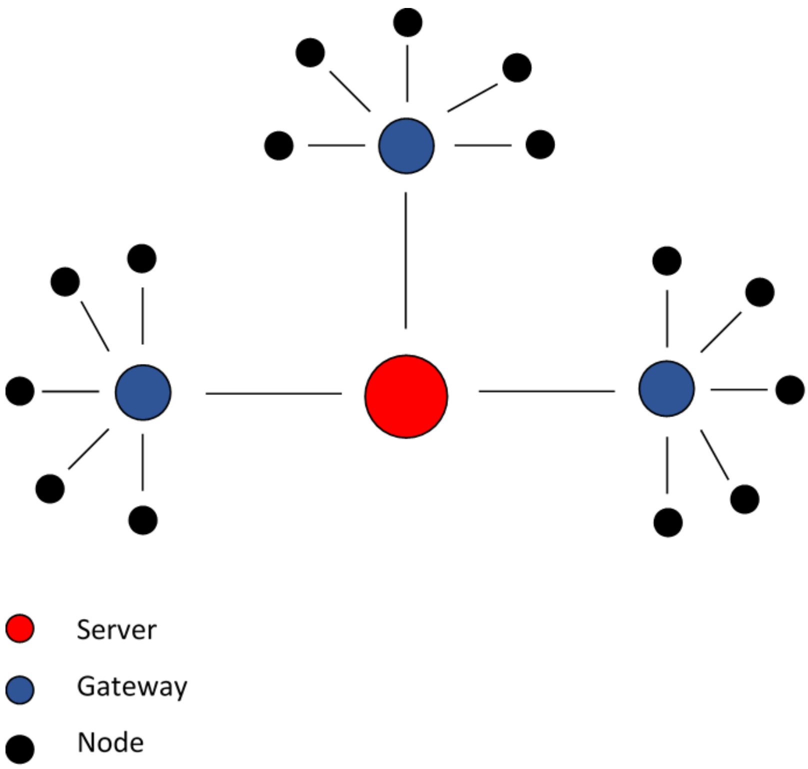


Figure 11. Star-of-star topology of a typical Lora network (Source: Authors)

3 Method

Information about different wireless communication technologies on the market has been gathered and compiled in a literature study. Their compatibility with the shipping industry and the special structure of ships, which often obscures tracking signals, has been examined. A field study has been conducted where a prototype transmitter and receiver pair has been tested and evaluated with regards to its working range, reliability and accuracy in different maritime environments. The real-world tests were performed aboard the 155m passenger ferry *Stena Danica* and in the waters of the Göta älv, Gothenburg.

The prototype consists of two Raspberry Pi 3, a single-board computer, both combined with a Dragino LoRa/GPS HAT with antenna (see Figure 12). The transmitter and gateway where both powered by battery packs to keep them mobile. For the measurements taken only the LoRa antenna was used and it was decided to rely on more extensive documents regarding the GPS limitations and possibilities. One unit was designated gateway/receiver while the other was designated node/transmitter and the two were installed with the corresponding open source software obtained from GitHub, a development platform for various software solutions (see appendix 1 for code).

To measure the signal loss caused by water the LoRa-node was placed in a waterproof container made of glass, which was submerged in the Göta älv at different depths while a gateway was held 1.5 metres above the water. Signal loss was then recorded for every 10 cm of submersion. Readings of the signal strength were also made at surface-level to provide a reference point, as well as both before and after placing the node inside the container to measure the signal loss caused from the glass and the battery pack.

Signal loss caused by onboard bulkheads and decks were measured onboard the RoRo passenger ferry *Stena Danica* en route between Gothenburg, Sweden, and Frederikshavn, Denmark, a 3.5 hours trip either way. Measurements were taken by keeping the receiving gateway stationary while moving the transmitting node around in various areas of the vessel, recording each position and the corresponding signal. The tests were then repeated with the receiver in a different location (see appendix 2 for the precise positioning of measure points)

The quantitative data gathered during the field studies were compiled and set in tables for an easier overview during comparison and the following analysis.

3.1 Choice of technology

As mentioned in chapter 2.4.2 and 3 the measurements were carried out using a LoRa RFM95W chip attached to a SX1276 module. The module was mounted to an Arduino LoRa/GPS HAT controlled by a Raspberry Pi 3, which in turn were powered by a portable power bank. The transmitter had an antenna gain of 14dB and was transmitting with SF 7.

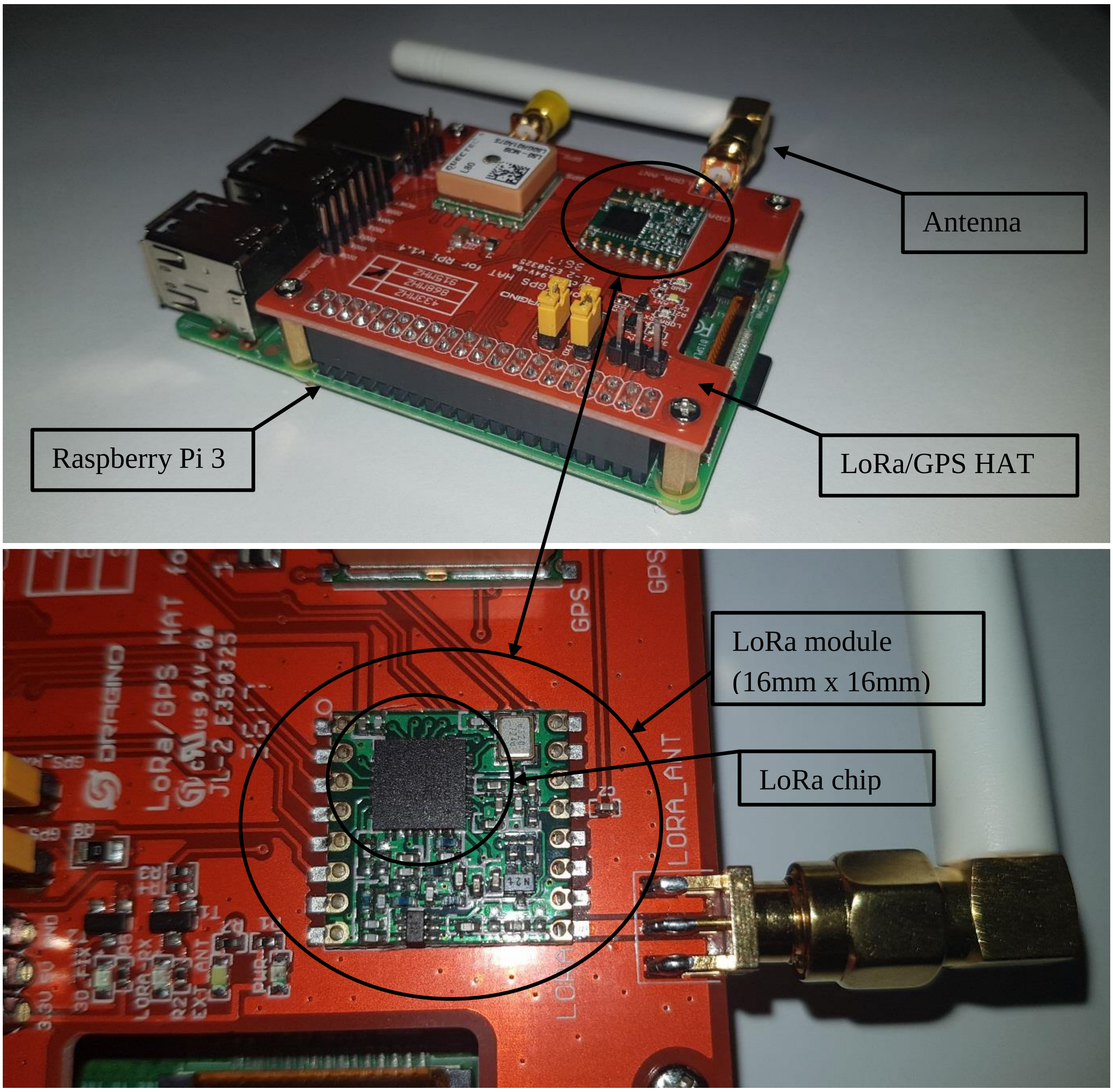


Figure 12. The prototype used in the field study and its main components (Source: Authors)

4 Result

The result describes the measurements obtained from the authors' field study as described in chapter 3.

4.1 Field study

The following chapter contain the results gathered from field studies performed by the authors.

4.1.1 Signal loss while submerged

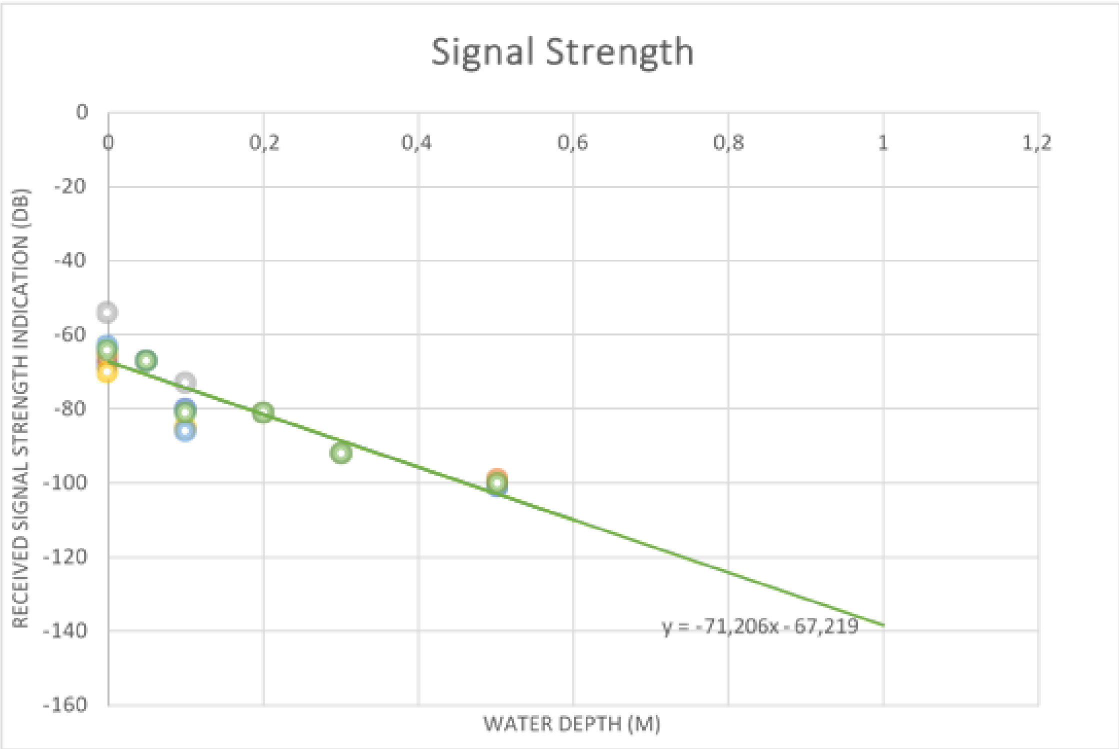


Figure 13. Diagram of the measured signal strength while immersed in water (Source: Authors)

The different coloureds spots represent the different measurements taken in Göta älv while the green dots show the combined average for every depth. The green line marks the average trend and projects it down to a depth of 1 metre, a decline which marks the attenuation as 71.2 dB/meter. Communication was possible until the signal was lost at a depth of somewhere between 50 and 60 cm at a signal strength below -101 dB.

The signal loss of the RF transmitted signal is depending on the conductivity of the water. The conductivity of water is very much dependent of the amount of dissolved solids, in the case of sea water these are primarily salts. Deionized water has a conductivity of 5.5 µS/m, drinking water can be between 5–50 mS/m, and sea water about 5 S/m (Lenntech, 2018).

The conductivity of the water in the Göta älv in January/February has over the period 2013-2016 stayed reasonable constant at 8-9 mS/m in Alelyckan, around 4.5 km upstream from where our measurements were taken. It is unclear exactly how much the saltwater intrusion affect the conductivity of the river at Lindholmen at the time the field study was conducted

The formula for the attenuation of the radio transmission in water is (Butler, 1987)

$$\alpha = 0{,}0173 \cdot \sqrt{f \cdot \sigma}$$

Where

0,0173 is a constant

α in [dB/m]

f , frequency in [Hz]

σ, conductivity in [S/m]

The conductivity of water calculated from the derived from the measured loss, 70,2 [dB/m], is:

$$\sigma = \frac{\left(\frac{\alpha}{0{,}0176}\right)^2}{f}$$

$$\sigma = \frac{\left(\frac{70{,}2}{0{,}0176}\right)^2}{8{,}68 \cdot 10^8} = 0{,}01956 [S/m]$$

σ = 0.01956 S/m = 19.56 mS/m which is a reasonable result

Due to the high conductivity of sea water radio signals in the MHz-bands do not travel very far underwater. Using the formula above and an assumed conductivity of salt water of 4 [S/m], the LoRa signal loss would be

$$\alpha = 0{,}0173 \cdot \sqrt{8{,}68 \cdot 10^8 \cdot 4}$$

α = 1019 dB/m.

This is a very high signal attenuation and thus this would cause the signal to be mostly faded within the first 10 cm from the antenna.

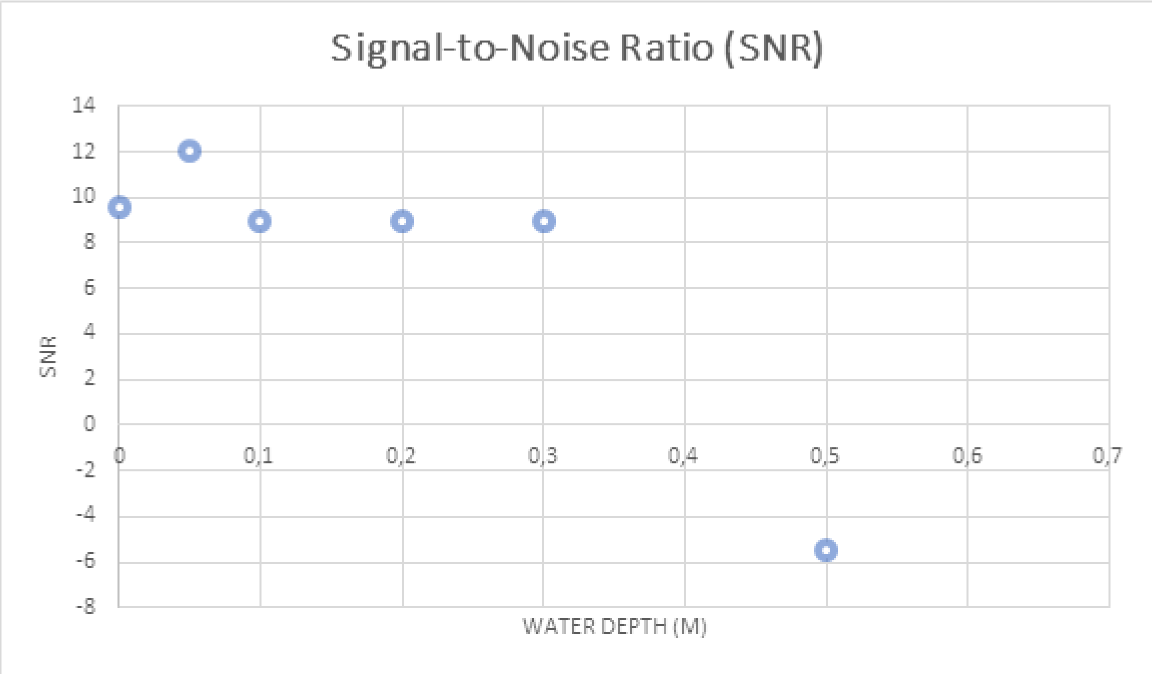


Figure 14. Diagram of average measured Signal-to-Noise Ratio while immersed in water (Source: Authors)

The blue circles in the diagram show the average SNR at the different measured depths. A higher SNR indicates a stronger signal compared to the background noise.

4.1.2 Signal Loss onboard

	Distance between measured points				Signal strength	
	Bulkheads	Decks	m horizontal	m vertical	RSSI	SNR
1.1	0	0	24	0	−75	9
1.2	1	0	28	0	−70	9
1.3	4	1	35	3	−84	9
1.4	9	1	60	3	−95	1
1.5	3	2	56	6	−97	−3
2.1	1	1	3	3	−59	9
2.2	4	1	97	3	N/A	N/A
2.3	5	1	87	3	−99	−3
2.4	4	1	82	3	−98	1
2.5	2	0	92	0	−95	5
2.6	3	1	92	3	−101	−5
2.7	13	1	80	3	N/A	N/A
2.8	*	2	14	6	−64	8
2.9	*	3	14	9	−88	8
2.10	*	4	14	12	−78	9
2.11	*	5	15	15	−89	8

Table 2. The result from the Stena Danica tests.
** due to the angle between transmitter and receiver it is hard to calculate the number of passed bulkheads.*

In this table all the onboard measures are presented. 1.1-1.5 represents the results of the 5 measurements taken with the receiver in position 1. 2.1-2.11 represents the result of the 11 measurements taken with the receiver in position 2. The number of bulkheads indicates how many vertical bulkheads the signal would need to penetrate if the signal were to travel in a straight path between the transmitter and the receiver. Decks show how many horizontal decks separated the transmitter and the receiver.

No regard has been taken to humans moving in the area or onboard equipment that may further block the signal. The distances are estimations based on the on-board general arrangement plan (for location of measurement points; see appendix 2).

Both the measurements in the Göta älv and aboard *Stena Danica* indicate that the devise loses its signal slightly above -100 RSSI. *Danica* measurement points 2.2 and 2.6 were only a few metres apart yet 2.6 had an RSSI of -101 while 2.2 had lost all connection to the transmitter.

5 Discussion

Even though the LoRa module has a good range in line of sight and a small form factor[7], which makes it technically possible to fit inside a bracelet or similar, the physical characteristics of radio waves in combination with water makes it very difficult to track a person who have fallen overboard (see section 5.3). In order to allow the use of a RF device for locating and tracking the device or its antenna must at least sometimes be on or close to the surface.

5.1 Result discussion

Although the transmitter were operating at SF 7 and did not have the maximum available link budget, this would not impact the loss of signal strength measured underwater. This since the attenuation only are affected by the frequency and conductivity of the water. However a greater loss of signal due to submersion would be acceptable to still be able to receive the signals at the surface.

The onboard measurements on the other hand would benefit from a higher SF since it would give the transmitter a longer range, but a SF of 7 seems reasonable taking into account all the transmitters that would need to be transmitting simultaneously.

The results gathered at Stena Danica may not accurately represents results given by similar measurements on board a large cruise ship. This due to a different bulkhead arrangement and smaller spaces such as staterooms where the passengers would reside. It is presumed that such a ship structure would cause greater loss of signal and need more receivers to continuously track all of the transmitters on board.

The underwater measurements were due to technical difficulties only performed in freshwater and a higher attenuation in saltwater is expected according to calculations.

The SNR in the performed field study were inconsistent. For the underwater measurements the inconsistency could be caused by the different occasions on which the measurements were done. Different levels of background noise could have been present on different days. As on the onboard measurements the inconsistency could be caused by the variating vicinity to land and also the proximity to onboard wireless equipment.

5.1.1 Conceptual weaknesses and limitations

The most prominent challenge in developing an automatic MOB system using wireless signals is the short range most wireless signals have when immersed in water in general and salt water in particular. This means that a reactive MOB-system using any wireless technology would have to rely on either:

1. the victim being aware and both mentally and physically capable of keeping the tracking device above water (assuming the device is attached to a bracelet or similar),
2. the device releasing a free-floating antenna when in contact with water, or

[7] Form factor is the physical specification of the circuit board, such as the dimensions and required power supply.

3. the device being free-floating itself to a certain extent (such as a buoyant necklace)

However, these requirements all fail if one takes into consideration things like the human psyche and onboard facilities

1. If a person has fallen into the water from a large vessel they are likely going to be
    - disoriented due to the fall, possible impacts during the fall and the impact with water
    - choking on water
    - possibly unconscious
    - focused on keeping mouth and nose above water
    - not realising the importance of keeping the device above water
    - the passenger may also be a child or elderly which lowers the likelihood of being capable of keeping the device above water
    - possibly dead from the impact with the water or possible impacts during the fall
2. Many cruise vessels offer pool facilities on board which would mean passengers would have to remove the device before entering the water, passengers may go swimming during port stops, or a simple shower may deploy the antenna.
    - the risk of theft increases if passengers are required to remove the device before any water activity
    - there is a risk of passengers falling overboard while not wearing the device
    - high possibility of losing or misplacing the device
    - risk of tangling with antenna
    - high amount of false alarms
3. A free-floating device in the form of a necklace adds a number of requirements to the product design, such as
    - weight, if it is too heavy it will be uncomfortable to wear
    - length/tightness, the band around the neck must be tight enough not to slip over the head, but loose enough to be comfortable and able to reach the surface
    - not so bulky that it risks getting stuck beneath clothes
    - not uncomfortable to wear at all times, including sleeping
    - preferably aesthetically pleasing so as to avoid encouraging passengers to forego it during events such as dinners
    - limitations regarding water related activities, see 2., still apply

A active MOB-system could be considered more practical on board a cruise vessel. However this kind of system have its own challenges;

- The use of a on board pool could cause the transmitter to lose contact with the receiver and cause a false alarm.
- A faulty device could stop transmitting and therefore trigger a false alarm.
- A nearby boat might cause interference with the system with unknown results.
- The amount of receivers needed to provide the passenger areas with flawless coverage will be high.

- A MOB would not be able to be positioned, except for the vessels position at the last known contact with the transmitter.
- The transmitters would need to have a synchronized transmitting-schedule to not cause interference amongst each other.

5.2 Method discussion

The results gathered were acquired through a literature study combined with field testing of a selected wireless technology.

The measurements carried out where made with a Raspberry Pi 3 and a LoRa-hat transceiver since it is the closest to a functioning personal MOB tracker the authors could acquire at a reasonable price within the time limits of this report. Said LoRa transceiver could only transmit and receive at spreading factor 7, which gives the device a shorter range but faster transmit speed.

The on-board measurements were carried out on the ferry *Stena Danica* due to its close proximity to the authors location and the continuous departures.

The underwater measurements were originally planned to be executed in both fresh and saltwater. However, due to the necessity of having access to the power grid during setup of the transmitter/receiver, in combination with the unreliability of said devices, the saltwater measurements were not done. Instead the theoretical maximum depth of which a LoRa device could be received in saltwater were calculated.

Some unexplained errors were experienced during the later days of measuring when the transmitter stopped sending while walking between the activation area[8] and the measurement point. The suspected cause is an ineffective program, which caused the CPU-load to reach 100%, that needed more power than the battery pack was capable of supplying. Optimal power input for a Raspberry Pi 3 is 2.8 A while the power output from the selected battery pack is 2.1 A. The program was running at 100% CPU and the battery pack was therefore insufficient.

Alternative methods could include; using a different code and/or spreading factor, performing the onboard measurements on a proper cruise ship, taking more measurements, obtaining different LoRa-tranceivers and performing the measurements in saltwater.

5.2.1 Reliability and validity

A more extensive study of the waters effect on radio waves would provide more reliable results. However, since the results were compared with the expected conductivity in Göta älv they could be considered reasonable accurate. The measurements performed at different

[8] Devices were activated in the computer hall of house Jupiter, Chalmers Lindholmen, approximately 30 metres from the measurement point in the Göta älv.

occasions also indicated a consistent level of attenuation. As mentioned in 5.1 the measurements were not executed in saltwater as planned.

The onboard study could benefit from repeated measurements taken in the same positions to calculate an average RSSI for each measured distance.

At both the underwater and the onboard measurements the receiver lost communication with the transmitter around approximately -101dB. This appears to validate the minimum signal strength required to successfully make a connection with SF 7, which was used in the field study.

6 Conclusions

Questions:

How could one develop a functioning wireless technology based tracking system capable of working in a larger passenger ship environment?

- *Which wireless technology is best suited for Man Overboard tracking and why?*
- *What are the technical challenges?*

Out of the four wireless communication technologies evaluated in this literature study, LoRa would be the most suitable technology for use in an automated MOB-detecting system due to its long range, low price, low power consumption, small size and high network capacity.

Both active and reactive systems have a high risk of false alarms caused by water whilst on board, either due to contact with the water or the loss of signal caused by attenuation.

A reactive MOB-system has a low chance of working as intended since the sea water effectively would suppress the signals emitted from the MOB-device.

An active MOB-system on the other hand could be deemed plausible, but it would still have some challenges to overcome. Besides having to rely on a large amount of receivers on board, the system would need a technology to prevent possible interference from transmitters on board other ships in the vicinity. A way to eliminate false alarms would also be necessary.

Based on the results from this study, the conclusion is that the concept of a MOB-system on board a large cruise vessel, based on radio signals, would need further development.

6.1 Recommendations for further studies

A recommendation for future field studies of similar sort is to write or find a better code for the transmitting unit to prevent issues related to low power input. We do not know what parts of the used code could be optimized nor do we have the required experience to alter it or write new code.

It could also be interesting to investigate the possibility of using acoustic signals for the location of a person who has fallen into the water.

References

Baker, N. (2005). ZigBee and bluetooth strengths and weaknesses for industrial applications. *IEE Computing and Control Engineering, Vol. 16* (Issue 2), p. 20-25. https://doi.org/10.1049/cce:20050204

Bardyn, J-P., Melly, T., Seller, O., & Sornin, N. (2016). IoT: The era of LPWAN is starting now. *Paper presented at the European Solid-State Circuits Conference, 2016-October* p. 25-30. https://doi.org/10.1109/ESSCIRC.2016.7598235

Business Research and Economic Advisors (BREA) (2017). The Global Economic Contribution of Cruise Tourism 2016. Prepared for CLIA. Retrieved from http://cruising.org/docs/default-source/research/global_economic_contribution_2016.pdf?sfvrsn=2

Butler, L. (1987) Underwater Radio Communication. *Originally published in Amateur Radio, April 1987*

Casilari, E., Cano-García, J. M., & Campos-Garrido, G. (2010). Modeling of current consumption in 802.15.4/ZigBee sensor motes. *Sensors*, *Vol 10* (Issue 6), p.5443-5468. https://doi.org/10.3390/s100605443

Cruise Lines International Association (CLIA) (2017). 2018 Cruise Industry Outlook. Retrieved from http://cruising.org/docs/default-source/research/clia-2018-state-of-the-industry.pdf?sfvrsn=2

Civic Impulse. (2018). H.R. 3360 — 111th Congress: Cruise Vessel Security and Safety Act of 2010. Retrieved from https://www.govtrack.us/congress/bills/111/hr3360

Denscombe, M. (2017) *The Good Research Guide: For Small-Scale Social Research Projects*. Swedish Edition. Studentlitteratur AB

Digi-Key Electronics (2018) RFM95 Ultra-Long Range Transceiver; *Product information.* Retrieved from https://www.digikey.se/product-detail/en/seeed-technology-co-ltd/109990166/1597-1488-ND/7033232?utm_campaign=buynow&utm_medium=aggregator&WT.z_cid=ref_findchips_standard&utm_source=findchips&cur=EUR&lang=en

Digi-Key Electronics (2018) SX1276IMLTRTCT-ND; *Product information.* Retrieved from https://www.digikey.se/product-detail/en/semtech-corporation/SX1276IMLTRT/SX1276IMLTRTCT-ND/4259551

Gomez, C., Oller, J., & Paradells, J. (2012). Overview and evaluation of bluetooth low energy: An emerging low-power wireless technology. *Sensors (Switzerland), Vol 12* (Issue 9), p. 11734-11753. https://doi.org/10.3390/s120911734

Grewal, M. S., Weill, L. R., & Andrews, A. P. (2006). Global positioning systems, inertial navigation, and integration, second edition. *Global positioning systems, inertial navigation, and integration, second edition.* p. 1-525 https://doi.org/10.1002/9780470099728

Gustafsson, F., & Gunnarsson, F. (2003). Positioning using time-difference of arrival measurements. Paper presented at the *ICASSP, IEEE International Conference on Acoustics, Speech and Signal Processing - Proceedings, Vol 6* p. 553-556. Retrieved from www.scopus.com

Göta älvs vattenvårdsförbund (2017) Rapport avseende Vattendragskontroll 2016 (Swedish). Retrieved from http://www.gotaalvvvf.org/download/18.473cb86c15cc2730b738036a/1498047119719/Vattendragskontroll+2016+G%C3%B6ta+%C3%A4lv+%2B+Norra+tillfl%C3%B6den.pdf

Hernandez, D. M., Peralta, G., Manero, L., Gomez, R., Bilbao, J., & Zubia, C. (2017). Energy and coverage study of LPWAN schemes for industry 4.0. *Paper presented at the Proceedings of the 2017 IEEE International Workshop of Electronics, Control, Measurement, Signals and their Application to Mechatronics, ECMSM 2017,* https://doi.org/10.1109/ECMSM.2017.7945893

Jainchill, J. (2010) UPDATE: Why the news media's cruise reporting goes negative. *Travel Weekly, January 26, 2010*. Retrieved from http://www.travelweekly.com/Cruise-Travel/UPDATE-Why-the-news-media-s-cruise-reporting-goes-negative

Kamath, S., & Lindh, J. (2012). Measuring Bluetooth Low Energy Power Consumption. *Texas Industries.* Retrieved from http://www.ti.com/lit/an/swra347a/swra347a.pdf

Klein, R. A. (2017). Cruise and Ferry Passengers and Crew Overboard 1995 - 2018. Ongoing statistics. Retrieved from http://www.cruisejunkie.com/Overboard.html 07-12-17.

Labiod, H., Afifi, H., & de Santis, C. (2007) *Wi-Fi, Bluetooth, ZigBee and WiMax*. Dordrecht, The Netherlands. Springer.

Lenntech (2018) Water Conductivity; Definition and description. Retrieved from https://www.lenntech.com/applications/ultrapure/conductivity/water-conductivity.htm

Lewins, K., & Gaskell, N. (2013) Jurisdiction over criminal acts on cruise ships: perhaps, perhaps, perhaps?. *Criminal Law Journal, Vol 37* (Issue 4) p. 221-245. Retrieved from https://www.google.se/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&ved=0ahUKEwjGyICIkqPZAhWH1iwKHSSrAPwQFgg0MAE&url=https%3A%2F%2Fwww.aph.gov.au%2Fparliamentary_business%2Fcommittees%2Fhouse_of_representatives_committees%3Furl%3Dspla%2Fcrimes%2520at%2520sea%2Fsubs%2Fsub001.pdf&usg=AOvVaw1jKzbU9fD1NeCnUJKQqHLb

LoRa Alliance. (2018). LoRa Alliance™ Technology. Retrieved from https://www.lora-alliance.org/what-is-lora

Maali, F., & Barnes, M. W. (2017). U. S. patent No. US20170154223. Alexandria, VA: U.S. Patent and Trademark Office

Mankari, A. A., & Navale, M. (2017). A Survey on Underwater Positioning System Based on GPS and Signals. *International Journal for Research in Applied Science & Engineering Technology (IJRASET) Vol 5* (Issue VI), June 2017, p. 427-431. Retrieved from https://www.ijraset.com/fileserve.php?FID=8061

Marine Resource Technologies (MRT). (2016). Sea Marshall AU9 User Manual. Retrieved from https://www.mrtsos.com/uploads/User%20guides%20and%20Manuals/Sea%20Marshall%20AU9/Sea%20Marshall%20AU9%20User%20Manual%20v2.8.pdf

Marine Resource Technologies (MRT). (2016). sMRT V100 Technical Data Sheet. Retrieved from https://www.mrtsos.com/uploads/Technical%20Data%20Sheets/QD-79%20sMRT%20V100%20Technical%20Data%20Sheet%20Iss%2003.pdf

Mikhaylov, K., Petäjäjärvi, J., & Hänninen, T. (2016). Analysis of capacity and scalability of the LoRa low power wide area network technology. Paper presented at the *European Wireless Conference 2016, EW 2016*, 119-124. Retrieved from http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7499263

Moore, S. K. (2017) Superaccurate GPS Coming to Smartphones in 2018; *Broadcom's mass-market GPS chips boost accuracy to 30 centimeters.* Retrieved from https://spectrum.ieee.org/semiconductors/design/superaccurate-gps-coming-to-smartphones-in-2018

Mouser Electronics (2018). ARTIK-020-AV2R; Product information. Retrieved from https://www.mouser.se/ProductDetail/Samsung-ARTIK/ARTIK-020-AV2R?qs=sGAEpiMZZMsGelYiB%252bjHzoug4L%2fWODSMb76imSSBW5BWhdFefmnM8g%3d%3d

Mouser Electronics (2018). ETRX357; Product information. Retrieved from https://www.mouser.se/ProductDetail/Silicon-Labs/ETRX357?qs=sGAEpiMZZMtJacPDJcUJYz3dDwnkASsiYhytdULndfb6vdXmWvJKrw%3d%3d

Pace, S., Frost, G. P., Lachow, I., Frelinger, D. R, Fossum, D., Wassem, D., & Pinto, M. M. (1995) The Global Positioning System: Assessing National Policies; Appendix B, GPS History, Chronology, and Budgets. Santa Monica, CA: RAND Corporation, 1995. https://www.rand.org/pubs/monograph_reports/MR614.html. Also available in print form

Polischuk, G. M., Kozlov, V. I., Ilitchov, V. V., Kozlov, A. G., Bartenev, V. A., Kossenko, V. E., Anphimov, N. A., Revnivykh, S. G., Pisarev, S. B., Tyulyakov, A. E., Shebshaevitch, B.

V., Basevitch, A. B., Vorokhovsky, Y. L. (2002). The global navigation satellite system GLONASS: Development and usage in the 21st century. *34th Annual Precise Time and Time Interval (PTTI) Meeting*

PureTech Systems (2017) Man Overboard Detection; Cruise Ship Safety. White Paper. Retrieved from http://www.puretechsystems.com/docs/White-Paper-Man-Overboard-Detection.pdf

PureTech Systems (2018) *System Diagram - Superliner Class Ship, Camera Layout for Superliner Class Ships, Man Overboard Detection User Interface*. Reprinted with permission from http://www.puretechsystems.com/man-overboard-detection.html)

Qureshi, U.M., Shaikh, F.K., Aziz, Z., Shah, S.M., Sheikh, A.A., Felemban & E., Qaisar, S.B. (2016) RF Path and Absorption Loss Estimation for Underwater Wireless Sensor Networks in Different Water Environments. *Sensors (Basel). Vol 16*(Issue 6). https://doi.org/10.3390/s16060890.

Raymarine (2018) Raymarine LifeTag man overboard system; LifeTag features. Retrieved from http://www.raymarine.se/view/index.cfm?id=157. Combined Swedish and English

Reynders, B., & Pollin, S. (2016). Chirp spread spectrum as a modulation technique for long range communication. *Paper presented at the 2016 IEEE Symposium on Communications and Vehicular Technology in the Benelux, SCVT 2016*, https://doi.org/10.1109/SCVT.2016.7797659

Royal Caribbean. (2016) A Super-Quick Tour of Harmony of the Seas. Retrieved from http://www.royalcaribbean.com/connect/a-super-quick-tour-of-harmony-of-the-seas/

Royal Caribbean Blog (2015) What is a WOW band. Image retrieved from https://www.royalcaribbeanblog.com/questions/what-wow-band

Safety-Marine (2018). Raymarine LifeTag wireless Man Overboard system; product information. Retrieved from http://www.safety-marine.co.uk/products/p3352s0/raymarine-lifetag-wireless-man-overboard-system.htm

Schmidt, D. (2015) *Electronics: Sailors have lots of choices when it comes to minimizing risks from falling overboard.* Retrieved from https://www.cruisingworld.com/preventing-man-overboards

Selmy, A. K. E. S. (2017) Boost to Man Overboard Detecting Regulations Needed. *The Maritime Executive.* Retrieved from https://www.maritime-executive.com/editorials/boost-to-man-overboard-detecting-regulations-needed#gs.w5y6LNY on 2018-02-12

Sigfox. (2018). Official web page. Retrieved from https://www.sigfox.com/en

Sigfox (2017) Sigfox's ecosystem delivers the world's first ultra-low cost modules to fuel the Internet of Things mass market deployment. Retrieved from https://www.sigfox.com/en/news/sigfoxs-ecosystem-delivers-worlds-first-ultra-low-cost-modules-fuel-internet-things-mass

Sigfox (2018). WSSFM10R1; Product information. Retrieved from https://partners.sigfox.com/products/sfm10r1

Sinha, R. S., Wei, Y., & Hwang, S. (2017). A survey on LPWA technology: LoRa and NB-IoT. *ICT Express* Vol 3, (Issue 1) March 2017, p. 14-21. https://doi.org/10.1016/j.icte.2017.03.004

US Coast Guard (2015). Cruise Vessel Security and Safety Act of 2010; Implementation; A Proposed Rule. Retrieved from https://www.gpo.gov/fdsys/pkg/FR-2015-01-16/pdf/2015-00464.pdf

U.S. National Coordination Office for Space-Based Positioning, Navigation, and Timing (2018) GPS.gov; Official U.S. government information about the Global Positioning System (GPS) and related topics. Retrieved from https://www.gps.gov/

Xu, B., Sun, G., Yu, R., & Yang, Z. (2013). High-accuracy TDOA-based localization without time synchronization. *IEEE Transactions on Parallel and Distributed Systems, Vol 24*(Issue 8), p. 1567-1576. https://doi.org/10.1109/TPDS.2012.248

Appendix

Appendix 1

The codes used in the Raspberry Pi/LoRa/GPS HAT field tests.

Code for programming the transmitter:

https://github.com/ernstdevreede/lmic_pi

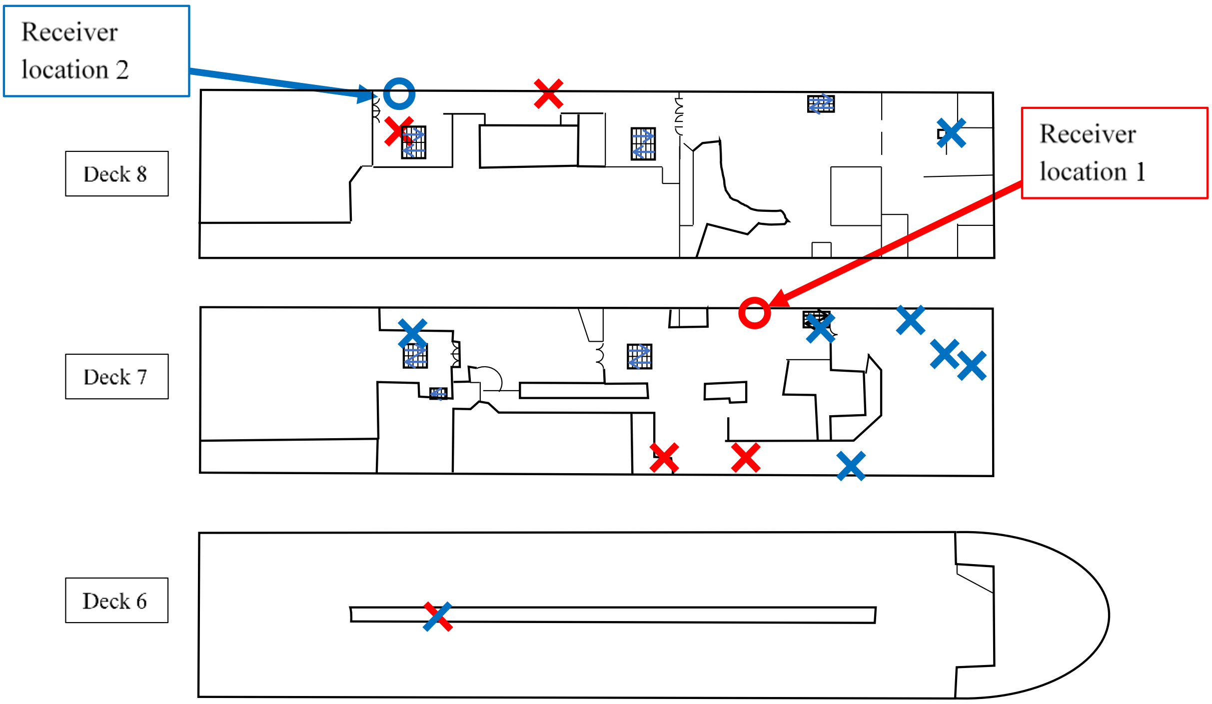
(lmic_pi > examples > thethingsnetwork-send-v1)

Code for programming the receiver/gateway

https://github.com/bokse001/dual_chan_pkt_fwd/tree/dual_chan_pkt_fwd_up_down

Appendix 2

Locations for the *Stena Danica* measurements



Red crosses – First round of measurements

Blue crosses – Second round of measurements