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Internet of Things and Marine Aids to Navigation

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PREFACE

The thesis includes a study about Internet of Things (IoT) networks that could be used for marine aids to navigation data transmission. In the study I was able to utilize the knowledge and wide experience in Finnish Transport Infrastructure Agency about current transmission methods as well as challenges encountered during past years related to remote monitoring and remote controlling services of an aid to navigation. I did deepen my knowledge about IoT technology and especially related to networks designed for low power and wide area coverage and the presence of those networks in Finland. The field experience from Finnish Meteorological Institute about different IoT networks including satellite networks was valuable especially concerning meteorological measurement buoys located at the Baltic Sea.
I want to thank everybody helped me to do this thesis, especially people in Finnish Transport Infrastructure Agency, in Finnish Meteorological Institute, in Finnish Transport and Communications Agency, in Arctia Meritaito Oy, in Mitta Oy and in SPX Aids to Navigation Oy. Special thanks to instructors in Metropolia University of Applied Sciences and in Finnish Transport Infrastructure Agency.

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Abstract

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The thesis is about Internet of Things (IoT) networks and marine aids to navigation. The thesis main goal was to find out suitable networks for marine aids to navigation data transmission needs. The thesis answers to questions about the availability of IoT networks which could be used for marine aids data transmission. Field tests of the possible transmission networks were left out from the study.

The analysis of the current state examined transmission networks in use and presented detailed information about remote monitoring and remote controlling services of marine aids. Marine aids to navigation locations with a data transfer functionality were introduced. Requirements for remote monitoring and remote controlling services were clarified.

The theory analysis from suitable IoT networks technologies was formed based on literature sources, information from operators and experiences got from Finnish Meteorological Institute, from Mitta Oy and from SPX Aids to Navigation Oy. The result of the thesis shows that from technology point of view there exist several IoT networks suitable for marine aids data transfer. Thesis conclusions show also that there are several factors that need to be considered when selecting an alternative network technology for marine aids data transmission.

Keywords: IoT, marine aid to navigation, AtoN, remote monitored AtoN, remote controlled AtoN, smart fairway, smart AtoN

Contents

List of Abbreviations

2G	Second generation cellular network technology
3G	The third generation of wireless mobile telecommunications technology
3GPP	3rd Generation Partnership Program
4G	The fourth generation of broadband cellular network technology
5G	The fifth-generation standard for broadband cellular network technology
A5/1	A stream cipher used to provide over-the-air communication privacy in the GSM cellular telephone standard.
AES	Advanced Encryption Standard
AIS	Automatic Identification System
AtoN	Aid to Navigation
B	Byte, eight bits
BeiDou	Chinese Satellite Navigation System
CCM	Cipher block Chaining Message authentication
DGPS	Differential Global Positioning System
DL	Downlink
ECDIS	Electronic Chart Display and Information System
eDRX	Extended Discontinuous Reception
eUICC	Embedded Universal Integrated Circuit Card
eSIM	Embedded SIM
FDMA	Frequency Division Multiple Access
Finnpilot	Finnpilot Pilotage Ltd is a special assignment company entirely owned by the State of Finland. The company has the exclusive statutory right to carry out pilotage activities.
Fintraffic	Fintraffic is a special assignment company entirely owned by the State of Finland. Provides Vessel Traffic Service (VTS) to merchant shipping and other marine traffic and maintains safety radio operations.
FTIA	Finnish Transport Infrastructure Agency
Galileo	Europe's Global Satellite Navigation System

GEO	Geostationary orbit, Geosynchronous Equatorial Orbit
GLONASS	Russian satellite-based navigation system
GNSS	Global Navigation Satellite Systems
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	The Global System for Mobile Communications
GSO	Geosynchronous Orbit
Haavi	Application for fairway information management in the Waterway database
HARQ	Hybrid Automatic Repeat Requests
HEO	Highly Elliptical Orbit
IALA	The International Association of Marine Aids to Navigation and Lighthouse Authorities
IHO	International Hydrographic Organization
IMO	International Maritime Organization
INS	Integrated Navigation System
IoT	Internet of Things
ISM	Industrial, Scientific, and Medical, an unlicensed frequency band
UHF	Ultra High Frequency
LAT	Latitude coordinates
LEO	Low Earth Orbit
Lightguard	Third party service contractor’s AtoN remote monitoring system
LPGAN	Low Power Global Area Network
LPWAN	Low Power Wide Area Network
LON	Longitude coordinates
LoRaWAN	Low Power Wide Area Network
LTE	Long Term Evolution
LTE-M	Long Term Evolution for Machines, also known with abbreviations LTE-MTC and LTE Cat M
MEO	Medium Earth Orbit
MMSI	Maritime Mobile Service Identity
NB-IoT	Narrowband Internet of Things cellular network technology
OFDMA	Orthogonal frequency-division multiple access
Pooki	Waterways information service system

PSM	Power Save Mode
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Offset quadrature phase-shift keying modulation
RAIM	Receiver Autonomous Integrity Monitoring
Reimari	A centralized database for maritime safety equipment maintenance
SAT-IoT	Satellite Internet of Things network
SBD	Short Burst Data (Iridium)
SC-FDMA	Single Carrier Frequency Division Multiple Access
Seadatics	Third party service contractor’s AtoN remote monitoring system
SigFox	LPWAN network technology
SIM	Subscriber Identity Module
SMS	Short Message Service
SMSC	Short Message Service Center
SOAP	Simple Object Access Protocol
TDMA	Time Division Multiple Access
TBS	Transport Block Size
Tevinsa	Third party service contractor’s AtoN remote monitoring system
Traficom	Finnish Transport and Communications Agency
UHF	Ultra High Frequency
UL	Uplink
UNB	Ultra Narrow Band
VHF	Very High Frequency
VTS	Vessel Traffic Service
Waterway	Database for fairway information
WWAN	Wireless Wide Area Network
XML	Extensible Markup Language

1 Introduction

The subject of the thesis work is Internet of Things (IoT) and marine aids to navigation. The aim of the thesis is to find out the special needs of maritime aids for sending and receiving data from external environments and which IoT networks could be used for data transfer. Due to the challenging and demanding environmental conditions and limitations such as lack of power due to battery capacity and remote physical locations at sea, special requirements are placed on the technology and equipment used for data transmission. During last years, IoT technology has emerged strongly, and new low power wide area networks are available. This creates a question about the availability of alternative IoT networks which could be used for data transmission for aids to navigation. What could be the advantages and the weaknesses of possible other IoT network technology? This thesis work is about finding answers to these questions.

In the current state analysis, the number of marine aids in Finland which have a network connection for data transmission is investigated. Utilized network technology and marine aids requirements for data transfer are found out. This includes the volume of data sent and received, transmission frequency, typical data content and encryption. As maritime sector is internationally steered by standardization organizations and state authorities there is a need to investigate what kind of guidelines there exist around networks and data transmission for marine aids.

The thesis work was done for Finnish Transport Infrastructure Agency (FTIA) and more specifically for the Waterways Management unit. FTIA main responsibilities are to plan, develop and maintain road, rail, and maritime transport infrastructure in Finland. FTIA is responsible for about 8,300 kilometers of coastal fairways and 8,000 kilometers of inland waterways. This includes nearly 4,000 kilometers of fairways used for merchant shipping. FTIA is responsible for maintaining 25700 marine aids to navigation.

The goal of the study is to give an overall view about wireless technologies which could be used for data transmission for marine aids. The main differentiations will be presented for each possible IoT network technology. Thesis results can be used when deciding future purchase of marine aids and in the selection of the data transmission networks. Different transmission networks can be used also as an alternative network during situations when there are problems in the primary network in use. Actual cost comparison of different transmission networks is excluded from the study. Network coverage is based on information given by service providers. The network coverage was not verified with field tests in the study.

This thesis is divided into 6 sections. The first section introduces questions or problems to be investigated and the scope of the work. The second section explains methods and tools used in the study. The third section is about status analysis of marine aids using data transmission. Marine aids transmission network requirements are presented. Network requirements are influenced by environmental characters, data transmission needs, and other criteria. Standards and regulative information from authorities related to marine aids data transmission are also presented. The fourth section is about theory related to data transmission networks in question. The fifth section sums up the study results and shows the comparison results of the possible alternative networks and their characters. Cons and advantages of the networks are listed. The sixth section is about the summary of the results and the answers to the study questions. It includes summarized conclusions and other requirements needed to be considered related to marine aids data transmission technology selection when an alternative IoT network technology is considered.

2 Research method and design

This section describes research methods used in the thesis, as well as the research plan and its phases. The reliability and validity of the research is discussed in the last chapter.

2.1 Research method

The method used in this thesis was mainly qualitative. Information used in this thesis was from the status of marine aids to navigation, information available in the Waterway database and documentation and other material managed by Finnish Transport Infrastructure Agency. Network operators' information was obtained from their internet pages. International marine organizations' documentation and recommendations have been utilized in the thesis work. Information from legislation and other government authority organizations were found out concerning the topic of the thesis work. Related internet research sources and literature were used as a source of information. An important role was the opinions and interviews of the Finnish Transport Agency's fairway unit, the Finnish Transport and Communications Agency, the Finnish Meteorological Institute, Mitta Oy and experts who manufacture navigation lanterns.

2.2 Research design

The research design was divided to four major phases, see Figure 1. First phase was to analyse the current state of the marine aids to navigation that utilize data transmission to realize remote monitoring and remote controlling services in Finland. The analyse included number of marine aids to navigation, geographical location, data sending schedule, data amounts used, traffic models, related hardware components and IoT networks used. The requirements for marine aids to navigation data transmission were formed.

Based on the current state analysis a theory phase was conducted. The requirements from the current state analysis were used to better focus to the suitable IoT networks theory. In the research work a network coverage information was used as a key differentiator to include a technology into the research. Technologies belonging to the Wireless Wide Area Network (WWAN) in Finland were included to the research work. Besides IoT networks theory part there was also an investigation about generic requirements for marine aids to navigation data transmission. Generic requirements were investigated from international navigational organizations' sources as well as from authority recommendations and principles, and from national legislation.

In the Results and Analysis phase a comparison of IoT networks was done against the FTIA requirements for marine aids to navigation data transmission networks.

In the summary and conclusion phase answers to the research questions were given.

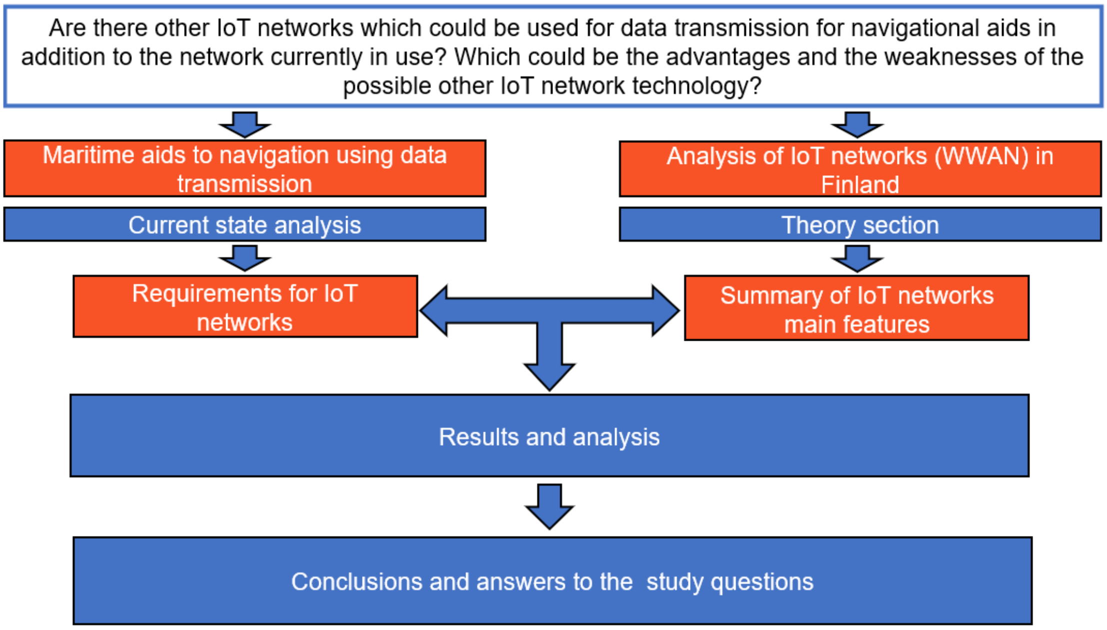

Figure 1. Research Design.

2.3 Reliability and Validity

The results of the research were based on the current state analysis and the theory analysis, and conclusions based on those. Current state analysis was done according to the data in operative and in maintenance databases managed by Finnish Transport Infrastructure Agency. Theory analysis of the network technologies was based on the information found from the sources used in the research. The sources used were from scientific publications and from technical information from manufactures of Aid to Navigation (AtoN), from IoT devices manufactures and from IoT networks service providers. IoT networks information was based on the information that the local network operators in Finland have released. Information about network coverage might not be valid in every geographical location in coastal and inland waterways areas in Finland. Field tests at the AtoN location provide real information about network coverage and other features, which should be compared against the navigational aid requirements.

3 Current State Analysis

This section introduces marine AtoN and current methods used for data transfer. This concerns remote monitored and remote controlled AtoNs administrated by Finnish Transport Infrastructure Agency. Firstly, a short review to the different AtoN types and to early experiments with remote monitoring is included. Remote monitoring is mainly in use in the major merchant shipping waterways (fairway class 1). In fairway class 1 exists about 1500 lighted AtoNs which includes about 1000 floating marks. The benefits and reasons to use remote monitoring and remote controlling were explained. The amount and locations of AtoNs were found out as well as the current wireless networks in use. Guidelines and requirements from standardization organizations and other guidelines and legislation connected to AtoN data transmission and connectivity were summarized. New emerging requirements seen in the future were briefly presented.

3.1 Aid to Navigation

An Aid to Navigation (AtoN) is a fixed or a floating construction with devices designed and operated to enhance safe and efficient navigation of vessel traffic. Examples of a AtoNs are a spar buoy, lighthouse, or an edge mark. The purpose is to improve marine safety and efficiency of navigation, to assist position and to safe course and to warn of dangers or obstructions. AtoNs are also called navigation marks or seamarks or waterway safety devices.

A floating aid to navigation is moored to the seabed with an anchor chain or a wire, usually buoys and spar buoys. For buoys, the part above sea level has a height/diameter ratio up to 5:1. A buoy is typically moored with a slack anchor chain allowing it to float freely around its mooring position. Spar buoy is a floating aid to navigation moored to the seabed. The part above sea level has a height/diameter ratio bigger than 5:1. The spar buoy is pretensioned so that the anchor chain or wire is tight; therefore, the spar buoy does not float around its position. Fixed safety devices are permanently established on land or water (seabed), e.g., lighthouse, beacons, edge marks, line marks and sector beacons. AtoNs can be lighted or unlighted.

3.2 Remote monitoring, early experiments

The Maritime Administration's remote monitoring experiments started already in 1953, when the first remote monitoring equipment was installed in the Kallbådagrund radio beacon, which transmitted regularly simple status report (ok, minor alert or major alert message) about beacon operational condition. Later, more AtoNs were included in the scope of the system, but when the electric generators serving as the energy source were replaced with batteries, monitoring devices installed had to be removed to avoid excessive power consumption. Remote monitoring experiments got a new start when Oy Sabik Ab from Porvoo made a remote monitoring device, which allows status information of AtoNs, e.g., battery voltage, light burning time and status, and other parameters which could be read from a close distance wirelessly. The device also helped to adjust the flashing light parameters wirelessly from a short range. The construction of the first actual remote monitoring and remote controlling system began at the end of the 1980s on Rauma's deep channel. A system operating in the Very High Frequency (VHF) bandwidth was completed in 1996. However, the system had to be dismantled already in 2002, when the frequency bandwidth of the remote-control system was reserved for other use. At the same time in Lauttasaari at the sea station, there were experiments on the suitability of Ultra High Frequency (UHF) devices for nearby waterways and ports for remote monitoring and controlling. A larger-scale remote monitoring experiment was started in 2001, when remote monitoring and controlling devices based on the Global System for Mobile Communications (GSM) technology were introduced in Sköldholmas on the upper fairway and later in the autumn on the Rauma fairway. At first the control of the lighting devices took place from Vessel Traffic Service (VTS) stations with a GSM phone. Later system was expanded so that pilots on ships could send from registered GSM phones control commands directly to the AtoN’s light. In 2001, the first and so far, the only device based on the Orbcomm satellite system was installed in the Armbågen lighthouse. This was a good test for the satellite technology, which enabled remote monitoring of aids to navigation outside the GSM coverage area [1].

3.3 AtoNs with wireless data transfer

This chapter describes the different AtoN wireless data services used in FTIA. AtoN locations using wireless services are displayed. The techniques used are explained along with examples of sent and received remote AtoN messages.

3.3.1 Remote monitored AtoN

Today there are 2066 AtoNs in place which are equipped with remote monitoring capability. From the remote monitored AtoNs there exists 1699 marks which are equipped with navigational light and 367 AtoNs are floating without navigational light (situation at 11/2022). Figure 2 shows the remote monitored AtoN places owned by the Finnish Transport Infrastructure Agency [2].

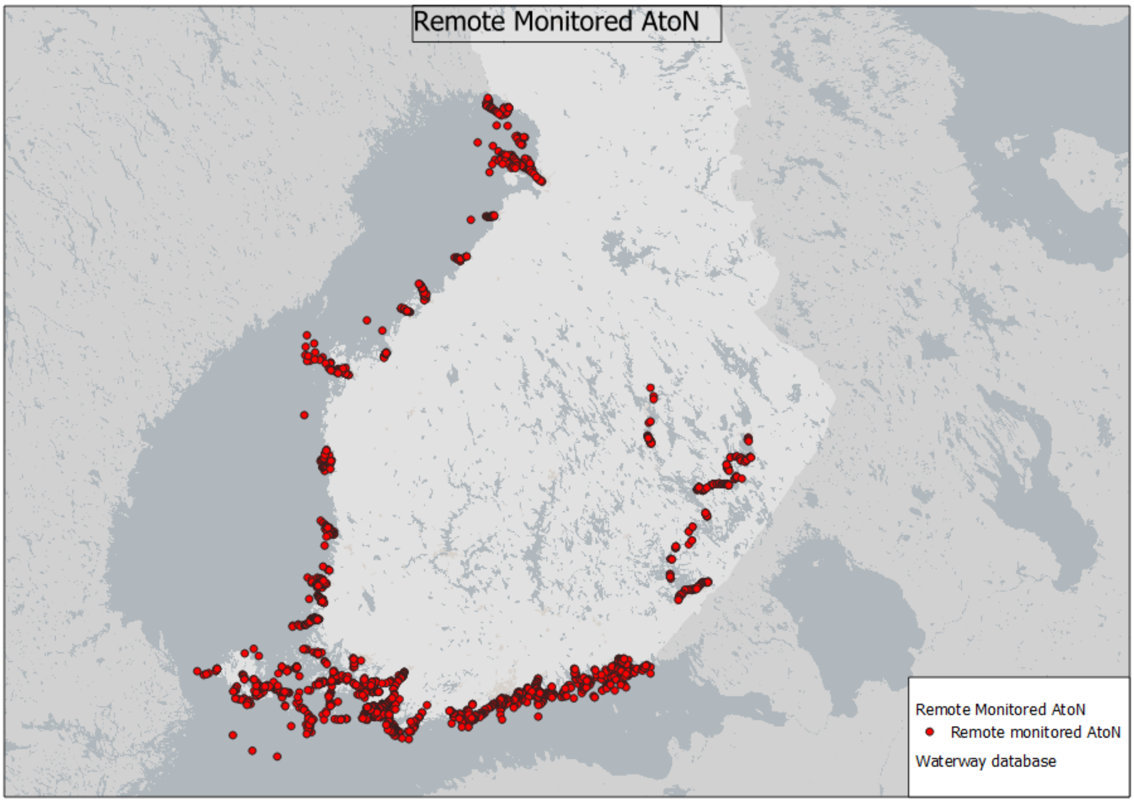

Figure 2. Remote monitored AtoNs [2].

AtoN remote monitoring gathers below mentioned parameters to service contractor's AtoN remote monitoring system:

- last flashing off time
- last flashing on time
- temperature, average
- battery voltage, 24 h average and the lowest measured
- voltage level of the backup battery
- charged amper hours at the last 24 h
- maximum charging current on the last 24 h
- spare battery voltage
- AtoN power consumption while light on
- heel angle
- optical feedback level 0-255
- last measured position coordinates Latitude, Longitude
- lantern light on counter

- alarm for light failure and wrong position
- warnings for light, position, lantern tilted, battery voltage, optical feedback
- AtoN identification number.

Monitored data categories vary and are depending on AtoN type and configuration and installed sensors. Service contractor’s AtoN monitoring system gathers and processes information sent from AtoN before transmitting it to the centralized database for maritime safety equipment maintenance (Reimari). Typically, data is transmitted once or twice a day from AtoN to service contractor’s monitoring application. Alarms are transmitted immediately after their appearance.

3.3.2 Remote controlled AtoN

With remote controlled AtoN functionality it is possible to increase the brightness of navigational lights to ensure AtoN visibility and safety on the fairways during harsh visibility conditions. Upon request, Vessel Traffic Service (VTS) center can adjust the brightness of AtoN lights in the following fairways and ports in Finland:

- Långnäs-Färjsundet fairway (Godby, Åland)
- Kokkola 14 m fairway
- Port of Hanko
- 15,3 m fairway between Kiviletto and Mussalo (Kotka)
- Rauma 12 m fairway and at the Port of Kaskinen
- Laitaatsalmi fairway section (Savonlinna)
- Haponlahti-Heinsalmi fairway section (Savonlinna).

In the Haponlahti-Heinsalmi fairway section AtoNs brightness is automatically adjusted according to the visibility conditions and the use of the Automatic Identification System (AIS). Vessels with an A-class tracking system are considered when arriving at the fairway area. Automatic adjustment is available only in the dark and can only increase the light output of the aids to navigation beyond their nominal intensity. Visibility is measured using a visibility sensor placed at the Vihtakanta bridge. Wide local variations may occur in visibility conditions, so the information provided by the visibility sensor does not necessarily represent visibility throughout the entire fairway. Upon request, the VTS station can also manually increase the brightness of aids to navigation [3]. All remote controlled AtoNs also belong to the remote monitoring service. Figure 3 shows FTIA's remote controlled AtoN locations [2].

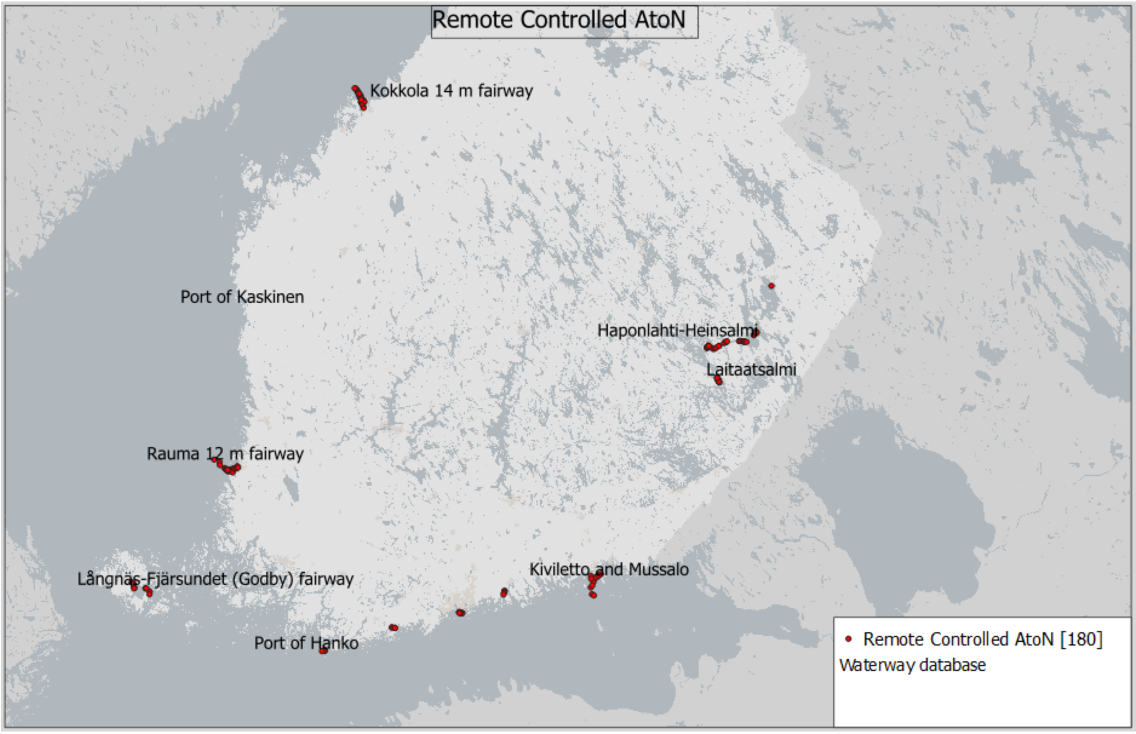

Figure 3: FTIA's remote Controlled AtoN locations [2].

3.3.3 Automatic Identification System

Two types of AIS AtoN, virtual and synthetic, are in use in Finland. Figure 4 presents all permanent AIS AtoNs in Finland. The information is obtained from the Waterway database [2]. In addition, temporary virtual AIS AtoNs are in use in coastline, in restricted waters, and in port approaches. Those are activated to mark some temporary hazardous positions such as wrecks or places where the sea depth is temporarily lower than presented in the navigational charts. There exists also temporary virtual AIS AtoNs that upon request can be switched on by the VTS centre. One example of virtual AIS AtoN is between the Oulu 12,5 m fairway and the pilot boarding position.

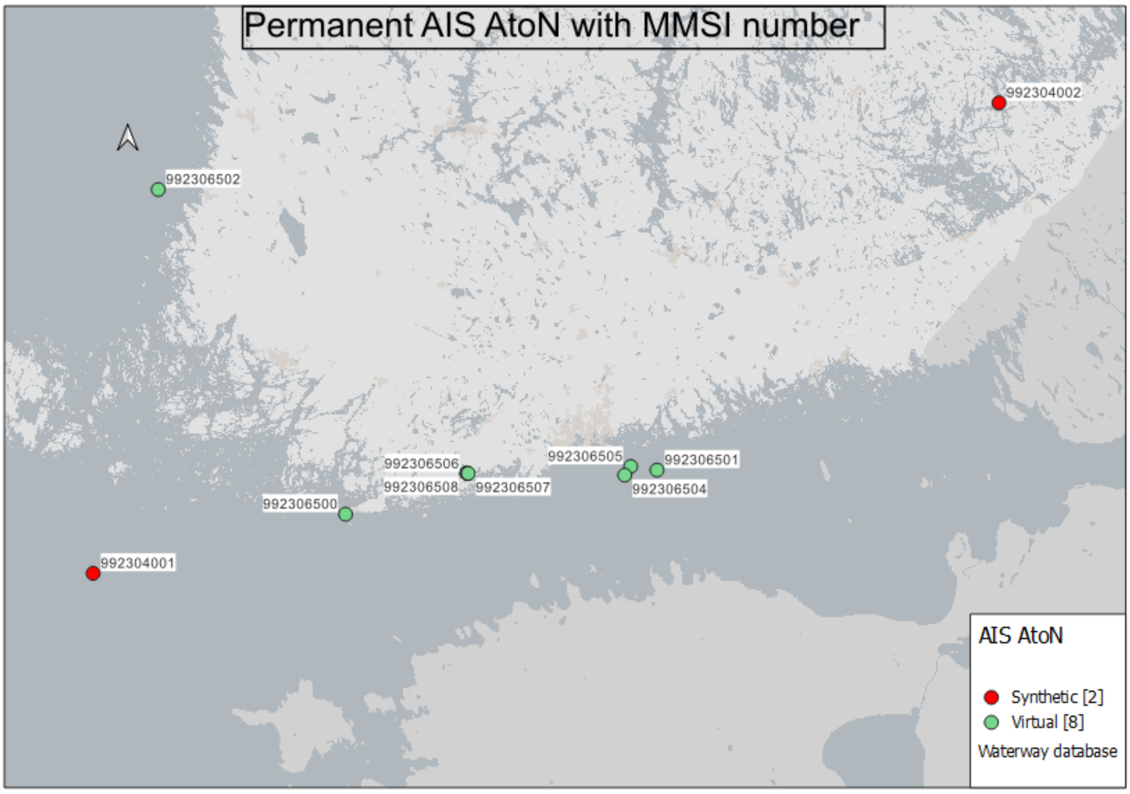

Figure 4. Permanent AIS AtoNs with Maritime Mobile Service Identity (MMSI) number in Finland [2].

3.4 Technology overview

In data transfer and network connections, 2G network technology is used in SMS messages and partly also in General Packet Radio Service (GPRS) data. This is the mostly used network connectivity solution. Long Term Evolution for Machines (LTE-M) technology is in use utilizing 4G and 5G cellular networks in the latest installations. The network connectivity device is integrated with the marine lantern installed to the AtoN. VP LED and MVP LED are the most common lantern types used by FTIA for floating AtoNs. For fixed AtoNs LED 155, LED 160, LO 200M and ODSL 200 types are in use. All these are products manufactured by SPX Aids to Navigation Oy. Data transfer protocols are owned by the manufacturer and are not publicly available [4]. The data sheet of MPV led lantern is shown in the Appendix 1 [5]. Wireless data connection to AtoNs which do not have a light functionality is established with Taival GNSS trackers' 2G (GSM/GPRS) product. Appendix 2 shows technical specifications for the Taival GNSS tracker [6].

Remote monitoring information is gathered to the following service providers' AtoN monitoring systems (system, company, amount of monitored AtoNs):

- Seadatics, Arctia Meritaito Oy [7], 2049 pcs
- Tevinsa, SPX Aids to Navigation Oy [8], 13 pcs
- Lightguard, SPX Aids to Navigation Oy [9], 4 pcs.

All remote-controlled safety devices belong to the Seadatics - system. Remote controlling is performed by VTS with an interface in the Seadatics application. Appendix 3 presents an example of remote monitored information received from an AtoN Katajaluoto No. 12888 to the Seadatics remote monitoring system. Finnish Transport Infrastructure Agency has published Reimari interface for remote monitoring, to which all service providers must submit information. AtoN remote status monitoring data flow with Reimari Web Service [10] is shown in Figure 5.

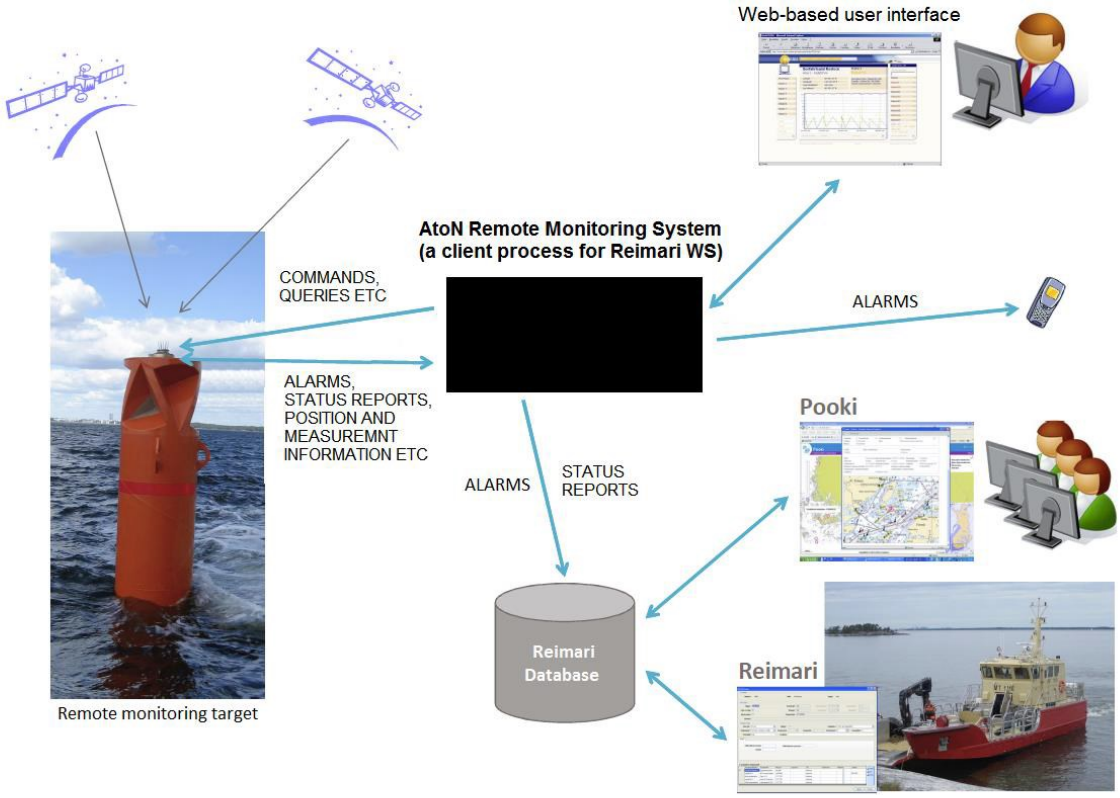

Figure 5: AtoN remote status monitoring data flow with Reimari Web Service [10].

Communication with the Reimari Web Service is achieved using an Extensible Markup Language (XML) based on a Simple Object Access Protocol (SOAP). Two types of messages are supported, an AtoN information query message, and six types of AtoN report messages:

- AtoN Settings Message
- Floating AtoN Status Message
- Fixed AtoN Status Message
- AtoN Alarm Message
- AtoN Warning Message
- AtoN Warning Ended Message

Query message is used to ask AtoN information from Reimari Web Service. The AtoN Settings Message method is used to submit AtoN Settings to the Reimari Web Service. This message type is preferably sent when AtoN configuration has changed. There are messages for floating and fixed AtoN status reports. AtoN status report message is sent to Reimari WS by the service provider upon receiving reports from a floating AtoN (for example, a buoy, ice buoy or a spar buoy). Table 1 presents floating AtoN status message elements.

Table 1: Floating AtoN status Message elements.

Element name in Finnish	Datatype	Description
janniteKeskiarvo	Double (1)	Battery voltage (24 h average) [V]
janniteMinimi	Double (1)	The lowest measured voltage within 24 hours [V]
lampotilaKeskiarvo	Double (1)	Temperature [°C]
paivasiirtyma	Date Time	Last „flashing off ”time
yosiirtyma	Date Time	Last „flashing on ”time
password	String	Web service password
tlnumero	Integer	AtoN identification number
username	String	Web service username
valoaikaLaskuri	Long	Lantern light on counter [h]
tehonkulutus	Double (1)	AtoN power consumption while light on [W]
optinenTakaisinKytkenta	Integer	Optical feedback level 0-255
kallistuskulma	Double (1)	Current heel angle [deg]
mitattuSijaintiLat	Double (5)	Last measured coordinates LAT
mitattuSijaintiLon	Double (5)	Last measured coordinates LON

Alarm messages are for light failure and incorrect location. Warning messages concerns light, location, lantern tilted, low voltage, low voltage backup battery and optical feedback measured from lantern sensors. An example of an AtoN (Katajaluoto No. 12888) remote monitored data which has been transferred from the service providers remote monitoring system to the Reimari database [10] is shown in the Appendix 4.

AtoNs with installed Automatic Identification System (AIS) transponder are not in use in Finland. AIS functionality to send status information from AtoN is thus currently not in use and the AIS transmission of virtual – and synthetic AtoNs comes from VTS center using AIS stations located alongside the coastline. Currently there is no sensor data transferred from physical AtoN using AIS transmission.

3.5 Standardization organizations

The International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) has released a guideline G1008 'Remote Control and Monitoring of Marine Aids to Navigation' [11]. The guideline gives advice when considering to set-up or update a system for remote monitoring and for remote controlling of marine AtoN. The guideline describes some overall advice about data transmission links and their integrity, reference costs, and transfer delays. The document also catalogues monitoring and controlling requirements and messages related to these. As an example, the monitored functionalities could consist of following parameters: navigation light, racon, AtoN AIS, Differential Global Positioning System (DGPS), power supplies, mains with a battery backup system, renewable (solar, wind) battery charging system, ancillary systems, and sensors. Examples of ancillary site equipment and sensors are fire alarm and security systems, measurement apparatus, tidal height gauges, wind speed and direction meters, temperature and motion sensors. The guideline also includes a chapter about design considerations. One of the most relevant is energy consumption. This is the case with solar powered AtoN and the ones with a battery and with limited power supply. One way to limit energy consumption is to limit transmission and send data only when there is a change in measured parameters or when an alarm occurs. Transmission could happen only at a predefined time per day as status updates from the remote AtoN. The guideline describes in general level following data transmission networks: public and private networks, radio links, cellular telephone systems and satellite communication systems.

Guideline G1179 'An Introduction to the Internet of Things (IoT) from and IALA perspective' [12] provides general advice on utilizing IoT technology for marine AtoN monitoring and controlling needs, as well as a description of IoT layers and potential communication protocols.

IALA recommendation R0143 ‘Provision of virtual aids to navigation (O-143)’ offers guidance on the provision of Virtual Aids to Navigation (Virtual AtoN). The recommendation includes different typical applications of virtual AIS AtoN. Temporary and permanent usage of AIS AtoN is explained as well as some risks and limitations related to use of AIS AtoN [13]. In IALA guideline G1081 ‘Provision of virtual marine aids to navigation’ there are mentioned the risk mitigation recommendations and opened limitations related to virtual marine aids to navigation. This includes GNSS vulnerability, spoofing and jamming of virtual AtoNs. Display restrictions on ships Electronic Chart Display Information System (ECDIS) and radar display are highlighted if AIS symbols overlap with chart symbols [14].

International Maritime Organization (IMO) has a definition for AIS Aids to Navigation which could be portrayed on devices or systems such as ECDIS, radar or Integrated Navigation System (INS). IMO defines two different implementations of AIS AtoN, a physical AIS AtoN and a virtual AIS AtoN [15].

International Hydrographic Organization (IHO) has released specifications and guidance regarding Electronic Navigational Charts (ENC) and their display in ECDIS in S-52 portrayal bulleting 8: ‘Portrayal of virtual AIS aids to navigation’ [16].

3.6 National legislation and regulation

Marine AtoN legislation is in the Water Traffic Act (782/2019) in the article 4 which includes definitions of both physical and virtual AtoN. In the article 4 there is also included legislation about the right to decide to set up a new AtoN or to remove an AtoN and what procedures are needed to be followed [17]. The Water act (587/2011) includes in the article 10 definitions and requirements about public fairway channels and the legislation about aids to navigation installation [18]. The Traffic and Communications Agency publication (2.7.2021, TRAFICOM/85503/03.04.01.00/2021) regulates the use and the installation of navigational aids [19]. For remote monitoring and remote controlling there are some practises agreed with Traficom to inform about the network technology for data transmission, protocols and processes and security practises.

3.7 Benefits using remote monitored and remote controlled AtoNs

The functionality of an AtoN remote monitor and control can provide several benefits, which can be categorized as experienced by a fairway user, benefits for safety and savings in fairway maintenance procedures. The main benefits are:

- Failures in AtoNs functionality are known in real time (this leads to fault notifications in real time, information sharing about failures in time and warnings to fairway users without delays).
- AtoN’s actual location and possible light functionality can be checked from monitored data (this is practical in cases where the AtoN has been lost from the intended location or when the functionality of the AtoN light needs to be verified. With remote monitoring, the location and status of the light can be verified).
- The predictability of the need for maintenance of marine safety devices and the timeliness of fairway maintenance measures reduces faults and safety device visits and thus the costs of fairway maintenance.
- The occupational safety risk decreases with the timely maintenance of hard-to-reach areas.
- Reducing periodic inspection and maintenance visits with remote monitored safety devices reduces costs and environmental harm, such as emissions, disturbance of animal nesting.
- The visibility of remote controlled safety devices improves when the light output can be adjusted according to the weather conditions (for example fog, snow, background light).

3.8 Goals for remote monitoring and remote controlling

Finnish Transport Infrastructure Agency is aiming to utilize the above-mentioned benefits of remote monitoring and controlling as much as possible. This goal can be defined with following targets:

- The cost of a remote monitored safety device should not be higher than the cost of traditional AtoN maintenance (inspection, maintenance, fault repair).
- Remote monitoring and controlling must not become a significant new source of failure.
- The production of remote monitoring and controlling must not become a monopoly and it must serve all fairway maintenance

contractors independently. FTIA must not act as an AtoN monitored information relay operator.

The Finnish Transport Infrastructure Agency address above targets with the following measures:

- The Finnish Transport Infrastructure Agency has published the Reimari interface for remote monitoring, to which all service providers must submit information.
- The service provider must have available a monitoring system for a more detailed review of sensor data sent from AtoNs.

In the future, it is planned to increase remote monitoring for lighted commercial shipping fairways including also fairways' unlighted floating safety devices such as buoys.

3.9 Technical requirements for AtoN IoT equipment

Finnish Transport Infrastructure Agency is ordering remote monitoring and controlling functionality for AtoNs from contractors. There are criteria for location accuracy and to the physical durability of the modules against harsh natural conditions. Special criteria are in place for location accuracy sensor. The frequency of accuracy measurements affects to power consumption. A practical compromise is to require an accuracy of 2.5 meters from the average value of five consecutive measurements. It is sufficient from a monitoring point of view and at the same time achievable with current commercial Global Navigation Satellite Systems (GNSS) sensors.

Reliability in harsh environments means that the modules are enough physically protected against the demanding elements at the sea. Physical phenomena such as a wide variation of temperature as well as mechanical stress are significant in marine conditions. Temperatures at sea vary roughly between -30°C and +30°C, but in special cases temperatures can be also outside this range. The temperature of the modules integrated in the AtoN can rise significantly higher than the air temperature due to solar radiation. Temperatures up to +60°C are completely possible, even higher. Because of this, the modules must work at a temperature range from – 30°C to +60°C. Various impacts are the most significant cause of mechanical stress. Impacts are caused, for example, by sea conditions or by the effect of ice. Entire AtoN can get under the ice. Accelerations of up to 10G can occur. Appendix 5 shows criteria for vibration and acceleration testing of a solar powered led marine beacon. Maritime safety equipment such as buoys with lantern in difficult ice conditions must withstand a force of 65 kN. Lantern devices for buoys and a spar buoy in other ice conditions must withstand a force of 14 kN. Permanent, measurable, or noticeable changes to the structure and seals in the lantern device should not happen. In addition, sensors and communication modules are at the mercy of the weather. Waterproof at different temperatures is a basic assumption. The AtoN with the installed modules may end up below the water surface for a long period of time. The modules are required to withstand a 24-hour immersion to a depth of 3 meters without breaking. Especially in marine conditions, the water is not clean and can contain other minerals such as salt, increasing the corrosiveness of the water. Corrosion-prone materials should be avoided. Most plastics are resistant to the corrosive effect of salt water.

3.10 Remote monitoring and controlling functionality in coming years

The amount of remote monitored and controlled AtoNs is going to increase gradually in the merchant shipping fairways. The new automatically adjustable AtoN light brightness according to visibility conditions and AIS traffic (class A) on the fairway is analysed based on the results of the first installations. FTIA will follow the recommendations from IALA and other international organizations and authorities in maritime about AtoN remote monitoring and controlling functionality. The manufactures’ products and releases are followed. Remote monitored and controlled aid to navigation will be important part of the future smart fairway concept. Smart AtoN functionalities are still under investigation by several maritime organizations and authorities. A smart AtoN is gradually expected to provide new services as part of the intelligent fairway to enable autonomous vessel traffic.

4 IoT network technologies

In this section there was found out theoretical background about the suitable IoT networks technologies that fulfil the requirements of a marine aid to navigation. The main requirements were a low power consumption, long battery life, small amount of data transmission over long distances and a network coverage and availability in the coastline and inner waters in AtoNs locations.

IoT Networks technologies which could fulfil the needs of marine aids data transmission requirements are part of Low Power Wide Area Networks (LPWAN) and to cellular networks. These technologies belong to the Wireless Wide Area Network (WWAN) technologies. LPWAN networks typically fulfil requirements such as low power sensor networks and low bandwidth hardware controls. They are suitable for devices that require long battery life and send small amounts of data over long distances. Cellular Networks are typically used for various data communication needs. From cellular networks, 3G was excluded from the thesis because networks are widely going to be removed due to newer technologies available. Released frequencies will be later available for 4G and 5G networks. In Finland Elisa, Telia and DNA have decided to remove 3G networks from use during year 2023 [20], [21], [22]. From 4G and 5G networks only the narrowband IoT technologies were included into the thesis. Automatic Identification System (AIS) which utilizes Very High Frequency (VHF) maritime band radio technology is included as it is used also for AtoN status data transmission. Satellite networks services are a superior technology in terms of global coverage. During last years the amount of satellite IoT service providers has increased. As a conclusion following IoT technologies were included into the thesis work:

- SigFox
- Low Power Wide Area Network
- 2G network
- Short Message Service
- Narrowband-IoT
- Long Term Evolution for Machines

- Satellite networks
- Automatic Identification System

4.1 SigFox

Sigfox is a radio access end to end network technology that is operating on an unlicensed Industrial, Scientific, and Medical (ISM) frequency band. The network is based on Sigfox's proprietary standard. Sigfox is a global network with presence in Europe, in the U.S., in South America, in Asia, and in Africa and the networks are managed by local operators. A local operator sets up the base stations and cloud service and provides access to registered Sigfox chip IoT devices. Every IoT-device connected to the Sigfox network needs a subscription. Sigfox IoT-devices are directly connected to public base stations (i.e., star topology). Figure 6 shows a typical Sigfox architecture. The connectivity fee is low and there are no spectrum costs. It is not possible to establish a private Sigfox network [23].

Figure 6. Sigfox architecture [23].

Sigfox uses a patented Ultra Narrow Band (UNB) radio technology. In Europe Sigfox networks are utilizing 868 MHz frequency band and 100 Hz bandwidth. Sigfox uses Differential Binary Phase Shift Keying (DBPSK) in its uplink modulation, and Gaussian Phase Shift Keying (GFSK) in its downlink modulation. Sigfox was initially designed only for uplink transmission but now it is advanced to bidirectional communication. The number of uplink messages is limited to 140 messages per day per end-device. The maximum payload length for uplink message is 12 bytes. The number of downlink messages per day is limited to four and the maximum payload length of each downlink message is 8 bytes. As the uplink messages are not acknowledged there is used time/frequency diversity and transmission duplication to ensure uplink transmission reliability. Sigfox uses AES encryption. Each Sigfox base station can handle up to a million connected objects. The network coverage area is between 30 - 50 km in rural areas and between 3 - 10 km in urban areas. The end-devices do not listen to radio channels before transmitting messages and they are in sleep mode most of the time. Hence a device power consumption is very low which ensures a long device battery life cycle. Typical use cases are smart metering, water monitoring, energy management system, electric monitoring, smart waste management, asset tracking, and home security [24]. Connected Finland Oy is the Sigfox operator in Finland. Sigfox outdoor network coverage in Finland is shown with blue colour in Figure 7 [25].

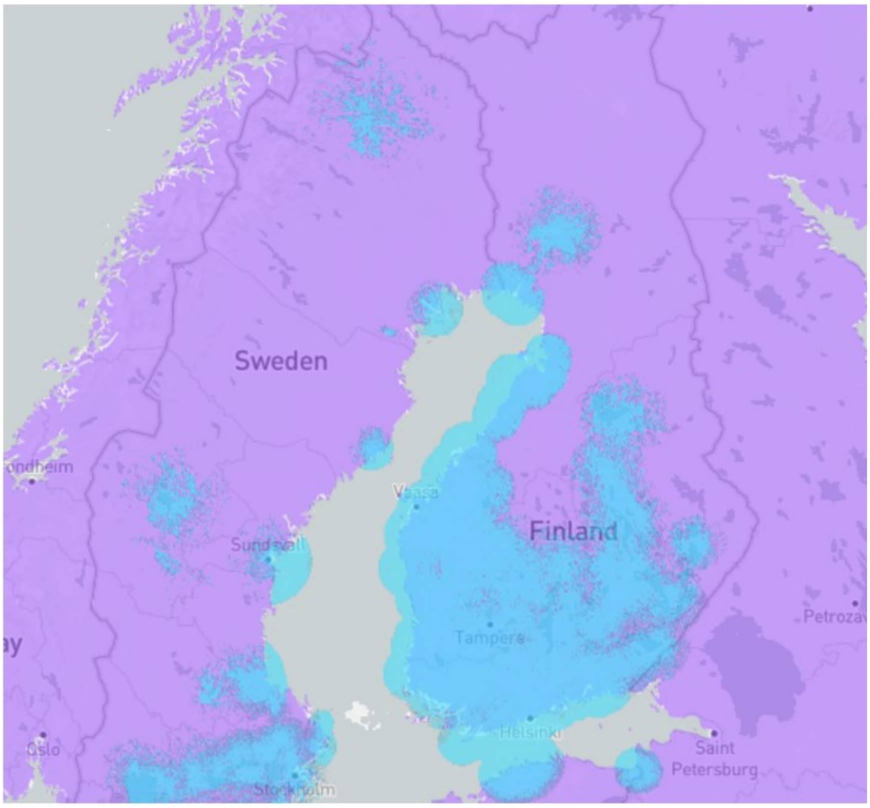

Figure 7. Sixfox network outdoor coverage in Finland (shown with blue colour) [25].

4.2 Low Power Wide Area Network

Low Power Wide Area Network (LoRaWAN) was initially created in 2009 by Cycleo, a start-up company in Grenoble, France and then purchased by Semtech (USA) in 2012. LoRaWAN is a wireless Low Power Wide Area Network (LPWAN) technology which was standardized by LoRA-Alliance in 2015. It is deployed in 42 countries, and new rollouts are still ongoing. LoRa is a spread spectrum technology using unlicensed sub-GHZ band. In Europe, LoRa uses 868 MHz frequency bands with 125 Hz and 250 Hz bandwidths. LoRa utilizes chirp spread spectrums (CSS) modulations which ensures full bidirectional communication. Generated LoRa signals have low noise levels which enables high interference resilience and signals are difficult to detect and to jam. The network range is about 5 km at urban and about 20 km at rural areas. LoRaWAN supports six spreading factors (SF7 to SF12) to adapt the data rate and the range. Higher spreading factor provides longer transmission range and lowest data rate. Data rates varies between 300 bps to 50 bps and the maximum payload length for each message is 243 bytes. LoRaWAN network is a star network where each transmitted message by an end-device is received by all base stations in the range. With this redundant reception LoRaWAN improves the communication reliability ratio. Redundant messages are filtered by the backend system and the message is forwarded to the corresponding application servers. Because of the reception of each message by multiple base stations there is no need for handovers.

LoRaWAN defines multiple communication classes:

- Class A (bidirectional end-devices): end-device is receiving downlink messages only after it's uplink transmission period. There are two short windows for receiving downlink messages. End-device schedules uplink transmissions based on its own communication needs. This is the lowest power consuming class.
- Class B (bidirectional end-devices with scheduled receive slots): same as in class A but in addition there exists an extra receive window at scheduled times. The end-device is receiving a time synchronized beacon from the base station to be able to know when to listen incoming messages.

- Class C (bidirectional end-devices with maximal receive slots): end-devices are listening almost all the time for incoming messages. This leads to excessive energy consumption and the method is meant meanly for IoT applications with a continuous energy power resource.

LoRaWAN utilize unlicensed frequency bands which means that spectrum costs are free, which is contributing to low end-device costs. It is also possible to set up and to manage private LoRa networks. A hybrid operating model combines local private networks with public networks base stations. One disadvantage is that all LoRa radio modules come only from one manufacturer, Semtech. In those cases where long battery lifetime is required, and low cost of sensors is important, LoRaWAN is the selected technology. LoRaWan is a reliable communication method also in cases where devices are moving at high speed. Typical use cases are in smart metering, agriculture, smart buildings, smart environments, logistics, smart homes, and smart environments. [26]. Digita is the local LoRa operator in Finland. Digita's LoRaWAN network coverage is shown in Figure 8 [27].

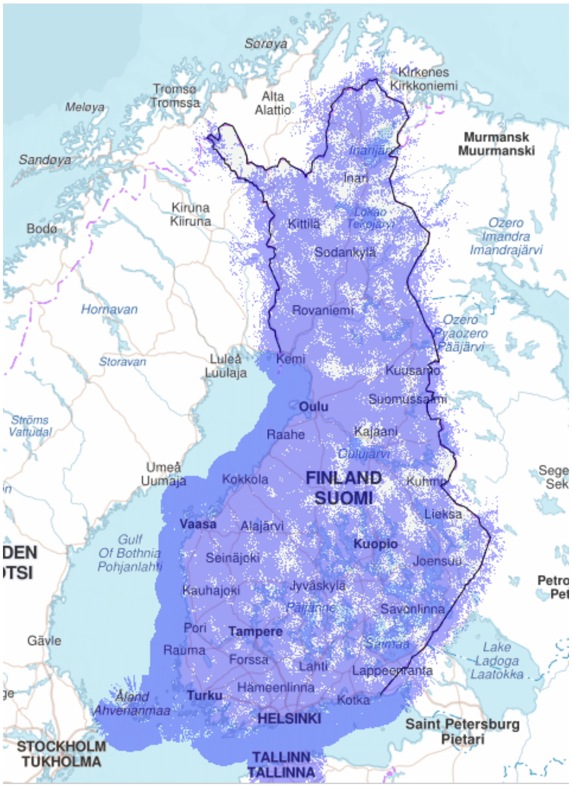

Figure 8. Digita’s wireless LoRaWAN network coverage in Finland [27].

4.3 2G network

2G network is a second-generation wireless telephone technology also known as the global system for mobile communication (GSM). GSM is the first cellular system based on digital technology. The technology was launched in Finland in the year 1991. The 2G was standardized by European Telecommunications Standards Institute (ETSI) and continued in 3rd Generation Partnership Program (3GPP). Data rate is up to 64 Kbps. Latency is between 300-1000 milliseconds. DNA Oyj, Elisa Oyj, Telia Finland Oyj and Ålands Telekommunikation Ab are the 2G operators in Finland. In Finland 2G uses licensed mobile 900 MHz and 1800 MHz bands. 2G utilizes multiplexing and allows communication of multiple users on a single channel with GMSK modulation. The range is up to 40 km. Main services are digital voice, Short Message Service (SMS), Multimedia Message (MMS) and Internet access [28].

The improvement of 2.5G also known as a General Packet Radio Service (GPRS) technology was launched which increased the data speed up to 150 Kbps. After that an umbrella of 2G technology called Enhanced Data rate for GSM Evolution (EDGE) was introduced. This is also known as 2.75G which is an upgrade to GPRS with maximum data rate up to 384 Kbps [29]. In Figure 9 can be seen 2G networks coverage per operator in Finland [30], [31], [32].

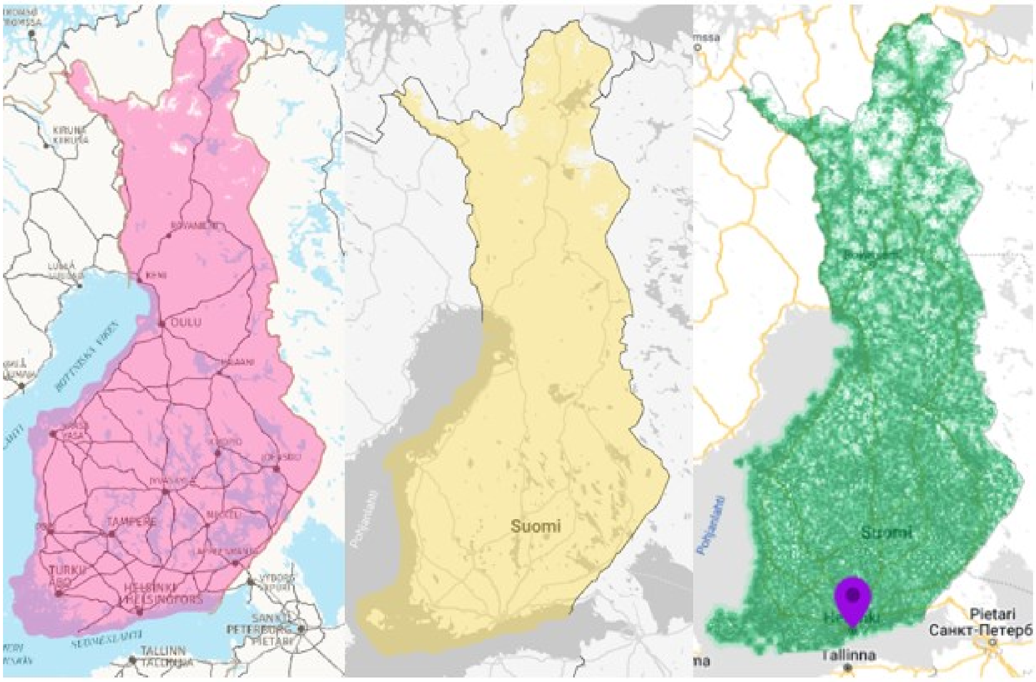

Figure 9. 2G network coverage area by operators DNA, Elisa and Telia from left to right [30], [31], [32].

4.4 Short Message Service

The Short Message Service (SMS) is standardized by 3GPP and utilizes 2G, 3G, 4G and 5G mobile networks licensed bands. SMS is used for sending messages of limited size (max 160 7-bit characters or 140 8-bit bytes) to and from mobile devices. SMS are sent to the Short Message Service Centre (SMSC), which has a store forward mechanism. It attempts to send messages to the SMSC's recipients. If a recipient is not reachable, the SMSC queues the message for later retry. If the response is inactive, then SMSC will hold the message. Message delivery is 'best effort' so there might be situations that some messages are lost. However, delays and complete loss of a message are not common. The SMS message sending started in 1992. Nokia made the first mobile phone that was able to send messages in 1993. Typically, SMS has been used for text messaging between mobile phones. New mobile chat applications have reduced traditional use of SMS in text messaging. Instead, it is more used in password confirmation, product verification, reminders, appointments, and alerts. The use of SMS for IoT device communication has increased rapidly. There are several advantages to use SMS for IoT communication such as very low power consumption in devices, network coverage is global, and network is reliable [33].

4.5 Narrowband-IoT

Narrowband-IoT (NB-IoT) is a low power wide-area network which is based on Long Term Evolution (LTE) or GSM technology under licensed frequency bands. NB-IoT is standardized by 3GPP. NB-IoT is using one 200 kHz frequency band which equals one resource block in GSM or in LTE transmission. There are following operation modes possible with this frequency band:

- Stand-alone operation: a scenario where currently used GSM frequencies bands are utilized.
- Guard band operation: a mode where unused resource blocks in the LTE carrier's guard-band are utilized.
- In-band operation: resource blocks in the LTE-carrier are used.

In Figure 10 the different operation modes for NB-IoT are presented [24].

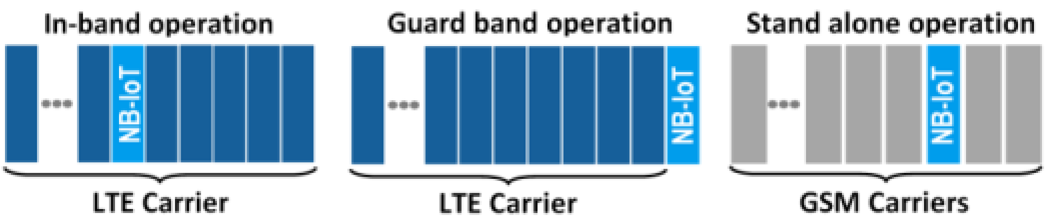

Figure 10: Operation modes for NB-IoT [24].

NB-IoT communication protocol is based on LTE protocol, but NB-IoT reduces LTE functionalities to the minimum and enhance some functionalities required for IoT applications. This is done to make the end-devices simpler, cheaper and to minimize the use of battery power. NB-IoT allows more than 100K devices per cell and this can be increased by using multiple NB-IoT carriers. In uplink NB-IoT utilizes QPSK modulation and Frequency Division Multiple Access (FDMA) and Orthogonal FDMA (OFDMA) in downlink. The maximum throughput rate is 200 kbps downlink and 20 kbps uplink. The latency times are short, about 1.5 s - 10 s. Each message has maximum 1600 bytes of payload. There is no limitation in the number of messages per day. NB-IoT technology supports long battery lifetime. With LTE-based synchronous protocol and use of licensed spectrum NB-IoT is providing guaranteed QoS transmission. The network range is 1 km (urban) and 10 km in rural areas. NB-IoT uses LTE encryption.

NB-IoT networks are rolled out almost all around the world since the standard was published in 2016. Typical use cases are electric metering, smart parking, manufacturing automation, smart fire protection, and smart Cities [24]. Private NB-IoT network is not possible to set-up. In Finland DNA, Elisa and Telia are offering NB-IoT networks. IoT networks coverage per operator in Finland can be seen in Figure 11 [30], [31], [32].

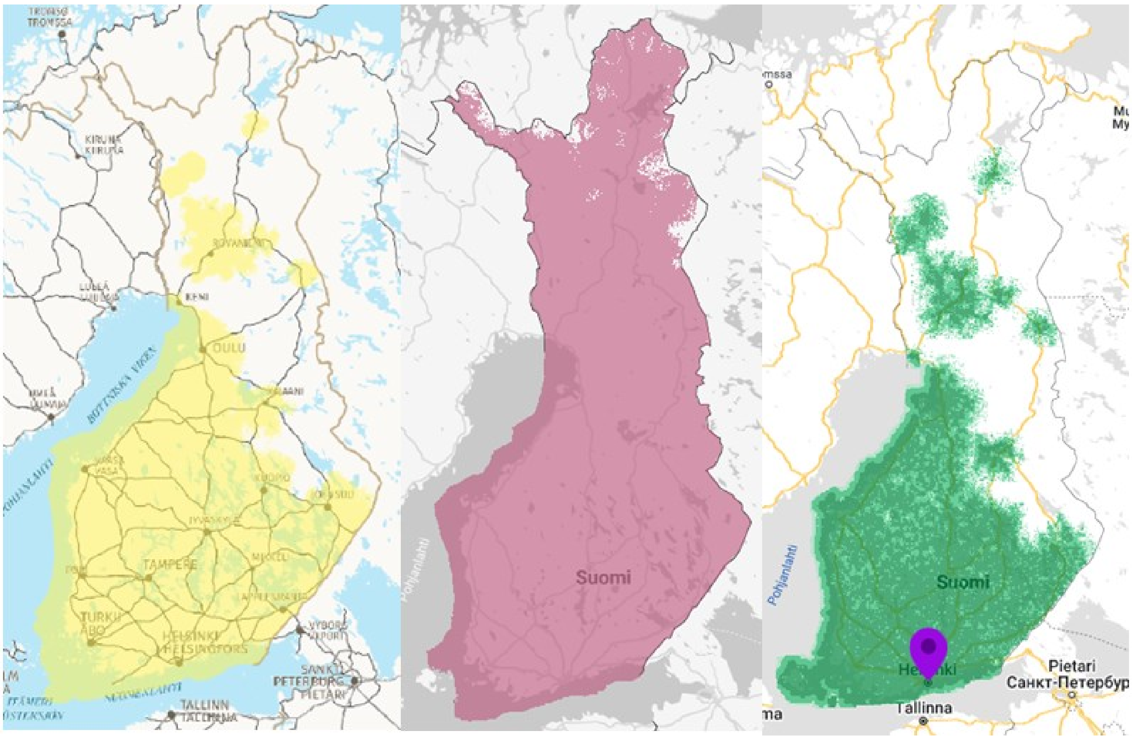

Figure 11: NB-IoT network coverage by operators DNA, Elisa, Telia from left to right [30], [31], [32].

4.6 Long Term Evolution for Machines

Long Term Evolution for Machines (LTE-M) is a narrowband Machine-to-Machine (M2M) technology based on existing LTE networks. It is also known as LTE CAT-M1 or enhanced Machine Type Communication (eMTC). LTE-M is a LPWA cellular technology, and the standardization is agreed in the 3GPP in the LTE-MTC low power wide area releases. The idea is to use already deployed LTE networks. LTE base stations might need to be upgraded to support LTE-M functionality. LTE-M works in a smaller bandwidth and can share spectrum with current broadband LTE systems. LTE-M provides speed of 384 kbps in downlink and up to 1 Mbps in uplink for 3GPP Release 13 and 4 Mbps for Release 14. The data peak rates are depending on the bandwidth used and the configuration of the maximum number of hybrid automatic repeat requests (HARQ) and the Transport Block Size (TBS). Latency is between 50-100 milliseconds. LTE-M is suitable for human interaction and real-time communication between nodes using multicast communication scheme. It also supports cell-based positioning with some added functionalities for improving the position accuracy in Release 14. The battery lifetime for a IoT terminal is designed to be around 10 years. LTE-M uses two power saving mechanisms called ‘Power Save Mode’ (PSM) and ‘extended Discontinuous Reception’ (eDRX). In release 12 the PSM was added, and it allows the IoT terminal to be online but cannot be reached by signalling thus allowing the IoT terminal to be in a sleep mode for long period of time and save battery life. eDRX is further extending the sleep cycles of the terminal in idle mode and reduces unnecessary start-ups of receiving cell. eDRX functionality was added in release 13. LTE-M supports voice transmission to IoT device in half duplex mode. LTE-M is secured with LTE Encryption and regular software updates. LTE-M uses the existing LTE bandwidths with orthogonal frequency-division multiple-access (OFDMA) and 16 Quadrature Amplitude Modulation (16 QAM) modulation in downlink and Single Carrier Frequency Division Multiple Access (SC-FDMA) in uplink. LTE-M uses repetitions in message sending for coverage enhancements. This gives range up to 10 km coverage [34].

LTE-M is supported nationwide on DNA's, Elisa's and Telia’s mobile networks in Finland. LTE-M network coverage by operators DNA, Elisa and Telia is presented in Figure 12 [30], [31], [32].

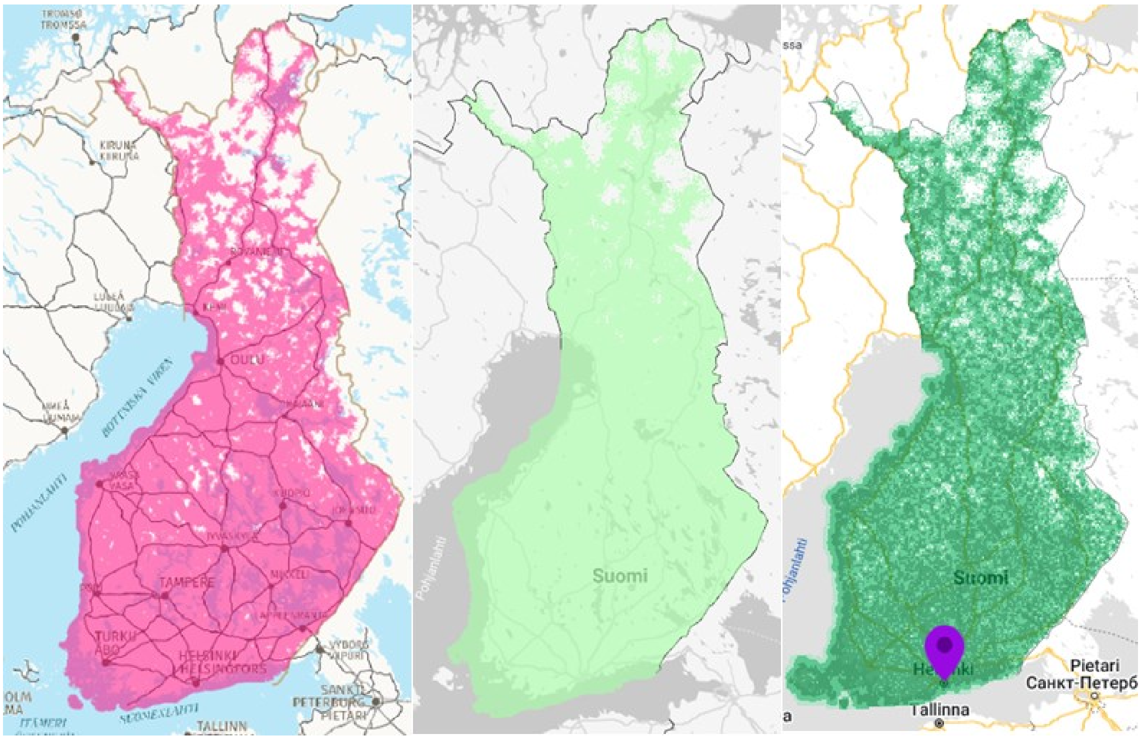

Figure 12: LTE-M network coverage by operators DNA, Elisa and Telia from left to right [30], [31], [32].

LTE-M is suitable for more real-time applications requiring higher capacity with telecom grade data transmission quality, long battery life and is suitable for moving devices. LTE-M support 3GPP remote SIM swap (eUICC and eSIM) with standardized process using SMS messages. LTE-M is truly globally and in use in more than 180 countries and over in 400 mobile networks. Typical use cases of LTE-M are metering (smart cities), retail, healthcare, asset monitoring, asset tracking and smart buildings [35].

4.7 Satellite networks

Besides IoT terrestrial networks it is needed to extend the coverage of networks to over vast and remote offshore sea areas. A satellite network is an alternative connectivity method for a marine AtoN. Satellites are classified in to three categories:

- High-Earth orbit satellites, reaching about 36000 km of altitude. In this altitude the satellite moves at the same angular velocity as the Earth, thus following a Geosynchronous Orbit (GSO). If a satellite circles Earth above the equator it is called a GEO satellite as it appears in a fixed position (geostationary). GEO satellites are used for example in telecommunication as they are suitable to provide coverage to a specific ground area.

- Low-Earth Orbit (LEO) satellites are situated between 160 and 1000 km from Earth surface. LEO satellites have gained more interest because of small cubic size and thus the lighter weights of the satellites. Because satellites are situated in lower orbit, they offer lower propagation delay and smaller propagation loss as compared to GEO satellites.
- Medium-Earth Orbit (MEO) satellites have orbits anywhere between LEO and GEO.

Usually, the satellite orbit is circular or almost circular. There exist also highly elliptical orbit (HEO) satellites for specific needs, for example to monitor polar regions. The classification of satellite orbits is shown in Figure 13. The blue shaded area shows typical satellite orbits suitable for IoT networks [36].

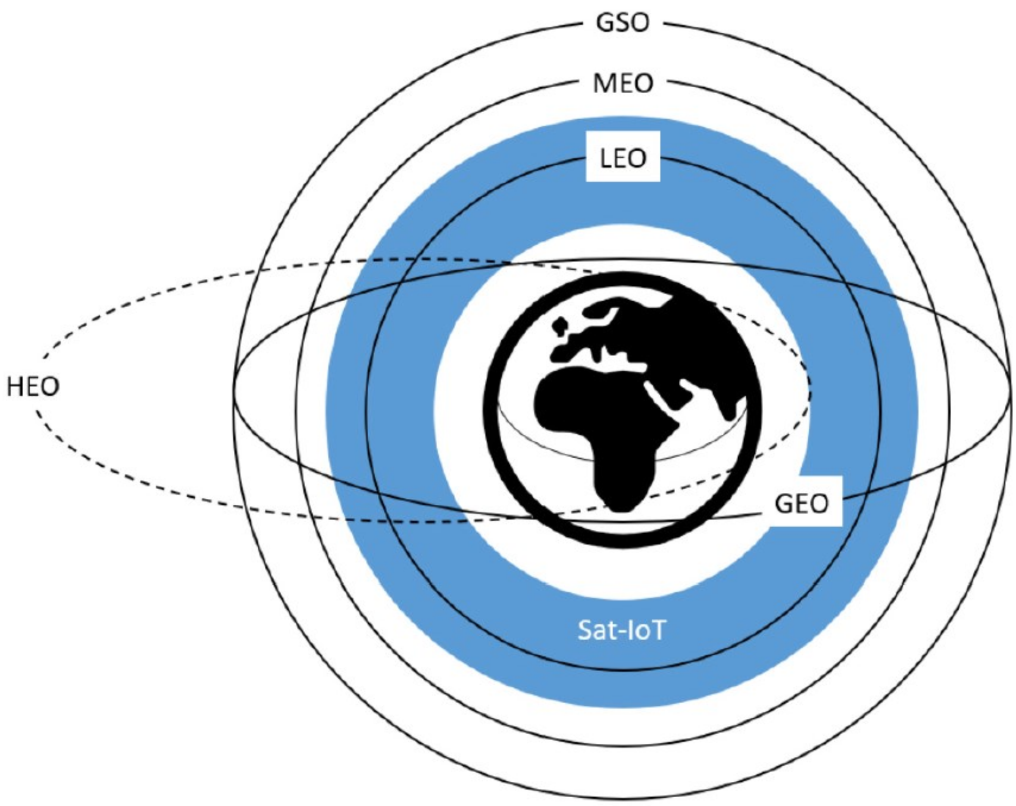

Figure 13. Satellite orbits and typical satellite orbits suitable for IoT networks in blue. [36].

The classification of small satellites is based on weight: femto (less than 0.1 kg), pico (0.1-1 kg), nano (1-10 kg), micro (10-100kg), and mini (100-1000 kg) satellites. A basic unit called 1U is defined in the CubeSat architecture. 1U is a cubic shape with side dimension of 10 cm. Mass is limited to 1.33 kg per 1U. CubeSat satellites are designed as multiples of 1U up to 16U. The transmission power for uplink and downlink is restricted. The standard also defines beam coverage and antenna type and constellation [37].

Satellite links have been used for a long time for telecommunication in the areas where there are no other networks available. Typically, data transmission speeds have been low and latency times have been long. Also, the cost for data transmission has been high. Examples of satellite network providers are Iridium, Eutelsat, and Inmarsat. Eutelsat is providing also IoT network services with GEO satellites. For navigational use, there is Global Navigation Satellite Systems (GNSS) services, with different establishment as the US Global Positioning System (GPS), the European Galileo, the Russian GLONASS-system, and the Chinese BeiDou - system.

Satellite broadband internet providers using LEO satellites have started to compete against traditional terrestrial broadband cellular networks. Iridium is providing networks based on LEO satellites that converge at the poles thus having good coverage in the high-latitude regions. For narrow band communication Iridium is providing for example Short Burst Data (SBD) service which is a packet-based service for frequent two-way small amount of data transmission. It supports low-power consumption and small size of modules. SpaceX has already 3300 operational satellites on orbit and is planning to launch nearly 30000 of LEO satellites. SpaceX aims to launch next generation Starlink satellites which give beaming services directly to smartphones [38]. Starlink's broadband internet network availability map is shown in the Figure 14. Maritim coverage at the Baltic Sea is released to be starting at Q1 2023 [38].

Figure 14. Starlink satellite network coverage [38].

The number of satellite-IoT networks providers is increasing constantly. Swarm technologies is building global LEO IoT satellite network in co-operation with SpaceX [39]. Satellite links in LPWAN technology are enlarging the networks to global coverage and thus these can be called low-power global area networks (LPGAN). There are research and development efforts ongoing to use LoRaWAN and NB-IoT technologies over satellite links. Several standardization and regulatory bodies are involved to define future satellite IoT systems [36].

4.8 Automatic Identification System

Automatic Identification System (AIS) is a short-range coastal tracking system currently used on ships. AIS is based on Very High Frequency (VHF) marine bands radio technology, and it is implemented in Time Division Multiple Access (TDMA) technology. AIS is a digital positional awareness system that is mostly used to show vessels position, Maritime Mobile Service Identity (MMSI) number, IMO number, name and call sign and other data to other vessels. It is also used to assist in search and rescue operations. There are class A AIS devices for mercantile shipping and class B devices for pleasure crafts. Figure 15 shows different use cases of AIS [40].

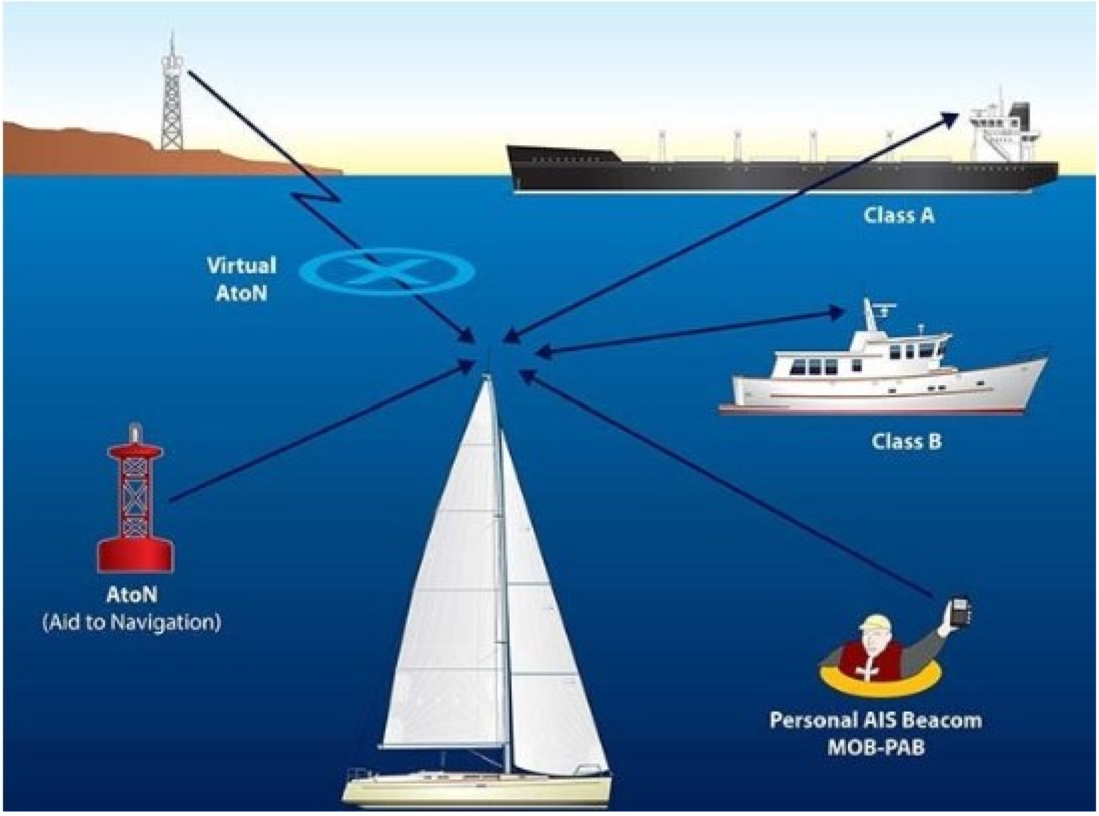

Figure 15. AIS use cases [40].

AIS technology is in use also for AtoN's identification and data transmission. AIS AtoN can broadcast several messages such as aids to navigation message 21, AtoN status report message 6 and hydrological message 8 on VHF data link. In message 21 an AIS AtoN can transmit following information: MMSI number, type of AtoN, position, accuracy indicator, type of position fixing device, off position indicator, time stamp, dimensions of the AtoN and reference position, virtual AtoN flag and Receiver Autonomous Integrity Monitoring (RAIM) flag. With message 6 AIS AtoN can send status report including battery, lantern status and solar power system charging current data. With broadcast message 8 an AIS AtoN can send meteorological and hydrological data which is measured by sensors on the AtoN [41].

AIS AtoN can be implemented in three ways:

- Physical, physical AtoN which is fitted with an AIS device.
- Synthetic, physical AtoN exists but the AIS AtoN transmission is coming from an AIS coast station. There exist two types of Synthetic AIS AtoN, a Monitored Synthetic AIS AtoN and a Predicted Synthetic AIS AtoN. In a monitored synthetic AIS AtoN, there is a separate communication link between the AIS coast station and the AtoN. With this communication the location and the status of an AtoN is confirmed. With predicted synthetic AIS AtoN location and status is not confirmed. Thus, this means that it is not recommended for use on floating AtoN. It can be used for fixed AtoN as the location will not change but still the status of an AtoN is not verified.
- Virtual, AtoN does not physically exists, and a 'virtual AIS AtoN' is transmitted as a Message 21 from an AIS coast station.

All AIS AtoN stations have a radio license, and they must include a Maritime Service Identity (MMSI) number in their transmissions. MMSI is a unique identifier which is issued by the national MMSI issuing authority, in Finland Finnish Transport and Communications Agency (Traficom) [42].

5 Results and Analysis

In this section answers to the study questions are proceeded. What is the availability of alternative IoT networks that could be used for marine aids to navigation data transfer? What could be the advantages and the weaknesses of the possible alternative IoT network technology? Results were obtained comparing the current state analysis findings in the section 3 against the theoretical background analysis in the section 4. FTIA's goals and technical requirements for remote monitoring and for remote controlling were used to evaluate different IoT networks. As part of the research, technical requirements for the data transmission networks were specified.

5.1 Networks in use

FTIA uses 2G network with SMS and GPRS for an AtoN data transmission. LTE-M network technology is used in the newest installations. As the remote monitoring and controlling is purchased as a service, the network connection is bundled together with the total solution. For FTIA the most important thing is to get the requested service that fulfils the requirements listed in the section 3.

5.2 Technical requirements for a transmission network

Following technical requirements were specified for an AtoN transmission network as part of the research work:

- commercially available solution
- solution must be based on endure and proven technology
- low power consumption
- long battery lifetime
- security and encryption of the messages
- sensor's availability and connectivity
- network coverage in AtoN locations
- capability to send and receive required amounts of data in requested intervals

- easy network configuration.

In a normal procurement procedure contractor is offering their remote monitoring and controlling as a solution where the network technology is part of the whole delivery according to the specifications in the order. A part of the remote monitoring and remote controlling service is combined to the lantern equipment which includes an IoT network circuit, an antenna and a control board with the sensors connected to it. Remote monitoring is also requested for AtoNs which are unlighted. Remote monitoring and remote controlling functionality can be divided and ordered in several parts where one part is the actual sensors and modems in the AtoN which are typically part of the lantern equipment. Network subscription is ordered from a network operator and the AtoN monitoring system with the transfer interface to Reimari Web Service is acquired from a third party. Obligatory sensors that need to be available vary based on the AtoN in question. Typically, there must be sensors for location tracking, for light brightness and for lantern on-and-off times, for battery capacity and for battery load currency when a solar power is used.

The basic requirement for commercially available solution is that there are companies providing these solutions at the market throughout the lifespan of an AtoN. It means that the network technology and chosen equipment must be available for long time also in the future. Preferably several providers of the needed components, modules, sensors, and lantern manufactures exists on the market. Typically, lifespan of a lantern equipment, which determines the network connection, is from 15 to 20 years.

Low power consumption requires battery lifetime for ten years for sensors with the network connectivity. In usual cases the AtoN is equipped with a lantern which is an element that consumes most of the energy. The battery replacement time should not shorten remarkably because of the use of remote monitoring and remote controlling functionality.

Message protection and encryption must be in place at a generally accepted level which is typically used in IoT network services and other integrated cloud and device monitoring systems.

Sensor’s availability and connectivity mean availability of good quality sensors, which are possible to add to the AtoN’s IoT module.

Network coverage in AtoNs locations is a basic assumption. Future expansion of the remote monitoring and remote controlling service needs to be considered. Current locations of installed AtoNs can be checked easily from Waterways Information Service System (Pooki). Network coverage in remote locations must be verified by onsite measures. Network coverage should be ensured with a capability to utilize hybrid transmission networks. In the case of lost transmission, an AtoN’s IoT modules can automatically change to an alternative transmission network. Global IoT SIM cards which utilizes connections locally to other operators’ available base stations and their networks with better connectivity should be used when available.

Ability to send and receive required amounts of data with requested intervals means that the network is not limiting the transfer of needed messages between the AtoN and the service providers AtoN monitoring system. The payload of a message must be enough to send needed data in one message. The amount of send and receive messages defined by the network technology should not limit needed AtoN transmission. Message transportation must be reliable, and every message must arrive at least within a day. However, there are external factors that can completely prevent message sending and receiving, for example a disturbance in the radio network or the IoT modules being submerged under the ice and the water surface. The service provider is expected to alert about the lack of connection at the latest when the third consecutive acknowledge message has not been received. This can be done at the monitoring system when noticing that no messages have been received from an AtoN during three consecutive days [43].

Special attention should be paid to easy network configuration. The installation of an AtoN should be quick from the network configuration's point of view. This could be achieved by pre-configurating transmission module parameters before the installation. Near field networks could be used to configure the module on-site at the AtoN location. In mobile networks, the physical installation of the SIM card requires visits to the AtoN locations if the network operator changes. This could be avoided by using an embedded SIM (eSIM). To be able to manage several operators network service an Embedded Universal Integrated Circuit Card (eUICC) functionality could be used. The use of the functionalities is dependent on the networks ability to support these services.

5.3 IoT networks comparison

In this chapter IoT networks were compared and analysed against FTIA's technical requirements. Technical requirements for AtoN networks were listed in chapter 5.2. In the Table 2 technical requirements related to wireless networks were verified against the selected IoT technologies.

Table 2: FTIA's technical requirements and IoT networks comparison [24], [34], [36].

	SigFox	**LoRaWAN**	**2G/SMS**	**NB-IoT**	**LTE-M**	**Satellite**	**AIS**
commercially available / operator in Finland	Yes/ Connected Finland Oy	Yes/ Digita	Yes/DNA, Elisa, Telia	Yes/DNA, Elisa, Telia	Yes/DNA, Elisa, Telia	Yes/ Swarm, Eutelsat, Iridium	Yes/ regulated VHF marine radio/ Traficom
power consumption	Very low	Very low	Low	Medium low (higher than Lora)	Medium (higher than NB-IoT)	Low	High/Very high

	SigFox	LoRaWAN	2G/SMS	NB-IoT	LTE-M	Satellite	AIS
battery lifetime (ref.2000 mAh)	150 months	105 months	not available	90 months	18 months	12 months	2-20 days, type 2 – type 3
security and encryption	AES	AES CCM 128	A5/1	NSA/AES 256	AES 256	Service provider dependent	Normally open
network coverage in AtoN locations (outside)	~40 km	~15 km	~35-40 km	~10 km	~5 km	global	~30 km
Maximum data rate	~100Bps in UL, ~600 Bps in DL	~50 Kbps in UL, ~290 Bps in DL	~SMS 9,6 Kbps GPRS 384 Kbps	~220 Kbps	Up to 1 Mbps	340B UL/ 270 B DL (Iridium IoT-satellite Modem)	Only pre-defined AIS messages
Maximum messages/day	140 (UL)/4 (DL)	Depends on the amount of devices/gateway	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited
Maximum payload length	12 B (UL), 8 B (DL)	248 B	~SMS 160/140 characters (7/8-bit characters)	1600 B	1000 B	Varies based on service provider	Defined in AIS message descriptions

Power consumption and battery lifetime are tightly depending on many variables such as number of messages per day, network coverage and environmental parameters. The utilization of power save-mode and the use of hibernating lengthens battery lifetime remarkably. Battery lifetime presented in the Table 2 is only for reference and to be able compare different technologies.

All network technologies analysed in the study are commercially available in Finland, and there are operators providing the services for data transmission and cloud services for sensor data storage. There are commercially available manufactures who provide radio modules needed to connect to the networks. Only exception is LoRaWAN, where radio modules come only from one manufacturer, Semtech. This might restrict the offering of specific scientific sensors which are compatible with LoRaWAN network technology.

Power consumption is the lowest with SigFox. Next is LoRaWAN with very low power consumption. From cellular technologies lowest power consumption is with NB-IoT but still higher than LoRaWAN power consumption. 2G/SMS power consumption is also low. NB-IoT and LTE-M technologies are designed for 10 years of battery lifetime by transmitting on average 200 bytes per day. Satellite network technologies vary, and this has effects to the power consumption. Satellite IoT networks provide in the best cases very low or low power consumption. This applies especially to networks which are based on the LEO satellite networks. AIS technology is due to the radio technology dependent to listen continuously messages and free channels and thus consuming more energy. AIS network solution is not the best choice for only battery driven solutions.

Encryption is in use in all technologies except AIS technology where the messages are open. However, it is possible to use secure AIS with identity-based authentication and encryption techniques.

Network coverage is the best with satellite networks. SigFox provides largest network coverage with one base station. According to the Figure 7, there are areas that Sigfox does not have any coverage. LoRaWAN has a good network coverage and deep signal penetration through metal, glass, and concrete. Cellular 2G/SMS has a good coverage also in the rural areas. NB-IoT and LTE-

M are based on 4G and 5G cellular networks. 3G networks are gradually going to be shut down and released frequencies are utilized in 4G – and in 5G -networks. This will improve NB-IoT and LTE-M networks coverage in the rural areas.

Maximum data rates are adequate in all network technologies for AtoN remote monitoring and remote controlling. Maximum messages per day in SixFox technology may restrict messages in cases where there is a need to send downlink message to modify light intensity in the AtoN. This would only be possible after uplink transmission, because the downlink transmission can follow the uplink transmission. The number of messages over the downlink is limited to 4 messages per day meaning that light intensity changes would have been limited to maximum 4 changes per day. The maximum payload length for each downlink message is 8 bytes. Sigfox has the smallest uplink payload length of 12 bytes, which limits its use in AtoN when larger data sizes need to be sent. SixFox and LoRaWAN cannot acknowledge all messages received by the sensor, which limits the use of the technology in the most critical services. Sigfox and LoRaWAN technologies are optimal for monitoring purposes [24], [34], [36].

6 Summary and Conclusions

The scope of the research was to investigate which wireless networks could be used for a marine aid to navigation data transmission in Finland. The research focused on finding answers to a question about LPWAN IoT networks which could be used as transmission networks for marine AtoNs. What are the advantages and the weaknesses of the possible alternative IoT network technology? The research work started with the current state analysis where network technologies used for AtoNs wireless data transmission were investigated. AtoN locations were presented as well as used networks. Analysis showed that currently 2G SMS service, 2G GPRS and in some new installations LTE-M technologies were used for AtoN data transmission. The transmitted sensor data from an AtoN was presented. The benefits for FTIA to use remote monitoring and remote controlling features were investigated. The goals and technical requirements from FTIA for remote monitoring and remote controlling functionality were important inputs when finding answers to the research questions about other networks suitable for AtoN data transmission. Technical requirements for AtoN networks were specified as part of the research. In the results and analysis phase it was found out that there are several LPWAN network technologies that could be used for AtoN data transmission.

From a technology point of view following network technologies could be named best candidates to be used for AtoN data transmission: SMS, NB-IoT, LTE-M, LoraWAN and satellite IoT networks. A 2G network with SMS and GPRS connection is currently in use and has proven to have good coverage in remotely monitored and remotely controlled AtoN locations. 2G is suitable for low data amount transfer and it supports long battery lifetime. The lifetime of 2G networks in Europe is gradually coming to an end. In several countries, operators have announced that 2G networks will be closed by the end of 2025. In Finland, Ålands Telekommunikation Ab, the private operator of Åland, has started shutting down its 2G network. There were no indications of other operators' plans to close 2G networks in Finland. The lifetime of the 2G network and network shutdowns soon must be considered when deciding on the use of 2G technology in the new AtoN installations. NB-IoT is the most suitable because its sufficient data transmission capability, lower battery consumption, quality of service and good coverage. LTE-M has been designed more to broadband communication needs which increases a bit battery consumption. LoraWAN is a good candidate for remote monitoring purposes because of low power consumption. LoRAWAN is not suitable for remote control, because the message cannot always be acknowledged. Satellite LPWAN services are increasing all the time with LEO satellites and more operators offering services that have made them a good candidate for terrestrial networks. Satellite networks technology provides the best coverage globally.

SigFox has limitations in the number of messages per day in downlink and uplink and its payload size is low. This will restrict its usage especially in remote controlling of AtoN functionality. AIS technology consumes more power which is a challenge for AtoNs driven only by battery source. For AtoNs with a constant electricity connection AIS is a good candidate especially in cases where AIS messages are needed to be broadcasted directly from the AtoN to the nearby vessels.

The network technology should be selected based on the communication needs. When the actual data transmission requirements are clarified a most suitable network should be selected. This could lead to a situation where several different network technologies are in use. The transfer protocol of the AtoN messages should be harmonized to be able to utilize a common monitoring system. Lantern elements should also be able to support several network technologies. Lantern could support for example LoRAWAN network, cellular networks, and a satellite IoT network.

There are also other requirements which need to be taken in to account when making decision about the best suitable transmission solution. First, the installed volume of AtoNs is considerable large and the usage of remote monitoring and remote controlling functionality will still grow in the future. The selected technologies need to be available for coming 10-20 years and they need to be largely used and proven and supported by several manufactures. It has been decided to shut down 3G networks during 2023 from all operators in Finland. This would have been a challenging situation if the transmission of AtoNs would have been solely based on 3G network. Renewing the installed base is an expensive procedure. It would take rather long time to be completed as the AtoN locations are remote and not easily reachable all around the year due to harsh weather and sea conditions. It would be also preferable that several network service providers are available.

FTIA is ordering remote monitoring and remote controlling as a service. The transmission network modems and antennas are typically integrated to the AtoN's lantern equipment. This means that networks need to be supported by the lantern manufacture's products. Ideally, there would be several manufactures offering solutions that could be considered when verifying tenders. Before selecting an alternative network for transmission, it should be verified thoroughly against the requirements presented in the section 3 and technical requirements specified for an AtoN transmission network in the chapter 5.2. FTIA is also following and contributing to international organizations' guidelines and recommendations. For example, IALA has working groups investigating the usage of IoT networks related to AtoN and finding recommendations to harmonize AtoNs' data transmission. IALA will come out with recommendations that are used when considering transmission technology selection. There are plans to implement an open, secure, and standardized non-propriety communication protocol which could be used by AtoNs. By utilizing LPWAN IoT networks, close to real time situation awareness could be achieved without excessive data costs and energy consumption. In national level Traficom is giving instructions and guidelines to fairway operators. All that information will guide the selection of suitable transmission technology for coming years.

Crisis resilience and recovery is also a topic that affects the choice of network technology. First, the selected network needs to be cyber secure against all vulnerabilities towards the fairway information and its consistence. In crisis situations, the AtoN transmission network must be secured. For example, during long local electricity breaks the base stations will not work after their possible reserve batteries are worn up. AtoNs have power from their installed solar panels and batteries. In some conflict situation base stations might be easy targets to be deactivated and thus locally the networks are down. Coping with these situations requires the possibility to switch to a redundancy communication networks. AtoNs could have a redundancy network available in cases where the primary network is unreachable. The possibility to access two different networks with different technology is called a hybrid model. Example of this is a hybrid model with a cellular IoT network and a satellite Iridium SBD network modules in a single AtoN. If the primary IoT network would be unreachable the module could automatically switch to a secondary Iridium satellite-based transmission network.

FTIA is currently running a smart fairway project, which aims to develop a smart fairway concept on a national level. A smart fairway is also commonly known with a name ‘Intelligent Fairway’. The project involves a wide range of other actors (Traficom, Finnish Meteorological Institute, Fintraffic, Finnpilot). The project is preparing to define intelligent fairways that can inform mariners about the prevailing conditions and vessel movements in the fairway. For example, up-to-date weather reports, water level data and a model of the seabed will be transmitted directly to the bridge systems of a vessel approaching an intelligent fairway. The AtoNs are important part of the infrastructure of a smart fairway concept. An AtoN as part of the intelligent fairway adapts to the conditions and vessel movements. There are features such as remote monitoring and remote controlling already today implemented in the AtoN. In the future, the utilization of additional sensors in AtoN will be based on the needs of a smart fairway. The project affects to the transmission network requirements of a smart AtoN. One example could be a need to transmit data between an AtoN’s sensors and an approaching vessel directly. FTIA is involved in developing guidance for IALA members for the development and implementation of a smart fairway.

As a conclusion it is not an easy or straight forward decision to select between various network technologies for AtoN transmission. There are several requirements and instances which have effects to the final selection. In any case, the technologies already offer good opportunities to create reliable, secure and flexible services for AtoN's data transfer now and in the future.

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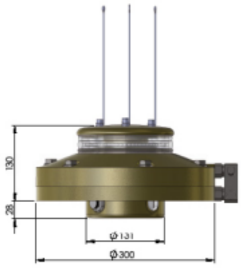
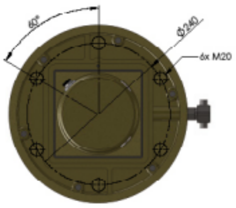
MPV LED technical datasheet (Sabik-Marine)

Datasheet **MPV LED**





Optical performance

Maximum fixed intensity				
At full power 6 W	120 cd	160 cd	240 cd	120 cd

Main Technical Specification

Lens visual/Mechanical diameter	160 mm
Lens material	UV stabilized Polycarbonate
Light source	Light Emitting Diodes (LEDs)
Vertical divergence (wide lens)	10° @ 50% (±1°) of peak intensity
Unit lifetime	Up to 10 years
Weight	25 kg
Temperature range	-40°...+60°C
Supply Voltage	10 – 32 VDC
Power consumption	max 6 watts
Degree of protection	IP 68
Cable length	2 m / 6 m

Order Overview MPV LED

Product code

Code	Note
MPV-LED-c10D-OPT	
c	Color (R, W, G or Y)
10D	Vertical divergence 10°
OPT	Options

Option matrix

OPT 4: GPS sync	Integrated GPS sync including GPS antenna
OPT 9: LightGuard GSM + GPS	Integrated GSM based monitoring including GSM/ GPS antennas
OPT 10: LightGuard GSM	Integrated GSM based monitoring including GSM antenna
OPT 11: Control card	Control card for secondary battery
OPT 12: Aux card with I/O	Aux card including I/O ports
OPT 13: Aux card with RS485 and I/O	Aux card including RS 485 and I/O port

Technical specifications of Taival location tracking device

2. Technical Specifications

2.1. General

Operation:

- Location data is provided typically more than 8 times a day, determined by:
  - profile
  - asset movement
  - power (battery) level
- Device lifetime estimated up to 10 years
- Operates entire device lifetime without need for maintenance (in typical conditions with sun available)
- Recovers from temporary low-battery through harvesting solar power

Location Tracking:

- GNSS: GPS, GLONASS or Galileo, or a combination (default)
- Receive (RX) only operation
- Location accuracy better than 5 meters (with unblocked GNSS signals)

Connectivity:

- Cellular 2G (GSM/GPRS)
  - Quad band (850/900/1800/1900)[1] support
  - +33 dBm maximum transmit power on 850/900 bands
  - +30 dBm maximum transmit power on 1800/1900 bands
  - eSIM (integrated circuit) subscriber identity module
- Bluetooth
  - BLE 4.2 physical layer and framework
  - 2400-2479 MHz (RX&TX)

[1] 850: 824.2-848.8 MHz (TX) / 869.2-893.8 MHz (RX)
900: 890-915 MHz (TX) / 935-960 MHz (RX)
1800: 1710.2-1784.8 MHz (TX) / 1805.2 – 1879.8 MHz (RX)
1900: 1850.2-1909.8 MHz (TX) / 1930.1 – 1989.8 MHz (RX)

- +8 dBm maximum transmit power
- Proprietary messaging
- NFC
  - Only field detection, no communication capability
  - 13.78 MHz (RX only)
  - No transmitter

Device:

- 120x58x30 mm
- 180 g
- fully sealed with no connectors (IP67)

Battery:

- Single battery
  - Battery type 18650
  - 2900 mAh
  - Li-ion
  - 3.63V
  - Individual protection circuitry
- Battery pack consisting of 3 batteries connected in parallel
- Charged by harvesting solar power

Solar Panel:

- 42x62 mm
- Short circuit voltage 5.5V
- Maximum operating voltage 5.1V
- Maximum output current

Certifications:

- CE, RED
- UN38.3 for battery

2.2. Operating conditions

Normal operation:

- -20 to +60 °C (normal)
- -30 to +60 °C (extended, requires battery charge level > 70%)
- Humidity 0-100%
- Air transport requires setting device into idle mode during transport (non-operational idle mode implies all radios off, and thus no positioning or reporting supported)
- GNSS requires clear sky (does not operate indoors)
- Solar panel shall not be covered (not even partly), heavy dust and dirt on solar panel lens will degrade the efficiency implying reduced amount of location reports per day

2.3. Storage and Transportation

Storage:

- 0 to 40 °C
- Humidity 20-80%
- Battery discharged in 2-3 years (leaving factory with full battery)
- Battery charging from empty to full in 9000 lumen artificial light approximately 160 h

Transport:

- -20 to +40 °C
- Humidity 20-80%
- Air transport allowed until provisioned and taken into use (the device leaves the factory in non-operational idle mode)

3. Warranty

Warranty:

- Included in service contract

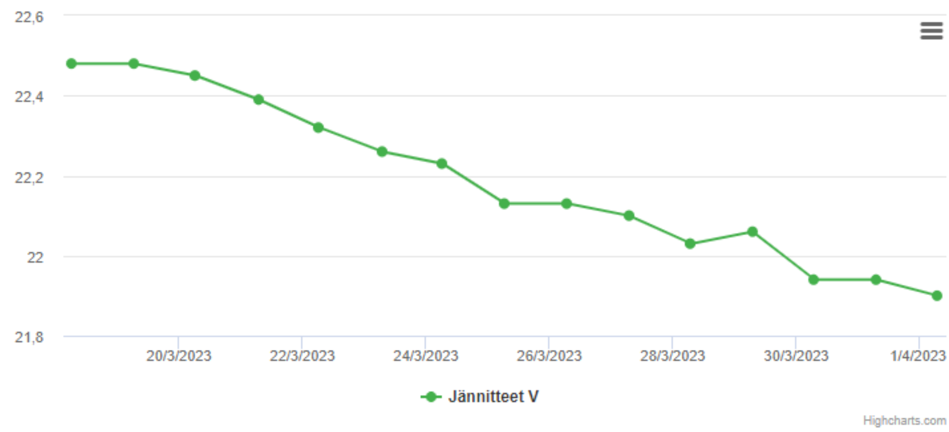
Remote monitored AtoN (Katajaluoto No. 12888) information from Seadatics (Arctia Meritaito Oy)

Katajaluoto - 12888

Status | Asetusarvot | Lisää | Reitit

Viimeisin yhteys **01.04.2023 09.57**	Jännite **21,9 V**	24h jännitteen keskiarvio **22 V**	24h jännitteen minimi **21,8 V**
Yhteyden tila **Active**	Alkuperäinen sijainti **60° 06,09028' N, 24° 54,19699' E**	Tila **OK**	Poikkeuma **22 m (Laite)**
Lämpötila **0°C**	Tehonkulutus **1 W**	Nykyinen sijainti **60° 06,08711' N, 24° 54,19521' E**	Päiväsiirtymä **01.04.2023 06.22**
Yösiirtymä **31.03.2023 20.31**		HDOP **1,4**	

Jännite | Sijainti | Päiväsiirtymä | Aurinkokennon maksimi latausvirta | Lämpötila | Vara-akun jännite | Valoaikalaskuri | Aurinkoenergian tuotanto 24h | Kallistuskulma | Valotunnus | Minimi jännite



Remote monitored AtoN (Katajaluoto No. 12888) information from Reimari database

Aika	Jännite avg	Jännite min	Lämpötila	Valo päälle	Valo pois	Paloaika	Tehon kulutus	Optinen takaisinkytker	Lataustun	Latausvirt	Varaparist	Kallistum	LAT	LON	Toimittaja
1.4.2023 12:08	22	21,8	-0,5	31.3.2023 17:31	1.4.2023 3:22	1254	1	100				0	60.10145	24.90325	SEADATICS
31.3.2023 12:11	22,1	21,9	-1	30.3.2023 17:23	31.3.2023 3:45	1254	1	100				0	60.10145	24.90325	SEADATICS
30.3.2023 12:16	22,1	21,9	-2	29.3.2023 17:25	30.3.2023 3:27	1254	1	100				0	60.10145	24.90325	SEADATICS
30.3.2023 12:11	22,1	21,9	-2	29.3.2023 17:25	30.3.2023 3:27	1254	1	100				0	60.10145	24.90325	SEADATICS
29.3.2023 12:11	22,1	21,9	0,5	28.3.2023 17:21	29.3.2023 3:40	1254	1	100				0	60.10145	24.90325	SEADATICS
28.3.2023 12:11	22,2	21,9	-1	27.3.2023 17:08	28.3.2023 3:50	1254	1	100				0	60.10145	24.90325	SEADATICS
27.3.2023 12:08	22,2	22	-1	26.3.2023 17:11	27.3.2023 3:55	1254	1	100				0	60.10145	24.90325	SEADATICS
26.3.2023 12:14	22,3	22,1	2	25.3.2023 17:04	26.3.2023 4:59	1254	1	100				0	60.10145	24.90325	SEADATICS
26.3.2023 12:09	22,3	22,1	2	25.3.2023 17:04	26.3.2023 4:59	1254	1	100				0	60.10145	24.90325	SEADATICS
25.3.2023 11:10	22,3	22,1	2,5	24.3.2023 16:59	25.3.2023 4:00	1254	1	100				0	60.10145	24.90325	SEADATICS
24.3.2023 11:12	22,3	22,1	3	23.3.2023 17:08	24.3.2023 3:58	1254	1	100				0	60.10145	24.90325	SEADATICS
24.3.2023 11:10	22,3	22,1	3	23.3.2023 17:08	24.3.2023 3:58	1254	1	100				0	60.10145	24.90325	SEADATICS
23.3.2023 11:10	22,4	22,2	2	22.3.2023 16:52	23.3.2023 3:59	1254	1	100				0	60.10145	24.90325	SEADATICS
22.3.2023 11:09	22,4	22,2	2	21.3.2023 17:01	22.3.2023 4:02	1254	1	100				0	60.10145	24.90325	SEADATICS
21.3.2023 11:09	22,5	22,3	1	20.3.2023 16:43	21.3.2023 3:55	1254	1	100				0	60.10145	24.90325	SEADATICS
20.3.2023 11:08	22,6	22,3	2	19.3.2023 16:55	20.3.2023 4:10	1254	1	100				0	60.10145	24.90325	SEADATICS
19.3.2023 11:08	22,6	22,4	3	18.3.2023 16:50	19.3.2023 4:16	1254	1	100				0	60.10145	24.90325	SEADATICS
18.3.2023 11:07	22,7	22,5	1	17.3.2023 16:49	18.3.2023 4:17	1254	1	100				0	60.10145	24.90325	SEADATICS
17.3.2023 11:17	22,7	22,1	-0,5	16.3.2023 16:51	17.3.2023 4:03	1254	1	100				0	60.10145	24.90325	SEADATICS
16.3.2023 11:13	17,1	16,8	1	15.3.2023 16:49	16.3.2023 4:10	1254	1	100				0	60.10145	24.90325	SEADATICS
15.3.2023 11:16	17,1	16,8	2	14.3.2023 16:32	15.3.2023 4:24	1254	1	100				0	60.10145	24.90325	SEADATICS
14.3.2023 11:15	17,1	16,8	0,5	13.3.2023 16:35	14.3.2023 4:46	1254	1	100				0	60.10145	24.90325	SEADATICS
13.3.2023 11:13	17,1	16,8	-3	12.3.2023 16:42	13.3.2023 4:17	1254	1	100				0	60.10145	24.90325	SEADATICS
12.3.2023 11:16	17,1	16,6	-4	11.3.2023 16:35	12.3.2023 4:22	1254	1	100				0	60.10145	24.90325	SEADATICS
11.3.2023 11:13	17,1	16,8	-1,5	10.3.2023 16:35	11.3.2023 4:26	1254	1	100				0	60.10145	24.90325	SEADATICS
10.3.2023 11:14	17,1	16,7	-4,5	9.3.2023 16:34	10.3.2023 4:27	1254	1	100				0	60.10145	24.90325	SEADATICS
9.3.2023 11:15	17,1	16,8	-4,5	8.3.2023 16:28	9.3.2023 4:32	1254	1	100				0	60.10145	24.90325	SEADATICS
8.3.2023 11:13	17,2	16,9	-3	7.3.2023 16:25	8.3.2023 5:05	1254	1	100				0	60.10145	24.90325	SEADATICS
7.3.2023 11:12	17,2	16,9	-3,5	6.3.2023 16:24	7.3.2023 4:35	1254	1	100				0	60.10145	24.90325	SEADATICS
6.3.2023 11:11	17,2	16,9	-2	5.3.2023 16:17	6.3.2023 4:49	1254	1	100				0	60.10145	24.90325	SEADATICS
5.3.2023 11:12	17,2	17	-0,5	4.3.2023 16:19	5.3.2023 4:52	1254	1	100				0	60.10145	24.90325	SEADATICS
4.3.2023 11:13	17,2	17	1,5	3.3.2023 16:12	4.3.2023 5:06	1254	1	100				0	60.10145	24.90325	SEADATICS
3.3.2023 11:13	17,2	16,9	2,5	2.3.2023 16:17	3.3.2023 4:50	1254	1	100				0	60.10145	24.90325	SEADATICS
2.3.2023 11:12	17,2	17	1,5	1.3.2023 16:11	2.3.2023 4:53	1254	1	100				0	60.10145	24.90325	SEADATICS
1.3.2023 11:12	17,2	16,8	0,5	28.2.2023 16:09	1.3.2023 4:55	1254	1	100				0	60.10145	24.90325	SEADATICS
28.2.2023 11:11	17,2	16,9	-1,5	27.2.2023 16:06	28.2.2023 5:00	1254	1	100				0	60.10145	24.90325	SEADATICS
27.2.2023 11:13	17,2	16,9	-5,5	26.2.2023 16:10	27.2.2023 4:57	1254	1	100				0	60.10145	24.90325	SEADATICS
26.2.2023 11:13	17,2	17	-3,5	25.2.2023 16:03	26.2.2023 5:07	1254	1	100				0	60.10145	24.90325	SEADATICS
25.2.2023 11:09	17,2	16,9	-2	24.2.2023 15:55	25.2.2023 5:19	1254	1	100				0	60.10145	24.90325	SEADATICS
24.2.2023 11:16	17,2	17	-1,5	23.2.2023 15:51	24.2.2023 5:20	1254	1	100				0	60.10145	24.90325	SEADATICS
24.2.2023 11:11	17,2	17	-1,5	23.2.2023 15:51	24.2.2023 5:20	1254	1	100				0	60.10145	24.90325	SEADATICS
23.2.2023 11:09	17,3	17	-6	22.2.2023 15:55	23.2.2023 5:24	1254	1	100				0	60.10145	24.90325	SEADATICS
22.2.2023 11:10	17,3	17	-6	21.2.2023 15:55	22.2.2023 5:14	1254	1	100				0	60.10145	24.90325	SEADATICS
21.2.2023 11:09	17,3	17,1	-3	20.2.2023 15:43	21.2.2023 5:39	1254	1	100				0	60.10145	24.90325	SEADATICS
20.2.2023 11:09	17,3	17,1	-3	19.2.2023 15:34	20.2.2023 5:21	1254	1	100				0	60.10145	24.90325	SEADATICS
19.2.2023 11:16	17,3	17,1	-0,5	18.2.2023 15:38	19.2.2023 5:49	1254	1	100				0	60.10145	24.90325	SEADATICS
19.2.2023 11:09	17,3	17,1	-0,5	18.2.2023 15:38	19.2.2023 5:49	1254	1	100				0	60.10145	24.90325	SEADATICS
18.2.2023 11:09	17,3	17,1	1,5	17.2.2023 15:26	18.2.2023 5:46	1254	1	100				0	60.10145	24.90325	SEADATICS
17.2.2023 11:10	17,4	17,1	1,5	16.2.2023 15:28	17.2.2023 5:52	1254	1	100				0	60.10145	24.90325	SEADATICS
16.2.2023 11:08	17,4	17,1	1	15.2.2023 15:26	16.2.2023 5:41	1254	1	100				0	60.10145	24.90325	SEADATICS
15.2.2023 11:08	17,4	17,1	2	14.2.2023 15:42	15.2.2023 5:24	1254	1	100				0	60.10145	24.90325	SEADATICS
14.2.2023 11:08	17,4	17,2	3,5	13.2.2023 15:33	14.2.2023 5:28	1254	1	100				0	60.10145	24.90325	SEADATICS
13.2.2023 11:08	17,4	17,1	0,5	12.2.2023 15:21	13.2.2023 5:39	1254	1	100				0	60.10145	24.90325	SEADATICS
12.2.2023 11:08	17,4	17,2	-1,5	12.2.2023 5:31	12.2.2023 5:32	1254	1	100				0	60.10145	24.90325	SEADATICS
11.2.2023 11:08	17,4	17,1	0,5	10.2.2023 15:25	10.2.2023 5:56	1254	1	100				0	60.10145	24.90325	SEADATICS
10.2.2023 11:08	17,4	17,2	1,5	9.2.2023 15:10	10.2.2023 5:56	1254	1	100				0	60.10145	24.90325	SEADATICS
9.2.2023 11:08	17,4	17,2	2	8.2.2023 15:07	9.2.2023 5:49	1254	1	100				0	60.10145	24.90325	SEADATICS
8.2.2023 11:08	17,4	17,2	1	7.2.2023 15:16	7.2.2023 6:05	1254	1	100				0	60.10145	24.90325	SEADATICS

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Vibration testing of a solar powered led marine beacon

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VIBRATION TESTING of SOLAR-POWERED LED MARINE BEACON

Purpose

The main purpose of experimental testing is to find out weaknesses in commercial products before products can be taken into use. These weaknesses can cause a malfunction or failure during operating life of product. Malfunctions or failure in use can cause economical, environmental or human losses.

The measuring instruction gives minimum requirements for vibration testing of solar-powered LED marine beacon. Testing is divided into two parts that will test durability of maximum and fatigue accelerations of the equipment. Accelerations have chosen, because they represent forces that are affecting to beacon.

Required test

In each test, equipment motion shall be sinusoidal function of time. Motion has to take place in the plane that corresponds the horizontal plane when beacon is mounted to channel mark. Equipment has to be tested at least in two orthogonal directions, which should be chosen so that faults are most likely to be revealed.

Accelerations given below are the amplitude (0-p) values of harmonic motion. Both tests have to be performed in previously mentioned directions. Accelerations should be confirmed using an accelerometer.

Ultimate load test

Beacon should stand ±25g (245 m/s^2) accelerations at least 250*N cycles, where N is the required lifetime in years.

Fatigue test

Beacon should stand ±7g (69 m/s^2) accelerations at least 30 000*N cycles, where N is the required lifetime in years.

Procedure during and after tests

During the tests, the beacon has to work properly the whole time. This should be recorded. After each test, it is necessary to do a visual examination of an exterior area of beacon, installation and assembly to detect obvious damage or failure.

Terms of acceptance

If solar-powered led marine beacon (including all the components that are needed in operation) works properly in every test and there is no obvious damage or failure, beacon passed the test. The results have to be reported in written form.