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Application of LPWA-technology in IoT for Outdoor Sports

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Application of LPWA-technology in IoT for Outdoor Sports

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This thesis project represents 35 ECTS points.

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Abstract

This project analyses how an IoT-concept for Outdoor Sports, using LPWA technology with reduced power consumption and long-range connectivity, can be developed to address some of the shortcomings of today's IoT-devices for sports, i.e. Wearables. The project implementation is designed with use of sensors to track relevant data for use cases regarding the safety of outdoor athletes.

Outdoor Sports; MTB, skiing, trail-running, rafting, climbing etc., are typically practiced in mountains and forests, where cellular network coverage is limited. Additionally, some of these activities, often categorized as extreme sports by insurance companies, due to the high risk of injuries, combined with a distinctive long endurance from 1-2 hours up to multiple days/weeks, demand requirements that are not currently addressed in State of The Art IoT-solutions for sports, e.g. Wearables, Smartwatches, Fitness trackers.

A skier's movements and technique can be measured with use of sensors; time from edge-to-edge transition and turn-rate, carving-angle using gyro sensor, height-meters and distance, speed, acceleration, air-time, gravitational force and centrifugal force during turns, fall- and impact-detection and lastly biological measures, such as heart rate and cortisol level.

This project addresses the challenges of designing and implementing IoT Wearables for Outdoor Sports with use of LPWA technology.

Keywords: Internet of Things (IoT); Low Power Wide Area (LPWA) networks; LoRaWAN; NB-IoT; Sigfox; Ultra Narrow-Band (UNB); Long Range; eHealth; Wearables; Safety; Outdoor Sports; Fall- and impact-detection.

List of acronyms and abbreviations

3GPP	The 3rd Generation Partnership Project
ADR	Adaptive Data Rate
AS	Application Server
bps	Bit per second, also known as bit/s
BS	Base Station
BTS	Base Transceiver Station
CAT-M1	Category M1
CAT-NB1	Category Narrowband IoT 1
CIoT	Cellular Internet of Things
dB	Decibel
DL	Downlink
EC-GSM-IoT	Extended Coverage GSM for the Internet of Things
EDGE	Enhanced Data Rates for GSM Evolution
eDRX	Extended Discontinuous Reception
eGPRS	Enhanced General Packet Radio Service
ETSI	European Telecommunications Standards Institute
FDD	Frequency Division Duplexing
Gbps	Gigabits per second, also known as Gb/s, Gbit/s
GHz	Giga Hertz
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
GSMA	GSM Association
ICT	Information and Communication Technology
IoT	Internet of Things
IP	Internet Protocol
Kbps	Kilobits per second, also known as Kb/s, kbit/s
LoRa	Long Range Alliance
LoRaWAN	Long Range Wide Area Network
LPUC	Low Power Use Case
LPWA	Low Power Wide Area
LPWAN	Low-Power Wide Area Network
LTE	Long Term Evolution
LTE eMTC	Long-Term Evolution Enhanced Machine Type Communications
LTE MBB	Long-Term Evolution Mobile Broadband
LTE MTC	Long-Term Evolution Machine Type Communications
LTE PSM	LTE Power Saving Mode
LTE-M	LTE-M2M
LTN	Low Throughput Network
M-IoT	Mobile Internet of Things
M2M	Machine-to-Machine communication
Mbps	Megabits per second, also known as Mb/s, Mbit/s
MHz	Mega Hertz
MNO	Mobile Network Operator
MTB	Mountain bike

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Reading guideline

- First chapter explains the motivation for this project and the challenges this thesis project seeks to solve, as well as the methodology applied to do so.
- The second chapter is a technical background research, which will elaborate on the applicable technologies and standards available.
- Third chapter – the current State of The Art technologies and business solutions available in the defined problem area will be explained to give a comprehensive view of the feasibility of this problem area.
- Fourth chapter contains the analysis of the user needs to solve the defined problems using the available technology. Initially, the focus will be on requirements engineering; gathering requirements, analysing and establishing User Stories to fit the user requirements for the given problem area.
- In the fifth chapter the Agile Requirements elicited will be described with User Stories and Personas.
- In chapter six the System Design and high-level Architecture for the overall conceptual solution.
- The seventh chapter walks through the implementation parts.
- Eight chapter discusses uncertainties of the project analysis and the choices of methodologies and technologies to solve the problem defined.
- Final and ninth chapter concludes on the problems defined and elaborates on how this project has contributed to the field of study. Finally, the chapter provides recommendations for future work in the field of study.

1 INTRODUCTION

1.1 Motivation

The Internet of Things (IoT) market continues to grow rapidly and by 2020, the total number of devices connected through wireless communication is expected to exceed 20 billions [1]. The 2020 predictions vary and go as high as an estimated 40 billion devices, as predicted by ABI Research [2]:

> *"The number of active wireless connected devices will exceed 40.9 billion by 2020 – more than double the current total"*

By 2020, 95% of electronics will have IoT technology in new product designs, with the minimal costs of integrating IoT into a product. This forecasts the shift to *IoT in Everything* comprising all the different electronics using IoT-technology. [3]

The trend forces companies to address the IoT market and find valid IoT solutions to stay competitive. With the data collected in new IoT-solutions there is a great potential for disruption across industries and markets.

1.1.1 Progression of LPWA-technology

The progression of IoT has brought Low-Power Wide Area (LPWA) technology to address the shortcomings of the existing short range IoT network technologies. LPWA connections are forecasted to grow beyond three billion by 2025, according to Machina Research [4]. The LPWA networks (LPWAN) are characterised by the use of Narrow Band frequencies, operating below one GHz these LPWANs, also called "Sub-1GHz", can transmit data over wide areas, but at lower bit rates between the connected objects; sensors, devices and gateways. The use of lower frequency radio waves enables low-power consumption and extends the range and better penetration through objects significantly in comparison to other IoT technologies.

1.1.2 Challenges in outdoor sports

The main challenge to address in outdoor sports is coping with the extensive risks associated with these sports. The safety of outdoor sport athletes is at stake on a daily basis. Outdoor sports are often exercised in various rural locations, and the nature of the sports imply a high risk of e.g. injury and even death. In rural geographical areas, mobile phones and traditional Wearables can have fluctuating connectivity due to the limited network coverage in these areas.

The potential of reducing risk and creating safer environments for outdoor sport athletes is a challenge that requires development of devices with a higher focus on durability and wide area connectivity than seen in traditional Wearable IoT-devices today.

Some emerging network technologies have a focus on long distance coverage and low power consumption in trade-off for lower data rates. These could be key to developing solutions for emergency situations in remote locations, with shifting weather conditions and high risk of injury from impact or falling, depending on the outdoor sport exercised. The task of locating an athlete in a distress situation can be time critical and essential for rescue teams, relatives etc..

In many sports, the athletes benefit from tracking their health- and performance-data using sensors. Either to analyse performance data after workouts in order to improve technique in a specific sport or in general to monitor health data while exercising a sport. In outdoor conditions these benefits would be just as useful. But another challenge with outdoor sports is that they are typically exercised over a full day or at least extensive periods of time in rural areas, where the typical activity-/fitness trackers have limited usability due to use of technologies with high data rates, high power consumption and short ranged connectivity combined with small sized batteries. If eHealth data from outdoor sport athletes can be transferred from rural locations, the analytics of eHealth data could be used in scenarios with rescue missions, team sports, competitions and more.

Another challenge faced in IoT-products for sports is the limited battery life of the user device. The complexity of the user or end-devices and traditional use communication technologies, e.g. Bluetooth, GSM and GPS are costly and demands relatively much power consumption in active use. Batteries have limited capacity because of the small form-factor in Wearables and Smartphones, which is naturally a challenge when used over extended time periods and possibly cold environments in the outdoors. Depending on the geographical location, urban or sub-urban, the propagation and penetration of radio waves between end-devices and the gateways can also be challenging in GSM and LTE networks.

1.1.3 Problem definition

Given the motivation and challenges introduced above this thesis project intends to resolve the following problem formulation:

> *"How can LPWA-technology be implemented in consumer-IoT to improve the safety for people practicing outdoor sports?"*

And subsequently the following sub-problems:

- *What are the current approaches to address the risks and challenges faced in outdoor sports?*
- *Which of the emerging LPWA technologies can be applied for coverage in rural areas?*
- *What limitations are currently present for developing IoT solutions using LPWA-network technology?*

1.2 Delimitations

Hardware

The implementation part of the project was limited to the listed hardware below. The details of these are described further in chapter 7, section 7.1.1. The HATs (Hardware Attached on Top) are designed to work as add-on boards for development purposes and fast prototyping.

- 1x Raspberry Pi 3 Model B
- 1x Raspberry Pi 2 Model B
- 2x LoRa Dragino shields GPS/LoRaWAN HAT
- 1x Raspberry Pi SenseHAT

Development Scope

The extensive field of study, the Internet of Things, spans technologies, protocols, platforms, architectures, applications and services across all OSI-layers. Inherently, this project will not cover all aspects, as the timespan of this thesis project is limited to approximately three months. The focus is on the process of developing an end-device with sensors and connection to the Internet using LPWAN-gateways. Thus, the background research is primarily assessing IoT standards and LPWA technologies in the network OSI-layer and will disregard aspects concerning IoT-Security, -Analytics, -Management, -Processing.

Expected Outcome

The expected outcome for this project is the delivery of a thesis project, weighted 35 ECTS to fulfil the requirements for graduating as Master of Science in Innovative Communication Technologies and Entrepreneurship from Aalborg University Copenhagen. The thesis project includes the development of a prototype beside the theoretical documentation. The implemented prototype is expected to work as a proof-of-concept to test the solution to the stated problems and challenges.

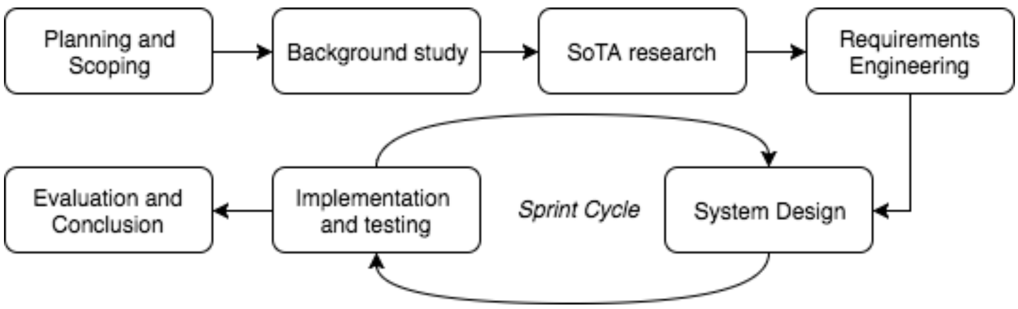
1.3 Methodology

To provide an understanding of the choices and methods that were applied in this project the following two parts describe the research methods for the software requirements engineering and the project process of gathering and eliciting requirements for the IoT concept. Furthermore, the Agile Software Development section describes how the design and development process was organised using a Scrum-inspired approach.

1.3.1 Thesis Process

The workflow of this thesis project was planned and executed as described in Figure 1-1. The planning and Scoping process was done in collaboration with the project manager and supervisor. The following Background study served as the basis for applying LPWA technology in the project and acquiring knowledge about the capabilities and limitations from a technical perspective. With the targeted project scope the State of The Art research stands as an initial analysis of how the problems have been addressed until now. The following phase is the requirements engineering, which is the process of eliciting requirements, in form of User Stories and translating them into a viable System Design that can be implemented and tested against Acceptance Criteria. The requirements or User Stories were prioritized in a backlog for the following System Design, Implementation and Testing. This phase is illustrated as an iterative *Sprint Cycle,* as it follows the Agile methodology described in the following section.

Figure 1-1: Thesis Process diagram



1.3.2 Agile Software Development

The project comprises both a theoretical and a practical side. The practical part is the development of a prototype or a proof-of-concept implementation, and for that reason, this project follows the principles as defined in the Manifesto for Agile Software Development by *The Agile Alliance* [5].

As the project is written and developed by only one person, the Agile approach is scaled down and does not consider Scrum-roles as normally done in a team process. The Agile approach is used as a guideline for the development process to establish implementation early in the process, and then iteratively be developed according to the inputs from the theoretical research. The Agile Manifesto comprises the following four values [5]:

- **Individuals and interactions** over processes and tools

- **Working software** over comprehensive documentation
- **Customer collaboration** over contract negotiation
- **Responding to change** over following a plan

An Agile method, that is gaining popularity within software development is the use of *Themes*, *Epics*, *Stories* and *Tasks*, to document and break down the requirements needed for implementation. The approach follows the semantic structure of information as it flows through an organization and redefines the process of the comprehensive but more rigid Software Requirements Specification. The development team and product manager can communicate value proposition on Post It-notes in informal language instead of highly technical details in a large SRS-document. This fit well with the short time span of this thesis project to do short iterative sprints as compared to a comprehensive Software Requirement Specification.

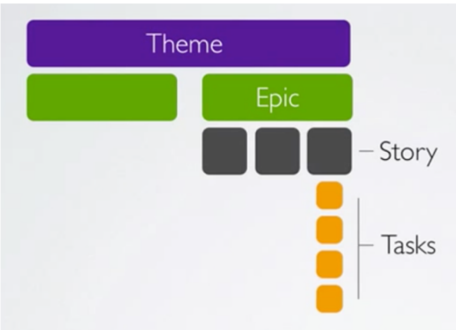
To understand the logic behind how this software development method was applied, to organise the development tasks, the following terms and definitions were used, and their meaning are briefly outlined below.
The Theme (or Feature*) is the overall idea or group of functionalities that is worked on, e.g. Usability, Scalability, User Adoption. *The term "Feature" is also widely used.

The Epic is the collection of features that are sellable to the customer. The Minimal Viable Product (MVP) is the minimal goal of the Epic. The Epic is what the Product Manager can "sell" to the user or customer.

The Story is typically created by the Product team and the Development team to serve as a tactical planning of the functionalities needed and provides an immediate work plan of the Epic broken into more detailed Stories for implementation.is developed during a Sprint, and is usually not larger than what can be implemented in 1-2 weeks.

The Tasks comprise all the things that need to be done to fulfil the User Stories (definition below). The tasks are usually only relevant for the development team and provides a more technical approach than the User Stories.

Figure 1-2: Agile: Themes, Epics, Stories and Tasks

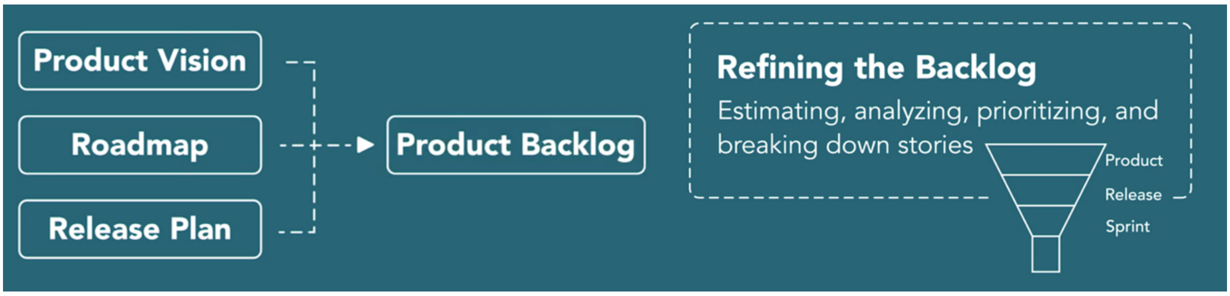


In Figure 1-2, the relation is illustrated with the overlying Theme, comprising multiple Epics, which are subdivided into Stories/User Stories, the Stories are then again subdivided into tangible

Tasks for implementation sprints. When all Tasks in a Story are fulfilled they should address the Acceptance Criteria of the given User Story.

To get started, an initial product Backlog should be established for the development to begin. A roadmap and Backlog can then be refined and prioritized for coming Sprints, as illustrated in Figure 1-3.

Figure 1-3: Product Backlog



The requirement elicitation will make use of empirical data and research to define User Stories and initial requirements. These User Stories will then be tested against Acceptance Criteria for revision. The final iteration of the requirements specification will be assessing the proof-of-concept solution as well as the delimited part of the overall system design.

The definition of a User Story is a short story seen from the user's perspective about what the user finds valuable in the product.

The format in general looks as below and in its essence, comes down to the components; the who, the what and the why, but the specific definitions vary.

Table 1: User Story template

As a ***< user role/persona >****,* *I want/need to* ***< requirement/goal >****,* *so that <* ***reason*** *>.*

The User Story should be written in the language of the customer. The Product Owner does not need to be a programmer to ask questions. Technical decisions will be up to the development team. The User Story should be linked to a business value. The three C's: Card, Conversation and Confirmation derived from Extreme Programming (XP). The team can bring the Card to a Conversation to discuss and confirm the User Story to finally define an Acceptance Criteria in detail written on the back of the Card. When this Criteria is fulfilled, the User Story can be considered done.

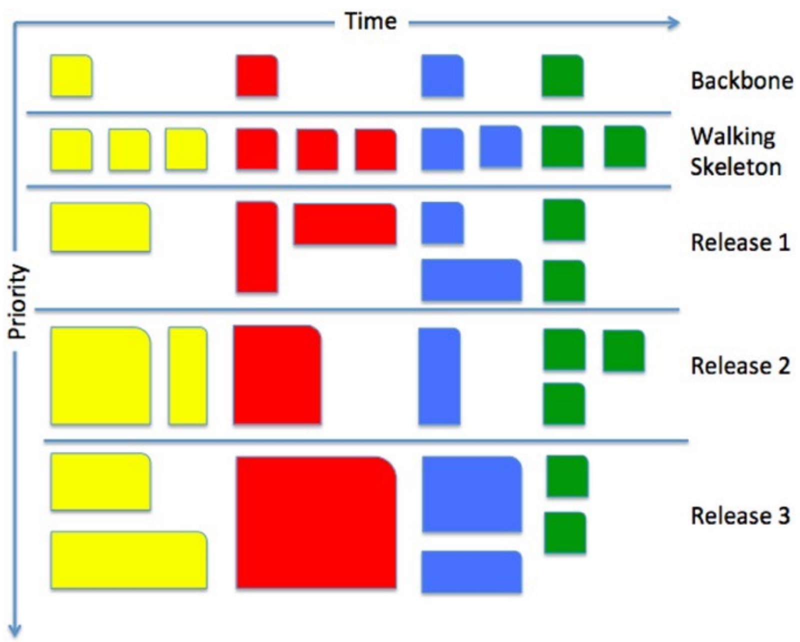
The Acceptance Criteria defines a fixed finish line for the User Story at hand. It should be developed in conjunction with the key stakeholders. Acceptance tests are sets of logical criteria for testing the User Stories. In practice, User Stories and Acceptance Criteria can be written on cards, e.g. large Post-It's, with the User Story on the front in a language understandable by all stakeholders, thus non-technical. On the back of the card, the relating Acceptance Criteria should be described in technical language helping the developers to fulfil the User Story.

Table 2: Acceptance Criteria template

A ***< user role >*** *should* ***< be able to do >*** *the following:* ***< Acceptance Criteria 1,2,3 etc. >***

User Story Mapping is an agile method for prioritising the backlog of User Stories. This is important to ensure, that the most relevant User Stories from the backlog will be developed first and to maintain changes in the backlog. The developers can then work on the highest prioritised User Stories within the defined Epics. A one-dimensional list is not always suitable, because there are likely multiple Epics being developed in parallel. By adding a second axis, both Priority and Time can be visualised in an x-y grid list, a method also known as User Story Mapping [6].

Figure 1-4: USM - User Story Mapping



The Epics in different colours comprise the "Backbone" of the product, as seen in the top of Figure 1-4 . "The Walking Skeleton" should comprise all the functions for the minimal viable product (MVP). The following prioritised Stories are mapped underneath with prioritisation for the following Releases. This approach is applied in practice in chapter 5, *Agile Requirements Engineering*.

2 BACKGROUND

The purpose of this chapter is to establish a general understanding of the Internet of Things and the different evolving Low Power Wide Area (LPWA) technologies. The background research was mainly focused around the IoT factors related to the challenges in outdoor sports, and has been reduced to five main concerns or objectives.

1) Extended range connectivity of end-nodes (Low Power Wide Area)
2) Sensor actuation (system reacts to abnormal movements e.g. fall- or impact-detection)
3) Data rates (the low frequency use and long-distance messages require small amounts of data payload)
4) Cost (low complexity of end device)
5) Autonomy (low power consumption)

2.1 Internet of Things

The following section provides a general overview of the IoT standards and protocols, and where LPWA technology fits in to the IoT landscape. Because of the many competing LPWA technologies the characteristics were examined and compared to better guide the choice of technology in the project design and implementation.

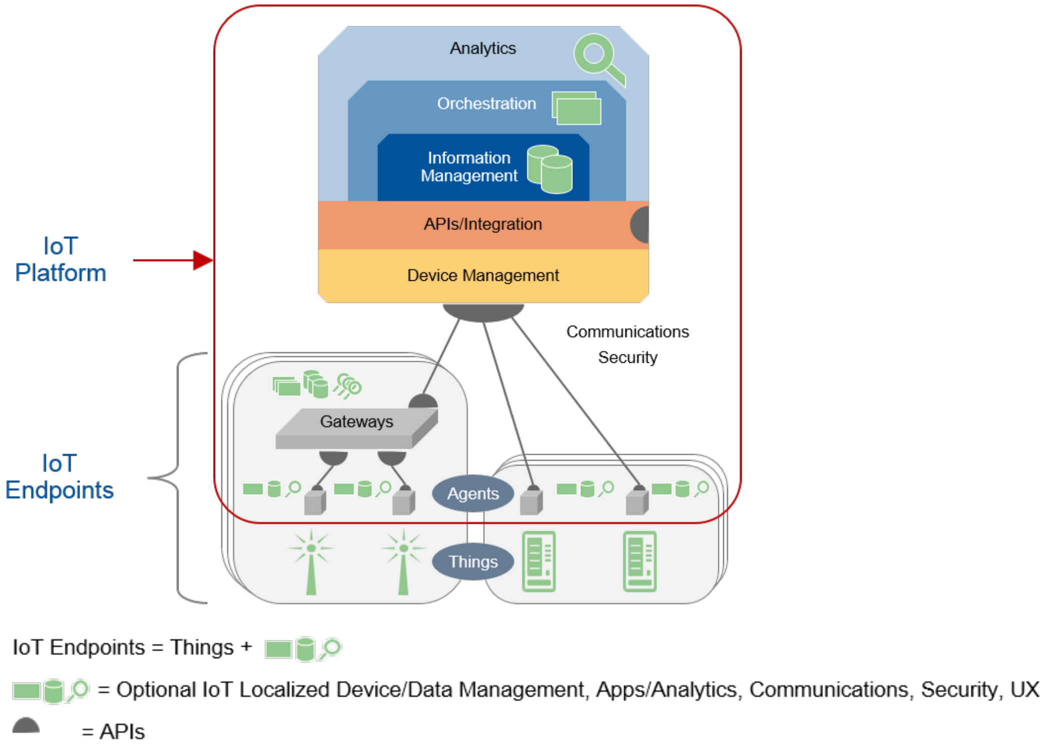
2.1.1 IoT Standards and Protocols

The complexity of developing full-scale IoT-projects lies in the many levels that need be considered. The IoT reference framework describes IoT as having four main levels.

1) IoT-device level; sensors and actuators (the “Things” in IoT)
2) Network level; IoT gateways, routers, switches (the Internet in IoT)
3) Application Service Platform level; IoT-platform (the management platform of IoT)
4) IoT application level (the applications operating in IoT)

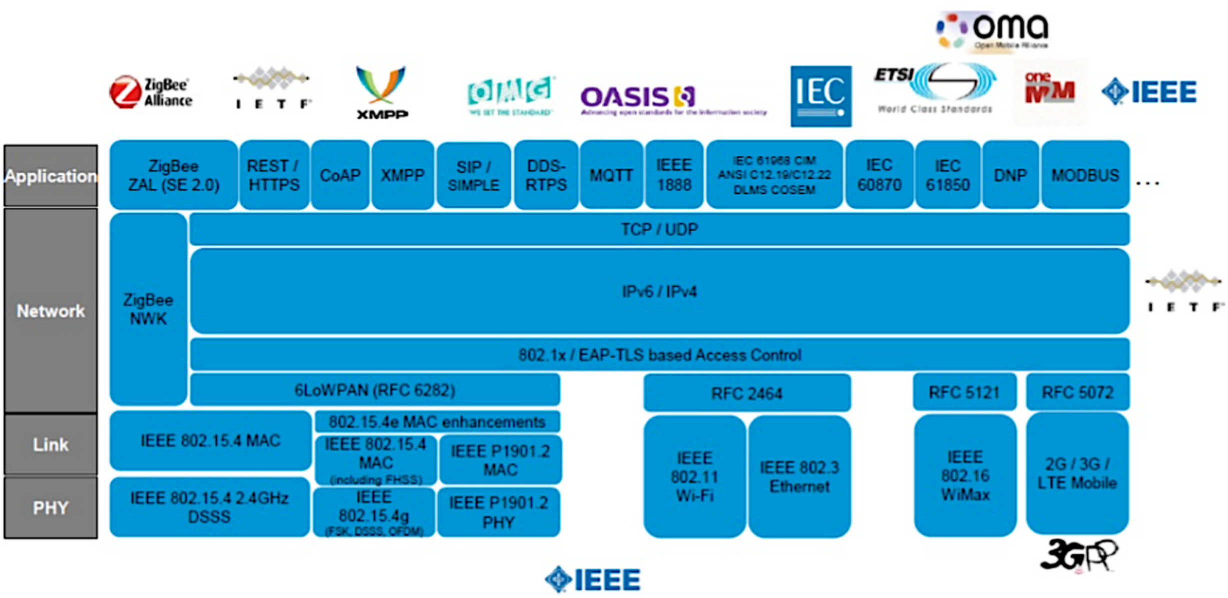
In Figure 2-1below, the four levels are illustrated comprise the “Things”, IoT Endpoints and IoT Platform. This is illustrated as part of the IoT Endpoints outside the large red square. At the Network level, the Gateways are the ones connecting the “Things” to the IoT platform.

Figure 2-1: IoT levels



Each level has multiple different protocols and approaches, that suit different purposes. The technical specifications of IoT standards and protocols operating behind these IoT levels have been mapped in an IoT standards landscape corresponding with the OSI reference model, in the layers: Physical (PHY), Link, Network, Application and Application Services, as seen in Figure 2-2 below [7, p. 258].

Figure 2-2: IoT standards landscape



Multiple LPWA technologies have become a part of the IoT landscape, e.g. LoRaWAN, Sigfox and extensions to the mobile GSM networks, such as LTE-M and LTE-N, also known as

Narrowband-IoT (NB-IoT). The development of IoT solutions can be challenging for companies, due to the lack of one common standard to ensure interoperability between IoT-devices and the integration across the technology stack increases the complexity. The abstraction levels in IoT comprising end-nodes, gateways, cloud platforms, applications and services can help visualise and understand how IoT solutions can be designed.

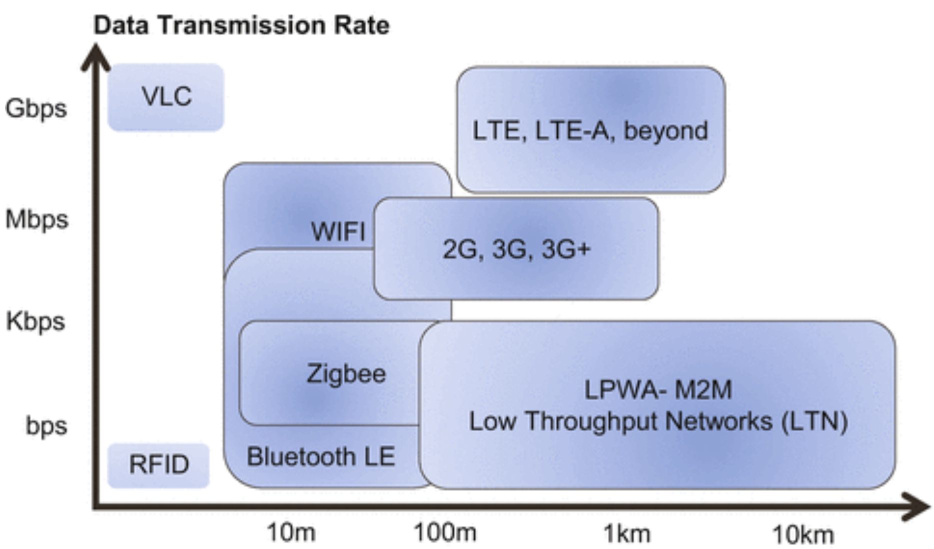
2.2 LPWA technology

There are multiple LPWA (Low-Power Wide-Area) standards and as the name implies, they are characterised by low-power consumption and wide-area network coverage. To navigate in the widespread market of LPWA technologies, this section provides an overview regarding the most adopted technologies.

The LPWA technologies use “Sub-1 GHz” frequency bands and have much lower bitrates than e.g. Wi-Fi and LTE networks. The LPWA standards are also known as Narrow Band or Ultra Narrow Band networks.

Typical for most LPWAN technologies is the lower data rates in comparison to other wireless communication standards, e.g. GSM/LTE and short-range wireless technologies. As can be seen in Figure 2-3 below, LPWA networks have low data rates but offers long-range communication in exchange.

Figure 2-3: Wireless technologies data rates



The lower complexity and data rates of the LPWA networks also reduce the power consumption improving battery life at the edges.

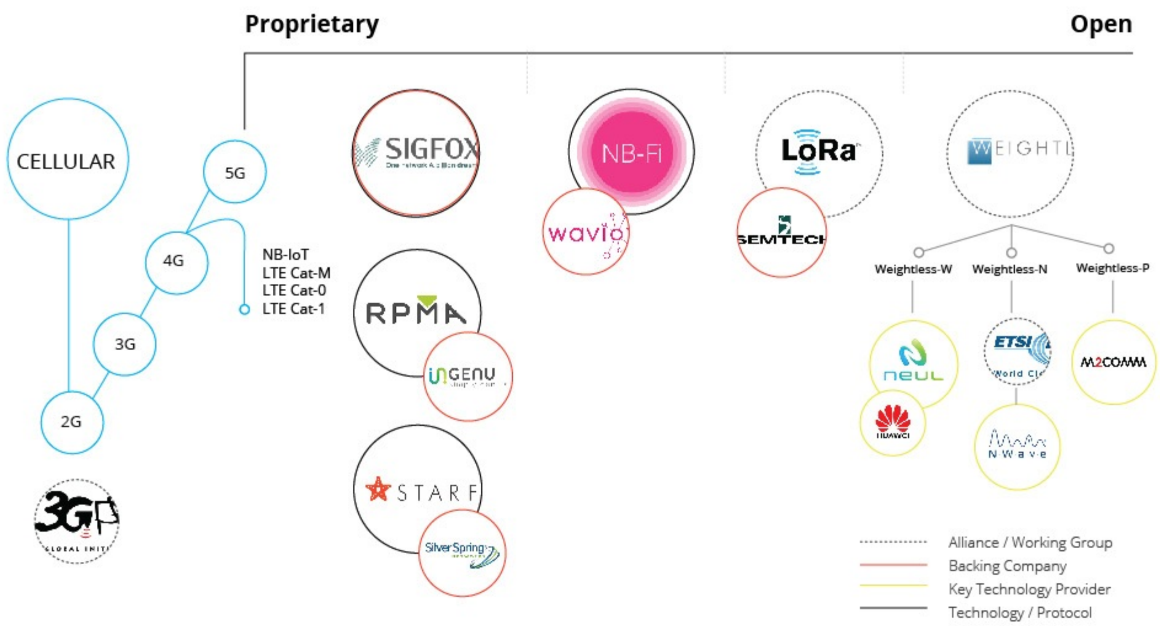
The network coverage differs and proprietary and non-proprietary standards have different benefits. Power Saving Mode (PSM), Quality of Service (QoS), latency of transmission all has a direct impact on cost and power consumption. There is a trade-off between spectrum cost and having QoS. The different standards also differ on this point.

In the following section the different standards are assessed and compared. The factors compared in technical detail will primarily focus on the following performance objectives:

- Deployment models and coverage
- Power consumption and latency
- Device complexity and cost
- Data rate and Range

Before diving into the technical details of the different standards, note that they also differ in being either Proprietary or more Open standards, as depicted in Figure 2-4 below [8]. The dotted and coloured circles in the figure indicates if the technologies or protocols are backed by an alliance, working group, company or other providers, which can be important to take the right choice.

Figure 2-4: LPWAN IoT Market technologies[8]



2.2.1 Proprietary vs Open

The Proprietary standards, i.e. NB-IoT, Sigfox, RPMA and STARF are subscription-based and use the licensed frequency bands. Third Generation Partnership Project (3GGP) standardization group is moving cellular IoT forward, i.e. NB-IoT, LTE-Cat-M, -0, -1. The 3GGP standards are structured in so-called *Releases*. Currently advancing from *Release 13* to *Release 14* and a planned *Release 15,* for 5G support, in September 2018.

The cellular standards can utilize existing infrastructure owned by telecommunication companies, and extending from the existing LTE networks, these standards already have Quality of Service measures in place in the licensed frequency bands. In Denmark, the company *TDC* one of the largest telecom providers, is aiming at the NB-IoT standard [9]. These standards are especially interesting for companies lacking the knowledge of deployment of RF-technologies, in which case costs of deployment and time-to-market can be reduced. On the contrary, if companies have know-how in RF-technology, the non-proprietary standards have less costly deployment and device costs. In particular, Weightless-W, -N, -P, and to some extent LoRa are the cheaper choices for deploying network gateways.

The NB-Fi is an LPWAN protocol developed by WAVIoT. NB-Fi is an open wireless protocol with solutions utilizing both proprietary standards and the proprietary LoRa technology.
NB-IoT/CAT-NB1, Sigfox and LoRaWAN are currently the leading narrow band standards. However, the adoption of the different standards varies, depending on the regions in which the networks are deployed. The LTE-M/CAT-M1 is the first nationwide LPWAN technology deployed in the US and the EC-GSM-IoT (Extended Coverage-GSM-IoT).

2.2.2 Technical comparison

LPWA technologies; LoRaWAN, Sigfox, NB-IoT etc., have shown useful in many IoT-verticals and scenarios. However, the specifications of the competing technologies vary significantly. In general, they promise long-range connectivity, low power consumption and transmission of data from large numbers of IoT devices and objects. Sigfox is using licensed frequency bands and deploys the antennas, LoRaWAN is open source but with no antenna deployment and NB-IoT has subscription fees but use existing antennas. The LPWANs have been applied in many industry-IoT use cases where power efficient sensors and long-range transmitters have proven useful to gather data from thousands of end-points over wide areas.

In this section, the most viable technologies are compared. Each technology is assessed with their characteristics, pros and cons and lastly summarised in an overview comparison table.

2.2.2.1 Narrow Band-IoT (NB-IoT)

NB-IoT or the *Narrowband Internet of Things* is a mobile IoT radio wave technology standardised by the 3GPP with the latest *Release 13* in the series. *Release 14* is expected to implement Positioning capabilities and Multicast downlink transmission for e.g. firmware and software updates.

Deployment model

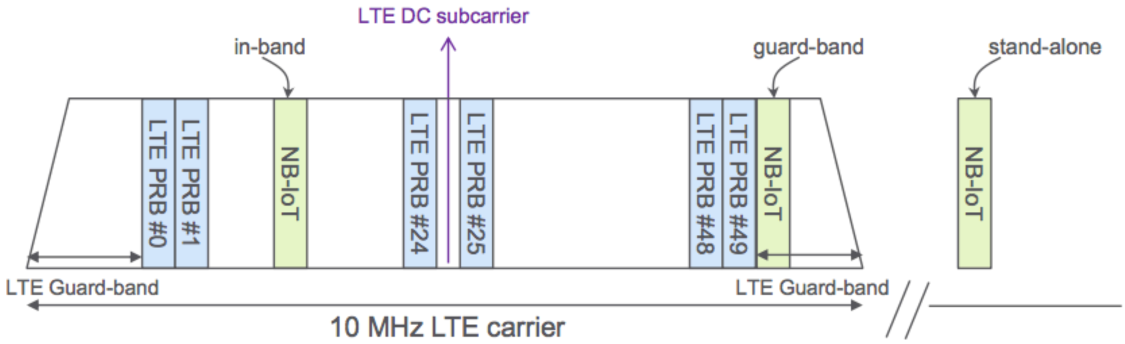


Fig. 1. Examples of NB-IoT stand-alone deployment and LTE in-band and guard-band deployments in the downlink.

Frequency Bands

The frequency bands used for NB-IoT are listed below in Table 2-1, from the whitepaper on NB-IoT by Rohde & Schwarz [10]. The NB-IoT standard uses licensed spectrum and a time slotted synchronization protocol, which is preferable for QoS, but it does come with a high spectrum cost.

Table 2-1: NB-IoT Frequency Bands

Band Number	Uplink frequency range / MHz	Downlink frequency range / MHz
1	1920 - 1980	2110 - 2170
2	1850 - 1910	1930 - 1990
3	1710 - 1785	1805 - 1880
5	824 - 849	869 - 894
8	880 - 915	925 - 960
12	699 - 716	729 - 746
13	777 - 787	746 - 756
17	704 - 716	734 - 746
18	815 - 830	860 - 875
19	830 - 845	875 - 890
20	832 - 862	791 - 821
26	814 - 849	859 - 894
28	703 - 748	758 - 803
66	1710 - 1780	2110 - 2200

NB-IoT characteristics

Pros

- Deployment flexibility, existing LTE-infrastructure
- QoS (Quality of Service)
- Supports massive number of devices (≈50.000 connections per cell)
- Low report latency <10 seconds
- Extended coverage, 164 dB MCL, which is 20 dB better than GPRS
- Optimized for small and infrequent data packets
- Multi-band construction allows for broad spectrum use

Cons

- Licensed spectrum only
- High spectrum cost

2.2.2.2 Sigfox

Sigfox is a French company that builds wireless services and networks that enable low-power wide-area communication. Their proprietary Sigfox technology uses an Ultra Narrow Band (UNB) signal, which should have capabilities of covering large areas and penetrating through materials for good indoor and even underground usage.

Payload

The limitation of the technology is a very low data rate, carrying only a payload up to 12 bytes uplink and 8 bytes downlink, and only 4 messages per day. Thus, the fitting use cases are mostly concerned with industry and M2M (machine-to-machine) applications.

Frequency Bands

The Sigfox technology uses the ISM-bands, 868 MHz in EU and 902 MHz in the US as seen in Table 2-2 below.

Table 2-2: Sigfox Configuration and Regulation

Sigfox RCZ	Countries	Configuration	Regulation
RCZ1	Europe, Iran, Oman, South Africa	868MHz, 14dBm output	ETSI 300-220
RCZ2	USA, Mexico, Brazil	902MHz, 22dBm output	FCC part 15
RCZ3	Japan	923MHz, 14dBm output	ARIB STD-T108
RCZ4	Argentina, Colombia, Australia, New Zealand, Hong-Kong, Singapore, Taiwan	920MHz 22 dBm output	ANATEL 506, AS/NZS 4268, IDA TS SRD

Sigfox characteristics

Pros

- Widely deployed on antenna towers
- Ecosystem with many vendors, e.g. Silicon Labs, Texas Instruments, Axom
- Very power efficient
- Ideal for large sensor networks

Cons

- Traffic limitations, downstream constraints for end devices (max 15 bytes per message, max 10 messages and four acknowledgements (Acks) per day
- Challenges with rolling out deployment in the U.S. market
- Proprietary, Sigfox owns the network

2.2.2.3 LoRaWAN™

The LoRa Alliance[11] is a non-profit association of behind the proprietary Chirp Spread Spectrum modulation (CSS) technology, named LoRa, which is short for Long Range. LoRa and LoRaWAN should not be confused as the same, where LoRa is a proprietary technology, LoRaWAN is an open network protocol and specification [12]. The LoRa technology is applied worldwide in Low Power Wide Area Networks (LPWAN) by LoRaWAN among others, for IoT use cases. The patented LoRa-hardware is owned by the California based *Semtech Corporation* [13]. LoRaWAN is an open network standard with a large community supporting it.

Especially an initiative like *The Things Network* helps pushing the deployment forward with crowd-sourced IoT data networks, and currently the Public LoRaWAN has been deployed worldwide with more than 2.4 million measurement points, 1480 measured gateways and more than a thousand contributing users.

Frequency Bands

LoRaWAN can be used with the following frequency bands in the EU:

Uplink

868.1 - SF7BW125 to SF12BW125
868.3 - SF7BW125 to SF12BW125 and SF7BW250
868.5 - SF7BW125 to SF12BW125
867.1 - SF7BW125 to SF12BW125
867.3 - SF7BW125 to SF12BW125
867.5 - SF7BW125 to SF12BW125
867.7 - SF7BW125 to SF12BW125
867.9 - SF7BW125 to SF12BW12544
868.8 – FSK

Downlink

Uplink channels 1-9 (RX1)
869.525 - SF9BW125 (RX2 downlink only)

LoRaWAN characteristics

Pros

- Flexible
- Ideal for sensor devices
- Open Ecosystem, open software and many vendors

Cons

- Lacks packetisation, roaming, retry, QoS, firmware updates OTA, repeaters, disconnected operations
- Only one provider of chips (*Semtech*)

2.2.2.4 Weightless (-W, -N, -P)

The Weightless Alliance comprise three LPWAN open standards: The Weightless-W, Weightless-N and Weightless-P, all operate in the Sub-1GHz frequency bands. All three standards have end-to-end network authentication and AES-encryption and are mainly for M2M (machine to machine) communication.

The Weightless-W is using TV whitespace spectrum and is intended for two-way communication with data-rates from 1 Kbps up to 10 Mbps. The standard is costly in comparison to many other LPWA standards and only provides around 3-5 years battery life for edge-nodes. Based on narrowband FDMA channels it uses TDD between DL and UL. The -W standard takes advantage of the TV-whitespaces, 470 MHz-790MHz.

The Weightless-N standard is different by having low-cost and UNB modulation technique for unidirectional communication of 100 bps, similar to Sigfox. The low complexity of Weightless-N reduces the power consumption and thus improves the battery life capabilities up to 10 years at the edge. It operates in the UHF 800-900 MHz frequency band and provides only UL communication.

The Weightless-P, is the latest of the three, and is more specifically aiming at industry use cases where high performance and bidirectional communication is valued over range. It provides an adaptive data rate around 200 bps up to 100 Kbps. The standard has a limited 2 km range and shorter battery life in comparison to -W and –N, but where it stands out, is on reliability with acknowledged transmissions, auto re-transmissions, and modulation schemes. The -P standard can operate in the 169, 433, 470, 868, 915 and 923 MHz bands.

Weightless characteristics

Pros

- Performance
- Two-way communication

Cons

- Not widely adopted
- Range is limited

2.2.2.5 Summary

To sum up – the choice of technology was finally taken after a comparison of the three most promising standards, chosen to be Sigfox, LoRaWAN and NB-IoT. The characteristics of these three standards are compared in Table 2-3 below. The industry also trends toward backing those three LPWA technologies over the competitors.

Table 2-3: Comparison of LPWAN specifications

	Sigfox/UNB	**LoRaWAN**	**NB-IoT/CAT-NB1 *Release 13***
Coverage -Rural areas: (long range) -Urban areas: (deep indoor penetration)	<17 km	<14 km 2-5 km	<22 km 10-15 km +20dB > GSM/LTE
Connections per cell	>50.000	10.000-50.000	52.000
Frequency Band	Unlicensed spectrum	Unlicensed spectrum	Licensed spectrum
Deployment Mode			LTE In-band, Guard-Band or Stand-alone
Signal Bandwidth	0.1 KHz	125/250/500 KHz	180 KHz
Peak Data Rate - Downlink - Uplink	- 100 bps	10 Kbps	300 bps to 250 Kbps 20 bps to 250 Kbps
Data Payload / Packet Size	Max 12 bytes	≈100 bytes depending on data rate	
Latency			1.6 - 10 seconds
Battery life	5-10 years	5-10 years	5-10 years
Configuration/ Spectrum Band	RCZ1: EU 868 MHz, and 915 MHz 14 dBm	RCZ1: 867-868 MHz	
Modulation -Highest modulation	Differential Binary phase-shift keying (DBPSK) and Gaussian filter-shift keying (GFSK)	Lora Spread Spectrum (derive from CSS)	Chirp Spread Spectrum (CSS) QPSK
Upstream/ Downstream bias	Suited for upstream	3 device classes; balancing up/down-stream depending on the use case	Suitable for two-way communication
Duplex mode	Half duplex (HDX)	Half duplex (HDX)	Half Duplex (HDX)
Network deployment	Public deployment except in the U.S.	Non-public deployment	Leveraging existing GSM networks

3 STATE OF THE ART

The purpose of this chapter is to analyse the State of The Art approaches related to the problem area as well as describing existing solutions related to this project. With the safety aspect for outdoor sports practitioners geo-positioning, fall-/impact-detection, eHealth monitoring and emergency applications are considered. Lastly, the related existing solutions are assessed to highlight shortcomings or what can be built upon.

3.1 Location tracking

The estimation or identification of an object's real-world geographical location is often achieved using geo-positioning systems and simplified to a set of geographic coordinates, which represent the latitude and longitude. Different standards have been defined worldwide but with the same purpose for positioning systems or geolocation. A device can be implemented to have "location awareness" but the many technologies and approaches should be considered, to achieve the best results. From an infrastructure point of view the approaches can be divided into three main groups as illustrated in the Table 3-1 overview; local, wide and global, as elaborated in the following.

Table 3-1: Wireless communication infrastructure for outdoor navigation[14]

Infrastructure	Coverage	Technology	Bandwidth	Cost to User
Global	Anywhere on earth	Satellite communication systems	100 Kb/s	Receiver, service
Wide	City, state, region	Cell based	1 Mb/s	Mobile device, service
Local	Campus, city	WiFi	110 Mb/s	Device (HW/SW), service

The local infrastructure approach can be achieved with wireless triangulation, where the position of a wireless object or node is estimated by measuring the RSSI-values (received signal strength indication). This is useful for indoor-positioning where satellite systems are insufficient due to multipath signal propagation and signal blocking. RSSI could be determined with wireless short-range technologies e.g. Bluetooth, ZigBee or Wi-Fi.

The wide approach comprises city, state or region wide coverage and the positioning can be determined with use of telecommunication infrastructure e.g. GSM, LTE and 3GPP-standards (e.g. *Release 13* addresses indoor-positioning). In recent years LPWA standards have been introduced and marketed with a focus on very low cost, a wide area coverage and extended battery life.

The global approach is probably the most well-known with use of satellite navigation. The Global Navigation Satellite Systems (GNSS) comprises three operational global systems, that use geo-spatial positioning; the United States' GPS (Global Positioning System), Russia's GLONASS (Global Navigation Satellite System) and the European Union's Galileo. China's BeiDou-2 should be mentioned as well and is expected to be ready for global coverage by 2020. To locate objects using GNSS' a device with a GPS receiver is needed. The receiver will use radio signals from multiple satellites within line-of-sight (LoS) to determine a high precision position, based on longitude, latitude and altitude. The mentioned GNSS vary between one to fifteen meters accuracy. GNSS use frequencies ranging from 1.164 GHz to 1.602 GHz and CDMA coding (except GLONASS with FDMA).

RTLS (Real-time Location System) is the term used for various approaches, when tracking assets using wireless hardware and real-time software. The choice of technology is important with regards to cost, coverage, bandwidth, power consumption etc., and these parameters will therefore be assessed below for a variety of existing solutions.

3.1.1 Mobike – Smart Bikes using GNSS-positioning

The Mobike solution is an IoT solution, which integrates GNSS-positioning to locate Smart bikes around in the cities where the technology is implemented in real-time.

"The integrated GNSS positioning helps Mobikers to easily locate the nearest available Mobike in real-time, while supporting Mobike's real-time tracking and health status monitoring." [15]

The technology used is Qualcomm's LTE IoT modem chip, which has low battery consumption and reliable location tracking [16].

Figure 3-1: Mobike Smart Bike technology

3.2 Fall and impact detection

3.2.1 Hövding bicycle "helmet"

The Hövding bicycle helmet is not a helmet in the traditional sense. It has an inflatable airbag system, which is worn around the neck, and it only inflates to protect the head as a helmet when the system recognizes that the bicyclist is in danger. This is possible with use of sensors and algorithms implemented to detect falling or impacts with their patented airbag system.

Figure 3-1: Hövding 2.0 bicycle airbag helmet

The system records the cyclist movements 200 times per second or every 5 milliseconds, and inflates the airbag in just 0,1 seconds in case of abnormal movement detections. The system's algorithms have been developed to distinguish accidents from normal cycling movements using accelerometer sensors. E.g. small bumps and crossing roadside pavements will not trigger it to inflate. The system is tested and approved for public use and one charge makes it last for approximately nine hours of active use. Stanford University praises the solution and concludes the potential is an eight-fold reduction of concussions as compared to traditional bicycle helmets [17]. The system is interesting for this project, as it shows how accurately and fast the detection of accidents can be measured and instantiate an action.

3.2.2 In&motion smart ski airbag vest

The In&Motion Smart ski airbag vest is intended for use in Ski Racing, where the athlete is often skiing at high speeds on hardly compressed snow or ice. The inflatable vest is already tested by World Cup racers in Alpine skiing and Skicross for two years, and supposedly adds four times greater protection than the standard dorsal impact protection.

Figure 3-2: In&Motion - The Smart ski airbag vest

The vest detects when the skier is unavoidable falling or crashing and inflates in 0,1 seconds, similarly to the Hövding helmet, to reduce the risk of getting injuries at impact with the ground and/or obstacles.

3.3 eHealth monitoring

Health data can be assessed electronically and global companies help pushing the development forward, e.g. Apple Health and Google Fit among others. As defined by the *The World Health Organisation* (WHO)*:*

> *"eHealth is the cost-effective and secure use of information communication technologies (ICT) in support of health and health- related fields, including health-care services, health surveillance, health literature, and health education, knowledge and research"* [18]

With the focus on safety for outdoor sport athletes in this project, eHealth should be considered. Including eHealth in the solution could add another value proposition to users as well as making health data accessible in emergency situations. The problem with some health data is how invasive methods are used for blood measurements. Therefore, the approach for eHealth monitoring will be limited to considering a person's heart rate only. The heart rate, blood oxygen, cortisol, blood glucose levels etc. can be measured using sensors. There already exist some eHealth or mHealth solutions that can handle health data and health records.

3.4 Performance tracking

Some current State of the Art technologies and solutions in the market of outdoor sports or tracking using LPWA technology are described in the following sections. With the purpose of analysing the current approaches to IoT for outdoor sports, the chosen solutions are based on solutions available in the market.

3.4.1 PIQ Sport Intelligence

The PIQ ROBOT product is developed for measuring an athlete's performance and movements on skis. *"PIQ Sport Intelligence is the leading French start-up in sports robotics, changing from today onwards the definition of sports wearables.* " [19]

With use of an IoT-device strapped onto the ski boot, as seen in Figure 3-3, the athlete can get insight into his own performance on the skis.

Figure 3-3: PIQ Robot - Ski boot IoT-device

4 ANALYSIS

Following the Background and State of The Art research, this chapter is an analysis done to extract requirements for the selected outdoor sports.

4.1 Target group

The various types of outdoor sports exercised makes the potential target group for an IoT application rather widely scoped. Narrowing the target group for this project, both context and target group will be limited to the high-risk outdoor sports, skiing and mountain biking. Coverage range and battery life are important steps to improve the safety for that particular target group, many other outdoor sports have similar or related challenges. In general, use cases focusing on safety of the end-user have potential outside the world of sports as well, such as safety gear for work places, military equipment and fall protection/detection for elderly people.

4.1.1 Sensor data

To understand which types of sensor data are relevant in a solution for outdoor sports, it is important to understand the details of the targeted sports. It is tempting to address the sports as simply mountain biking and skiing but each of these sports actually comprise a great number of sub-disciplines, with very different goals and movement patterns, leading to different requirements of sensor data.

Skiing can be categorised in two main groups Alpine and Nordic, which can be split further into specific disciplines:

Alpine skiing:

1) Backcountry skiing (off-piste)
   - Freeride / Free skiing
   - Ski Touring
   - Heli- and Cat-skiing
   - Ski Mountaineering
2) Freestyle skiing
   - Moguls
   - Slopestyle
   - Half-pipe
   - Ski Cross
3) Ski Racing
   - Giant Slalom (GS)
   - Slalom (SL)
   - Super-G (Super Giant Slalom)
   - Downhill
4) Telemark skiing (combines elements of both Alpine skiing and Nordic skiing)

Nordic skiing:

5) Cross-Country
    - Ski Orienteering
    - Ski Marathon
    - Biatlon (Cross-Country with rifles)
6) Ski Jumping

Skiing is practised either as a recreational sport, as a competitive sport or as part of the services carried out by mountain professionals e.g. people working in ski resorts or in mountain military corps. The categories above are the most common skiing disciplines.

In the first category; Alpine skiing, is what most people know as skiing on groomed snowy slopes marked with colours to show skiers the recommended skill-level. Backcountry skiing differs from that, in being exercised outside the secured boundaries of the marked slopes.
Backcountry skiing is considered riskier, because of the less predictable surroundings with rocks, trees, ungroomed and varying snow depth.

The starting point for this project is targeting the more extreme disciplines where the substantially higher risk for the athlete provides a greater incitement for solving the safety issue. The stated hypotheses of the outdoor sports challenges concerned with the sport is most profound when it comes to backcountry skiing, which will be the primary focus of skiing for this analysis.

Mountain biking is also exercised in various types. The most common are named as follows:

1) Cross-country (XC)
    a. XC Trail riding
    b. XC Racing
2) Enduro / All-mountain (AM)
3) Downhill (DH)
    a. Four-Cross (4X) / Mountain cross
    b. Freeride (FR)
4) Dirt jumping (DJ)

Mountain biking is also practised as a recreational sport, as well as in competition and professional contexts. And similar to skiing, the movement patterns and riding types between the MTB disciplines differ significantly.

Analysing athletes' movements in the different sports have provided insight in to which forces and physics are in play. The sensing and tracking possibilities related to skiing and mountain biking have been mapped out in Table 4-1 to break down each the sports further into what can be measured using sensors.

Table 4-1: Tracking types for outdoor sports

Sport	*Sensing / tracking possibilities*	*Hardware required*
Skiing	1) Fall detection 2) Impact detection 3) Trail mapping (location) 4) Speed and acceleration 5) G-force (at landing when jumping) 6) G-force (while turning/carving) 7) Transition (edge-to-edge transition) 8) Carving angle (ski angulation) 9) Air time 10) Air rotation 11) Vertical height meters (session/total) 12) Active time skiing (not in lift, etc.) 13) Total runs / sessions 14) Total motions (turns, jumps) 15) Turn rate (e.g. per minute)	a) 3-axis Accelerometer sensor b) 3-axis Gyroscope sensor c) Geolocation module d) Barometric altimeter sensor
Mountain biking	1) Speed and acceleration 2) Turning angle (bicycle angulation) 3) Distance, vertical and horizontal 4) Cadence (RPM) 5) Power (Watts) 6) Gear Ratio 7) Active time cycling (not in lift, etc.) 8) Total runs / sessions / rounds 9) Fall detection 10) Impact detection 11) Trail mapping (location)	a) 3-axis Accelerometer sensor b) 3-axis Gyroscope sensor c) Geolocation module d) Barometric altimeter sensor

Additional data tracking related to skiing and mountain biking

Some data is not specific to a given sport but to the athlete's health or surrounding environment. This type of data has been identified and listed here as additional data tracking since it can add valuable information to the outdoor sport athletes.

Weather data

- Local area forecasting (mountain and valley stations)
- 'Dangerous' / hazardous weather forecasting
- Snow condition data; depth, type, quality
- Avalanche risk level and reports
- Air temperature, with respect to altitude
- Wind speeds and wind direction

Health data

- Athlete health data (respiration, heart rate, body temperature)
- Emergency communication services
- eHealth, mHealth

Location data

- Trail maps
- Topographical maps
- GPS maps
- Huts, shelters (available or closed)
- Lifts, marked slopes, trails (open/closed)
- Local communities, clubs, hangouts, events related to the sport

As it was deducted in the State of the Art, chapter 3, there are already outdoor sports solutions which can address some of the performance related sensing possibilities (see Table 4-1).
For this project, regarding the safety aspect, weighs the heaviest. Thus, the following sections will assess the possibilities of fall detection, impact detection, long range data transmission to cover emergency scenarios, identifying vital sign data and how to best design the interaction with a safety system for the skiing and mountain biking scenarios.

4.2 Fall and impact detection

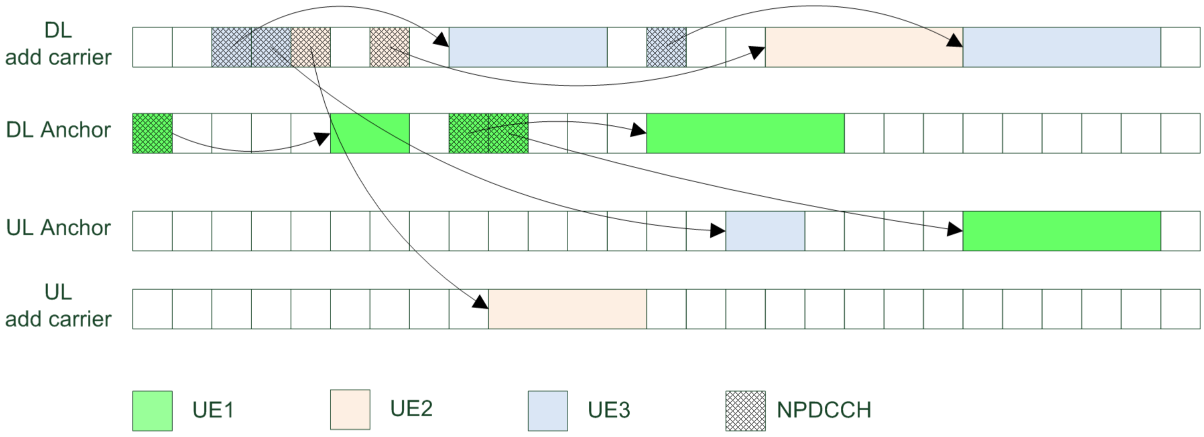
According to experimental results fall detection can be implemented using a 3-axis accelerometer and gyro sensor. Using algorithms, the data combined can detect a fall with more than 70 % accuracy [20].

Detecting an impact and how severe the impact was can estimate the trauma inflicted and the risk of the person having a concussion. Impact detection can be measured by the acceleration G-force at impact. ≈70-100 G is a concussion. I.e. IoT helmet with impact detection, could save and/or send G-force impact data above certain thresholds to alert competition rescue patrols, emergency contacts or relatives.

4.3 LPWAN performance

The amount of data that can be sent in each transmission is limited to small packets for LPWA networks because of the low data rates. The farther the athlete is located from the nearest LPWA antenna the smaller the data rate is possible to cover the distance. LoRaWANs have a functionality to use variable data rates, automatically adapting accordingly to the distance from the gateway.

Figur 4-1: DL/UL Scheduling for three User Equipment devices [10]



4.3.1.1 Limited Uplink/Downlink

As elaborated in chapter 2.2, one of the characteristics and limitations of the LPWA technologies is the limited data rates. The Uplink and Downlink of messages using LoRaWAN for transmission limits each packet size to approximately 100 bytes effectively.

4.3.2 Essential emergency data

It is essential to asses, which data is most critical to send in case of emergency situations due to the limited packet size that LPWA networks can send. This section analyses how much data can be transmitted and if it is feasible for an emergency situation.

To check for vital signs in an emergency situation, it would be relevant to check for e.g. heart-rate, oxygen blood saturation, respiration.

4.3.2.1 Identifier data

When critical data is sent from the UE to the Internet, it is crucial to identify the sender to contact the trusted persons associated with that user. Additionally, the identifier can be used for e.g. showing the rescue patrol if the person in need has any special medical conditions to notice for faster medical treatment etc..

4.3.2.2 Location data

The location of an athlete in the outdoors needs to be precise if the system should propose better safety for athletes. If a person's alert response is sent in time, but the position is too inaccurate it could have consequences for further rescue. This section analyses how much data can be sent using GPS, and the efficiency of live-tracking using LPWA-technology [14].

Table 4-2: Choosing appropriate geo-positioning sensors[14]

Mode of Travel	Speed*	Route Length**	Structure	Accuracy	Ambiguous Cases
Driving Car/ Motorbike	Fast	Long	Road segments	Better than 10 m	Intersections Close parallel roads (within geo-positioning accuracy range)
Walking (Pedestrian)	Slow	Short	Sidewalk segments	Better than 1 m	Intersections Narrow roads (close sidewalks on each side of a road)
Biking Bicycle	Medium	Medium	Road/Sidewalk segments	Better than 5 m	Intersections Close parallel roads (within geo-positioning accuracy range) Narrow roads (close sidewalks on each side of a road)
Riding Wheelchair	Slow	Short	Sidewalk segments	Better than 1 m	Intersections Narrow roads (close sidewalks on each side of a road)

*Speed: slow < 10 km/h; 10 km/h < medium < 40 km/h; fast > 40 km/h
**Route Length: short (2-3 short segments); medium (3-6 short/long segments); long (6 or more short/long segments)

4.3.2.3 Vital sign data

The status regarding an athlete's health could be relevant to address as data that should be sent along with the Identifier and Location data in an emergency situation.

In order for the vital sign data to be used as part of the system's alert response, the following section will discuss interaction design considerations, to ensure that relevant data is appropriately sent to the receiver in emergency situations.

4.4 Interaction design

The interaction design has relevance for the functionality of the system application with the focus on the outdoor athlete's health and well-being. This chapter analyses how the interaction design of the core functionalities can be achieved with sensors for danger detection and communication technologies for alert response to suggest requirements for safety.

4.4.1 Danger-detection using sensors

The following sensors are considered applicable for danger detection. The sensors will not do any detection alone, but are relevant as input for detecting danger with local based application actions being run from the athlete's UE.

- Accelerometer 3-axis; A sensor commonly used in Wearables is the 3-axis accelerometer, which can track movement or acceleration in three orthogonal axes. This dynamic sensor can be used in different modes; as an impact sensor, for measuring inclination, tilt and orientation in three dimensions or for an inertial velocity and position measurement.
- Gyroscope 3-axis; A sensor that can measure orientation and rotation.
- Barometric altimeter; An advanced form of an aneroid barometer, which can detect altitude by measuring the correlated pressure.
- Optical sensor; To monitor pulse or heart rate, an optical sensor is currently applied in most fitness trackers.
- Temperature sensor; A temperature sensor provides a reading of the heat in the body skin.

4.4.2 Manual and automated alert responses

The interaction design for the system’s alert response should be kept as simple and efficient as possible to ensure, that an alert response will be delivered in case of a critical situation. As the problem area regards outdoor sport athletes in risky environments, the system should be able to detect dangerous situations using the sensors as explained above, but even as important to send an alert response to relevant parties without the user needing to physically grab the device and activating the alert.

An automated interaction design can be achieved with algorithms and sensors, so that the system will work both in situations where the athlete is capable or incapable of sending/activating an alert response.

An important aspect of the solution would be the design and physical placement of the user equipment. An example is if the UE was fixed to e.g. the athlete’s skis or ski poles he could accidentally lose both the ski equipment and the UE in a fall, making the solution impractical. Ideally the user device should be attached close to the athlete’s body, e.g. the helmet, jacket or ski boots, which will not be misplaced away from the athlete in a crash.

5 AGILE REQUIREMENTS

The process of eliciting requirements was carried out with a method originating from Agile User Stories and XP Programming methodology, where the term "software requirement specification" is not regarded appropriate for the development process. Because of the many different stakeholders with different understandings of the requirements described in too comprehensive documents, that type of documentation is difficult to maintain throughout an agile iterative development process.

By using storytelling or the so-called User Stories, which are short and easy to comprehend for all stakeholders, a more agile process may support the iterative development process with many stakeholders and different understandings as also described in the Methodology chapter, section 1.3.2.. The Agile structure will be used throughout this chapter to elicit requirements.

Initially the following fictive Personas have been invented as a starting point for the possible roles seen in outdoor sports environments for skiing and mountain biking scenarios. In this way, initial requirements can be elicited from User Stories revolving around the Personas described.

5.1.1 Personas

Considering the context of outdoor sports, the following personas have been chosen as the typical personas for use in this project. Normally, user research would be the basis of eliciting fitting personas. However, with the limited timespan, the personas were developed based on my own knowledge in the field. With a professional background as Professional Ski Instructor since 2009 I have experienced all types of people exercising skiing on first hand. Additionally, coming from an active family, I have been doing outdoor sports, such as climbing, trekking and mountain biking frequently since my childhood. With my deep going know-how and experience in the field, combined with a large network in the outdoor sports communities, it was decided to produce "The-Quick-and-Dirty" proto-personas [21] of sports people based on that knowledge.

Proto-personas saves time from doing a time-consuming User research, which in this case can be left for later iterations.

> *"Proto-personas give an organization a starting point from which to begin evaluating their products and to create some early design hypotheses. (...) The initial value in producing proto-personas derives from the exercise of producing them, which restores the focus of an organization back onto the customer."* [22]

With two Epics of User Stories, the Personas have been grouped as follows. First, the *Skier Personas*, and second, the *MTB Personas.* i.e. rescue instances or relatives to the Athlete, who should be notified with alerts. The Main Personas applied for requirements engineering have been described below.

5.1.1.1 Skier Proto-Personas

Persona S01:  - Aged 31 - Ski-guide - Advanced level	**THE SEASONARY SKIER** Alice is a confident skier. She enjoys skiing with other season workers daily. She often explores new off-piste areas in the resort to find fresh untracked snow. **Goals:** ▪ To track personal performance ▪ To be able to help tourists in trouble on the job ▪ To minimise risks when skiing off-piste
Persona S02:  - Aged 28 - Pro Ski Instructor - Expert/Pro level	**THE SKI INSTRUCTOR** Bob is a fully educated professional ski instructor working part time in the Swiss Alps. Bob often skis with groups of less experienced people. He often goes exploring new off-piste areas in the resort to find fresh untracked snow. **Goals:** ▪ To analyse skiers' movements ▪ Improve technical feedback for clients ▪ To minimise risks when skiing backcountry
Persona S03:  - Aged 23 - Tourist skier - Intermediate level	**THE TOURIST SKIER** The unexperienced tourist skier skis once a year and sticks with the marked slopes in the ski resort. **Goals:** ▪ To have fun and improve skiing skills ▪ Be able to locate family and friends in the resort ▪ Get help in critical circumstances
Persona S04:  - Aged 28 - Freeride Competition skier - Expert/Pro level	**THE COMPETITION SKIER** Frank enjoys skiing with other season workers daily and when she is not working. Frank skis professional freeride competitions and often practises in the off-piste. **Goals:** ▪ To limit the risks of skiing off-piste ▪ Improve skills in off-piste skiing ▪ Be able to rescue friends in emergency situations

Persona S05:  - Aged 37 - Bartender in ski resort - Advanced level	**THE LOCAL SKIER** Lisa lives together with Frank, the competition skier, in the alps. She enjoys skiing with other season workers on daily basis. She occasionally goes off-piste skiing with Frank. **Goals:** ▪ To limit the risks of skiing off-piste ▪ Improve skills in off-piste skiing ▪ Be able to rescue friends in emergency situations
Persona S06:  - Aged 42 - Rescuer in ski resort - Professional level	**THE RESCUE PATROL SKIER** The rescue patrol skier works in the ski resorts. His job is to aid people in emergency situations and help them down the mountain in a rescue sled or toboggan (see picture). In case of heavy snowfall, he will help securing the slopes from avalanches, but when avalanche-accident happen he aids searching for any persons buried in it. **Goals:** ▪ To rescue people in dangerous/critical situations ▪ Locate people in avalanches as fast as possible ▪ Locate and aid injured or lost people in the resort
Persona S07:  - Aged 47 - Rescuer in ski resort - Professional pilot	**THE RESCUE HELICOPTER PILOT** The rescue patrol helicopter pilot is sent to rural off-piste areas in the ski resorts, in case of critical situations; severe injuries, avalanche accidents etc., where the persons in distress need immediate help or direct transport to a hospital. **Goals:** ▪ To rescue people in dangerous/critical situations ▪ Locate people in avalanches as fast as possible ▪ Locate and aid injured or lost people in the resort

5.1.1.2 MTB Proto-Personas

Persona M01:  - Aged 35 - Club rider for 4 years - Advanced level	**THE CLUB MTB RIDER** The club mtb-rider has ridden his MTB for the past 3-4 years and mostly rides with friends from the MTB-club. Sometimes Donny rides alone in the local forests, when no one from the club is available. **Goals:** ▪ To track performance and compare with others ▪ To stay safe even when riding ▪ Locate other club riders who crashed
Persona M02:  - Aged 28 - Motionist rider - Intermediate level	**THE RECREATIONAL ATHLETE RIDER** The recreational rider is often out exercising MTB in the forest, but she is not a club member, thus often rides alone. **Goals:** ▪ To track personal performance ▪ To stay safe even when riding the MTB alone ▪ Locate friends and family when riding
Persona M03:  - Aged 38 - Single track rider - Advanced level	**THE VACATION RIDER** The experienced tourist rider. Enjoys riding in scenic outdoors when on summer vacation. Rides MTB single tracks in the French Alps. **Goals:** ▪ Have fun and improve riding skills ▪ Be able to locate family and friends in the resort ▪ Get help and help others in critical situations
Persona M04:  - Aged 22 - Casual rider - Beginner level	**THE BEGINNER MTB RIDER** Has just been introduced to MTB and already loves it. Wants to learn as much as possible, but is unexperienced and often falls or loses control over the bike when the track gets difficult. **Goals:** ▪ Learn to ride without too much fear of falling ▪ Improve technical skills ▪ Be able to get help and to help friends in emergency situations

<table>
<tr>
<td>Persona M05:

- Aged 29
- Downhill rider
- Expert level</td>
<td>THE DOWNHILL RIDER
Rides often and pushes the limit in varying conditions, both downhill and forest tracks with a relatively high risk of crashing and possibly getting injured. Rides with friends on same level of experience.
Goals:
▪ To limit the risks of riding downhill
▪ Improve riding skills
▪ Be able to get help, and rescue friends, in emergency situations</td>
</tr>
<tr>
<td>Persona M06:

- Aged 25
- Competition rider
- Professional level</td>
<td>THE COMPETITION RIDER
Rides fast-paced competitions in varying conditions, both downhill and forest tracks with a relatively high risk of crashing and possibly getting injured.
Goals:
▪ To achieve good results in competitions
▪ Analyse personal riding skills for improvement
▪ Be able to get help, and rescue other riding companions, in emergency situations</td>
</tr>
</table>

5.1.2 Themes

The themes are broad containers of multiple Epics and User Stories. The Themes initially chosen for this project are:

- Onboarding
- Athlete
- Responder
- Rescue patrol

The Athlete in the User Stories related to the person using the end-device, while practicing his/her sport. The Responder in the User Stories are the Athlete's relatives/emergency contacts, who should receive the relevant alert and information, in order to commence a rescue or locate the Athlete.

5.1.3 Epics

As explained in section 1.3.2 the Epics are simply large User Stories, that contain the multiple user story fragments needed to address the Epics. They describe the main goals for the defined Personas and the format follows that of User Stories but is most usable when applied in a User Story Map (USM):

The Application Setup User Stories:

Table 5-1: Application Setup Epic

Backbone:	**1. On-boarding**	**2. User Profile**	**3. Add Responders**	**4. Device Function**	**5. View History**
Prototype / MVP	Demo application	RPi test user profile	Message to Server side application	Testing LoRaWAN	Testing Cloud platforms
Release 1	User Account creation	Choose Skiing and/or MTB Setup	Add contact information on Relatives	Send message over LPWAN	User can access Profile and Settings
Release 2	SSO Login Action – e.g. Facebook / Google	Choose other Sports	Add local Rescue/ Emergency Services	Location tracking, Fall-/Impact-detection.	User can access performance and tracking data visualised in application
Release 3	Integration with 3rd party sports apps	Choose other use cases		Avalanche rescue alert	

The Athlete Accident User Stories:

Tabel 5-2: Athletes Accident Epic

Backbone:	**1. Fall/ impact-detection**	**2. Collect vital sign + location data**	**3. Automated alert to Responder**	**4. Cancel alert**	**5. Alert Responder**
Release 1	Algorithm detects a fall	GPS coordinate and vital sign data is logged	Alert Message to Server-side application	Automated message is cancelled if athlete is ok	The Alert responder receives message

The Alert Responder User Stories:

Tabel 5-3: Alert Responders Epic

Backbone:	**1. Check status of Athlete**	**2. Receive Alerts on phone**	**3. Check vital sign data**	**4. Notify rescue patrol**	**5. "On my way" response**
Release 1	Interface shows relatives latest vital sign data	Alert with GPS-coordinate + vital sign data	Display Athlete information	Choose to notify or cancel rescue patrol	Athlete receives a message from Responder

5.1.4 User Stories

The User Stories are added to the "product backlog" and prioritized for implementation with the most essential User Stories first. In this section, the User Stories are arranged according to the USM in a prioritized order. The User Stories break down the Epics into more specific functionality, that can be implemented in Sprints and be tested against Acceptance Criteria.

User Stories related to the Epics in previous section:

1. Athlete Accident User Stories

User Story	**As a/an …** < Persona >	**I want/need …** < Requirement >	**, so that …** < Reason >
01	athlete	the device to detect when I am falling and send an automatic alert message if I do not move again afterwards	my responders can be alerted automatically if I cannot move myself or contact responders
02	athlete	the device to collect sensor data	the system can log relevant performance and eHealth data
03	athlete	the device to track my geographical location	my location can be shared with Responders when requested or in case of emergency

2. Alert Responder User Stories

User Story	**As a/an …** < Persona >	**I want/need …** < Requirement >	**, so that …** < Reason >
04	responder	to receive an alert message from the athlete in emergency situations	I get a chance to help the athlete and/or contact the needed assistance services
05	responder	to view the last known location data of the athlete's device	I can accurately locate the device and athlete
06	responder	to view additional eHealth data in emergency situations	I can provide the necessary information for rescue and assistance services
07	responder	to view the connected athlete's performance data updates	I can view and track the athlete's performance

3. Application Setup User Stories

User Story	**As a/an …** < Persona >	**I want/need …** < Requirement >	**, so that …** < Reason >
08	athlete/responder	to pair my user account with my athlete/responder's user account	I can send notifications to the relevant person when needed
09	athlete	to track my performance	I can compare to my earlier performance and friends
10	athlete	to track my location	I can save/share a map of my routes in the area

5.1.5 Acceptance Criteria

The Acceptance Criteria (AC) are listed accordingly in Table 5-4 below. They contain a set of logical criteria, that will be used for testing if the implementation fulfils the given requirements. The AC numbering is derived from the User Stories.

A < **role** > should < **see/be able to do** >
the following < **Acceptance Criteria 1,2,3 etc.** >

Table 5-4: Examples of Acceptance Criteria for the defined User Stories

AC	***Acceptance Criteria***
3.08	1) The mobile application is available on the Play Store for Android 2) The mobile application is available on the App Store for iOS 3) The mobile application can be installed on phone 4) User profile can be created 5) Responders/Relatives can be linked to my user profile
2.05	1) The User Equipment can track location data from GPS-module 2) The application is available on the App Store for iOS 3) The application can be installed

5.1.6 USM - Prioritization of User Stories

The backlog of Stories for implementation are continuously prioritized to make sure the minimal viable product (MVP) and backbone of the design solution are developed first and that the following development is focused on the functionalities of the highest priority.

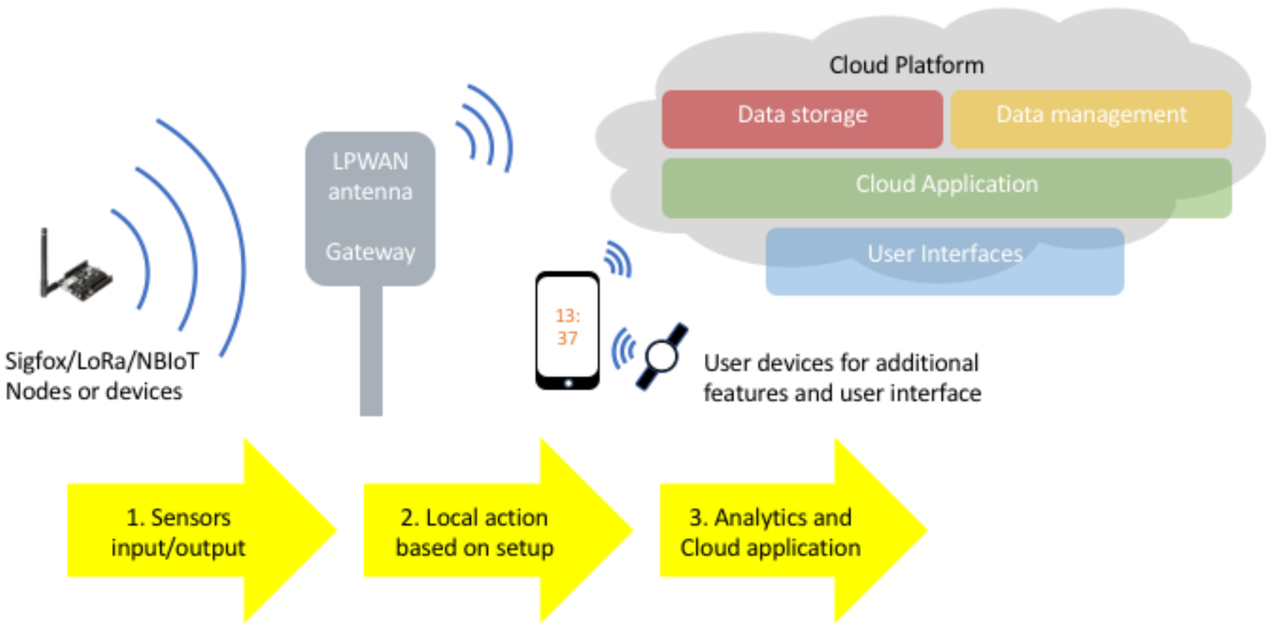
6 DESIGN

The design of IoT solutions can be divided into three basic components; end-device, gateway and cloud. The end-device represents the hardware and software that directly interacts with the physical world. The device can connect to the Internet directly or indirectly via a network. There can be multiple networked devices, which connect directly or indirectly to the Internet depending on the implementation. Clustered devices or sensors can be connected to a gateway or a cluster head with Internet connectivity to avoid high complexity and power consumption.

6.1 System Architecture

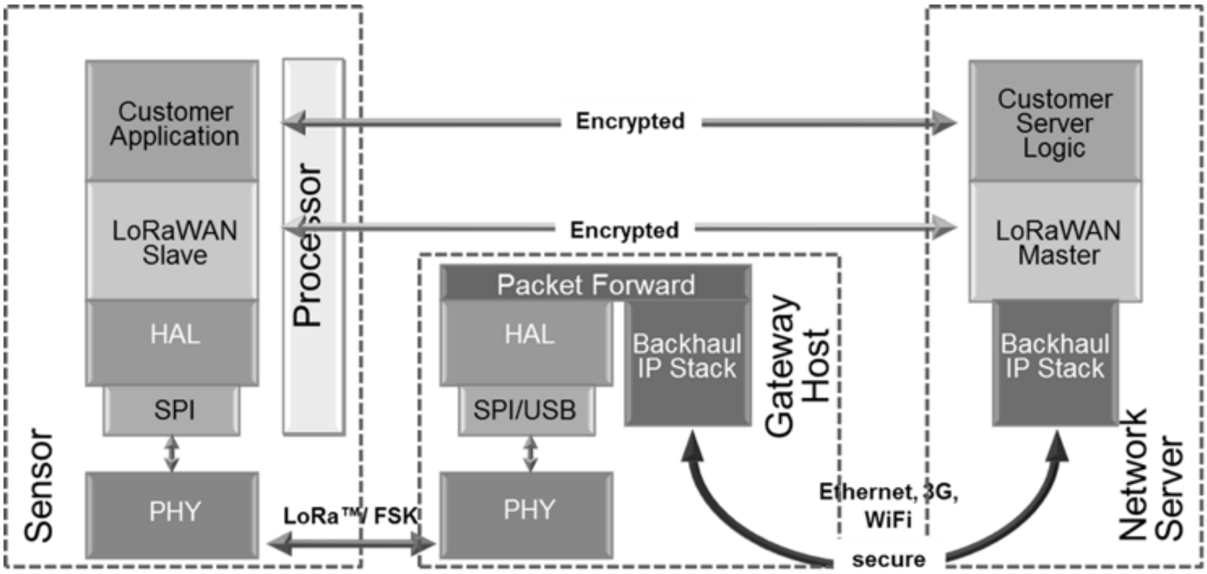
The overall system architecture was designed with multiple choices for LPWA technologies in mind. The system design comprise three steps as illustrated in Figure 6-1 below, where Step 1. is the LPWA end-node and sensor-device, which takes analogue input, followed by step 2., depending on the local code running, which will either keep the device dormant or have it take action based on the setup, to send the relevant output data via the LPWAN gateway to the IoT-application in the cloud. Step 3. is the data management, storage, and aggregation of the data server-side.

Figure 6-1: System Architecture and overall flow



With the delimitation of the development hardware, using LoRaWAN was the starting point of the system design. To elaborate on the logic between Sensor, Gateway and Server in LoRaWAN the layers can be seen in Figure 6-2 below.

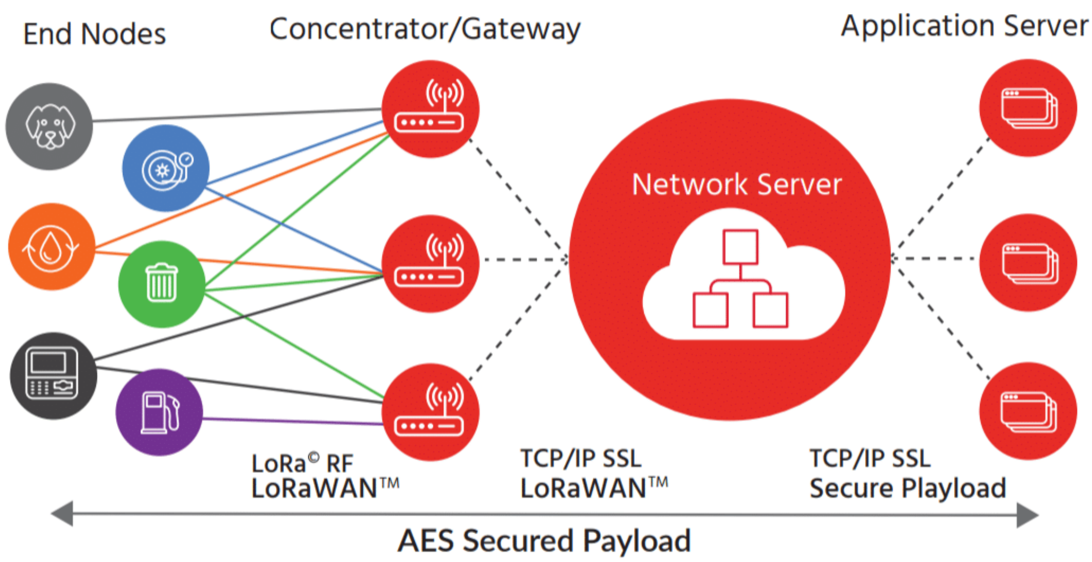
Figure 6-2: LoRaWAN logic



6.1.1 Network Topology

The LoRaWAN network architecture is typically a star-of-stars topology, using single-hop from end-nodes to the gateways. Gateways and servers are connected using IP based connections.

Figure 6-3: Network topology with LoRa technology



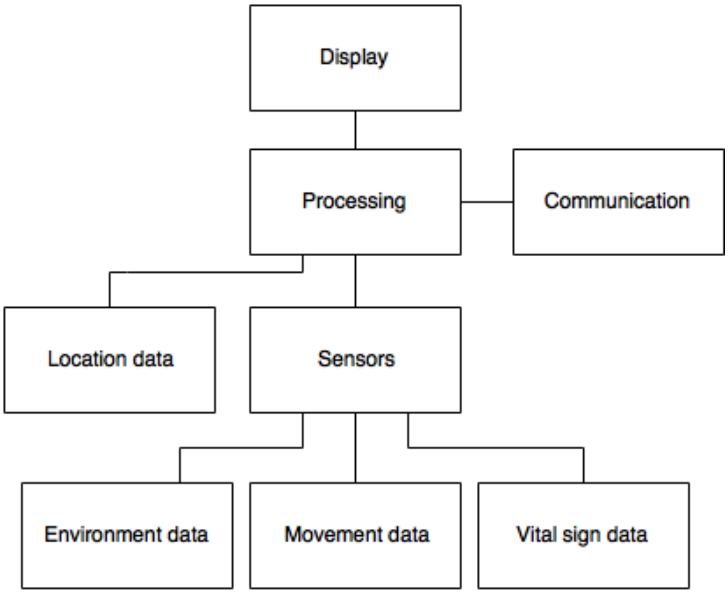
6.1.2 Structural Design

The LoRaWAN logic is depicted in Figure 6-2 below. On the left side, the Sensor connecting to the Network Server via the Gateway Host, seen in the middle. The end nodes or User Equipment will be located on the Athletes. If movement is detected they will activate and measure using sensors. In case of an anomaly in the tracked movement data, an alert message will be sent over the gateway to the Network server, from where the incident is logged and any relatives connected to the user will receive the alert.

6.1.2.1 User Equipment

The structural design of the UE was initially designed as seen in Figur 6-4, with a simple status display, indicating battery left, connectivity, a processor. The sensors including environmental sensing, e.g. temperature, movement data to detect performance as well as fall-/impact detection, the vital sign data e.g. heart rate, body-movement or body- temperature. Besides location data from either a BLE connected Smartphone or from an integrated GPS module.

Figur 6-4: User Equipment design



7 IMPLEMENTATION

This chapter describes the necessary prerequisites for the reader to redo what was achieved in the implementation part of the project. Following the prerequisites section is the actual steps taken and coding and setup of both hardware, devices, antenna modules and cloud platform. The development process of the proof-of-concept solution throughout this chapter is divided into grouped parts, i.e. Client-side/End-device, Gateway and Server-side/Cloud, to ease the understanding for the reader. It does not completely reflect the timely order.

7.1 Prerequisites

Because the project was written by a single person development "team", it was obviously a restricting factor, as to how much was achievable in the given timespan. The choices for the implementation should be regarded as solid choices for prototyping, developing and testing the possibilities of sensors and LPWA technology, rather than which specific components and parts should be implemented in a finalised go-to-market product.

7.1.1 Choice of hardware

The Raspberry Pi was chosen for implementation of the system end device, as it offers great variety and development choices in a relatively compact package. It can be deployed instantly with a few peripherals, running open source OS, and is supported by a large developer-community. Of course, a finalised solution could be simplified and benefit from more function specific modules and chips, to both reduce the physical size, power consumption and cost of an end-device. However, the capabilities of the RPi with multiple built-in technologies, sensors, etc., makes it a "Swiss-army-knife" for fast prototyping, deployment and testing, which was found appropriate for this project. Two RPis were utilised in the project, the latest RPi 3, seen in Figure 7-1 and the previous RPi 2, seen in Figure 7-2 below.

Figure 7-1: Raspberry Pi 3 Model B (RPi #1)

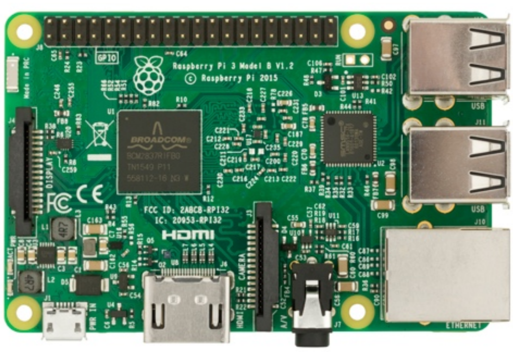
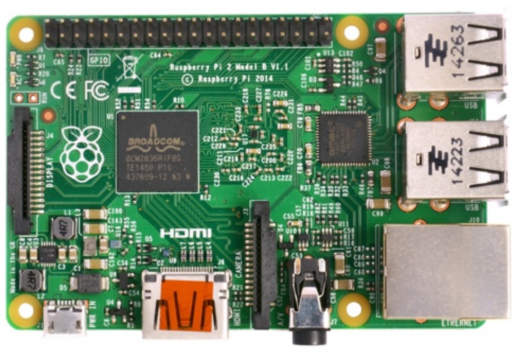


Figure 7-2: Raspberry Pi 2 Model B (RPi #2)



Recommended peripherals to develop with Raspberry Pi:

- Monitor and full-size HDMI cable
- Micro SD card
- Power supply 5 Volt, 2 Ampere for Micro USB

- Powerbank 5V, 2A for Micro USB (for running the RPi without power outlet)
- USB mouse and keyboard (or Bluetooth on RPi 3 Model B)

The HATs acquired for this project met the initial requirements researched, and both operate with the Raspberry Pi models described above. The Sense HAT shield, as seen in Figure 7-3 below, is developed specifically for RPi and can be attached directly on top to extend the capabilities with a wide range of sensors, LEDs joystick etc.. The Dragino LoRa HAT, seen to the right in Figure 7-4 , is also a shield for RPi, but the LoRa HAT extends capabilities of LPWA network technology, specifically LoRaWAN and GPS connectivity.

Figure 7-3: Sense HAT for Raspberry Pi (SenseHAT)

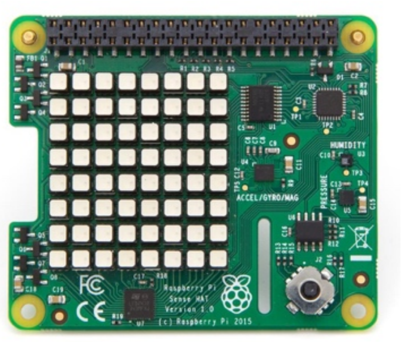
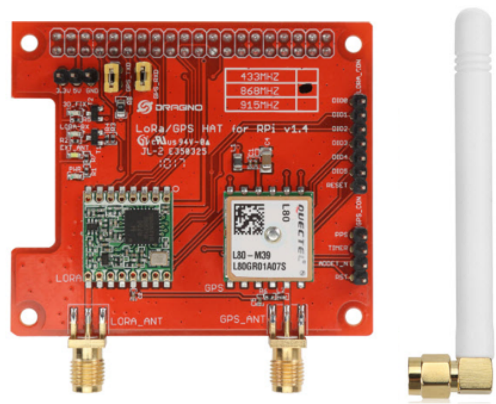


Figure 7-4: "Dragino" GPS/LoRa HAT (LoraHAT)



The detailed specification of the SenseHAT and LoRaHAT can be found in Appendix B.

SenseHAT features:

- Gyroscope, angular rate sensor: +/- 245/500/2000 dps
- Accelerometer, Linear acceleration sensor: +/- 2/4/8/16 G
- Magnetometer, Magnetic Sensor: +/- 4/8/12/16 gauss
- Barometer: 260-1260 hPa absolute range (accuracy depends on temperature and pressure, +/- 0.1 hPa in normal conditions)
- Temperature sensor (temperature accurate to +/- 2 °Celsius in the 0-65 °C range)
- Relative Humidity sensor (accurate to +/- 4.5% in the 20-80% rH range, accurate to +/- 0.5 °C in 15-40 °C range)
- 8x8 LED matrix display
- Small 5-button joystick

LoRaHAT features:

- LoRa™ Modem (LPWA antenna module)
- Frequency Band: 868 MHz/433 MHz/915 MHz (factory-settings)
- GPS antenna module
- Low power consumption
- Temperature sensor
- Compatibility with Raspberry Pi 2 Model B/Raspberry Pi 3 Model B
- FSK, GFSK, MSK, GMSK, LoRa™ and OOK modulation

7.1.2 Choice of LoRaWAN and The Things Network (TTN)

LoRaWAN was chosen for testing the LPWA capabilities, as it is an open wireless standard using unlicensed frequency bands, and is less costly for development purposes with a wide developer community. One of the largest LoRaWAN communities worldwide is established by The Things Network or TTN. TTN offers network servers that can be integrated with the previously mentioned IoT cloud services, Microsoft Azure, AWS and IBM Bluemix.

7.1.3 Choice of cloud platform

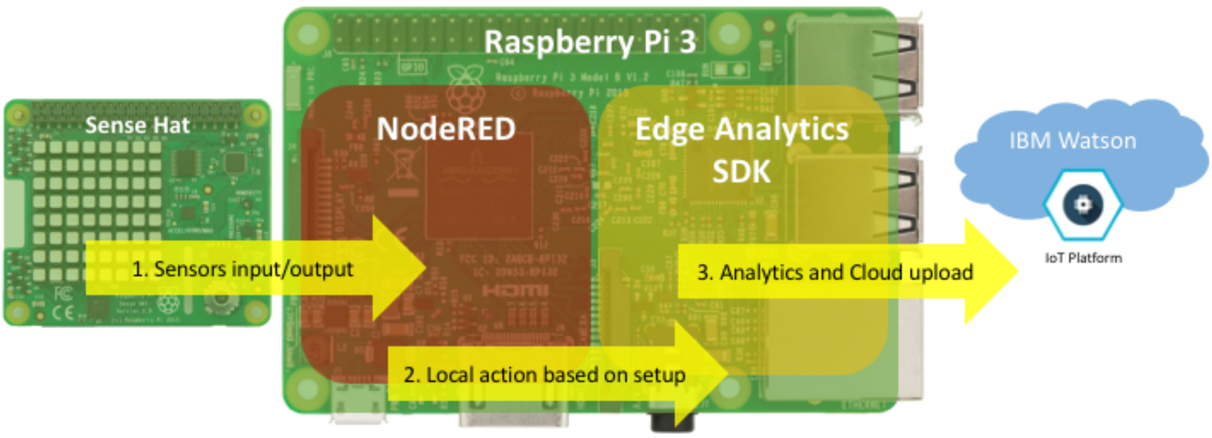
The server side of the implementation was chosen based on researching the different IoT Cloud development platforms e.g. Microsoft's Azure IoT Hub, Amazon's AWS IoT and IBM's Watson IoT Platform. The latter supports the following protocols and standards for application and IoT device development, which was found convenient for the project. The platform supports the MQTT messaging protocol, Python, Node.js, Java, C#, Embedded C and mBed C++.

Additionally, the Watson IoT platform has functionalities for visualizing a device's real-time data and historic data, which would be useful for cloud analytics e.g. specification of rule conditions based on real-time device data, to trigger actions and alerts.

7.2 Client side / User Equipment

The client side, also referred to as end-node or user equipment (UE), was implemented using the RPi#1. The first step was establishing the client side application software. Thus, to get started a fast prototype environment was chosen; the free RaspbianOS (v4.9 Jessie), based on Debian, which is optimized for RPi and comes with pre-packaged development software, such as NodeRED.

Figure 7-5: Components in the proof-of-concept design

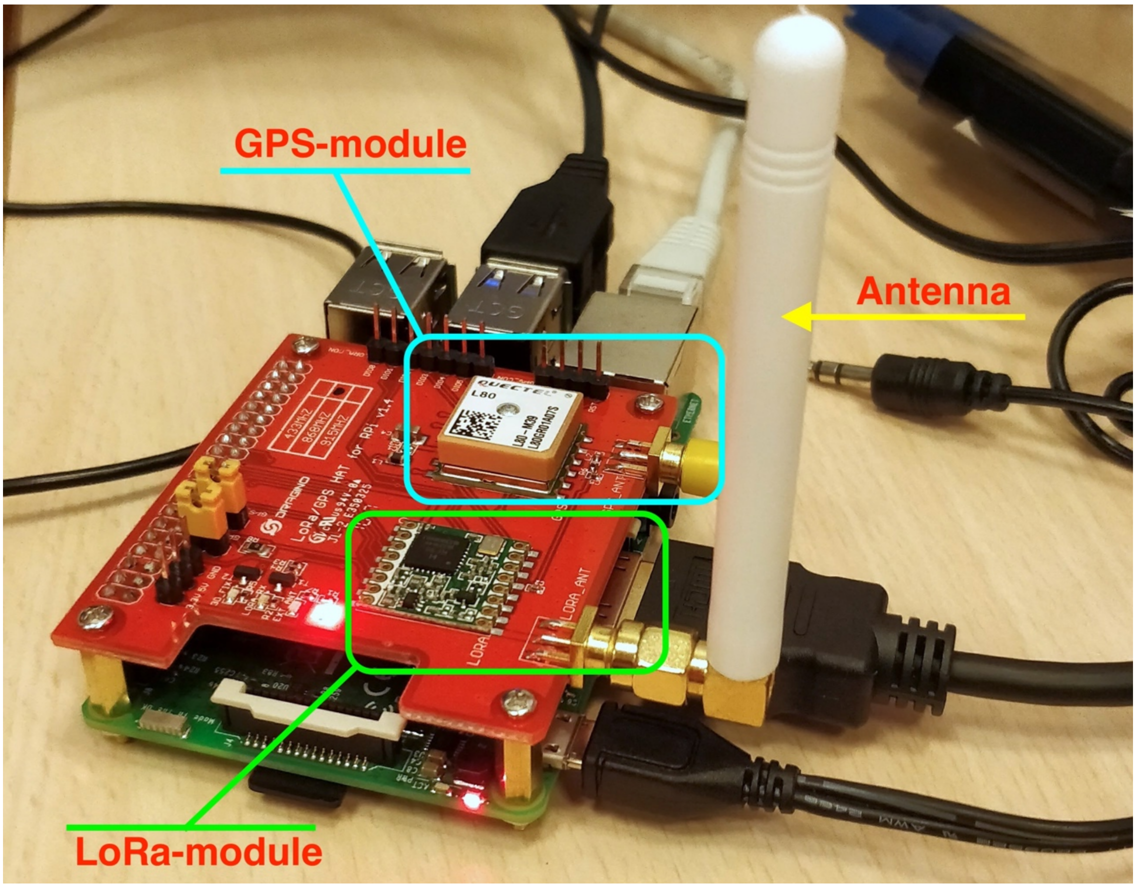


Node RED was used for fast prototyping of the data flow of the application, requiring more focus on system design and less on coding. The flow illustrated in Figure 7-5, shows the prototyping setup with a Raspberry Pi (RPi) running Node RED and connects to the Internet where the IBM

Watson IoT Cloud platform can process the data. The Sense HAT functions as the end user sensing device taking input from the user's surroundings.

The RPi with a Sense HAT can be set up for collecting sensor input and use Node RED flows running on the RPi to make local actions and possibly local edge analytics. Further processing can be achieved using a Cloud platform with more processing power.

Figure 7-6: Client-side RPi setup



The picture (Figure 7-6) shows the purchased hardware set up; the RPi 3 Model B and the Dragino LoRa/GPS HAT mounted on top. The *Dragino*-shield was initially tested from the RPi environment as described in the following sections.

7.2.1 Raspberry Pi setup

With the hardware in place, the OS was downloaded to the Micro SD card and booted up on the RPi. First step was updating the packages to ensure the latest software updates would be available for e.g. the Node RED environment. This was done with the commands below in Code example 7-1, typed in the Terminal (MacOS Sierra 10.12).

Code example 7-1: Input – Update RPi and enable serial pins

```
01 sudo apt-get update
02 sudo apt-get upgrade
03 sudo apt-get install wiring-pi
```

The first two code lines are simply run to get the latest software updates and to upgrade the packages. The *wiring-pi* install is a script enabling the serial pins for the LoRa/GPS HAT.

7.2.2 LoRa Packet forwarding

To ensure that the LoRa module was functioning properly, a single channel packet forwarding was installed, tested and linked to my *The Things Network* account. [23]

7.2.2.1 Single Channel Packet Forwarding

The following was done to test the gateway connection and the end device RPi with the LoRa/GPS HAT attached. The Code example 7-2 below shows the commands typed to access the settings and setup of the end node for specifying the frequency used to LoRa SF7 at 868.1 Mhz.

Code example 7-2: Input – Edit configuration file

```
cd ~/single_chan_pkt_fwd
nano main.cpp
```

Now the information was applied and registered at the TTN-console, from the web interface *console.thethingsnetwork.org*, and registering the device as a gateway. Following the code in the Code example 7-3 was run to compile and test run the gateway.

Code example 7-3: Input - Compile and test run

```
make
sudo /home/pi/single_chan_pkt_fwd/single_chan_pkt_fwd
```

The output from the terminal, see Code example 7-4 below, showing the detected gateway with the MAC-address of the gateway.

Code example 7-4: Terminal Output - Gateway started

```
SX1276 detected, starting.
Gateway ID: b8:27:eb:ff:ff:5b:fa:3b
Listening at SF7 on 868.100000 MHz.
-----------------------
stat update: {"stat":{"time":"2017-11-17 14:51:40
GMT","lati":0.00000,"long":0.00000,"alti":0,"rxnb":0,"rxok":0,"rxfw":0,
"ackr":0.0,"dwnb":0,"txnb":0,"pfrm":"Single Channel
Gateway","mail":"ajepp87@gmail.com","desc":"rpi3-lora-gw-01"}}
```

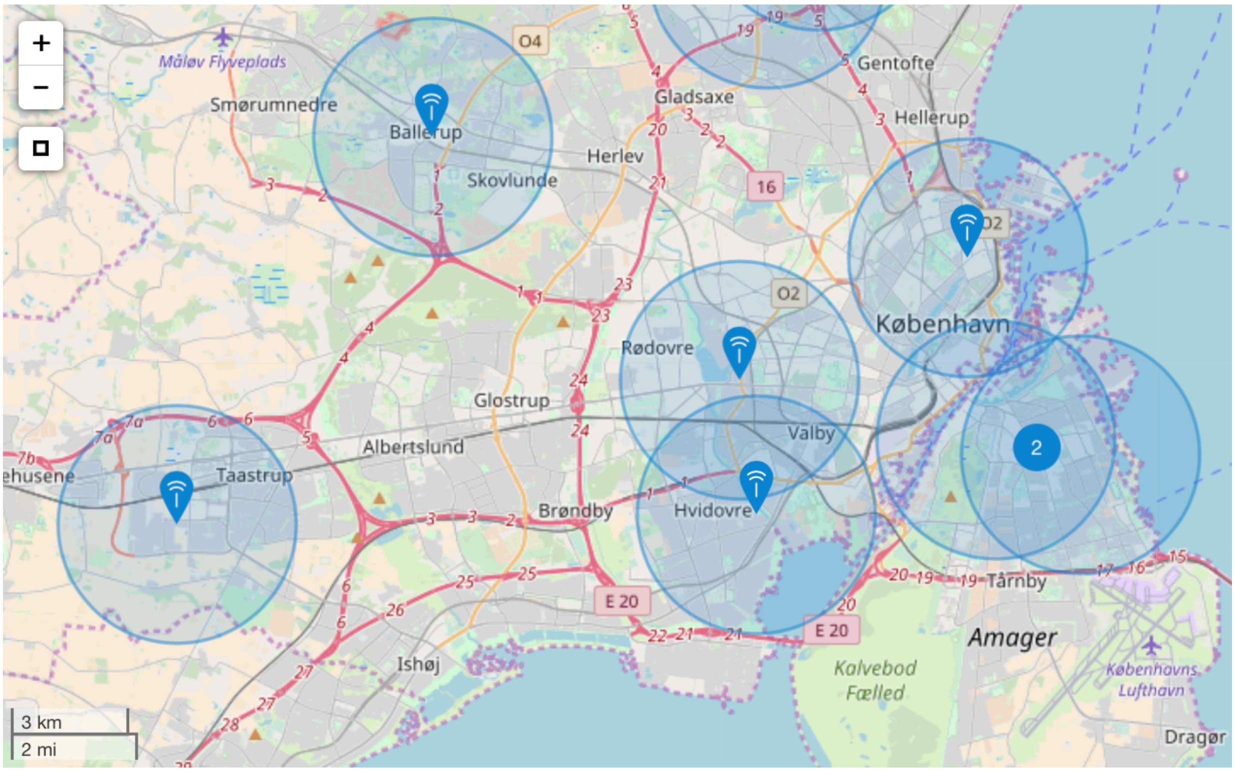
7.2.3 Gateway connection

During the development process, I involved myself in the community-owned data network in Copenhagen as a part of *The Things Network* (TTN), which is global and crowd-sourced. People from the TTN community have deployed public LoRaWAN gateways for developers to share all over the world. Therefore, with time being the most limited resource, to avoid prolonging the development process and have additional hardware expenses for building a new LoRaWAN gateway it was chosen to go about connecting to existing gateways in the Copenhagen area and focus on the implementation of an end-node.

The TTN-community has dedicated communication channels set up in the productivity tool *Slack*[1], where much of the communication is facilitated. The Copenhagen community forum is still quite small, only thirteen members at the time joining, so I got in contact with the initial establisher of the Copenhagen community in TTN, Sebastian Büttrich, to gain information regarding the public gateways deployed here.

For now, the Copenhagen community consists of around 40 contributors and 22 gateways have been registered. Five of which cover large parts of Greater Copenhagen, as shown in the seen in the screenshot overview map in Figure 7-7.

Figure 7-7: TTN Gateways in Greater Copenhagen area



The nearest gateways, seen in the screenshots below, Figure 7-8, Figure 7-9, Figure 7-10 and Figure 7-11, were the targeted gateway for testing the end device with LoRaWAN antennas in this project.

[1] *Slack, is a cloud-based set of proprietary services and team-collaboration tools. The name is acronym for "Searchable Log of All Conversation and Knowledge"*

Figure 7-8: TTN gateway at Østerbro

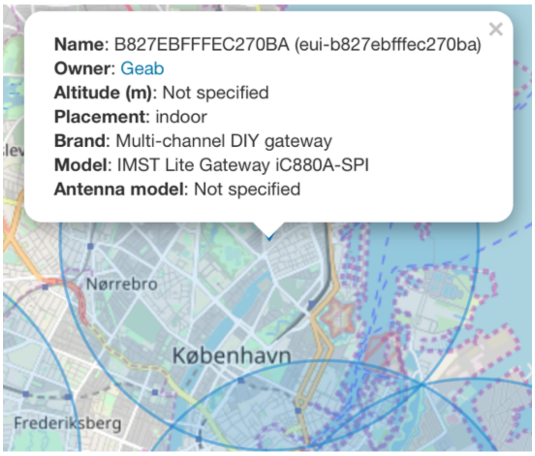


Figure 7-9: TTN gateway in Vanløse

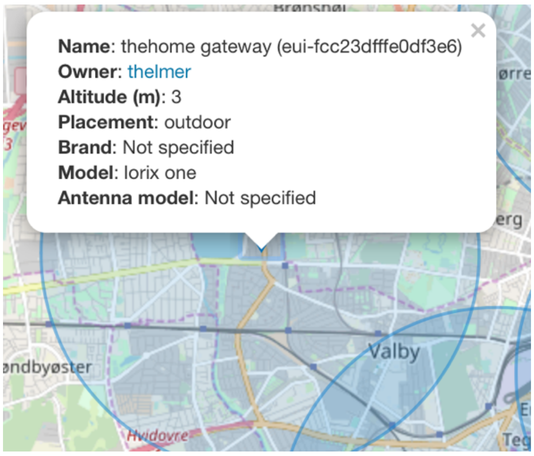


Figure 7-10: TTN gateway in Sydhavn

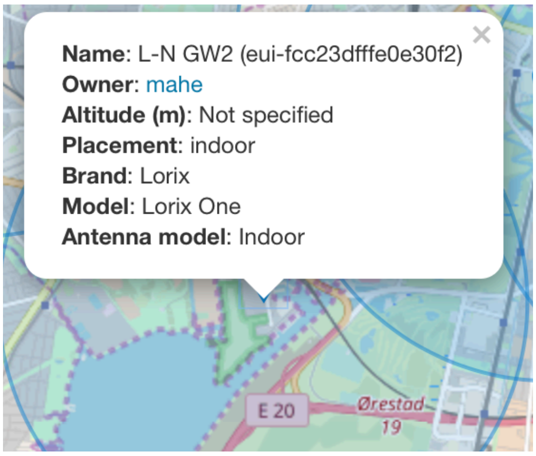
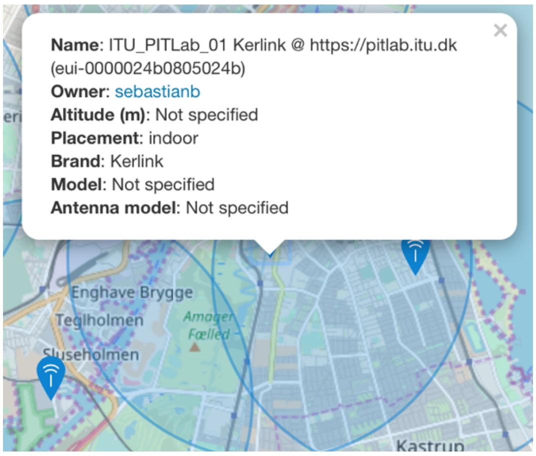


Figure 7-11: TTN gateway at the ITU University



7.2.4 Local Node RED flow

A Node-RED server was run on the Raspberry Pi, (ideally be run from a cloud platform) ,using the MQTT message protocol to transfer data from the input device via the RPi to the server. The data flow can then easily be managed from the server-side.

8 DISCUSSION

8.1.1 Scalability

Fall and impact detection is applicable in many scenarios and is not regarded unique for this specific use case. Many other outdoor sports and potentially high-risk activities could definitely benefit from automated distress responses.

8.1.2 Understanding limitations

Even though the theoretical use of LPWA networks applied in a concept like the one described in this thesis project, there are still many limitations present. The LPWA technologies currently most commonly used for industry use cases where sensors can be placed physically and stay dormant until activated. The problem with consumer-IoT such as sports trackers, is the real-time tracking and to some extent higher data rates. However, in certain scenarios using LPWA technology could be found useful, as discussed with the emergency scenarios in rural areas.

9 CONCLUSION

The initial project and problem formulation as defined in the first chapter was: "How can LPWA-technology be implemented in consumer-IoT to improve the safety for people practicing outdoor sports?" This was subsequently followed by the following sub-problems:

- *What are the current approaches to address the risks and challenges faced in outdoor sports?*
- *Which of the emerging LPWA technologies can be applied for coverage in rural areas?*
- *What limitations are currently present for developing IoT solutions using LPWA-network technology?*

From the background and state of the art research done in the project I have gained deep knowledge within the field of Internet of Things and the major topic it is. IoT spans most industries and has potential to change daily lives in so many ways. The emergence of LPWA technologies, which can address new scenarios with much longer battery life and long-distance radio coverage, using the Sub-1GHz frequency bands was found very intriguing for exploring unknown capabilities in consumer-IoT. Hoping to address safety issues that I have personally experienced.

However, the project has provided insight in the limitations of LPWA technology in the context of outdoor sports and the NB-IoT or LoRaWAN is likely to be seen in similar applications in the near future.

The limited resources of a one-person team did not fully reach the goals of implementation.

9.1.1 Recommendations for future work

- Automate the training process of the system
- In a full-scale solution, the system could benefit from automating the training of the algorithms to improve the usability.

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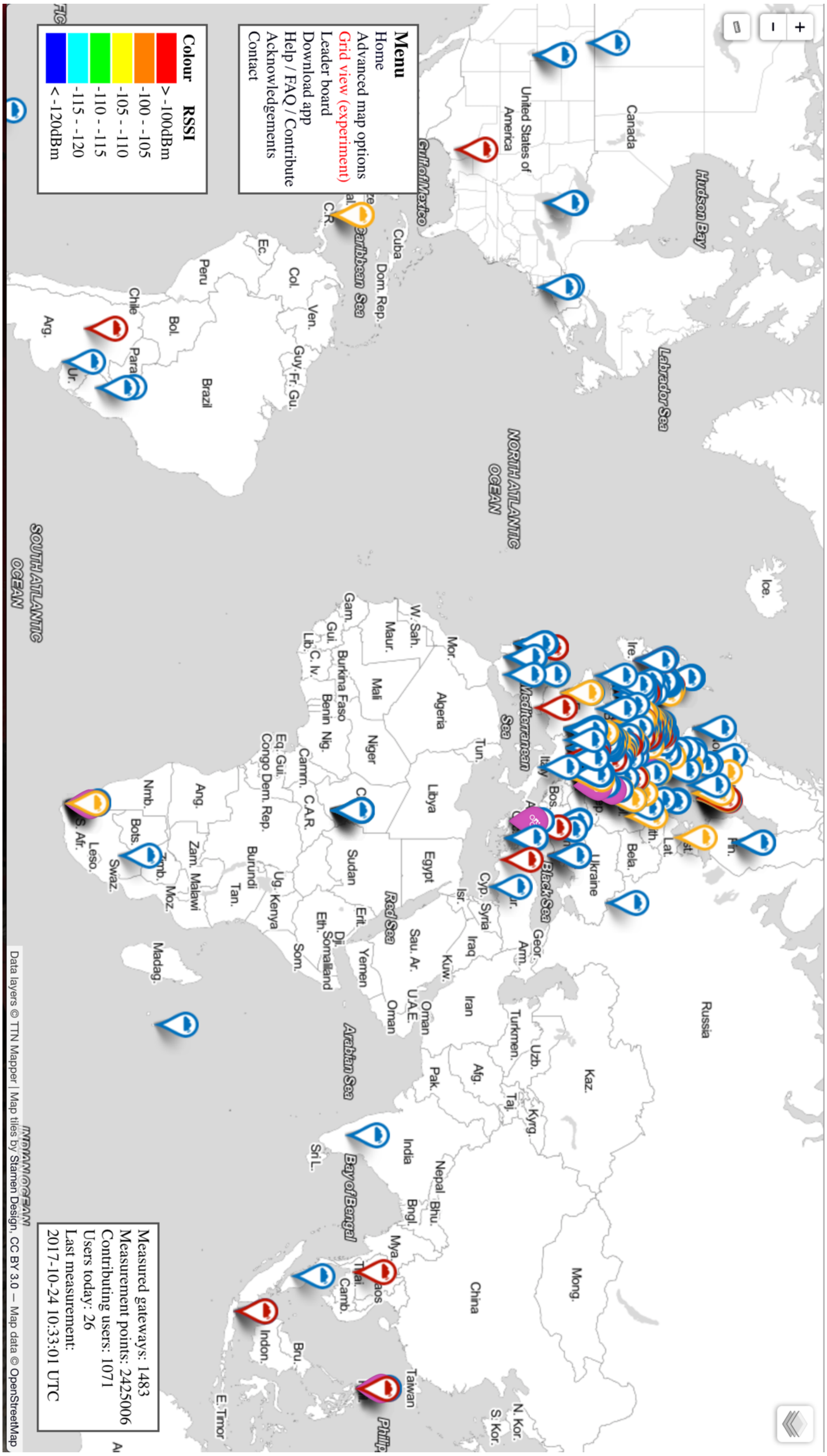
A APPENDIX

Active map of the nodes transmitting to *The Things Network* (Source: https://ttnmapper.org)



B APPENDIX

Dragino GPS/LoRa HAT specification

HAT features:

- Frequency Band: 868 MHz/433 MHz/915 MHz (factory-settings)
- Low power consumption
- Compatibility with Raspberry Pi 2 Model B/Raspberry Pi 3 Model B
- LoRa™ Modem
- FSK, GFSK, MSK, GMSK, LoRa™ and OOK modulation
- Preamble detection
- Baud rate configurable
- Built-in temperature sensor and low battery indicator
- Excellent blocking immunity
- Automatic RF Sense and CAD with ultra-fast AFC
- Support DGPS, SBAS (WAAS/EGNOS/MSAS/GAGAN)
- GPS automatic switching between int. patch antenna and ext. active antenna
- PPS vs. NMEA can be used in time service
- Support SDK command
- Built-in LNA for better sensitivity
- EASY™, Advanced AGPS technology without ext. memory
- AlwaysLocate™, an intelligent controller of periodic mode
- GPS FLP mode, about 50% power consumption of normal mode
- GPS support short circuit protection and antenna detection

Version 1.4 changes:

- Change SMA connector to support active antenna
- Add AADET_N LED to show if external antenna is active.
- Connect GPS PPP pin to RPi BCM pin 18
- Modify Silkscreen for GPS TXD/RXD

GPS-module specification:

- Based on MT3339
- Power Acquisition: 25mA, Power Tracking: 20mA
- Compliant with GPS, SBAS
- Programmable bit rate up to 300 kbps
- Serial Interfaces UART: Adjustable 4800~115200 bps, Default: 9600 bps
- Update rate:1Hz (Default), up to10 Hz
- I/O Voltage: 2.7V ~ 2.9V
- Protocols: NMEA 0183, PMTK
- Horizontal Position Accuracy: Autonomous <2.5 m CEP
- TTFF@-130dBm with EASY™: Cold Start <15s, Warm Start <5s, Hot start <1s; TTFF@-130dBm.without EASY™: Cold Start <35s, Warm Start <30s, Hot Start <1s.
- Timing Accuracy: 1PPS out 10ns, Reacquisition Time <1s
- Velocity Accuracy Without aid <0.1m/s, Acceleration Accuracy Without aid 0.1m/s²
- Sensitivity Acquisition -148dBm, Tracking -165dBm, Reacquisition -160dBm
- Environmental: Operating Temperature -40°C to 85°C, Storage Temperature -45°C to 125°C
- Dynamic Performance Altitude Max.18000m, Maximum Velocity Max.515m/s, Maximum Acceleration 4G
- L1 Band Receiver (1575.42MHz) Channel 22 (Tracking) /66 (Acquisition)