UNIVERSITY OF VAASA

FACULTY OF TECHNOLOGY

TELECOMMUNICATIONS ENGINEERING

Ville Vehniä

SIGFOX: OVERVIEW OF TECHNOLOGY, SERVICES AND EXPENDATURE

Bachelor’s thesis for the degree of Bachelor of Science in Technology submitted for inspection.

Vaasa 06.02.2019

Supervisor Professor Timo Mantere

Instructor Professor Timo Mantere

TABLE OF CONTENTS

TABLE OF CONTENTS 2

SYMBOLS AND ABBREVIATIONS 4

ABSTRACT: 6

TIIVISTELMÄ: 7

1 INTODUCTION 8

1.1 Background and definition 8

1.2 Throughput 9

1.3 Learning objective 9

2 SIGFOX TECHNOLOGY OVERVIEW 10

2.1 Network 10

2.1.1 Communication technology 11

2.1.2 Coverage and capacity 12

2.2 Cloud 14

2.2.1 Sigfox Support System 14

2.2.2 Sigfox Cloud interfaces 14

2.3 Security 15

2.4 Competition and advantages 16

3 PROVIDED SERVICES 18

3.1 Solutions 18

3.2 Partnership programs 22

3.3 Certifications and type approvals 24

3.3.1 Sigfox Verified™ 24

3.3.2 Sigfox Ready™ 25

4 ELEMENTS OF COST 27

4.1 Hardware 27

4.1.1 Communication module 27

4.1.2 Sensor 28

4.1.3 Antenna 29

4.1.4 Battery 30

4.2 Networking 31

5 RESULTS AND CONCLUSIONS 33

REFERENCES 35

SYMBOLS AND ABBREVIATIONS

IoT	Internet of Things
ICT	Information and Communication Technology
LPWA	Low Power Wide Area
ISM	Industrial, Scientific and Medical (band)
M2M	Machine to Machine
SNO	Sigfox Network Operator
BPSK	Binary Phase Shift Keying
bpm	bits per second
CRC	Cyclic Redundancy Check
GPS	Global Positioning System
SSS	Sigfox Support System
OSS	Operation Support System
BSS	Business Support System
API	Application Programming Interface
VPN	Virtual Private Network
HTTPS	Hypertext Transfer Protocol Secure
HMAC	Hash-based Message Authentication Code
PAC	Porting Authorization Code
TPM	Trusted Platform Module
LoRa	Long Range
MAC	Media Access Control
CSS	Chirp Spread Spectrum
P2P	Peer to Peer
CE	Conformité Européenne
FCC	Federal Communications Commission

RF	Radio Frequency
SDR	Software Defined Radio
LBT	Load-Based Teaming
ERP	Effective radiated power
Li-SOCl2	Primary cells Lithium Thionyl Chloride
IIoT	Industrial Internet of Things
dB	Decibel
dBi	dB (isotropic)
A	Ampere
Ah	Ampere hour
V	Voltage

UNIVERSITY OF VAASA	
Faculty of technology	
Author:	Ville Vehniä
Topic of the Thesis	Sigfox: Overview of technology, services and expendature
Supervisor:	Professor Timo Mantere
Instructor:	Professor Timo Mantere
Degree:	Bachelor of Science in Technology
Degree Programme:	Telecommunications Engineering
Year of Entering the University:	2015
Year of completing the Thesis:	2019 **Pages:** 40

ABSTRACT:

Sigfox is a French company established in 2009 offering their Low Power Wide Area Network termed wireless communication service in Internet of Things context. The main objective of this thesis is to explore what kind of services Sigfox offers as a company and how it technically operates as a cellular network communications provider. Thesis begins with an introduction to IoT and LPWANs combined with an outlook for the future evolution of these technologies in terms of popularity.

The introductions are followed by a technical overview of the Sigfox network architecture, communication technology, coverage, capacity and security measures. Besides their core connectivity solution, the Admiral Blue, Sigfox also offers more lightweight communication and tracking solutions. Another part of their service are device certifications, cloud platforms for device management and partnership programs with varying features depending on the partnership type (startup companies, academic institutions, incubators, developers and IoT platform creators).

Another point of interest was the direct cost structure of manufacturing a device operating under the Sigfox network. Direct costs mean the expenses from hardware (communication module, sensor, antenna and battery), network subscriptions and certifications required for a functional device. Hard to evaluate costs, such as administrative or development expenses, are not taken into consideration.

KEYWORDS: IoT, LPWAN, Network, Sigfox, Technology, Wireless Communication

VAASAN YLIOPISTO		
Teknillinen tiedekunta		
Tekijä:	Ville Vehniä	
Kandidaatin tutkielman nimi:	Sigfox: Overview of technology, services and expendature	
Valvoja:	Professori Timo Mantere	
Ohjaaja:	Professori Timo Mantere	
Tutkinto:	Tekniikan kandidaatti	
Oppiaine:	Tietoliikennetekniikka	
Opintojen aloitusvuosi:	2015	
Tutkielman valmistumisvuosi:	2019	**Sivumäärä:** 40

TIIVISTELMÄ:

Sigfox on vuonna 2009 perustettu ranskalainen yritys, jonka palvelu toimii esineiden internetin ratkaisuille tyypillisesti, mahdollistaen langattoman ja vähätehoisen tiedonsiirron pitkien välimatkojen yli. Tutkimuksen päätavoite on selvittää, millaisia palveluita Sigfox tarjoaa yrityksenä, ja kuinka se teknisesti toimii palveluntarjoajana. Tutkimus alkaa esineiden internetin ja LPWA-verkkojen käsitteiden määrittelyllä. Lisäksi teknologioiden tulevaisuuden näkymiä pohditaan keskittyen niiden oletettavasti kasvavaan suosioon.

Määrittelyjä seuraa yleiskatsaus Sigfox-teknologian hyödyntämästä tietoliikennetekniikasta, verkkoarkkitehtuurista, peitealueesta, kapasiteetista ja salauskeinoista. Pääasiallisen kommunikaatiopalvelunsa Admiral Bluen lisäksi Sigfox tarjoaa kevyempiä kommunikaatio- ja paikannuspalveluita. Yritys hoitaa myös heidän verkossaan toimivien laitteiden sertifioinnin, tarjoaa pilvipalveluita laitehallinnan helpottamiseksi ja erilaisia ohjelmia kumppaneilleen (Startup-yritykset, akateemiset laitokset, ajatushautomot ja kehittäjät).

Tutkimuksessa arvioidaan myös suorien kustannusten määrää Sigfox-verkossa toimivan laitteen valmistuksessa. Suorilla kustannuksilla tarkoitetaan laitteiston (viestintämoduuli, sensorit, antenni ja virtalähde) hankinnasta, verkkopalvelun tilausmaksuista ja laitteen sertifioinnista aiheutuneita kuluja. Vaikeasti arvioitavia kuluja, kuten hallinto- ja kehityskustannuksia, ei oteta lukuun.

AVAINSANAT: Esineiden internet, Langaton viestintä, LPWAN, Sigfox, Teknologia, Verkko

1 INTODUCTION

Future of computing and communications lays on Internet of Things (IoT) which consists of multiple innovational technologies. Basic idea of IoT is forming independent services by processing data from domain specific applications, whereas all physical objects share information together. The amount of connected smart devices will be enormous in the future, but with constraints like processing capability storage volume, short device power life and low radio range (Al-Sarawi, Anbar, Alieyan, Alzubaidi 2017: 685-686). New protocols are required and devices need to be developed to make the new services and applications more customer friendly. (Al-Fuqaha, Guizani, Mohammadi, Aledhari, Ayyash 2015: 2347-2348). Fragmentation of these protocols is one of the most crucial issues in making the IoT successful. Expansion to global scale will require clear technological standardization. (Tan, Wang 2010: 376-380). Low power wide area (LPWA) networks tackle the current constraints in the IoT environment with their typical characteristics of long distance communication, low energy consumption and low bandwidth transmissions. These networks are predicted to capture up to 55% share in the IoT market. (Nolan, Guibene, Kelly 2016: 439-440).

1.1 Background and definition

Sigfox is a French company established in 2009 offering their LPWA network solution in IoT context. Primary focus of this paper is on the Sigfox technology, service provision and direct costs when launching a device operating under the Sigfox network. This topic is made interesting by Sigfox claiming to bring down cost of connecting while the future increase in connected devices adds financial pressure in companies deploying their IoT systems (Bonavolontà, Tedesco, Schiano Lo Moriello, Tufano 2017). The topic was chosen at the supervisor’s suggestion and it is aimed at anyone who is looking to deploy their system using Sigfox or generally interested in the technology.

1.2 Throughput

Besides the primary focus, other objectives are to lower barriers of joining the third wave of information technology (IoT) (Nolan et al. 2016: 439) and to learn more about Information and Communication Technologies (ICT). These objectives are met by thoroughly studying relevant literature, utilizing many sources and maintaining neutral approach.

1.3 Learning objective

Many skills learned during the first three years of studies are taken in use. Including mathematical capabilities, experience with embedded systems and basic knowledge of communication technologies. Certain fuzziness of the topic gives a versatile view of many different technologies building strong capabilities for anyone aiming to work in the ICT field.

2 SIGFOX TECHNOLOGY OVERVIEW

Sigfox has adopted an operator model; the company provides a cellular network for IoT endpoints based on its patented technology. The core service consists of Sigfox cloud and bidirectional communication between client devices and base stations. The cloud service is used as a tool for managing objects and data in addition to retrieving messages. (Nolan et al. 2016: 441). Utilized protocols and technologies are reviewed in following sections.

2.1 Network

Sigfox's cloud-based approach is a variation of the cellular network used by mobile phones, but it is tailored for serving low power objects and Machine to Machine (M2M) applications instead of humans (Margelis, Piechocki, Kaleshi, Thomas 2015). Country specific Sigfox Network Operators (SNOs) deploy base stations equipped with cognitive software-defined radios and connect them directly to the backend server with a point-to-point link (Hernandez, Peralta, Manero, Gomez, Bilbao, Zubia 2017). For the endpoints Sigfox relies on its verified partners, the device manufacturers. Endpoints operate on a yearly subscription basis, connecting to base stations using Binary Phase Shift Keying (BPSK) in license free Industrial, Scientific and Medical (ISM) band (ranging from 862 to 928 MHz based on continent) with Ultra-Narrow Band (UNB) radio technology. When the base stations within range detect the radio signal sent, it is demodulated and reported to backend server. The data is pushed to customer's system after user callback is implemented. (Nolan et al. 2016: 441). Simplified version of the network architecture is presented in Figure 1.

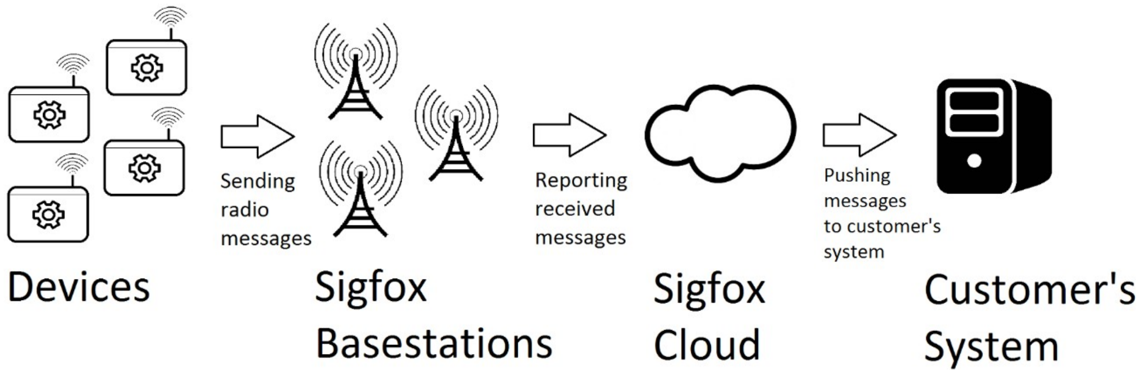


Figure 1. Sigfox network architecture

2.1.1 Communication technology

UNB technology uses channel bandwidths lower than 1 kHz generating a narrow radio signal. This allows a greater number of signals than usual to be carried at the same time with an equal amount of bandwidth. Ultra narrow spectral occupation leads to low noise contribution (around 150 dBm at 290K) allowing the demodulation of an extremely low received power signal (-142 dBm) (Margelis et al. 2015). Efficient bandwidth usage together with low noise levels result in high receiver density, increased battery life and inexpensive device antenna design. On the contrary, these features cause the maximum data throughput of only 100 bits per second (bps) restricting application possibilities for SigFox (Hernandez et al. 2017).

The number of daily transmissions and message payload sizes are limited to 140 uplink messages (up to 12 bytes) and only 4 downlink messages (up to 8 bytes). These restrictions are made due to regional regulations on use of the license-free spectrum (1% duty cycle limitation) (Hernandez et al. 2017). Uplink message overhead contains unique device ID (4 bytes), varying length hash and a Cyclic Redundancy Check (CRC) field (2 bytes) totaling up to 26 bytes. Some of the bytes are also used for security like a sequence counter for anti-replay. (Sigfox: Technical Overview 2017).

Downlink communication works only as an acknowledgement for uplink communication and it is always proceeded by an uplink message. Sigfox lacks support for acknowledgements of every uplink message because the amount of downlink messages are limited. Accordingly, uplink messaging reliability is improved with frequency diversity and redundant transmissions. Each message is sent three times, and the band in use is divided into 400 channels of 100 Hz bandwidth. Random carrier frequency is chosen for every message.

Information such as two precise Global Positioning System (GPS) coordinates, six thermometer readings (300-degree range), 12 speed radar reports (up to 255km/h) or 96 switch (on/off) reports can be carried in the 12-byte Sigfox uplink message. Notice that all 12 bytes do not have to be used. In some applications, the message itself can act as communication with zero bytes of payload. Transmitting the lowest amount of data possible shortens the radio signal length and lowers battery consumption. Downlink messages can be used for simple modifications, for example adjusting sensor scale or message frequency. Additional information about an event registered and reported by individual device can also be requested. Big firmware updates can not be done with downlink messages, but the channel can be used to put more powerful data transmission method in operation, until the required update has been downloaded. (Sigfox: Technical Overview 2017).

2.1.2 Coverage and capacity

Currently Sigfox network reaches over 803 million people in 45 countries connecting 2.5 million devices, and the numbers are growing rapidly. The aim is to reach billion people, 60 countries and 6 million objects by the end of 2018. The service coverage estimation for outdoor devices in Europe is marked as turquoise in Figure 2. While Sigfox reaches 85% of the population in Finland, the best coverage is in Western Europe. Coastal areas have particularly great service because objects can connect base station from a range up to 50km in propitious circumstances (outdoors and in line of sight). Coverage is also available in the biggest cities of United States, Mexico, Brazil, South Africa, Iran, Australia, Japan, New Zealand and many other countries. (Sigfox: About 2017).

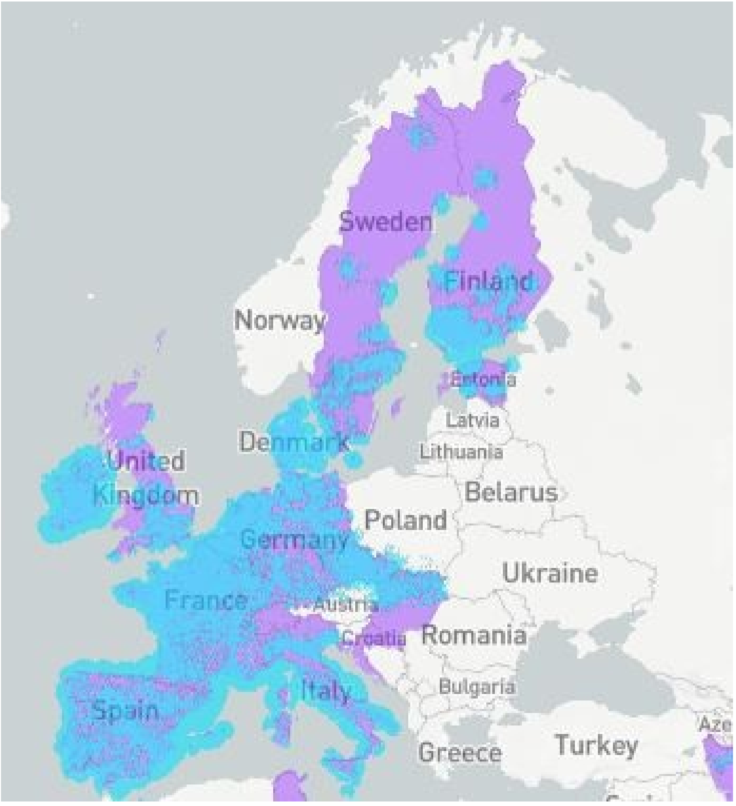


Figure 2. Service coverage estimation for outdoor devices in Europe

In a recent study, the coverage of Sigfox was simulated in interference-free scenario based on Telenor's commercially deployed cellular sites in Denmark. The study states that Sigfox provides coverage for over 99% of the outdoor locations in the simulation. The coverage remains over 99% even in light indoor conditions with 20 dB additional penetration loss. Deep indoor (basement) conditions with 30 dB additional penetration loss drag the area of coverage down to 87%. These results are considered decent and especially interesting in the cost perspective as the light indoor coverage remains over 95% even in filtered simulation conditions with fewer base stations. (Lauridsen, Nguyen, Vejlgaard, Kovács, Mogensen, Sørensen 2017).

However, Sigfox relies on the unlicensed band and may experience interference. Another related study surveys the interference in the EU 868 MHz ISM band. Measurements taken in urban Aalborg (Denmark) shows high power interference (-105 dBm) has 22% occurrence rate. Adding this interference rate to the existing simulation from the previous study Sigfox provides only 90% coverage for outdoor locations (down from over 99%). The light indoor coverage takes a massive drop falling under 50% (down from over 99%). (Vejlgaard et al. 2017).

2.2 Cloud

Sigfox Cloud consists of back-end servers and storage space. Back-end handles base station management, network status monitoring and message processing. Devices metadata and messages are saved in the storage space to support building services and customer message retrieval. The Cloud and interaction tools are considered as the Sigfox Support System (SSS) layer.

2.2.1 Sigfox Support System

SSS takes charge of processing messages and sending them to the customer's system. More thoroughly SSS provides an entry point (access to messages) for different actors (Sigfox, SNOs and end-users) to interact with the cloud through different interfaces. The SSS includes a data repository and several features to assist with data analysis, radio planning (network deployment and monitoring support), registering devices to SNOs (Operation Support System) and making orders & billing clients (Business Support System). These features ensure successful deployment, monitoring and operation of a network. The service access of different user types can be managed by system administrator. End-user can be restricted to see messages only, while the administrator user can manage users, device fleets or check contracts. A distributor can create the contracts and SNOs can make use of the Radio Planning tool. (Sigfox: Technical Overview 2017).

2.2.2 Sigfox Cloud interfaces

The Sigfox Cloud is reachable through three interfaces: a web portal, Application Programming Interfaces (APIs) and callbacks. The interfaces allow customers to access their messages and apply the platform features, but with varying methods. The web portal is accessible via internet browser and aimed for human end-users. The APIs are used for automating most common tasks needed for service delivery. Essentially anything manually done and accessible through the web portal can be achieved in a scriptable way utilizing the API access in pull mode. The callbacks are another method of computer interaction. Callbacks are used for automatically receiving new messages from the cloud in a push mode meaning data is sent without a specific request, while pull mode means data is only sent after a request. (Sigfox: Technical Overview 2017).

2.3 Security

Security of the Sigfox IoT chain is divided into three parts: a firewall, data in motion and data at rest. Sigfox Ready™ certificated devices are not directly connected to the internet or any other network. As stated in previous sections of this study, the devices broadcast a radio message when data is to be received or transmitted. The origin or destination of this message is predefined in the system, so the devices lack the ability of interacting with arbitrary entities via internet and are shielded by a firewall. (Sigfox: Security 2017).

The basis of data in motion security is message authentication and replay avoidance where Sigfox Ready™ certification comes into play again. Each certificated device is given a unique private key during manufacturing. The integrity of a message and authentication of its sender are secured with the varying length hash-based message authentication code (HMAC). It is computed from the device specific private key. The message protocol overhead also contains a sequence counter for detecting and discarding replay attempts. Message payload encryption is not done by default. Sigfox offers customers a chance to implement their own encryption solution or use one provided by the company. The security of communication between base stations and the SSS relies on Virtual Private Network (VPN) and Hypertext Transfer Protocol Secure (HTTPS). (Sigfox: Security 2017).

Critical data at rest for security includes credentials (device ID, private key and Porting Authorization Code (PAC)) and traffic metadata. Most of this data is stored on the Sigfox core network and secured with state-of-the-art approaches based on Trusted Platform Module (TPM) standard. (Sigfox: Security 2017).

2.4 Competition and advantages

As one may have expected, Sigfox is not the only actor in the LPWAN field. Long Range (LoRa) is another wireless communication technology with French origin. It has similar features with Sigfox given its long range and low power consumption. The approach of LoRa is based on two distinct layers: first a link layer based on Chirp Spread Spectrum (CSS) radio modulation technique to enable peer to peer (P2P) communication between nodes and secondly a Media Access Control (MAC) network layer (LoRaWAN) for sharing information between base stations connected to a cloud platform. LoRa can be thought as the chip which enables the physical communication. LoRaWAN is the software that's put on the chip to enable networking. LoRaWAN is an open standard backed by the LoRa Alliance association. (Silva, Rodrigues, Alberti, Solic, Aquino 2017).

The biggest difference compared to Sigfox is the fact one can build and manage their own network using LoRa without any subscription fees. This removes a huge drawback what comes to Sigfox: the network can be deployed anywhere. It is possible to setup gateways to have a coverage of few square kilometres and run a private network only with couple hundred euros. However, setting up and maintaining the network requires some expertise. With the spread-spectrum technology of LoRa-enabled devices both endpoint and base station can use the same radio receiver which is relatively inexpensive. Sigfox requires more sophisticated and therefore expensive base stations due to narrow spectrum use. When true bidirectionality is required LoRa should be considered because of the symmetric link: data rates and quantities are the same in both directions. Sigfox is asymmetrical since the capacity of downlink messages is constrained. (Ray 2018).

Anyhow, Sigfox does come with some advantages compared to LoRa. The company has long traditions (established in 2009), great global reach and has already raised a lot of money (over 300 million euros). Being sole end-to-end network and technology provider can also lead to faster development times: changes in the protocol do not have to be accepted by a committee. Possibly the greatest advantages are the facts that radio modules for Sigfox is the least expensive compared to similar technologies and the ease of use for end-customers: they only need to pay the subscription fees, no additional operational costs or increased workload from designing and managing a network of their own.

3 PROVIDED SERVICES

Besides their core connectivity solution called Admiral Blue, Sigfox offers services such as Admiral Ivory, Monarch, Atlas and Sunrise. The services are not only limited to these solutions, a variety of programs are provided for different Sigfox partners to help them reach their goals. Sigfox also offers and handles certification of devices operating under their network.

3.1 Solutions

The Admiral Ivory is a simplified connectivity service, designed for one-time IoT applications such as package tracking. It uses a cheap, simple and disposable hardware component priced at $0.20. The technology of Admiral Ivory is based on the core solution, Sigfox Admiral Blue. The operating frequency of Sigfox technology varies worldwide based on location. Sigfox Monarch is a radio recognition service for devices with certified modules. It enables systems covering large areas to run without complications by automatically recognizing and adapting to local frequency standards. The Atlas is a location service suitable for devices even with the simplest module, reaching preciseness of one kilometer. The location is computed from a received signal with a method based on the signal strength and a probability model. The service requires a monthly fee which is calculated as a percentage of the total connectivity costs. Final solution is the Sigfox Sunrise, process designed to cut product development time and costs for Sigfox partners. Sunrise includes access to online platforms such as Partner Network, Sigfox Build and Sigfox Buy. The platform interfaces are presented in Figures 3, 4 and 5.

The Partner Network is a promotion channel for the IoT solutions of Sigfox partners. These solutions include certified components, devices, cloud platforms and end-to-end solutions. The user can select the required operating zone, use case, battery life and more to find a suitable product for their needs. For example, when searching for a commercially available device for the water infrastructure operations use case provides the network an IoT leak guard from Finnish company Xortec Oy as a result (Figure 3).

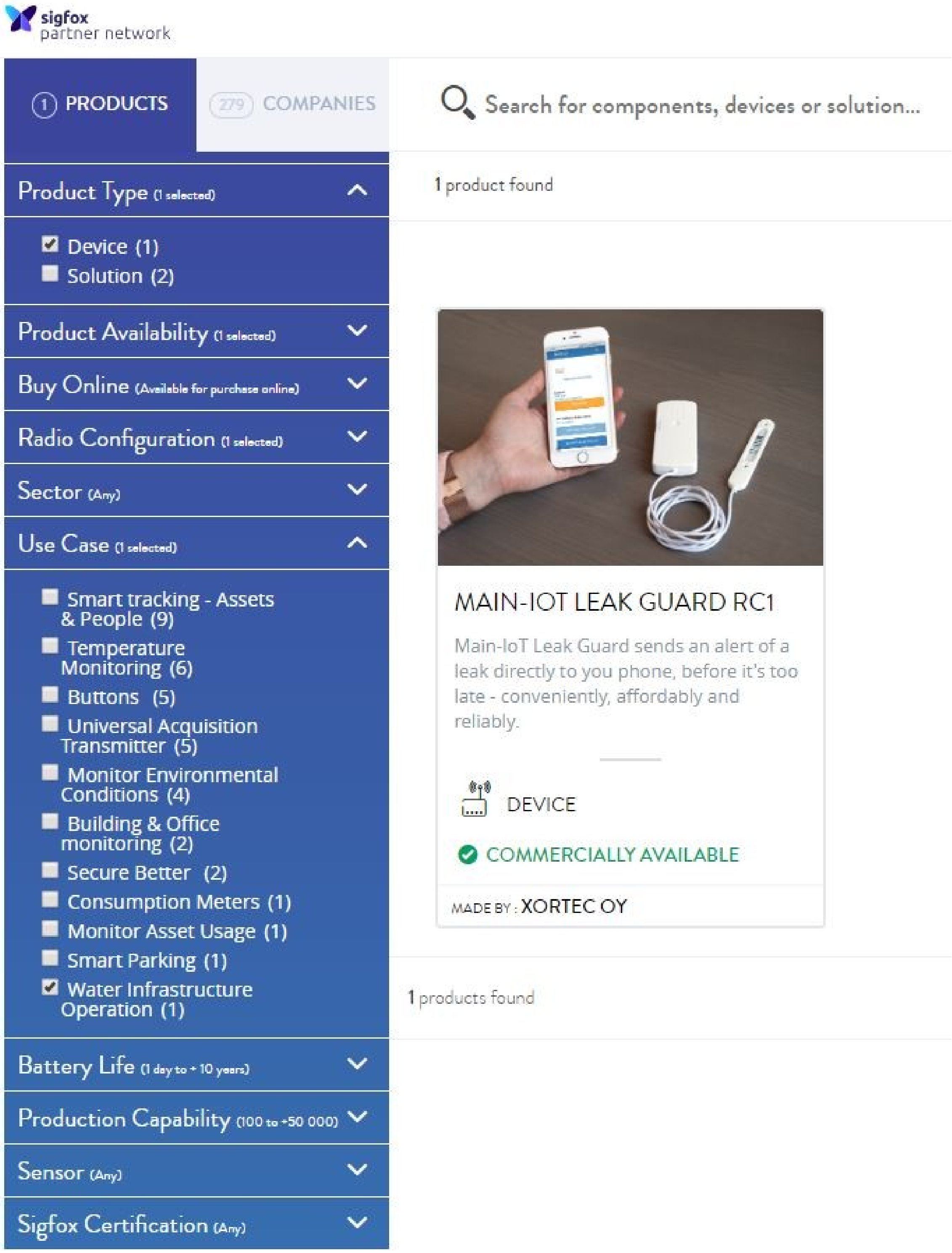


Figure 3. Sigfox Partner Network platform

The Build Platform includes access to a variety of resources such as user guides, how-to-articles and white papers. Information from understanding the basics of Sigfox technology to specific technical content is available. The resources are aimed to support device manufacturers and solution providers with the development process, certification and industrialization of a product. One of the most useful documents is the Sigfox device cookbook written in November 2018. It holds generic information about the best practices to avoid traps and build efficient products.

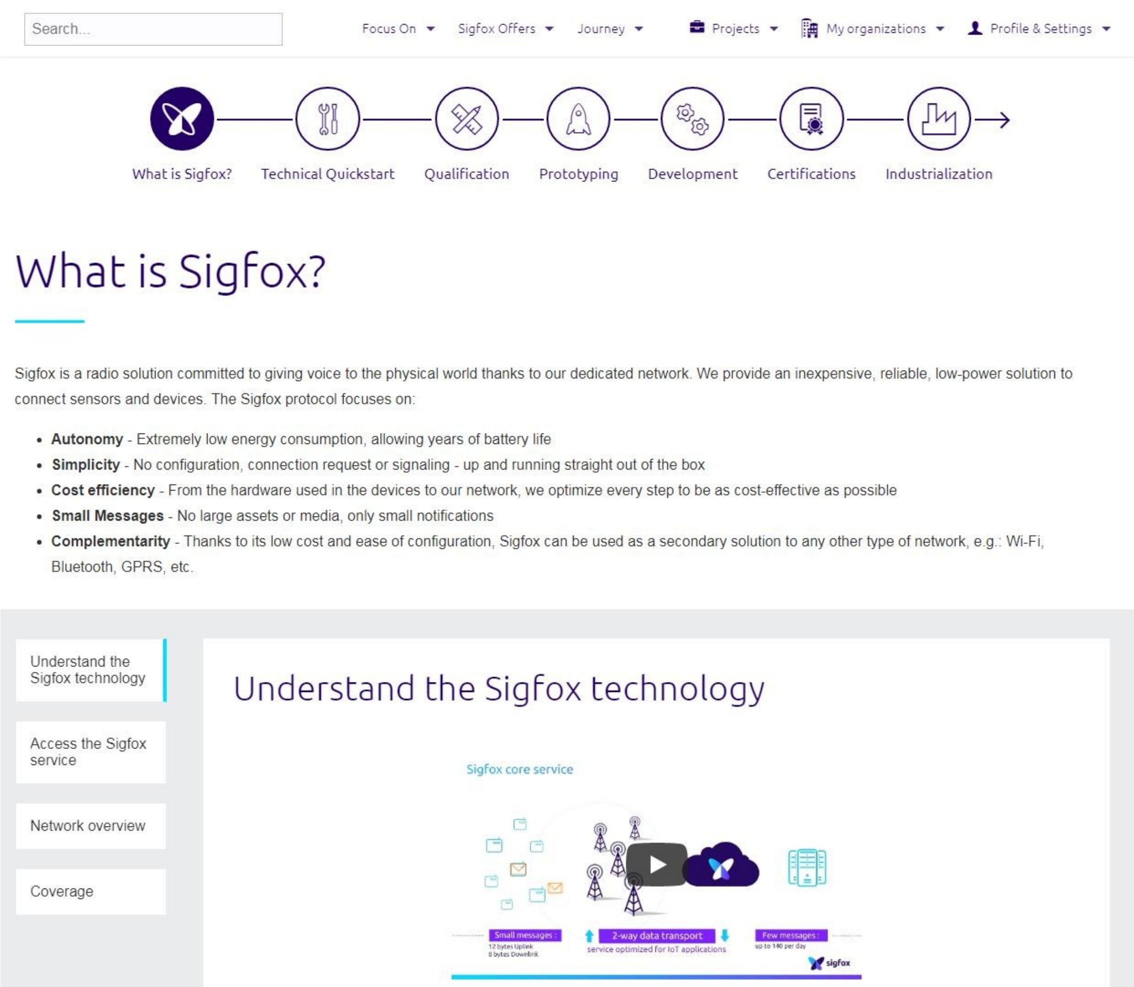


Figure 4. Sigfox Build platform starting page with basic information about Sigfox

Sigfox Buy is a connectivity purchasing platform for a small, from one to thousand, number of devices. It is a simple way to purchase subscriptions for start-ups or development purposes. Yet, the platform is supported only by a few SNOs around the world in Germany, France and Australia for example. Below in Figure 5 a price of 6.00€ per device is presented from a French Sigfox operator. The price varies depending on the number of daily messages and if Sigfox Atlas is selected. Enterprise customers also gain access to a cloud test environment, technical assistance and an account manager. The connectivity costs are further discussed in subsequent paragraphs.

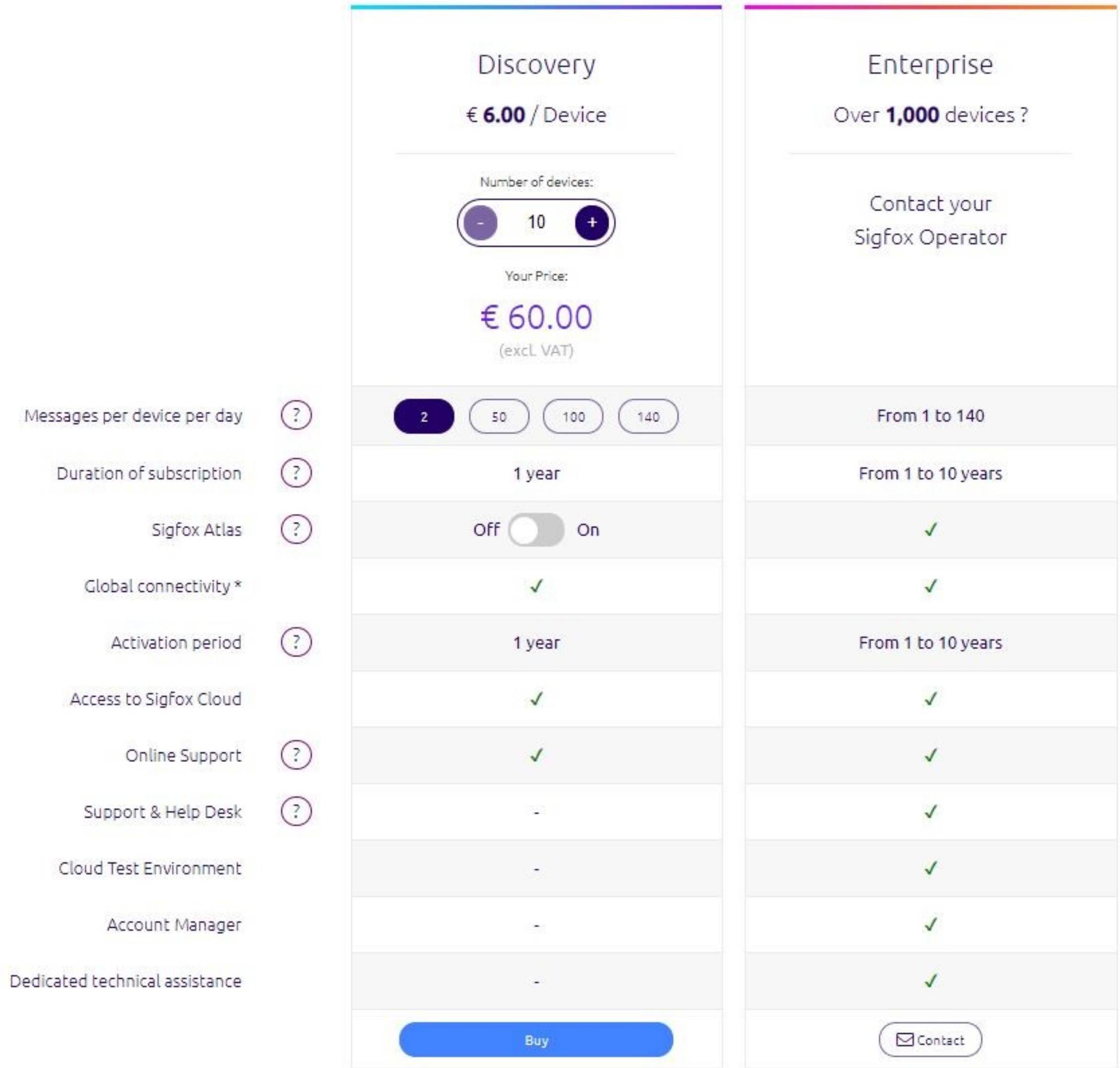


Figure 5. Sigfox Buy platform and pricing

3.2 Partnership programs

Sigfox partnership programs are targeted for startup companies, academic institutions, incubators, developers and IoT platform creators. Features and accesses granted by the programs vary depending on the partnership type. Detailed information about the programs is available in Table 1. Online Sigfox learning tools and platforms are provided by most of the programs, whereas academic institutions and IoT platform creators get more personalized service in terms of hands on IoT workshop guidance and platform reviews made by specialists from Sigfox. Assistance with networking and creating connections between parties interested in Sigfox technology is also widely provided in all of the partnership programs. Developers can access Sigfox developer groups, Github examples and join Sigfox Slack community. Incubators can provide their company of choice with Sigfox network emulator kit, starter packages, collaborate marketing and a dedicated global account manager.

In addition to the programs presented in Table 1, special scaling programs are available upon Sigfox’s selection for certain incubators and startup companies looking to upscale their businesses. Some of the most important features for startups are getting design support for their devices, help with creating and executing a marketing strategy and introduction to potential customers. For incubators, the upscaling means additional global or local account managers, on-site technical support, showroom at Sigfox demo day and access to deal-flow for their companies.

Table 1. Features of partnerships programs

Program targeted for	Access granted to	Other features
Startup Companies	A Sigfox learning platform	Automated introduction to Sigfox technology
	Local contacts	
	Technical support	
	Sigfox Slack community	
	Ecosystem partners	
Academic Institutions	Sigfox coverage at institution's location	
	Online IoT & Sigfox training materials	
	Hands on IoT workshop guidance	
	Technical webinars	
Incubators	Sigfox Starters Package	Free tools (5 Sigfox developer kits and 30 modules)
	A global network of incubators and VCs	Dedicated global account manager
	Sigfox network emulator kit	Co-marketing (collaterals, social media)
Developers	Documentation and github examples	Join Sigfox developer groups
	Workshops	
	Sigfox Ambassadors	
	Sigfox Slack community	
IoT Platform Creators	Sigfox backend	
	APIs for connecting to platform	
	Platform reviews made by specialists from Sigfox	
	Partner platforms	

3.3 Certifications and type approvals

Certifications are important part of every project ensuring end products, reference designs or radio solutions meet the required standards to maintain reliability and certain performance levels while operating. Sigfox proposes two different certification types, Sigfox Verified™ and Sigfox Ready™, both of which are required for a fully certified product. Local type approvals such as Conformité Européenne (CE) in Europe and Federal Communications Commission (FCC) Declaration of Conformity in the United States are also required to sell a product.

3.3.1 Sigfox Verified™

The Verified™ certification applies to implementing the Sigfox stack library inside a radio solution (ready to use module or reference design, a collection of schematics and material information). Hence this certification is aimed at semiconductor companies or anyone else looking to develop their own Sigfox radio solution. The Verified™ certification, a complex process including a series of conducted tests for radio configurations, checks the requirements are met especially in spectrum use and radio modulation. Sigfox has published a document about preparing for the verification process. Each step of this process is presented in Table 2. Once verified, the radio solution can be used in any future end product and it gets a Sigfox Verified™ label. (Sigfox: Certifications 2018)

Table 2. The steps and descriptions to get ready for Verified™ certification process (Be prepared for Sigfox Verified™ Certification 2018)

Step	Title	Description
1	Get modem specifications	Retrieve Sigfox modem specifications per radio configuration from the Sigfox Build website to properly match all Sigfox requirements on your device
2	Integrate protocol library	Integrate a built library into binary format and code Radio Frequency (RF) drivers
3	Validate your device	Get Software Defined Radio (SDR) dongle and Radio Signal Analyzer (RSA) tool from Sigfox to validate requirements presented in step 1
4	Prepare information on your candidate device	Deliver following information to the Sigfox laboratory for test execution: Modem datasheet(including nominal value and range of supply power voltage), Instructions how to test the full range of power, Load-Based Teaming (LBT) config word value, Radio oscillator datasheet (including Ageing value for 5 years and temeprature tolerance) and a User manual
5	Send candidate device to accredited laboratory	Send an application to your local test laboratory and discuss about the details. Ensure everything is up-to-date
6	File for Verified™ certificate	Deliver all technical documents to Sigfox

3.3.2 Sigfox Ready™

The Ready™ certification process contains a series of radiated tests to classify the final product undergoing testing based on how efficiently it communicates. The final product must be based on a Sigfox Verified™ module or reference design to become Ready™ certified. Hence, this certification is aimed at anyone looking to commercialize a Sigfox compatible product. Sigfox has published a preparation guide for the process (presented in Table 3). To start the certification process Sigfox requires a fee of 1500 euros for the first device and 1000 euros each following devices. If the device is based on Ready™ certified product and uses different communication module or sensor, the fee can be lowered to 500 euros. The laboratory tests are always required (unless only chancing the sensor) costing from 500 to 2000 euros depending on laboratory, radio configurations and number of devices. (Sigfox: Certifications 2018)

Table 3. The steps and descriptions to prepare for Ready™ certification process (Be prepated for Sigfox Ready™ certification 2018)

Step	Title	Description
1	Study device specifications	Study the Sigfox end-product radiated test specification and test plan for succesful Ready™ test completion. This information is available on the Build website
2	Match device pre-requisities	The device you send in a laboratory must be based on a Verified™ module/reference design and have the same mold, power supply, modem type, antenna, circuit board and bill of material as a finished end-product. It also has to last 30 minutes in continuous wave test mode emitting with a single carrier frequency and no modulation or interruption of the power signal
3	Validate your device	Roughly measure current consumption and effective radiated power (ERP) of your device. Use amperemeter to measure the current consumption and check if it's continuous. Measure ERP using spectrum analyser and a receiving antenna. Compare the measured values to reference ones found online
4	Prepare documentation	Request a list of required information about your device from a test laboratory. The information commonly includes device description, antenna type and gain, voltage level and receiver category. A device user manual is always requested
5	Send candidate device to accredited laboratory	Send an application to your local test laboratory and discuss about the details. Book a test slot and ensure everything is up-to-date
6	Submit the test laboratory report to Sigfox	Upload the test laboratory report and documentation of the end-product to Sigfox through the Build website

4 ELEMENTS OF COST

Launching a device consists of development, manufacturing and operational costs all of which are combined in the end products total price. Mandatory costs come from hardware, networking and certifications. To ensure the economic feasibility of implementing smart applications each IoT device can cost up to a few tens of euros (Bonavolontà et al. 2017).

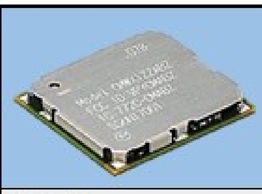
4.1 Hardware

Sigfox device is assembled from a communication module, sensor, antenna and a battery. For certified communication modules the starting price is approaching the $1 mark (Gluhak 2017). Sensor pricing varies greatly depending on its type. In 2016, the average cost of IoT device sensor was $0.50 (Statista 2018). The antenna section is also filled with different options varying on requirements of the device. The cheapest omnidirectional external antennas, such as the FLEXI-SMA, used mostly in development boards start from $3. Chip antennas like the ANT-868-USP-T from Linx Technologies come cheaper (starting from $1.5) but with some constrains like lower gain. One of the biggest contributors to the hardware expenses is the battery. A popular choice is a 3.6V Saft LS 14500 lithium thionyl chloride (Li-SOC12) battery with a capacity of 2.6Ah. This battery has a minimum 10 year shelf life and its priced at $5 per unit.

4.1.1 Communication module

Multiple LPWA communication modules from a variety of Sigfox partners are available on the market. To bring down prices the module specifications are royalty free. The main difference between the modules is which radio chipset is used. The leading chipset manufacturer is Semtech followed by Texas Instruments and smaller semiconductor companies such as STM, ON and NXP. Modules from Murata, Wisol and InnoComm with basic information including price are presented in Table 4. Lower hardware costs in the Admiral Ivory & Blue services are achieved by removing extra functionality not required in tracking use.

Table 4. Communication modules from Murata, Wisol and InnoComm. Data for Murata (Low Power Wide Area Network (LPWAN) Wireless Module 2018), for Wisol (Sigfox support: Product Information 2018), for InnoComm (SN10-11/12/13 Module for your SIGFOX application 2018).

			
Manufacturor	Murata	Wisol	InnoComm
Model	CMWX1ZZABZ	WSSFM10R2AT	SN10-12
Size (mm)	12.5x11.6x1.76	13.0x20.0x2.3	21.5x15.0x2.8
Chipset	SX1276 (Semtech) + STM32L (STM Semiconductors)	AX-SFUS-1-01 (ON semiconductor)	NXP OL2385 (NXP Semiconductors)
Frequency (MHz)	902	902	902
Power (dBm)	23	24	23
Input Voltage (VDC)	3.3 ~ 3.6	2.7 ~ 3.6	3.3 ~ 3.6
Operating Temp. (°C)	-40 ~ +85	-40 ~ +85	-40 ~ +85
Starting price ($)	11	4	5

4.1.2 Sensor

Sensor pricing varies greatly depending on its type. Popular sensor types are proximity, motion, temperature, pressure, image and many more. In 2016, the average cost of Industrial Internet of Things (IIoT) device sensor was $0.50 (Statista 2018). IIoT stands for “the use of internet of things technologies to enhance manufacturing and industrial processes” (Rouse 2018). The evolution of IIoT device sensor pricing from 2004 to 2020 is presented in Figure 6.

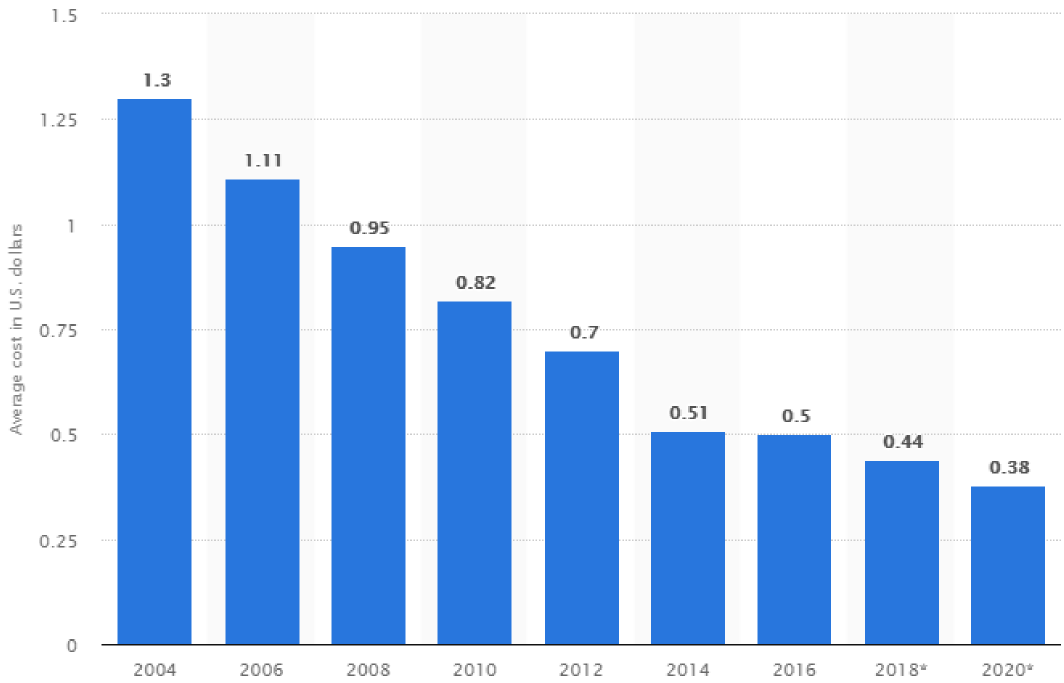


Figure 6. Average IIoT device sensor price is expected to hit $0.38 by 2020 (Statista 2018)

4.1.3 Antenna

Antenna theory is complicated and choosing the correct antenna type is critical for a functioning device. IoT products mostly use either a chip or a whip antenna due to their requirements in size, performance and cost (Schweber 2015). Common features for chip antennas are low efficiency and bandwidths compared to other typologies, small form factor (physical size) and easy reproducibility in manufacturing. Whip antennas then again have the highest performance, highest cost, requirement for connector on the circuit board and possible emissions (DeLisle 2015). Suitable products for 863MHz ~ 928MHz frequency range are introduced in Table 5.

Table 5. Antennas from Ethertronics, Multi-Tech Systems and Laird Technologies IAS with basic information (Digi-Key Electronics 2018)

			
Manufacturor	Ethertronics/AVX	Multi-Tech Systems	Laird Technologies IAS
Model	M620720	AN868-915A-10HRA	OF86315-FNF
Type	Chip	Whip, Tilt	Whip, Straight
Height (mm)	1.10	203.20	692.00
Gain (dBi)	2.56	3	5.6
Starting price ($)	0.86	7.98	78.77

4.1.4 Battery

When choosing a battery for Sigfox device three main things are taken into consideration: capacity, size and cost. These features do not go hand to hand, it is difficult to achieve high battery capacity while maintaining small size and especially low price point. Popular choice among Sigfox device manufacturers is using Primary cells Lithium Thionyl Chloride (Li-SOCl2) batteries. Li-SOCl2 is great option for IoT applications having the highest voltage and energy among all battery technologies while maintaining a minimum 10 years shelf life. Li-SOCl2 batteries of different capacities are presented in Table 6. All of which share the same voltage (3.6V) and yearly self-discharge rate (less than 1%).

Table 6. Different Li-SOCL2 batteries and basic information (Global Sources 2018)

			
Model	ER14505	ER18505	ER26500
Manufacturor	Hailei New Energy	Eastar Battery Co	Wecodo Technology
Dimensions (mm)	14.5 x 50.5	18.7 x 50.5	26.0 x 50.5
Voltage (V)	3.6		
Capacity (mAh)	2400	3600	9000
Weigth (g)	22	28	53.0
Storage life (years)	More than 10		
Self-discharge rate (%/year)	Less than 1		
Starting price ($)	0.8	1.45	2.5

4.2 Networking

Sigfox networking costs vary depending on SNO and provider of the device in use. Due to Sigfox's policy, the manufacturer purchases communication from a local SNO in a yearly subscription model. End-customers can not go straight to Sigfox or a SNO to get networking services for a device unless it is their own verified design. Final subscription costs can rise significantly caused by all the middlemen in the process. For example, a SNO can charge a device manufacturer $5/year for a single device from which Sigfox gets a royalty. Repeatedly, the manufacturer charges their end-customer for how much they find necessary.

Networking costs in small deployments (under 1000 devices) are presented in Table 7. The prices vary from $5.2 to $13.75 per year for one device in the United States, France and Japan. Number of messages is set to the minimum (2 per day) for the lowest price. Bigger volumes (over 1000 devices) can buy discounts depending on the SNO. The price may go as low as $1 per device per year (International Data Group 2017).

Table 7. Networking costs from different SNOs (Sigfox Buy Platform 2018)

Country	United States	France	Japan
SNO	Sigfox US	Sigfox France	KYOCERA Communication Systems
Amount of devices	1		
Messages per day	2		
Price per year ($)	13.75	5.2	6.3

5 RESULTS AND CONCLUSIONS

The most essential thing about Sigfox is the adoption of operator model and cellular network architecture. Other important technical aspects are use of BPSK and UNB, operation in license free sub 1GHz spectrum, limited number of daily transmissions and message payload sizes. The transmissions are handled by the Sigfox Cloud which can be interacted with via the web portal, APIs and callbacks. Integrity of these messages is protected by a device specific private key and a hashing mechanism. Communication between base stations and the SSS is covered with VPN and HTTPS. Critical data at rest is secured with TPM implementations. Total coverage of the network is over 803 million people in 45 counties. Coverage simulations provided great results in the study by Lauridsen et al. (2017). Over 99% of the area in the simulation was covered in light indoor conditions but in a physical world experiment with 22% occurrence rate of high-power interference the light indoor coverage dropped to under 50%. Important thing to note is that the LPWAN market in highly fragmented and other technologies exist such as LoRa or LoRaWAN which can be better choice than Sigfox for certain use cases.

Besides the core connectivity solution Admiral Blue, Sigfox also provides other services, partnership programs and certifications. Other solutions include simplified one-time messaging, location tracking, automatic adaption to local radio standards and online platforms to assist with developing, certificating and industrializing a product. Partnership programs grant access to a variety of resources depending on the targeted audience, for example technical support, contacts, communities, developer kits and the backend servers are available. Verified™ and Ready™ certifications exist to ensure correct functionality of a product. Verified™ applies to implementing the Sigfox stack into a communication module of reference design, whereas Ready™ certification applies to a finished product on the verge of industrialization. Total fees for the Ready™ process are between 1000 and 3500 euros.

Launching any electrical device has multiple cost generating factors. In this thesis the hardware and communication costs were studied. Communication modules, antennas and batteries with varying properties were introduced. Module prices range between $4 to $11 depending on its complexity and the chipset in use. Starting price for certified modules is told to be approaching $1 mark in a study by A. Gluhak. Considering sensors, the average price per IIoT sensor is expected to hit $0.38 by the year 2020. What comes to pricing, the greatest variance occurs in the antenna section. Chip antennas are easy to produce but have lower efficiency than other typologies. The M620720 presented in Table 5 has a starting price of $0.86. Whip antennas come with higher gain, but increased cost. The AN868-915A-10HRA costs $7.98 whereas the OF86315-FNF with almost twice as much gain (5.6 dBi) starts at $78.77.

SNOs provide communication service to device manufacturers in a yearly subscription basis. Sigfox receives a royalty from every subscription. In small deployments (under 1000 devices) subscriptions can be bought using the Buy Platform. With the number of daily messages limited to two, the yearly subscription price starts from $5.20 per device. Bigger deployments (over 1000 devices) can lower the yearly price to $1 according to a study by International Data Group. For end-customers the subscriptions costs may rise significantly, they must purchase it from the manufacturer of their product in use, whom can charge the customer for as much as they find necessary.

Most of the foreseeable future problems are caused by using ISM radio bands and low data rates. Since Sigfox has no control over other users of the frequency, increased number of users in the future will only cause more interference. With the low data rates message transmission times can be even 10 seconds which further increases the chance of collision with other devices. These issues were addressed in the study by Veilgaard. Another problem is the confusion of what Sigfox is and what it stands for. As previously mentioned, various technologies are combined in the communication protocol, which requires a lot of knowledge to understand how Sigfox truly functions. This thesis optimistically helps to create a clear view of the entirety. Future research could focus on running actual performance tests in Finland, possibly at the Vaasa region. Interesting point in the future is to see how the fragmented LPWAN market evolves and which technologies become dominant over time.

REFERENCES

Al-Fuqaha, A., Guizani, M., Mohammadi, M., Aledhari, M. & M. Ayyash (2015). Internet of Things: A survey on Enabling Technologies, Protocols, and Applications [Online]. [26.2.2018]. Available: http://ieeexplore.ieee.org/document/7123563/

Al-Sarawi, S., Anbar, M., Alieyan, K & M. Alzubaidi (2017). Internet of Things (IoT) Communication Protocols Review [Online]. [27.2.2018]. Available: http://ieeexplore.ieee.org/document/8079928/

Bonavolontà, F., Tedesco, A., Schiano Lo Moriello, R. & A. Tufano (2017). Enabling wireless technologies for Industry 4.0: State of the Art [Online]. [3.9.2018]. Available: https://ieeexplore.ieee.org/document/8078381/

DeLisle, J (2015). 5 Antenna Topologies Squeeze into IoT Modules [Online]. [10.9.2018]. Available: https://www.mwrf.com/passive-components/5-antenna-topologies-squeeze-iot-modules

Digi-Key Electronics (2018). RF Antennas (868MHz, 915MHz) [Online]. [10.9.2018]. Available: https://www.digikey.com/short/qt4wr2

Global Sources (2018). Lithium thionyl chloride batteries [Online]. [13.9.2018]. Available: http://vcellpowerbattery.manufacturer.globalsources.com/si/6008852824799/Showroom/3000000223283/39537/Lithium-thionyl-chloride-battery.htm

Gluhak, A (2017). An Overview of the Current Low Power Wide Area Network Market [Online]. [3.9.2018]. Available: https://iot.ieee.org/conferences-events/wf-iot-2014-videos/42-newsletter/september-2017.html

Hernandez, D.M., Peralta, G., Manero, L., Gomez, R., Bilbao, J & C. Zubia (2017). Energy and coverage study for LPWAN schemes for Industry 4.0 [Online]. [7.3.2018]. Available: http://ieeexplore.ieee.org/document/7945893/

InnoComm (2018). SN10-11/12/13 Module for your SIGFOX application [Online]. [10.9.2018]. Available: https://www.innocomm.com/product_inner.aspx?num=1122

International Data Group (2017). Turn Data Into Action to Streamline Business Operations and More [Online]. [14.9.2018]. Available: https://resources.idgenterprise.-com/original/AST-0185017_SigfoxIDG_2pWP07251711.pdf?SOURCE=01566630185017CSOQYQVTURPOM

Lauridsen, M., Nguyen, H., Vejlgaard, B., Kovács, I.Z., Mogensen, P. & M. Sørensen (2017). Coverage comparison or GPRS, NB-IoT, LoRa, and SigFox in a 7800 km^2 area [Online]. [13.3.2018]. Available: http://ieeexplore.ieee.org/document/8108182/

Lauridsen, M., Nguyen, H., Vejlgaard, B., Kovács, I.Z., Mogensen, P. & M. Sørensen (2017). Interference Impact on Coverage and Capacity for Low Power Wide Area IoT Networks [Online]. [14.3.2018]. Available: http://ieeexplore.ieee.org/document/7925510/

Margelis, G., Piechocki, R., Kaleshi, D & P. Thomas (2015). Low Throughput Networks for the IoT: Lessons Learned From Industrial Implementations [Online]. [7.3.2018]. Available: http://ieeexplore.ieee.org/document/7389049/

Murata (2018). Low Power Wide Area Network (LPWAN) Wireless Module [Online]. [10.9.2018]. Available: https://www.murata.com/products/lpwa/sigfox#sf2

Nolan, K.E., Guibene, W. & M.Y. Kelly (2016). An evaluation of low power wide area network technologies for the Internet of Things [Online]. [22.2.2018]. Available: http://ieeexplore.ieee.org/document/7577098/

Ray, B (2018). SigFox Vs. LoRa: A Comparison Between Technologies & Business Models [Online]. [19.1.2019]. Available: https://www.link-labs.com/blog/sigfox-vs-lora

Rouse, M (2018). Definiton: industrial internet of things (IIoT) [Online]. [10.9.2018]. Available: https://internetofthingsagenda.techtarget.com/definition/Industrial-Internet-of-Things-IIoT

Schweber, B (2015). Antenna Options for IoT and Mobile Devices [Online]. [10.9.2018]. Available: https://www.digikey.com/en/articles/techzone/2015/jun/antenna-options-for-iot-and-mobile-devices

Sigfox (2017). Technical Overview [Online]. [21.3.2018]. Available: https://www.disk91.com/wp-content/uploads/2017/05/4967675830228422064.pdf

Sigfox (2017). Make things come alive in a secure way [Online]. [21.3.2018]. Available: https://www.sigfox.com/sites/default/files/1701-SIGFOX-White_Paper_Security.pdf

Sigfox (2018). Be prepared for Sigfox Verified™ Certification [Online]. [17.4.2018]. Available: https://storage.sbg1.cloud.ovh.net/v1/AUTH_669d7dfced0b44518cb186841d7cbd75/staging_docs/att14425017-be_prepared_for_Sigfox_Verified.pdf

Sigfox (2018) About SIGFOX [Online]. [22.2.2018]. Available: https://www.sigfox.com/en#!/about

Sigfox (2018). Be prepared for Sigfox Verified™ Certification [Online]. [20.4.2018]. Available: https://storage.sbg1.cloud.ovh.net/v1/AUTH_669d7d-fced0b44518cb186841d7cbd75/staging_docs/att14423816-Be%20prepared%20for%20Sigfox%20Ready%20certification.pdf

Sigfox (2018). Sigfox Certifications [Online]. [18.04.2018]. Available: https://build.sigfox.com/steps/certification/

Silva, J., Rodrigues, J., Alberti, M., Solic, P & A. Aquino (2017). LoRaWAN – A Low Power WAN Protocol for Internet of Things: a Review and Opportunities [Online]. [20.1.2019]. Available: https://ieeexplore.ieee.org/document/8019271

Statista (2018). Average costs of industrial Internet of Things (IoT) sensors from 2004 to 2020 (in U.S. dollars) [Online]. [3.9.2018]. Available: https://www.statista.com/statistics/682846/vr-tethered-hmd-average-selling-price/

Tan, L. & N. Wang (2010). Future Internet: The Internet of Things [Online]. [26.2.2018]. Available: http://ieeexplore.ieee.org/abstract/document/5579543/

Wisol (2018). Sigfox support: Product Information [Online]. [10.9.2018]. Available: http://support.wisol.co.kr/en/