Introduction to Narrowband Communication

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Smart Grid, Smart Home, Smart City and Industry 4.0 need a lot of sensor data. However, the sensors, which collect this data, are often at locations, which are hard to reach with cables, and cable installation is usually expensive. Connecting the sensors with wireless technologies allows fast and easy use of the sensors. Therefore, wireless transmission of sensor values provides enormous advantages.

For wireless sensors the data rate is rarely important. More important are high energy efficiency, reliability, and coverage. Possible solutions that provide these features are narrowband (NB) technologies. Narrowband technologies allow the efficient transmission of rare and small data packets (for example, the average temperature transmitted every hour). Such small packets are important for Machine-to-Machine (M2M) communication. This M2M communication is a necessary building block for new trends such as Smart Grid, Smart Home, Smart City and Industry 4.0.

There are many technologies for narrowband communication, of which we will consider the most important ones in this tutorial. LoRa, Sigfox and NB-IoT (Narrowband - Internet of things) are the upcoming standards for the interconnection of many devices in the 'Internet of things'. These technologies will make it simpler to use mobile sensors and, thus, allow visionary innovations. Examples for this are: intelligent parking management, automatic reading of water/power meter (smart meters), environmental monitoring (for example, of rivers). However, many narrowband technologies exist. Selecting the technology that is best suited for a given task is complex.

In this tutorial, we will (1) give an overview of innovative applications based on narrowband technologies, (2) provide a classification of the most important wireless (narrowband) communication technologies, (3) describe the implementation of a simple application and the differences in the implementations using LoRa, Sigfox and NB-IoT, (4) demonstrate object localization, and (5) show an interactive online tool that helps to select a wireless (narrowband) communication technology.

1 Introduction

Narrowband transmission technology uses only a small frequency band to transmit data with high efficiency. The development of narrowband communication technologies has mainly been influenced and driven by the requirements of machine-to-machine (M2M) communication. M2M communication refers to the automatic exchange of information between different systems such as industrial machinery, vehicles, containers, storage systems or monitoring systems. Its purpose is an extensive automation of control, monitoring and maintenance activities. The massive additional use of networked sensors and actuators in and around the systems and machines is necessary for this development. The stated use cases for M2M communication provide particular opportunities in the fields of smart production and smart factory [1].

In general, machine-to-machine communication has different requirements compared to the networks, which have been designed for human users [2]. Instead of high-resolution video data and low latency for human interactions, computer-readable and compressed binary data will be sent with low volumes. Furthermore, the current application scenarios require message transmission only when certain events occur or at comparatively large time intervals (several minutes or even hours). From these requirements, narrowband transmission technologies were developed as a considerably more cost-effective alternative to established (broadband) mobile radio technologies such as LTE. Its abilities to transmit data over longer distances and to better penetrate walls create advantages in otherwise poorly supplied and inaccessible locations.

Narrowband technologies are used in particular in the monitoring of extended infrastructures, industrial process monitoring, environmental and terrain monitoring, localization and motion tracking, and smart city applications.

Its promised range is particularly advantageous to the operation of large-scale infrastructures such as power, gas, and water supply systems. Especially because many components of these systems are located in remote or inaccessible locations with weak communication coverage. The use of narrowband systems in particular can help to set up fine-meshed monitoring and control architectures, which, guarantee a complete overview of the system and enable more targeted maintenance. An application example can be found in water supply and disposal systems (e.g. [3]), where the pumps, pipelines, and valves are equipped with sensors that can independently send status and fault messages. An example of this is the transmission of a fault message by a pump that is used in a remote drinking water well.

In the field of industrial process control, the higher fault resistance of narrowband signals often plays an important role. This is important, for example, when measuring instruments are installed inside tanks whose metallic sheathing usually makes radio communication error-prone. Especially in chemical processes, the early detection of quality deviations by sensors can be counteracted in good time and production waste can be reduced.

In environmental and terrain monitoring, narrowband technology offers the connection of sensors [4], particularly in the area of civil protection, for example, as a warning system for avalanches, landslides, or flooding. In integrated systems, it also enables the automatic initiation of protective measures such as automatic alarms or road closures.

In the field of localization, sensor nodes are used to determine the current location of devices and objects. The sensor nodes consist of a satellite-based localization sensor (GPS) and a communication interface to transmit the position to a server at regular intervals or when a movement is detected [5]. Concrete applications in this area include the location of equipment on a factory site such as the position of a portable emergency generator. In advanced scenarios, condition information such as the generator tank level can also be transmitted along with the localization information.

Narrowband technologies also provide added value into Smart Cities [6]. The application scenarios for the automation of urban environments are manifold. One of the most frequently mentioned application cases is smart metering, in which water, gas, heating, and electricity meters are automatically read out (e.g., every 15 minutes) and the values are then transmitted to the utilities daily. This simplifies consumption planning and billing. One particular communication challenge is that these meters are usually installed in basements. Other than narrowband, current communication technologies such as 4G do not offer good enough reception in these locations.

As described narrowband technologies enable a number of interesting and promising future applications. However, they also have limiting properties such as lack of reliability in data transmission and limited bandwidth and data volumes. In addition, the different technologies differ in detail. These facts lead to the realization that in-depth analyses of the addressed problem must be carried out carefully before use [7]. While, for example, narrowband technology is well suited for locating objects that rarely change position or whose current position is rarely needed, the technology is by no means suited for applications such as the permanent monitoring of motion in real time. This article provides an overview of these considerations.

We first give an overview of the possibilities of narrowband technologies, compare them and give hints which technologies are suitable for which purposes (Section 2). Then, building on the overview, we compare the technologies on a high level in Section 3. Section 2 and 3 give insight into the possibilities of narrowband communication without dealing with the technical details. Section 4 describes how a simple system for remote temperature monitoring can be implemented with LoRa and outlines the differences to its implementation using Sigfox and NB-IoT. Section 5 provides an advanced demonstration using location-based tracking based on GPS. Section 6 describes our online-tool for selection of a wireless (narrowband) technology, before concluding in Section 7.

2 Overview and categorization of technologies

This section provides an abstract overview of the most important narrowband technologies (LoRa, SigFox, NB-IoT). It focuses on the architectural and management differences, instead of technical details of the physical channel and technical details (as others do [8]).

2.1 LoRa

The narrowband technology LoRa [9] is mainly developed by the LoRa Alliance.[1] LoRa consists of two components: The physical transmission layer (LoRa) and the architecture and messages (LoRaWAN) based on it.

The details of the physical LoRa layer are not publicly available, but were partly determined by reverse engineering [10][2]. The LoRaWAN layer, however, is an open standard. When "LoRa" is mentioned, it usually means LoRaWAN via LoRa.

To perform a LoRa transmission (LoRaWAN via LoRa), a gateway is required near the terminal device, which receives the LoRa packets. The architecture of a LoRa network is similar to that of WiFi: A terminal device can transmit data via a nearby gateway. However, because LoRa and WiFi are used for different purposes, the range of LoRa is higher and the data rate and the energy consumption are lower. Since LoRa is not based on IP (Internet Protocol) packets, the gateway cannot forward the received data packets directly to an IP network. A LoRa gateway is configured for a LoRa server to which all received data is forwarded. This LoRa server can then forward the data to other servers, store it in a database and visualize it. LoRa does not include any specifications regarding the processing of the data after it has been received by the LoRa server. This processing is the responsibility of the developer of the complete system that uses narrowband communication.

In Europe the physical transmission of LoRa is in the frequency band around 868 MHz. No licenses are required for this, however, it cannot be ruled out that other devices transmit in the same frequency band.

In general, each developer/operator that uses LoRa is responsible for the operation of LoRa gateways. Similar to associations of WiFi operators (e.g., eduroam) there are also associations of LoRa gateway operators. These either offer their gateways commercially or are open groups that try to achieve an area-wide LoRa coverage by sharing their gateways.[3]

2.2 Sigfox

Sigfox[4], like LoRa, transmits in the 868 MHz band. In contrast to LoRa, however, it is impossible to operate gateways yourself. Sigfox looks for a partner in each country to provide the infrastructure. This has the advantage that the developer does not have to operate his own infrastructure. However, this also has the disadvantage that the end customer is dependent on Sigfox as a monopoly provider.

Due to the structure of Sigfox, there is no more than one Sigfox provider in each country. Currently there is none in Austria.[5]

[1] https://www.lora-alliance.org

[2] https://media.ccc.de/v/33c3-7945-decoding_the_lora_phy

[3] Examples of mergers/operators of LoRa networks are: https://www.thethingsnetwork.org, https://objenious.com, https://loriot.io, https://www.actility.com, and https://www.orbiwise.com

[4] https://www.sigfox.com

[5] https://www.sigfox.com/en/coverage

2.3 NB-IoT

NB-IoT is a narrowband technology developed in the mobile radio sector. It was specified by 3GPP in Release 13 of LTE[6]. To use NB-IoT, a contract with a mobile phone provider offering NB-IoT is required in addition to the client hardware. A contract works similar to a standard mobile phone contract: By paying a monthly fee, the customer gets access to the provider's network with a SIM card. The future cost structure is still unclear. The costs depend on the data volume, but currently for about 500 KB per month the cost is in the order of 1 € per month per device. For this price, the customer gets the ability to transmit IP packets via a NB-IoT network. These can be sent to any server for processing and storage.

Alternatively, the providers of cellular networks offer storage, processing, and visualization in their cloud infrastructure. Which possibilities this includes, depends strongly on the offerer.

Unlike Sigfox, NB-IoT generally offers the possibility to change providers if several operators offer NB-IoT. However, as long as the SIM cards are issued as physical cards and not as eSIM, the SIM cards must be replaced on all devices when the provider is changed.

2.4 Other technolgies

In addition to the mentioned technologies (LoRa, Sigfox, NB-IoT), there are other technologies that meet similar requirements. In this section we will mention some of them. In general, these technologies function similarly to the technologies already mentioned, but are not as widespread or developed as the technologies we compare (LoRa, Sigfox and NB-IoT):

- Weightless: `http://www.weightless.org`
- IEEE 802.11ah: `https://standards.ieee.org/findstds/standard/802.11ah-2016.html`
- MIOTY: `http://www.iis.fraunhofer.de/mioty`
- NWave: `http://www.nwave.io`
- WavIoT: `http://waviot.com`
- DASH7: `http://www.dash7-alliance.org`
- RPMA: `https://www.ingenu.com`

[6] `http://www.3gpp.org/news-events/3gpp-news/1785-nb_iot_complete`

3 Comparison

This chapter compares the most important narrowband technologies. The focus here is not on technical details, but on conceptual differences.

The most important distinguishing features are:

- Used frequency and
- management of the infrastructure.

3.1 Frequency

The used frequency influences how well the radio waves can penetrate walls and whether it is a licensed frequency band.

In general, the lower the frequency, the better the radio waves can penetrate walls. Technologies such as WiFi, which transmit in the range of 2.4 GHz and 5 GHz, are only limitedly suitable for communicating through walls. Most narrowband technology applications need to communicate through walls. Therefore, they use frequency bands that can penetrate walls (at least to a limited extent). One recommendation, for example, is the use of frequencies below 2 GHz for NB-IoT.

There are also licensed and unlicensed frequency bands. Licensed frequency bands are exclusively available to the license holder. The license holder is the only one who is allowed to send in this frequency band. As a result, the operator can manage the interference emitted by other devices in the same frequency band. This does not mean that interference can be ignored, but gives the operator the assurance that interference can only occur from other devices under his control. This simplifies interference management. NB-IoT uses licensed frequency bands.

An unlicensed frequency band can be used by anyone (under certain conditions). This eliminates the (high) costs of exclusive use of the frequency band, but other transmitters can also use the frequency band in return. As a result, it is difficult to predict the available data rate and latency because it is not known if and which other transmitters use the same frequency band. To minimize the effects of a single transmitter, restrictions on the utilization rate in unlicensed frequency bands are common. For example, the utilization rate for the frequency bands in the 863 MHz to 870 MHz range is limited between 0.1% and 10%.[11] The most commonly used frequency band for narrowband communication is the already mentioned band around 868 MHz in Europe and 915 MHz in the USA. Both LoRa and Sigfox use these frequency bands.

3.2 Infrastructure

Generally devices that use wireless technology can communicate directly with each other. However, in the Internet of Things sensors mostly communicate with a central server. This requires a network infrastructure that receives the signals from the end devices and forwards them to a server via a (usually wired) network. There are various ways of organizing this network.

The necessary infrastructure can be operated by the provider of the sensor system. For this purpose, access points must be set up in such a way that reception is guaranteed in the required area. The access points must then be connected to the Internet (via cable or other wireless technologies). In the simplest case of an access point, the structure is similar to a private WiFi (only with a longer range). LoRa offers the possibility to operate such an infrastructure.

If it is necessary to supply a larger area (city, country, continent), it is no longer sensible to operate this infrastructure yourself. There are providers who operate these infrastructures and make it available to the developer (usually against payment). In this case, the developer only has to look after the end devices as long as they remain in the reception area of the network operator. This model is known from mobile communications, where every customer has a contract (or a prepaid card) with a mobile network operator. In the area of narrowband communication, this model is implemented in NB-IoT by the same providers. There are also providers that use LoRa to operate such a network[7] and cooperative initiatives that jointly build and operate such a network[8].

A special case for an infrastructure operated by a provider is a provider that has a monopoly on the operation of such an infrastructure. The monopoly structure allows the technology to be set up quickly and used uniformly. However, in case of a monopoly, a change of provider is impossible.

4 Implementation overview

This section gives a short overview how a simple use case can be implemented using narrowband technology. The focus is not on the technical details, but to provide a high level overview of the architecture and similarities between the technologies. More details can be found in our (german) Handbook [12]. We arbitrarily used Pycom Hardware for our implementation. Other suppliers also exist.

To be able to focus on the architecture, we selected a simple use case to demonstrate the architecture in this section: Measuring the temperature, transmitting it using narrowband technology, storing and visualizing it.

4.1 Basic setup using LoRa

First, we describe the basic setup using LoRa and, second, the differences to other implementations. Figure 1 illustrates the separation in measurement device, radio infrastructure, and cloud infrastructure.

The measurement device consists of a temperature sensor, a radio transmitter and a small microprocessor. It measures the temperature in regular intervals and transmits the measured value using LoRaWAN. In our example the temperature sensor is on a Pysense board, which has a variety of standard sensors. It is connected to a LoPy via I^2C. I^2C

[7] for example `https://loriot.io` and `https://www.actility.com`
[8] `https://www.thethingsnetwork.org`

	Measurement device		Radio infrastructure		Cloud infrastructure	
Provider	Pycom		LoRa		Self hosted	
Technology	Pysense	LoPy	LoRa-Gateway	LoRa-Server	InfluxDB	Grafana
Interface	I^2C	LoRa	UDP	MQTT	InfluxDB API	

Figure 1: The basic implementation needed to record, transmit, store and visualize temperature measurements.

is a wired serial bus protocol. The LoPy reads the sensor and transmits the measured value using its integrated radio after it has been encrypted.

The radio infrastructure consists of a LoRa Gateway, which receives the packets that the measurement device has sent. The LoRa gateway forwards the received packets to a Lora Server using UDP packets. This step can use cellular technology, but in our case is a wired local area network. The LoRa Gatway is basically an extended ear for the LoRa Server and only time stamps the received packets. The LoRa Server checks if the source is valid and decrypts the data. The LoRa Server forwards the data to other servers for processing and storage. For this it uses the publish-subscribe-based messaging protocol MQTT (Message Queuing Telemetry Transport).

The Cloud infrastructure provides storage and visualization of the measured temperatures. In our case, we use InfluxDB for storage and Grafana for visualization. A python script listens to MQTT events from the LoRa Server and writes the received temperatures into the InfluxDB. The measurements are stored in this time-series database with some additional data such as received signal strength. An end user can now connect to Grafana using a web browser and see the measured temperatures. To do this, Grafana requests the necessary values from the InfluxDB using the Influx API.

4.2 Other technologies

To use another narrowband technology only the parts that are directly related to LoRa have to be replaced by their equivalent in other technologies. In our case, it is necessary to change the radio infrastructure and the radio on the measurement device. The sensor, database, and visualization can stay the same as when using LoRa. Figure 2 illustrates this for Sigfox and NB-IoT.

In contrast to LoRa, it is usually impossible to run the radio infrastructure oneself using SigFox and NB-IoT. Thus, it is necessary to find a provider for these technologies. For Sigfox only a single provider exists for each country (if at all). For NB-IoT there might exist several providers. Despite this difference, the radio infrastructure still provides the same features: It receives the data, checks its security properties and forwards it to the database.

Measurement device		Radio infrastructure		Cloud infrastructure	
Pycom		**LoRa**		Self hosted	
Pysense	**LoPy**	**LoRa-Gateway**	**LoRa-Server**	InfluxDB	Grafana

Pycom		**Sigfox**	Self hosted	
Pysense	**SiPy**	**Sigfox Backend**	InfluxDB	Grafana

Pycom		**NB-IoT**	Self hosted	
Pysense	**FiPy**	**Provider network**	InfluxDB	Grafana

Figure 2: The actual transmission technology can be exchanged while keeping the sensors, database, and visualization system.

4.3 Hosting

Instead of self-hosting the database and the visualization, these can also be outsourced. The service can be bought as a package from the NB-IoT provider or from an external provider. The solution, again, needs to provide data storage and visualization, but its management and administration is provided by external partners. Figure 3 illustrates the self-hosted variant and using the solution of a provider.

Table 1: Categorization of Narrowband-Technologies

		Frequencyband	
		Licensed	Unlicensed
Architecture	From provider	NB-IoT	Sigfox
	Self hosted	-	LoRa

5 Demonstration: Object Localization

To demonstrate the ideas described in the last section, we show the implementation of an object localization use case. As already mentioned in the introduction, implementing object localization by using narrowband technologies is not viable for (near) real-time tracking applications due to the limited sending intervals narrowband technologies usually impose.

In this demonstration case we assume a manual lift truck shared between multiple departments of a company. The lift truck does not have a fixed location where it can be

Measurement device		Radio infrastructure	Cloud infrastructure	
Pycom		NB-IoT	**Self hosted**	
Pysense	FiPy	Provider network	**InfluxDB**	**Grafana**

Pycom		NB-IoT	**Solution of provider**	
Pysense	FiPy	Provider network	**Database**	**Visualization**

Figure 3: The database and visualization can be self hosted or operated by a cloud provider (shown here for NB-IoT).

found if not used, but may be located at arbitrary locations on the companies premises.

In this use case the complete lift truck localization service is self-operated including the narrowband network and all required servers and software components. This makes LoRa the narrowband technology of choice. On the roof of a central building at the companies premises, a LoRa gateway device has been installed and wire-connected to a server machine in a computing room inside this building. The server machine is supposed to host the LoRa server as well as the back end services of the localization application. A battery-driven Pycom LoPy device with a GPS-enabled Pytrack global navigation satellite system (GNSS) receiver has been attached to the lift truck. The Pytrack is configured to transmit the current location data every 10 minutes.

From the perspective of transmitted data (as shown in Figure 4), first, the Pycom device transmits latitude and longitude specifying the lift truck location along with a internal globally unique device identification towards the LoRa gateway via an encrypted LoRa channel. The device identification is used to differentiate between potentially multiple devices. The signals are received by the LoRa Gateway on the buildings' roof and are forwarded towards the LoRa server using the user datagram protocol (UDP). At the LoRa Gateway, the information originally received from the Pycom device is enriched with a reception time stamp, the signal quality (RSSI) and some additional administrative information. The LoRa Server process receives this information and forwards it to the visualization application using the MQTT protocol. In this step the global unique device ID is translated into a user configurable ID and a corresponding Application ID, which simplifies handling at the user application. The ID of the receiving LoRa Gateway is added to the other information. During transmission the volume of transmitted data grows at every hop due to the information enrichment from approximately 30 LoRa symbols on the encrypted physical LoRa channel up to around 500 bytes received at the application server.

At the application server, lift truck location records are written into an CSV text file. Each entry containing receiving time stamp at the LoRa gateway, longitude and latitude. A data processing and visualization application interprets the location records as GPS coordinates (in GPX format) and, in turn, displays the data on a map representation,

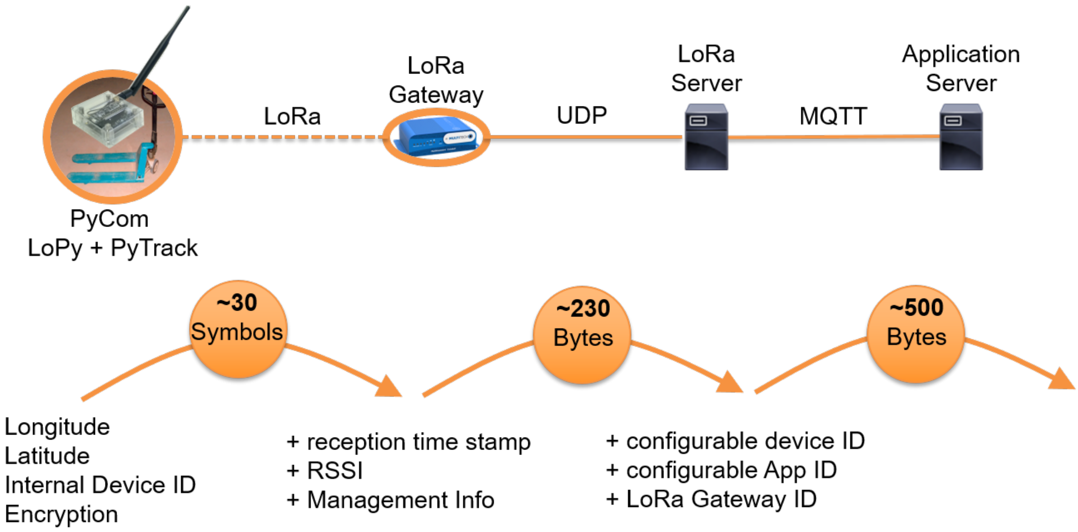

Figure 4: Information transmission from position tracker towards application server. During transmission, data volume grows together with information content from about 30 LoRa symbols up to approximately 500 bytes.

which is finally published by a web server to make it accessible via web browser.

6 Selection of a technology

Since selecting a suitable narrowband technology can prove difficult, we have created an online tool that can support this selection. The tool consists of a questionnaire with questions about the planned use of wireless communication technology. The short questionnaire helps in the selection of a communication technology for wireless transmission of sensor data. It should not be used as the sole selection criterion, but serves to obtain an initial overview. The questionnaire assumes that sensor data from distributed sensors are to be transmitted to a central location and processed or visualized from there.

The tool (currently only in German) is available at:

`https://srfg.at/nb-recommender`

6.1 Questions

The questions to be answered are (in the current version):

- How often must data be transmitted?
- How much data must be sent per transmission?
- What is the allowed latency in the transmission of data?

- What are the effects of lost packages?
- How long do the end devices have to survive without changing the batteries?
- Where should the sensors send data from?
- Which difficulties must communication technology be able to deal with?
- How many sensors are located on an area of $100\,\mathrm{m}^2$?
- Would you like to operate the required infrastructure yourself?
- How important is independence from other users of similar technologies nearby to you?
- When would you like to operate the technology?
- Which running costs are justifiable per end device?

6.2 Evaluation

The evaluation takes place in the form of a visual representation of the suitability of the respective technologies (Figure 5). The result is updated after each answer, so that it is possible to develop a sense of how much a given answer affects the recommendation for a technology. The evaluation should be used as the first tendency to select a technology and not as the sole criterion.

7 Conclusion

Narrowband technologies allow small data packets to be efficiently transmitted from a sensor to a central server. This efficiency results in long battery life and long ranges.

In practice, three technologies are currently most relevant: LoRa, Sigfox and NB-IoT. They differ both in the technical properties and in the administration. However, the technical details are irrelevant for most system developers. The differences in administration are: LoRa and Sigfox use a free license spectrum and can therefore make fewer statements about the availability of the technology at given locations than NB-IoT. With NB-IoT and Sigfox, the system developer is dependent on a provider of the technology who operates the radio network. It is possible to operate an own LoRa network or to purchase the service from a provider. Sigfox should be able to offer its service (if it is fully developed). For LoRa worldwide coverage by a single provider should not be expected. Although NB-IoT theoretically offers worldwide roaming, the details about its use are still open.

The different technologies are suitable for different purposes. These differences result in many applications of the technologies: from infrastructure monitoring to localization of portable objects to building automation. To make the selection of a technology easier, we have created an online tool that can help.

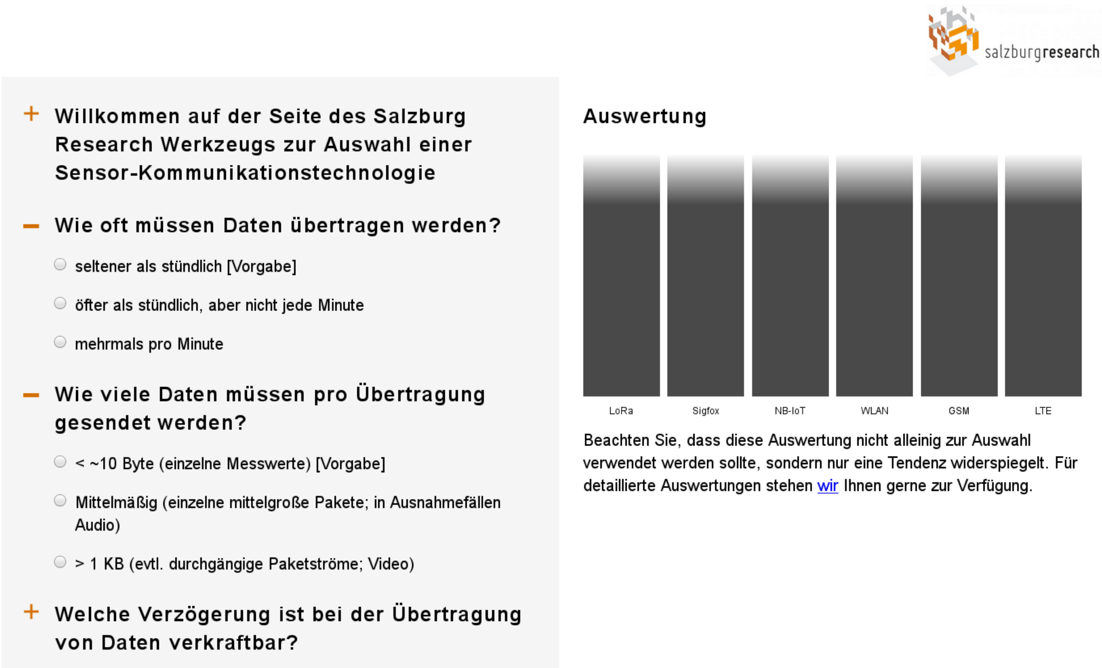

Figure 5: The tool for evaluation helps to select a technology and is available on the Internet at `https://srfg.at/nb-recommender`.

The three technologies LoRa, Sigfox and NB-IoT are similar on a high abstraction level: The measurement data is collected from a sensor and sent via the selected narrowband technology. These are received by a gateway and forwarded to a server for storage. The server can visualize the data in web browser. Using the example of a temperature measurement, we have shown how this can be implemented with different technologies. In addition, we have shown how the sensor and the visualization can be replaced using the GPS localization example.

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