Coverage comparison of GPRS, NB-IoT, LoRa, and SigFox in a 7800 km2 area

2017

INTRODUCTION

In the next years the number of Internet of Things (IoT) devices is predicted to increase rapidly [1], and many of these Internet-connected devices will rely on a wireless connection.

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In this section we describe the radio coverage methodology and our simulation assumptions. The target is to study the coverage of the four RATs in a large area

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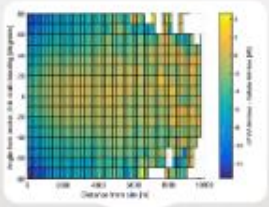

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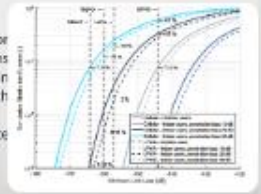

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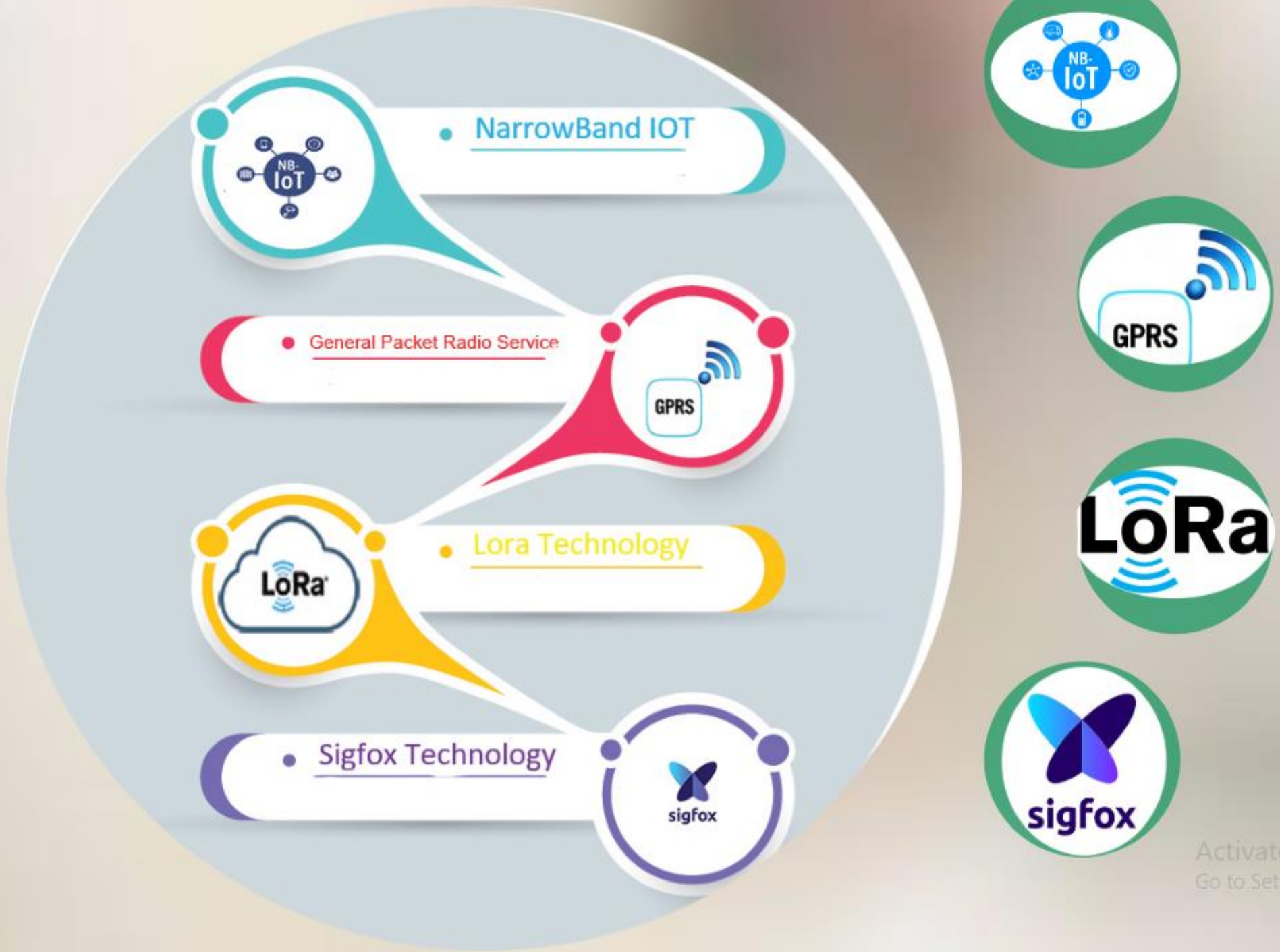

NarrowBand IOT

Is a Low Power Wide Area Network (LPWAN) radio technology standard developed to enable a wide range of devices and services to be connected using cellular telecommunications bands.

General Packet Radio Service

Is a packet oriented mobile data service on the 2G and 3G cellular communication system's global system for mobile communications (GSM). GPRS was originally standardized by European Telecommunications Standards Institute (ETSI) in response to the earlier CDPD and i-mode packet-switched cellular technologies.

lora Technology

Is a Low Power Wide Area Network (LPWAN) specification intended for wireless battery operated Things in a regional, national or global network. LoRaWAN targets key requirements of Internet of Things such as secure bi-directional communication, mobility and localization services.

Sigfox

Sigfox is a French company founded in 2009 that builds wireless networks to connect low-energy objects such as electricity meters, smartwatches, and washing machines, which need to be continuously on and emitting small amounts of data.

Coverage comparison of GPRS, NB-IoT, LoRa, and SigF...

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The four key wireless IoT candidates in a realistic scenar...

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In the next years the number of Internet of Things (IoT) devices is predicted to increase rapidly [1], and many of these Internet-connected devices will rely on a wireless connection.

- The four key wireless IoT candidates in a realistic scenario. The contribution of this study is thus to analyze the coverage of GPRS, NB-IoT, LoRa, and SigFox in a realistic scenario based on a 7800 km2 In addition the outage probability is studied as a function of the Inter-Site Distance (ISD), because all existing sites may not be upgraded with the new technologies

long-range

The geographical coverage probability is simulated

The network deployment is based on the local operator Telenor...

long-range

low power wireless Internet of Things technologies GPRS, NB-IoT, LoRa, and SigFox in a 7800 km2 area with 10 cities and large rural areas.

- The network deployment is based on the local operator Telenor’s configuration of 2G, 3G, and 4G sites
- with sub-GHz carriers are utilized
- and in the simulations the 319 sites are virtually upgraded to support the studied technologies.

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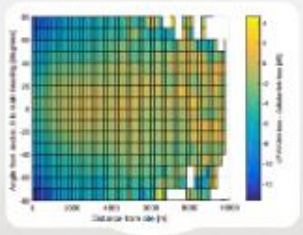

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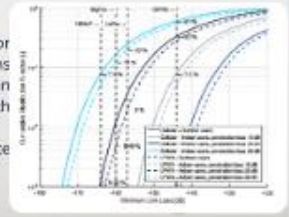


AFIFA KHALED

SWEENEY FISHAR

RADIO COVERAGE METHODOLOGY

The analysis is based on ISD filtering

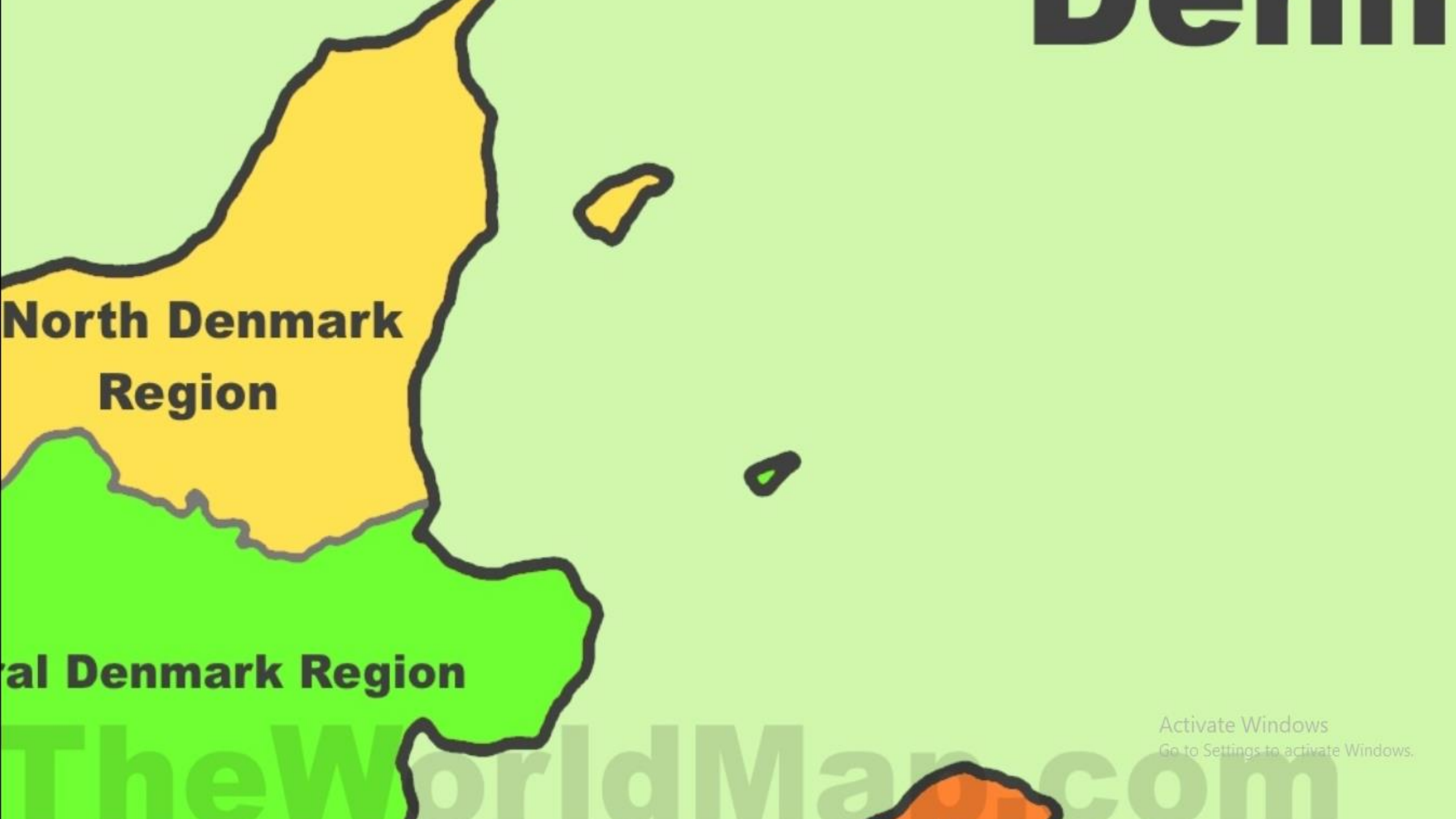
where a minimum ISD filter of 2, 4, or 6 km is used to remove sites that are closer than the current limit.

The LoRa and SigFox technologies do not rely ...

In order to perform realistic propagation modeling the ar...

In the urban areas each pixel is assumed to contain a devi...

Similar to the urban area the device locations can be bo...



- North Denmark region, which consists of 7800 km2 of rural area, predominantly farm land, forests and smaller villages and a combined urban area of 147 km2. The urban area is based on the city of Aalborg with 115k inhabitants and 9 other cities with 10-25k inhabitants each The borders of the urban areas are defined as polygons using [10]. The site location and configuration is based on Telenor’s commercial cellular network, consisting of 2G, 3G, and 4G deployments. Every 2G, 3G and 4G site, which currently is configured with a sub-GHz carrier has been included in the study

TABLE I

LOW POWER WIDE AREA RADIO TECHNOLOGIES. LINK SPECIFICS ARE GIVEN AS (UPLINK/DOWNLINK). BASED ON [3].

	GPRS	**NB-IoT**	**LoRa**	**SigFox**
Spectrum [MHz]	700-900	700-900	868	868
Band	Cellular, licensed	Cellular, licensed	ISM, unlicensed	ISM, unlicensed
Transmit power [dBm]	33/37	23/35	14	14/27
Bandwidth [kHz]	200	180	125	0.1/0.6
MCL [dB]	144	164	157	160

- The LoRa and SigFox technologies do not rely on sectorized site deployments and thus Telenor's deployment configuration is modified such that every site applies a 10 dBi omni-directional antenna with a typical monopole radiation pattern

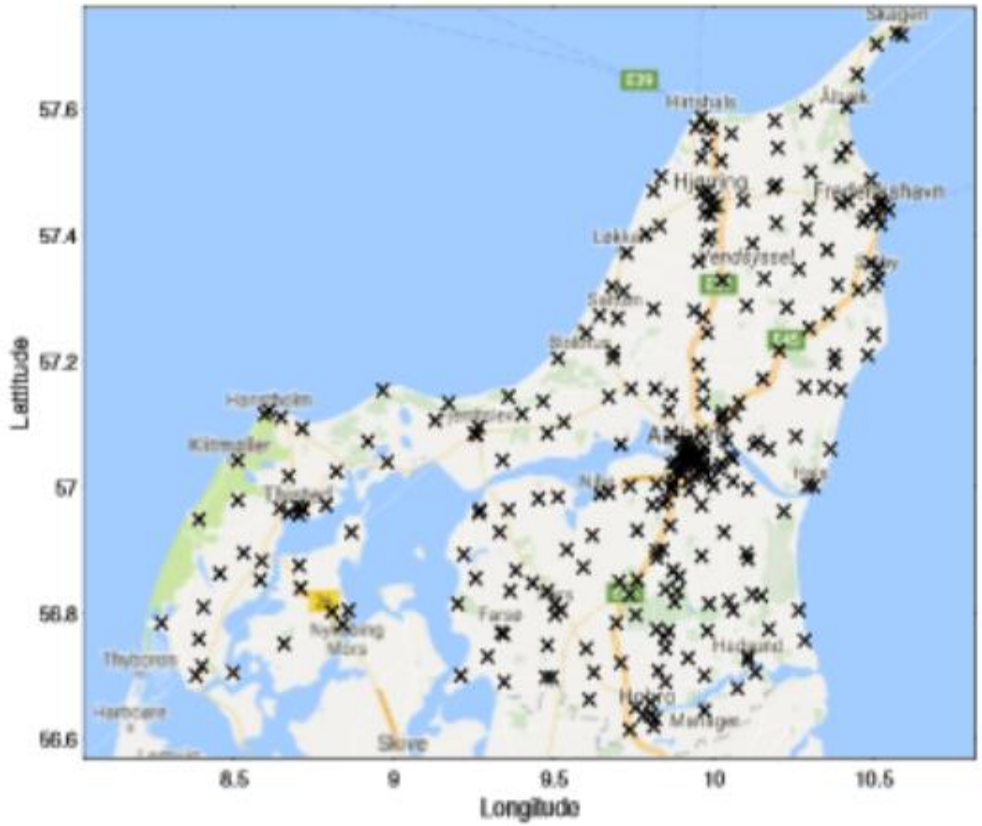
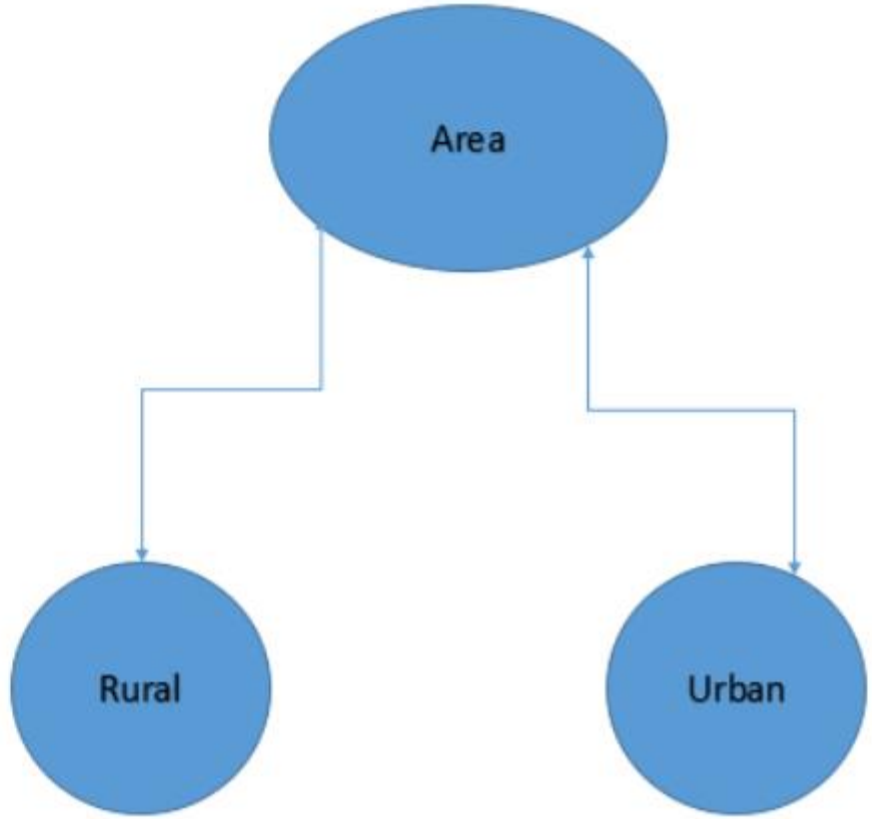
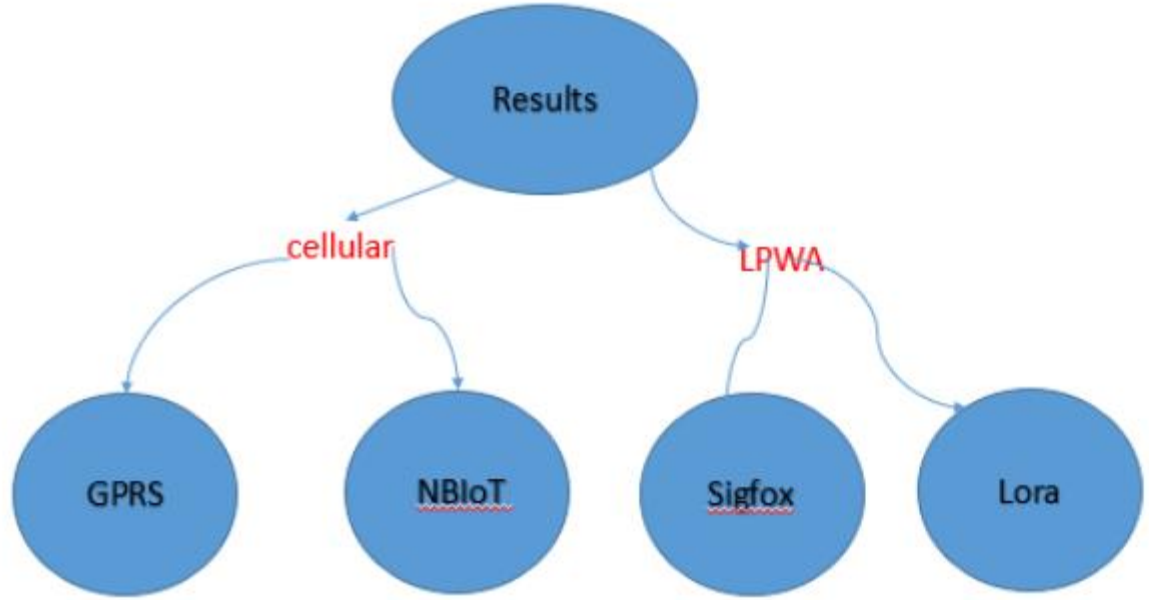


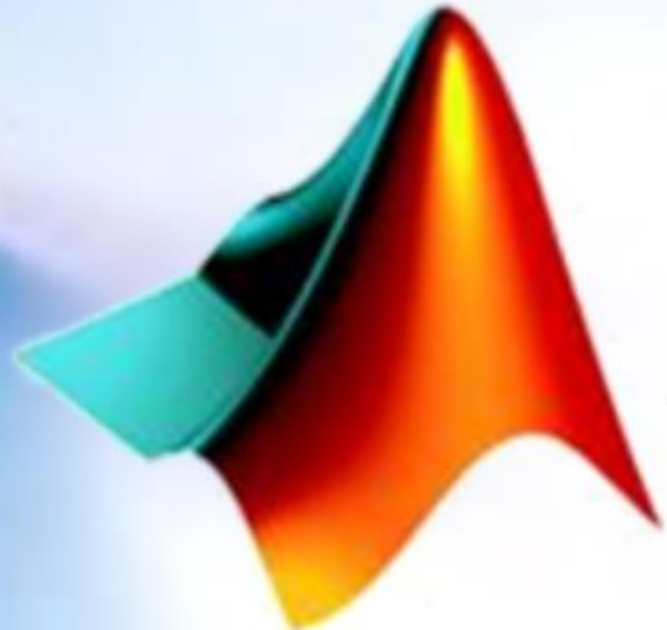
Fig. 1. Area under study, black crosses indicate a site location.

- In total this results in 319 sites with 920 sectors in the North Denmark region area





- In order to perform realistic propagation modeling the area has been implemented in our calibrated MatLab simulator using the 3GPP Rural Macro non-line-of-sight (NLOS) model



MATLAB®

- In the urban areas each pixel is assumed to contain a device, which can be located both outdoor and indoor

TABLE II
SIMULATION ASSUMPTIONS.

Parameter	Urban	Rural
Scenario	Varying number of sites & sectors in 800 MHz band	
Antenna gain	Omni: 10 dB; directional: 17 dB (65° beam)	
Path Loss	Urban Macro NLOS	Rural Macro NLOS
Shadow fading	σ=6 dB	σ=8 dB
Correlation distance	50 m	1000 m
	sector correlation = 1, site correlation = 0.5	
Terrain map	Danish Digital Height Model 2007	
Map resolution	100 m x 100 m	
Indoor locations	All pixels	Based on OSM house numbers
Indoor loss	10, 20, 30 dB in addition to the outdoor path loss	

The rural device locations are assigned to pixels, which according to the Open Street Maps database have a valid house number.

Similar to the urban area the device locations can be both outdoor and indoor. In total 9.6% of the rural pixels have a house address which together with the urban area amounts to 11% of all the 780k pixels. Since the IoT devices may be sensors located deep indoor the coverage study is performed for indoor locations by adding an additional penetration loss of 10, 20, or 30 dB to the estimated outdoor

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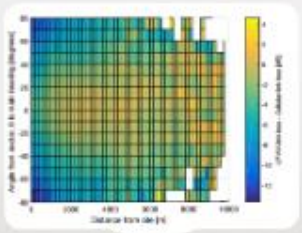

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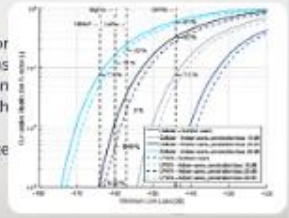

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The part of the CDF to the left of a dashed line indicate t...

Outage percentage is above 0.1%

All technologies provide full outdoor coverage

shows the minimum link loss for cellular and LPWA devi...

There are about 5 times more rural than urban device locations

8% outage

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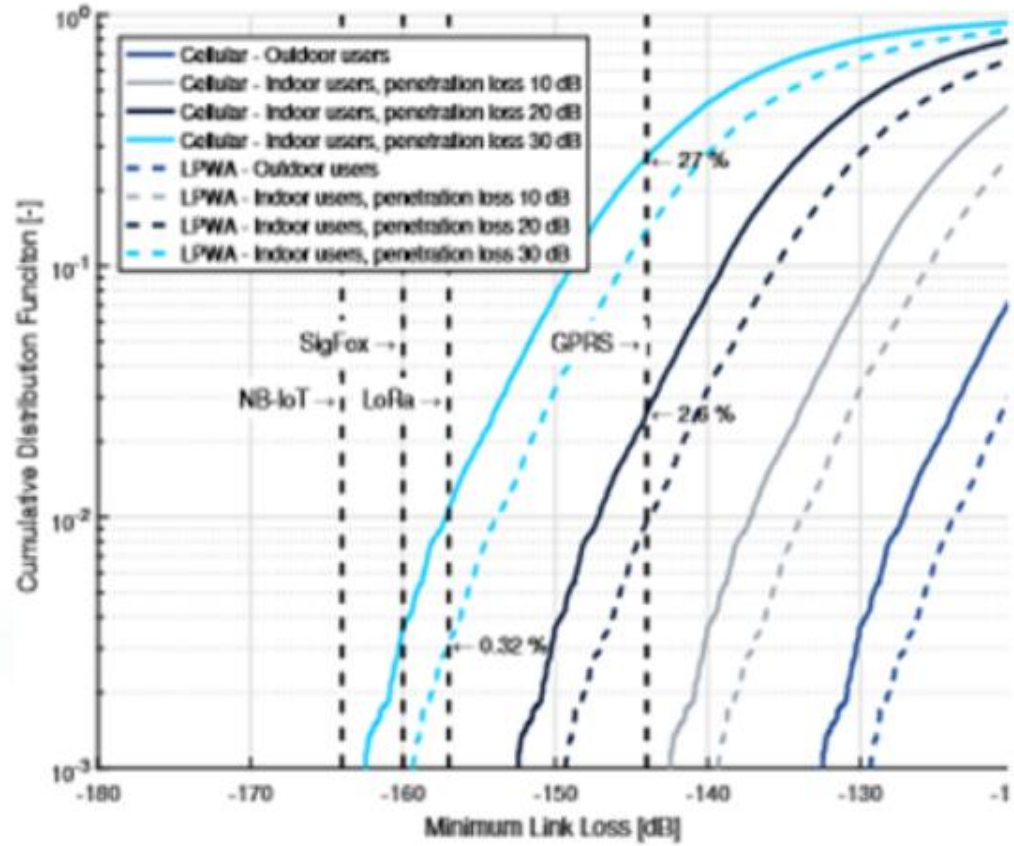


Fig. 2. MCL CDF for device locations in the urban areas with Telenor's original site deployment.

The part of the CDF to the left of a dashed line indicate the device locations which are in outage that is devices, which cannot be served by the technology due to the link loss exceeding the MCL

illustrates the Cumulative Distribution Function (CDF) of the minimum link loss (i.e. towards serving cell) at device locations in the 10 urban areas. The dashed vertical lines indicate the MCL of LoRa, SigFox, GPRS, and NB-IoT as defined in Table I.

All technologies provide full outdoor coverage

GPRS has 3% outage for indoor device locations with 20 dB penetration loss due to the low MCL of 144 dB.

✔ Telenor’s coverage is very good in the rural area

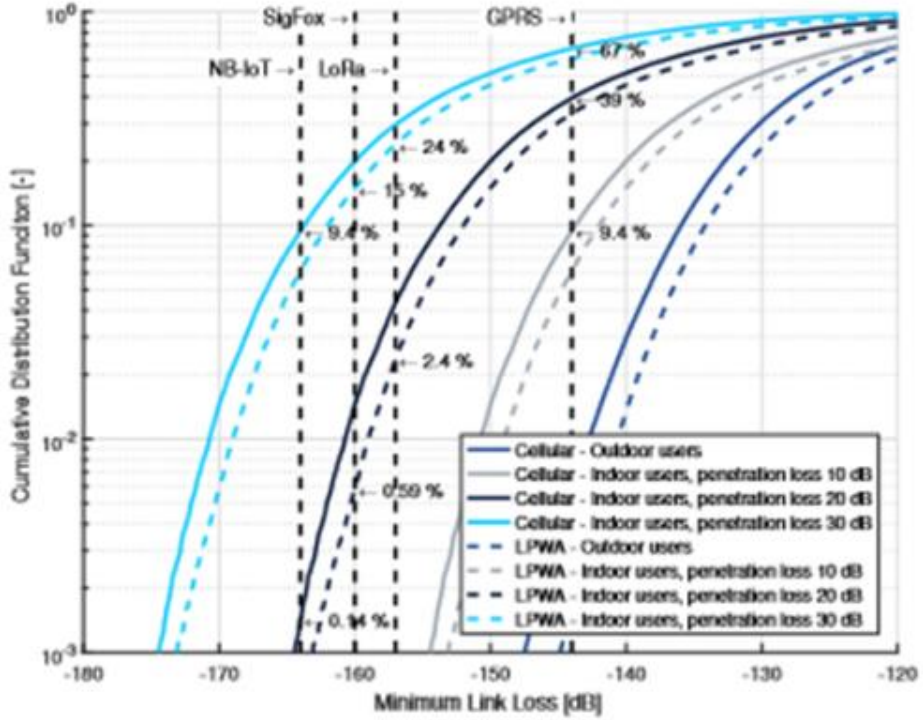


Fig. 3. MCL CDF for device locations in the rural areas with Telenor’s original site deployment.

shows the minimum link loss for cellular and LPWA device locations in the rural area. All outdoor locations are
covered, besides 1% of the GPRS devices, while the other RATs have outage of up to about 3% for the indoor device locations with 20 dB additional penetration loss

less than 10% of the deep indoor, rural device locations are in outage

outage of 15% and 24% respectively

- There are about 5 times more rural than urban device locations

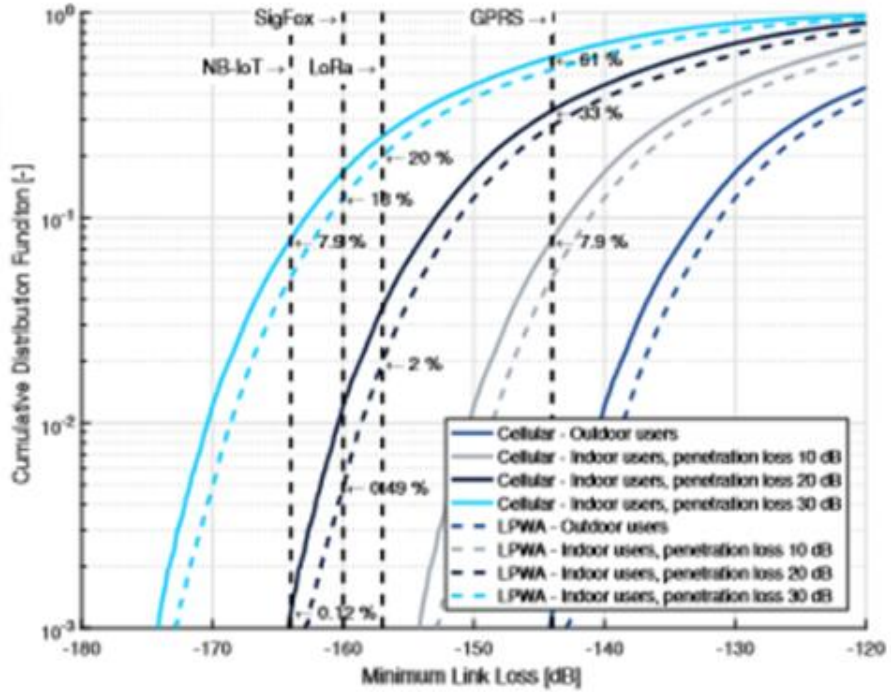


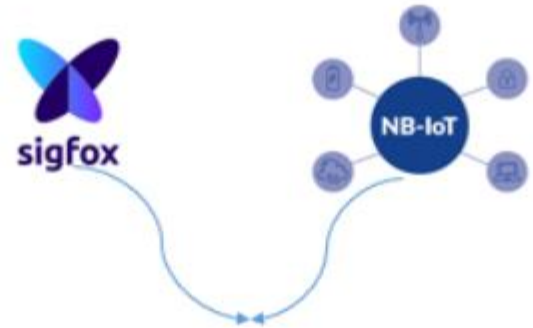
Fig. 4. MCL CDF for device locations in both the rural and urban areas with Telenor's original site deployment.

shows the combined outage statistics for both urban and rural device location

All technologies provide outdoor coverage and also light indoor coverage except for GPRS

8% outage

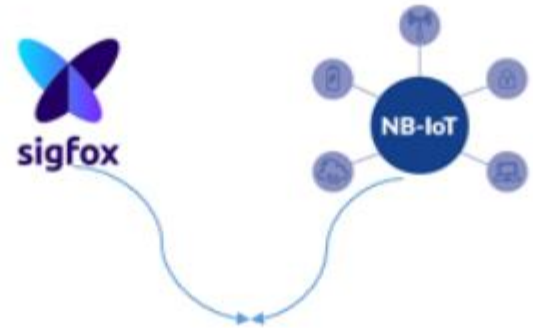
The deployed network has very good coverage for the typical indo...



outage

below 1%

for the device locations with 20 dB additional loss



outage

below 1%

for the device locations with 20 dB additional loss

- The deployed network has very good coverage for the typical indoor device location, experiencing up to 20 dB additional penetration loss, whereas the deep indoor location is challenging to reach for all the studied RATs.

An overview of the number of sites and sectors when applying...

Almost to half the original number for the 4 km filter going from 3...

TABLE III

SITE & SECTOR CONFIGURATION FOR SELECTED INTER-SITE DISTANCES.

Minimum ISD filter	All (0 km)	2 km	4 km	6 km
Sites	319	232	170	117
Sectors	920	667	495	328
Avg. ISD, 1 neighbor [km]	2.8	4.3	6.2	8.6
Avg. ISD, 3 neighbors [km]	4.1	5.6	8.9	11.1
Supported deployment at 1 % outage (I: indoor, O: outdoor)				
LoRa	I 10 dB	I 10 dB	I 10 dB	I 10 dB
SigFox	I 20 dB	I 20 dB	I 10 dB	I 10 dB
NB-IoT	I 20 dB	I 20 dB	I 10 dB	I 10 dB
GPRS	O	O	None	None

An overview of the number of sites and sectors when applying a minimum ISD filter to the original deployment (denoted All in the Table).

Almost to half the original number for the 4 km filter going from 319 sites to 170

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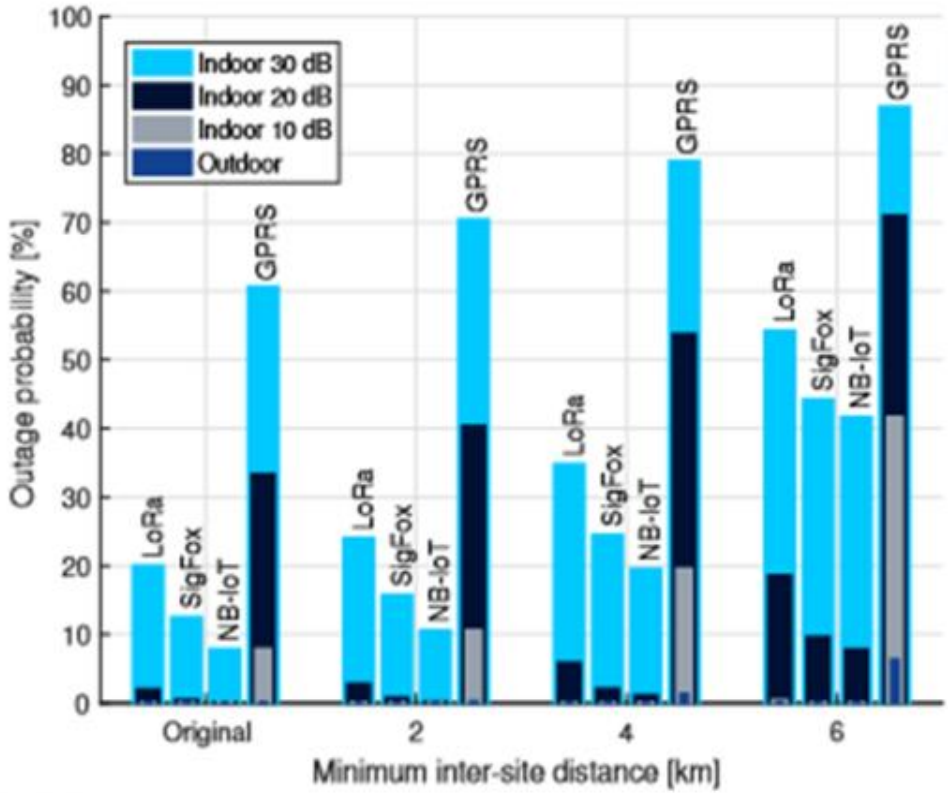
SigFox	I 20 dB	I 20 dB	I 10 dB	I 10 dB
NB-IoT	I 20 dB	I 20 dB	I 10 dB	I 10 dB
GPRS	O	O	None	None

The average ISD for the nearest neighbor is also more than doubled from 2.8 km to 6.2 km.



The outage probabilities as a function of the minimum ISD filter

sigfox

for the 6 km filter

outage

exceeds 10% for the 20 dB

The average is about -3 dB

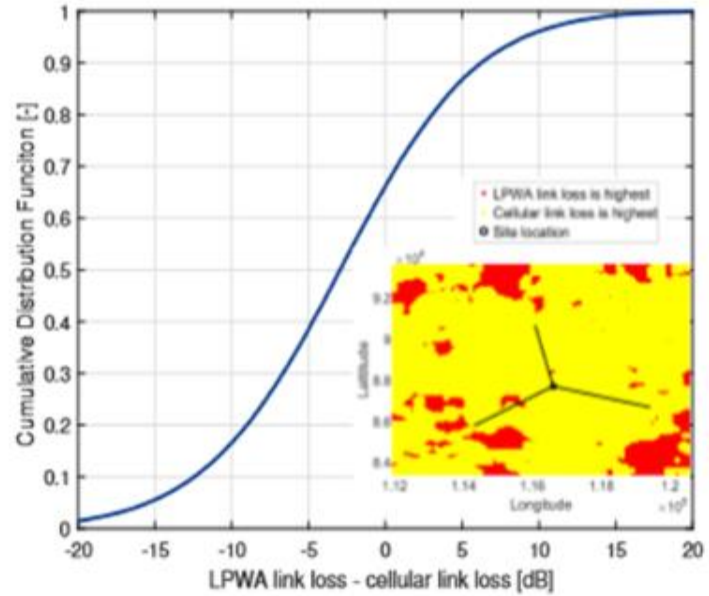


Fig. 6. CDF of the difference between LPWA and cellular link loss for the original deployment in both rural and urban areas. The inserted figure is an example of the link loss at a specific site. The black lines indicate the main bearing of the cellular site.

The difference between the link loss of the LPWA and cellular device locations

The areas where either LPWA (red) or cellular (yellow) link loss is highest for a specific site in the area.

The cellular antenna has a higher gain and thus provides better coverage in the direction of the main bearing and far away from the site, on average providing 2-4 dB lower link loss. In addition, Fig. 7 clearly shows the advantage of the omnidirectional antenna at the sides of the sector where the LPWA link loss can be 10-13 dB lower than the cellular link loss.

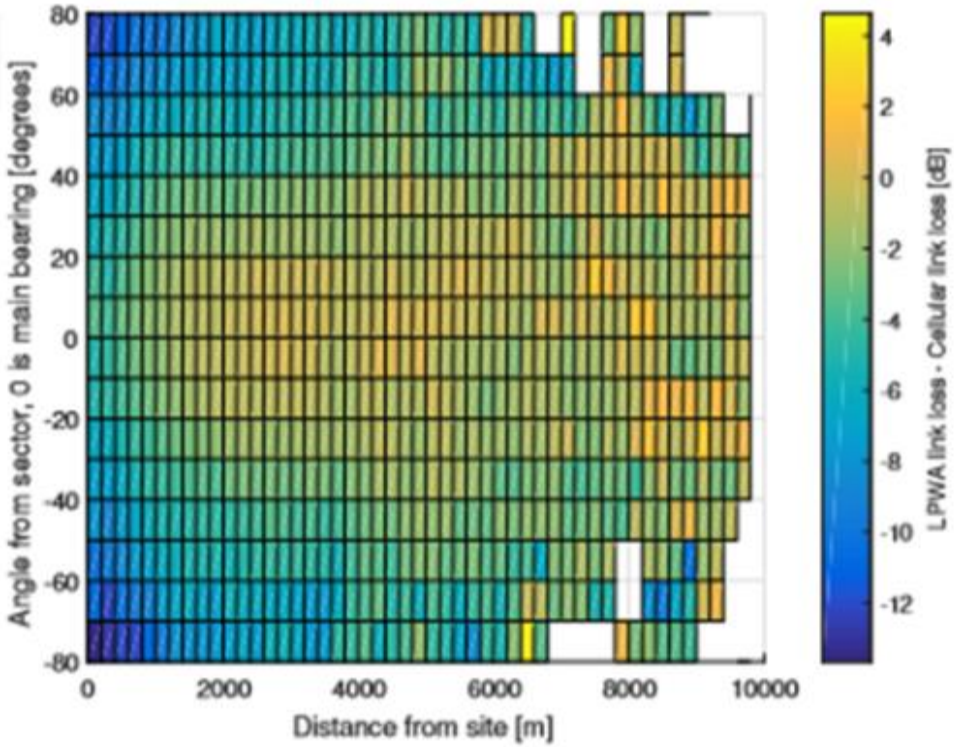
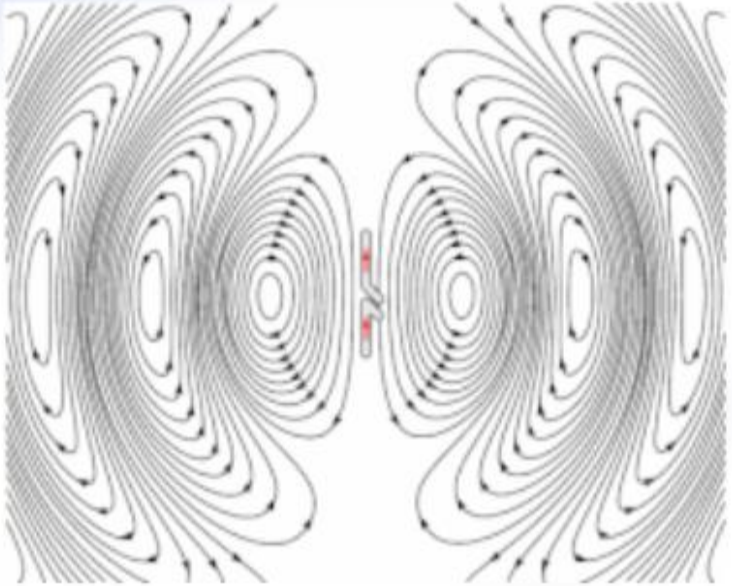


Fig. 7. Comparison of cellular and LPWA link loss as a function of angle from main bearing and distance from site. Data is averaged for all 920 sectors in the original deployment. Only device locations where the serving site is the same for the LPWA and cellular site is included in the analysis.



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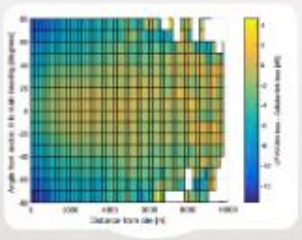

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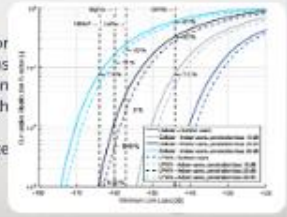

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ISD

Inter-Site Distance

Was used to only perform a partial upgrade of the deployed network

NB-IoT has better coverage probability even though the average link loss is higher for NB-IoT

LoRa and SigFox have a worse link budget

It will also be interesting to study how small cells or WiFi access points located indoor can improve coverage and capacity for IoT devices

Best coverage probability even though the devices experience a link loss, which on average is 3 dB

Indoor devices with 20 dB additional penetration loss

LoRa	outage	2%
SigFox and NB-IoT	outage	less than 1%

All technologies provide less than 1% outage for outdoor devices, located in areas with a house address

The deep indoor devices

NB-IoT

SigFox

LoRa

outage

8%

13%

20%

CONCLUSION

1. Increasing the minimum Inter-Site Distance to 4 km reduces the number of sites from 319 to 170

2. NB-IoT and SigFox are still able to provide less than 5% outage for all outdoor devices and indoor devices experiencing up to 20 dB

3. GPRS has 8% outage for light indoor devices, who experience 10 dB additional penetration loss