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# Propagation Measurements for Device-to-Device Communication in Forest Terrain

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**Abstract**—In this paper, we present a measurement campaign conducted in forest terrain with focus on path-loss. The aim of the measurement campaign is to study the coverage in a Device-to-Device (D2D) communication scenario. The measurement campaign was conducted in the LTE band 8 at 917.5 MHz with measurement ranges extending to more than 2.5 km. The measurements have been conducted using a purpose-developed measurement system with a dynamic range of 180 dB. The measurements showed that a D2D system with transmit and receive antenna at heights of 1.5 m could achieve a range of approximately 2 km using the 164 dB path-loss limit specified for Narrow Band Internet-of-Things (NB-IoT).

**Index Terms**—Forest, path loss, Device-to-Device, D2D, NB-IoT.

## I. INTRODUCTION

Unlike conventional cellular communication Device-to-Device (D2D) communication is the capability of a device to communicate directly with other devices by bypassing the network infrastructure [1]. The capability is described in the standard for long term evolution-advanced (LTE-A) mobile communication release 12 (Rel-12) by the 3rd generation partnership project (3GPP) [2] and also included as an important technique for the Next Generation Mobile Communication (5G) [3]–[5]. D2D communication is especially mentioned in relation to Internet-of-Things (IoT) where small devices might not have the ability or need to communicate with conventional cellular network infrastructure. A scenario where D2D communication could be used is a hiking trip with multiple participants. A small device could exchange the location information of the different participants allowing everyone keeping track of each other for either competition or safety reasons. These small devices should operate over a fair distance without consuming too much power. This together with the limited amount of information/data they have to exchange suggests a narrowband communication system as a solution. Such communication system is, in the contents of LTE-A, referred to as Narrow Band IoT (NB-IoT) in the literature [5]–[7].

The aim of this work is to study the communication range of an NB-IoT device utilizing D2D communication. The operation frequency is chosen to be in the lower range for LTE around 900 MHz. The antenna heights are chosen to be close to the ground due to the D2D scenario. Existing path-loss studies around 900 MHz close to the ground exist, as seen in [8]–[12]. However, they do not extend to the full 164 dB

path-loss which is specified in the standard for NB-IoT [6]. Due to this the measurement campaign presented in this work has been conducted.

The paper is organized as follows. Section II describes the planning of the measurement and presents the area in which the measurements were conducted. Section III describes the measurement system used for the measurements. Section IV presents the results of the measurement campaign. Section V summarizes this work.

## II. MEASUREMENT PLANING

### A. Measurement Frequency

It is wanted to measure a quite considerable path-loss of 164 dB which, for practical limits, results in a quite high transmit power. The high transmit signal power could cause interference in other communication systems operating in the same frequency band. Due to this, a study of the licensed frequencies in and around LTE band 8 (880 - 960 MHz) has to be conducted. In Denmark, the frequency range from 790 MHz - 960 MHz is mainly reserved for mobile communication while the range from 960 MHz - 1164 MHz is used for aeronautical navigation and communication [13]. The use of the frequency range from 840 MHz - 1000 MHz is shown in Fig. 1. The frequency allocation of the Danish spectrum is found in the government database [14].

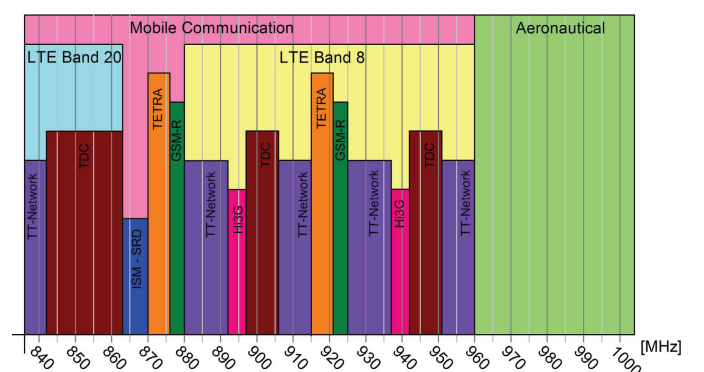


Fig. 1. Frequency allocation diagram.

Reading from the top of Fig. 1, the two overall allocations of mobile communication and aeronautical navigation/communication are marked as the background color. In the mobile communication allocation, LTE Band 20 and 8 are

illustrated as overlaid color. The subdivisions in the bands are marked by blocks of different heights and colors. From Fig. 1 it is clear that allocations have been made for the entire LTE band 8. Most of the allocations belong to the mobile operator's networks in Denmark:

- TT-Network (Telia and Telenor)
- TDC (YouSee)
- Hi3G (3)

The licenses to the mobile operators are 'technology neutral', meaning that the operator is free to use different wireless telephone technologies fitting their need. It is currently mostly used for GSM and LTE. As all of the mobile operator's spectrum blocks are heavily used and under licenses, it is not possible to transmit our measurement signal here.

The spectrum from 915 MHz - 925 MHz is allocated to TETRA (Terrestrial Trunked Radio) and GSM-R (Global System for Mobile Communications - Railway). The 921 MHz - 925 MHz range, allocated to GSM-R, is licensed to the national railway service (Banedanmark) and is in active use which is also restricting the use of this. The spectrum from 915 MHz - 921 MHz is allocated to TETRA type communication. In Denmark TETRA is used for the SINE (SikkerhedsNETtet) network which is the primary communication platform for emergency services. However, currently, the SINE network is confined to the frequency range 380 MHz - 400 MHz. The TETRA allocation in the 915 MHz - 921 MHz range is available for professional radio communication companies but there is no one currently holding the license. This means that this frequency range could be used for research purposes following the Listen Before Transmit (LBT) principle [13].

To investigate if there is a current use of the 915 MHz - 921 MHz frequency range, in the area where the measurement is intended to be conducted, a spectrum analyzer together with a dipole antenna was used to sweep the frequency range. A measurement where the maximum power spectrum over 24 hours was recorded. The resulting power spectrum is shown in Fig. 2.

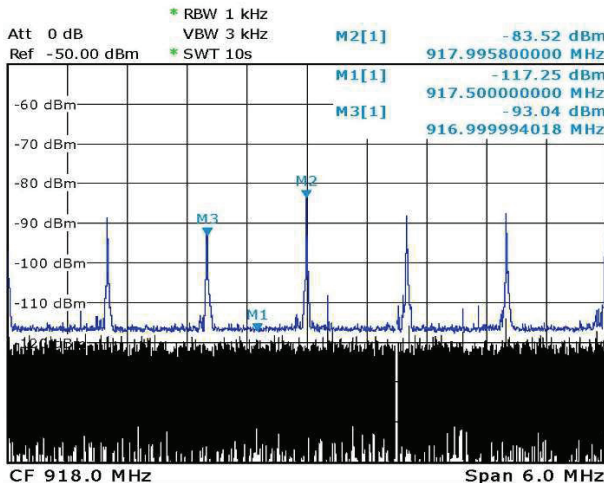


Fig. 2. 24 hours spectrum sweep of the 915 - 921 MHz frequency range.

From Fig. 2 it can be seen that there is activity in the band, even though no one is licensed to use it. This restricts the measurement signals to narrowband and, to minimize interference, single tone signals. No activity was recorded at 917.5 MHz. Due to this, it is chosen to use this frequency to transmit our measurement signal as a single tone.

### B. Measurement Area

The target application scenario is, as mentioned in the introduction, hiking in the forest. A forest called Rold Skov is located approximately 25 km south of Aalborg, Denmark. A large part of Rold Skov is so-called state forest meaning that it is governed by the government agency Naturstyrelsen. An area in this forest with only slow changes in terrain height and good access conditions were identified following the route indicated with yellow in Fig. 3.

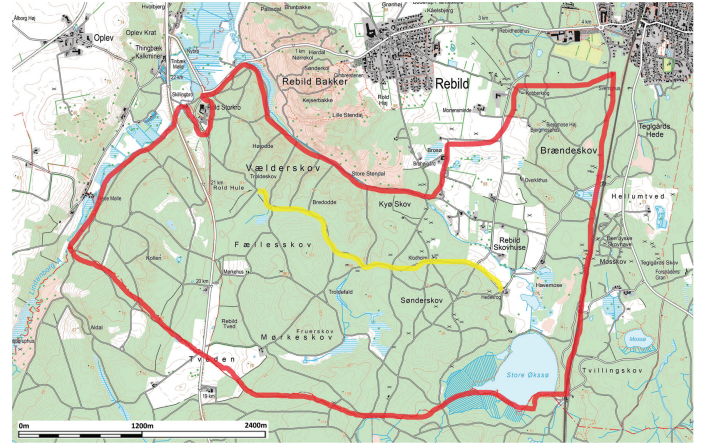


Fig. 3. Measurement area, boundary marked in red and used route in yellow. Map source: [15].

To conduct the measurements an official permit, allowing for entering the forest with a motor vehicle and conducting the measurements, had to be acquired. The acquired permit is valid for the area inside the red line shown in Fig. 3 allowing for the measurements to be conducted.

### C. Measurement Positions

The measurement positions were recorded with the Global Navigation Satellite System (GNSS) using Leica GPS1200 surveyor equipment. The equipment utilizes the Differential Global Positioning System (DGPS) where Real Time Kinematic (RTK) corrections are applied to improve precision, which allows for centimeter precision in ideal conditions. Due to the terrain and possible tree canopies, the expected uncertainty of the measured 3D coordinates will be less than 1 meter. The used geodetic datum is UTM zone 32 (UTM32V - ETRS89/DVR90) for the recorded coordinates. The recorded coordinates can be translated to latitude, longitude position in the WGS84 system for showing the position in other map systems as described in [16].

A total of 71 different measurement positions is used for the measurements. The recorded measurement positions



numbering is shown in Fig. 4 starting at the transmitter (Tx) in the upper left corner and then distributed towards the furthest point at the lower right corner. The measurement points have been distributed such that they are most dense close to the transmitter (Tx) and at the furthest measurement positions. The furthest measurement position is 71 where the straight line distance to Tx is 2580 m.

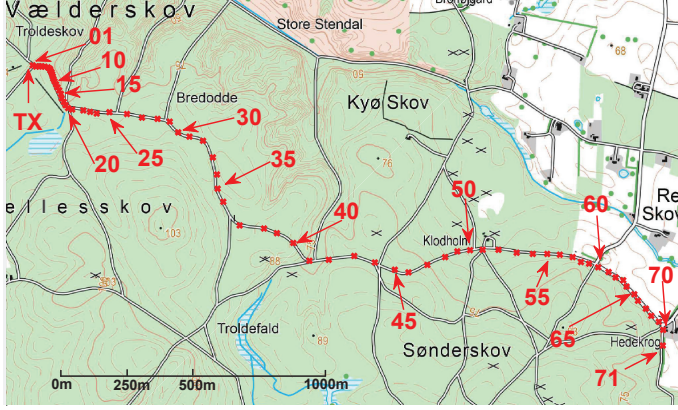


Fig. 4. Measurement locations. Tx position is marked at the left top in the figure. Map source: [15].

The changes in terrain elevation of the 71 measurement points have been plotted in Fig. 5. Note that the line between the measurement positions, marked with crosses, in Fig. 5 are added only to aid readability.

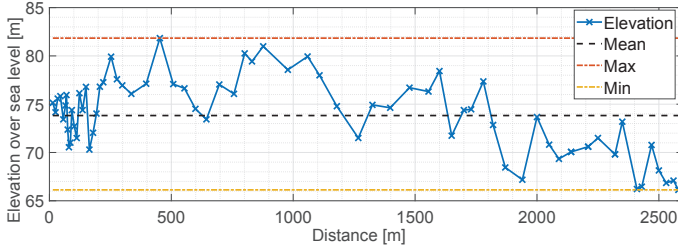


Fig. 5. Terrain elevation over sea level versus LOS distance to the Tx.

The transmitter is placed on a 1.5 m mast and the transmit position is located at an elevation of 76.8 m. The receiver is also placed on a 1.5 m mast which is moved to the 71 measurement positions. The mean elevation of the measurement positions is at approximately 74 m and from Fig. 5 it can be seen that the variations in terrain elevation are restricted to  $\pm 8$  m from the mean elevation.

### III. MEASUREMENT SYSTEM

The aim of this work is to establish the range of an NB-IoT D2D communication system. For this purpose, a system capable of transmitting a test signal and recording the power at the receiver is needed. Such a measurement system has been developed as illustrated in Fig. 6, using the equipment listed in TABLE I.

The test signal is generated as a single frequency tone at 917.5 MHz by the signal generator. Following this, the test

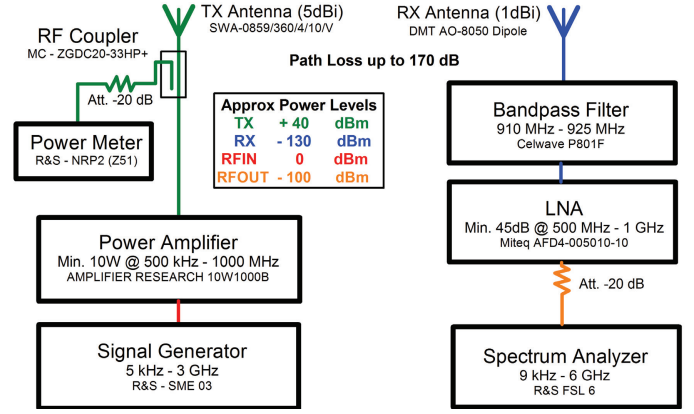


Fig. 6. Blockdiagram of the measurement system

TABLE I  
MEASUREMENT SYSTEM EQUIPMENT

Type	Model	Note
Signal Generator	Rohde & Schwarz SME03	
Power Amplifier	Amplifier Research 10W1000B	Min. 10 W @ 500 kHz - 1 GHz
Power Meter	Rohde & Schwarz NRP2	Using a Z51 sensor
RF Coupler	Mini-Circuits ZGDC20-33HP+	
TX Antenna	HUBER+SUHNER SWA-0859/360/4/10/V Folded Monopole	5 dBi @ 917.5 MHz
RX Antenna	DMT AO-8050 Dipole	1 dBi @ 917.5 MHz
Band-pass Filter	Celwave P801F	Tuned to CF 917.5 MHz
Low Noise Amplifier (LNA)	Miteq AFD4-005010-10	Min. 45 dBm @ 500 MHz - 1 GHz
Spectrum Analyzer	Rohde & Schwarz FLS6	

signal is amplified to 10 W (40 dBm) before transmitted. This power amplification is needed to overcome the intended path loss scenario for the measurement campaign of 164 dB. Just before the transmit (TX) antenna, a Radio Frequency (RF) coupler allows the attached power meter to record the actual input power at the TX antenna. This is needed as the power amplifier might drift in amplification during the measurement. Recording an accurate TX power level is needed to determine the correct path loss throughout the measurement. Before the input of the power meter, a linear RF attenuator is added to lower the RF power to the range acceptable by the power sensor. The receiver (RX) antenna is connected through a band-pass filter and a Low Noise Amplifier (LNA) to the spectrum analyzer (FSL6). The LNA is used to amplify the signal to a level within the dynamic range of the spectrum analyzer. The band-pass filter is used to protect the LNA and spectrum analyzer for unwanted high-powered signals. The

linear RF attenuator just before the spectrum analyzer is added to ensure that the RF power does not exceed the specified maximum accepted input power of the spectrum analyzer. Finally, the spectrum analyzer records the zero-span received power at the chosen measurement frequency.

As seen in Fig. 6 there is no connection between the TX and RX side of the measurement system. This is possible as only the power is recorded and therefore there is no need for phase/time synchronization between TX and RX. Any offset between the asynchronous oscillators is accounted for when the frequency for the zero-span measurement is chosen at the spectrum analyzer. The settings of the spectrum analyzer are shown in TABLE II.

TABLE II  
SPECTRUM ANALYZER SETUP

Parameter	Setting
Center Frequency	$\approx 917.5$ MHz
Resolution bandwidth (RBW)	1 kHz
Sweep Points	501
Sweep Time	5 s
Detector Mode	Root Mean Square (RMS)
Noise floor (with LNA)	-140 dBm

As seen in TABLE II the Resolution bandwidth (RBW) is chosen 1 kHz. Choosing a smaller RSB would lower the noise floor of the system. However, as the system is asynchronous it is needed to choose the RSB large enough to allow for small drifts during the 5 s sweep of the 501 points. The long sweep time is needed as a single tone will be used for the measurement. This means multipath fading cannot be averaged in the frequency domain. As a result, multiple snapshots of the channel, given by the different sweep points, have to be recorded distributed over an area corresponding at least one wavelength of the recorded frequency. This allows for an averaging of the multipath fading in the spatial domain. In practice the spatial averaging was done by moving the antenna around in a circle with a diameter of 35 cm during the 5 s sweep.

#### IV. RESULTS

A total of 265 measurements were performed over three different days. Each day the entire measurement route were measured together with some repetitions at key points. This means that each of the 71 different measurement positions was measured between 2 and 5 times. At each measurement, the collected data consisted of 501 sweep points. All the collected sweep points for each measurement position have been concatenated and used to calculate mean power and power variance for that given measurement position. Before the concatenation of the sweep points, each power reading has been corrected by using known values of the measurement systems gains and losses. The system gains and losses were found by RF power measurements throughout the system chain. The Tx power was tracked during the measurement

and the LNA gain was verified at the start and end of each measurement day. The cable, coupler, filter and connector losses were verified using vector network analyzer (VNA) measurements.

The plots shown in Fig. 7 describe the measured received power. The plot shows the received power without added gains from antennas and LNA. For reference, the calculated Friis path-loss, shown in Eq. 1, and the Two-ray model, shown in Eq. 2, have been plotted. The Friis path-loss is plotted for both path-loss exponents 2 and 4 giving free space and 4th power loss [17].

$$P_{Friis} = P_{Tx} + G_{Tx} + G_{Rx} + \gamma 10 \log_{10} \left( \frac{\lambda}{4\pi d} \right) \quad [dBm] \quad (1)$$

$$P_{2Ray} = P_{Tx} + 10 \log_{10} (G_{Tx} G_{Rx} h_{Tx}^2 h_{Rx}^2) - 40 \log_{10} (d) \quad [dBm] \quad (2)$$

where  $P_{Friis}$  and  $P_{2Ray}$  is the received power for the two models.  $P_{Tx}$  is the transmit power.  $G_{Tx}$  and  $G_{Rx}$  is the antenna gain for the transmit and receive antenna. The wavelength is expressed by  $\lambda$  and  $\gamma$  is the path-loss exponent. The distance between transmitter and receiver is denoted by  $d$  while  $h_{Tx}$  and  $h_{Rx}$  denotes the height of the transmit and receive antenna.

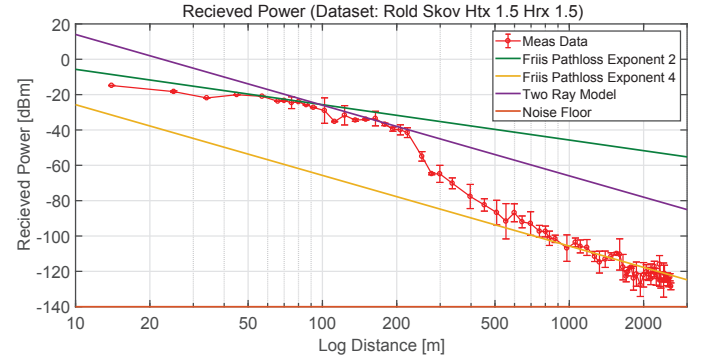


Fig. 7. Received power plotted against logarithmic distance scale.

In Fig. 7 it can be seen that the measured received power seems to follow the curve for free space loss from 10 m to 90 m. From 90 m to 220 m it fits quite well with the Two-ray model. Then there is a transition from 220 m to 800 m where after it settles and starts following the modeled 4th power loss.

The first approximately 200 m of the measurement route is quite open resulting in almost clean line-of-sight (LOS) conditions. This corresponds to the finding that the received power in this region follows what is expected for free space path-loss. After this, the forest gets denser which in the measurements can be seen as a transition towards the 4th power path-loss model. The measurements indicate that from approximately 800 m until the furthest measurement at 2580 m the received power can be fairly well predicted using the 4th power path-loss model.

The path-loss is given by the relation between the transmitted and received power, in dB expressed as  $P_L = P_{Tx} - P_{Rx}$ . Using the measurement data presented in Fig. 7 together with the transmit power of 40 dBm the mean path-loss can be found. A plot of this is shown in Fig. 8.

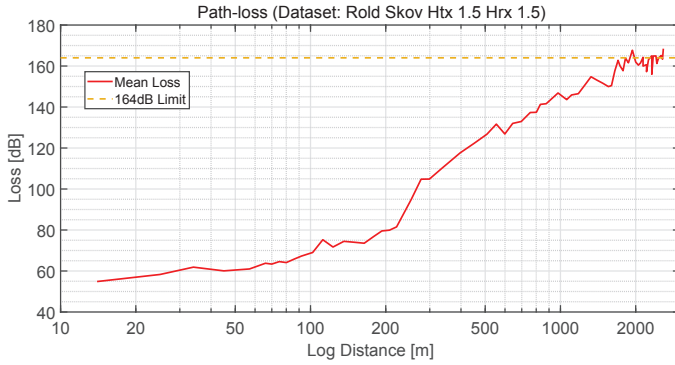


Fig. 8. Path-loss plotted against logarithmic distance scale.

From Fig. 8 it can be seen that the 164 dB path-loss limit, which is specified for NB-IoT, supports a distance between transmitter and receiver of approximately 2000 m.

## V. CONCLUSION

This paper presents a path-loss measurement campaign intended to illustrate the coverage range of a Device-to-Device (D2D) Narrow Band Internet-of-Things (NB-IoT) communication system in a forest scenario. A measurement system capable of high dynamic range was designed, as presented in this paper. Using the designed measurement system, measurements have been conducted at ranges up to 2580 m at 917.5 MHz. A total of 265 measurements were conducted at 71 different positions with both transmit and receive antenna in a height of 1.5 m above the terrain. The measurements showed that for the path-loss limit of 164 dB, specified for NB-IoT, a coverage range of approximately 2000 m could be achieved.

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