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Free Space Range Measurements with Semtech LoRa^{TM} Technology

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Abstract—**Although short range wireless communication explicitly targets local and very regional applications, range continues to be an extremely important issue. The range directly depends on the so called link budget, which can be increased by the choice of modulation and coding schemes. Especially, the recent transceiver generation comes with extensive and flexible support for Software Defined Radio (SDR). The SX127x family from Semtech Corp. is a member of this device class and promises significant benefits for range, robust performance, and battery lifetime compared to competing technologies.**

This contribution gives a short overview into the technologies to support Long Range (LoRa^{TM}), describes the outdoor setup at the Laboratory Embedded Systems and Communication Electronics of Offenburg University of Applied Sciences, shows detailed measurement results and discusses the strengths and weaknesses of this technology.

Keywords—Spread spectrum; software defined radio; packet error rate

I. Introduction

Short-range wireless networks (SRWN) continue to find their place in our everyday's life. Applications come from manifold fields. They include home and building automation, industrial and process automation, telehealth and telecare, traffic and safety communication.

In parallel, SRWN continue to be a fascinating field of research, as they have to answer the highest requirements with regard to range, energy efficiency, network scalability, and cost. As the applications pose diverging requirements, a huge diversity of different solutions evolves. However, with the advances of semiconductor industry, some "one-fits-all" or better "one-fits-many" solutions become reality [0]. This group of configurable devices, which is impelled by the continuously growing integration capabilities of modern semiconductor, allows the realization of the decades-old dream of Software Defined Radio (SDR) [0]. SDR promises a significant reduction of development cost for the semiconductor manufacturer, as the number of silicon runs can be reduced.

In addition, it also allows a fascinating flexibility for system designers. One of the directions of optimization is the increase of sensitivity, where now advanced digital signal processing technologies can be applied, which are well known from the last decades in mobile communication, but are now used for the first time in cost efficient and low power short range wireless networking.

The organization of the paper is as follow: Section II introduces some general issues on propagation and range. Section III presents an overview of the Lora technology. Section IV describes the test setup. Section V provides the measurement results. Discussion and conclusions are presented in section VI.

II. Some Issues on Range

With regard to range measurements, three general aspects should be taken into account.

A. Signal to Noise Ratio and Adaptivity

Generally, of course, a sufficient signal to noise ratio is required to achieve a bit error rate (BER), which results in a satisfying packet error rate (PER). The required SNR depends on the modulation and the coding schemes. Some specific coding aspects are discussed in ch. III.

In our case, two physical aspects are relevant to determine the signal power level at the receiver side.

B. Friis Free Space equation

Radio waves propagate through free space with a velocity of the speed of light ($3 \cdot 10^8$ m/s). There is no loss of energy in free space, but the power density is attenuated due to the spatial spreading. The relation between the transmission and receive power is given by Friis free space equation [0], which also takes the antenna aperture into account:

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi d}\right)^{\alpha} \quad (1)$$

where P_R is the absolute received power, P_T the absolute transmitted power, G_T is the transmitting antenna power gain, and G_R is the receiving antenna gain. The distance between the transmitter and the receiver is given by d, and the wavelength is given by λ. Finally α represents the path loss coefficient. Its value depends on the material, the reflection conditions and the frequency. It can be determined empirically. Typical values are between 2 and 6.

C. *Fresnel Zone*

When the radio signal travels between transmitter and receiver, it can take several ways. Reflected signals may arrive out of phase with the direct wave and then reduce the power of the received signal. On the other hand it may enhance the power of the received signal if it arrives in phase. Fresnel zones are used to calculate the reflections and diffractions loss between the transmitter and the receiver. A Fresnel zone is a cylindrical ellipse drawn between transmitter and receiver as shown in Fig. 1. The size of the ellipse is determined by the operation frequency and the distance between the transmitter and receiver. There are infinite numbers of calculable Fresnel zone, but the 1 st Fresnel zone always has the most effect on the performance of the wireless link. So the 1 st Fresnel zone is required to be at least 60% clear of any obstruction to ensure the highest performance of the wireless link.[5]

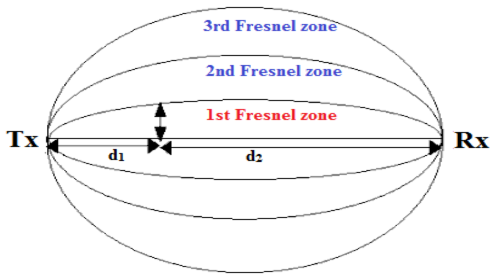

Figure 1. Fresnel Zones

The radius of the Fresnel zone at any point P in between the end points of the wireless link can be calculated by the formula listed below. Where F_n is the n^{th} Fresnel zone radius, d_1 is the distance of point P from the transmitter, and d_2 is the corresponding distance from the receiver.

$$F_n = \sqrt{\frac{n\,\lambda\,d_1\,d_2}{d_1 + d_2}} \qquad (2)$$

III. LoRa^{TM} Technology

A new perspective in short range wireless networking is opened by a good number of recent product releases. Amongst them, the semiconductor manufacturer Semtech with its Long-Range (LoRa^{TM}) product line [0] makes extensive use of advanced spread spectrum technologies. The available coding schemes support different spreading codes promising to an additional process gain, a better stability against deep fading and Doppler shift. Additionally, Forward Error Correction (FEC) schemes can be activated. The underlying technologies are well known from the last decades in mobile communication, but they are now used for the first time in cost efficient and low power short range wireless networking. The spread spectrum modulation, in contrast to the legacy modulation techniques, leads to an increased link budget and better immunity to interference. For this purpose, LoRa^{TM} utilizes broad band linear frequency modulated pulses to achieve good frequency characteristics.

Fig. 2 shows the LoRa^{TM} packet structure. The first field is the preamble which is used to synchronize the receiver with the incoming data flow. Next is the Header field which depends on the chosen mode of operation. There are two types of operation modes; the default is the explicit mode. In this mode the header field provides information about the number of bytes and the used forward error correction code rate. The other operation mode is the implicit mode, used when the payload and coding rate are fixed. In this mode the header field is removed from the packet, which gives the advantage of reducing transmission time. The third field in the packet structure is the payload length which contains the actual data. The last field contains cyclic redundancy check (CRC) bytes for error protection.

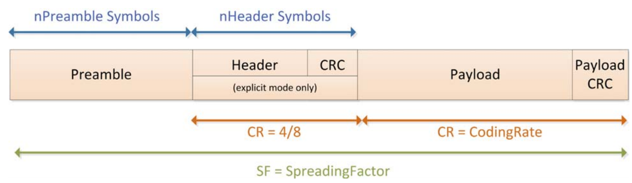

Figure 2. LoRa^{TM} packet structure

IV. Test Setup

Fig. 3 shows the outdoor setup at the Laboratory Embedded Systems and Communication Electronics of Offenburg University of Applied Sciences. As shown the transmitter device installed on a wooden stand with height of 2 meter located on the roof. The height of the three storey building is around 20 m.

Figure 3. Test setup

The measurement area can be divided into short range and long range areas. The short range area is for distances up to 6 km along the river Kinzig as shown in the map in Fig. 4. Node A is our reference point at Offenburg University of Applied Science building, and the remaining nodes from B to J represent the measurement points with different distances from A. The long range area is for distances longer than 6 km as shown in Fig. 5. Also node A represents the reference point and nodes K, L, M, and N are the measurement points.

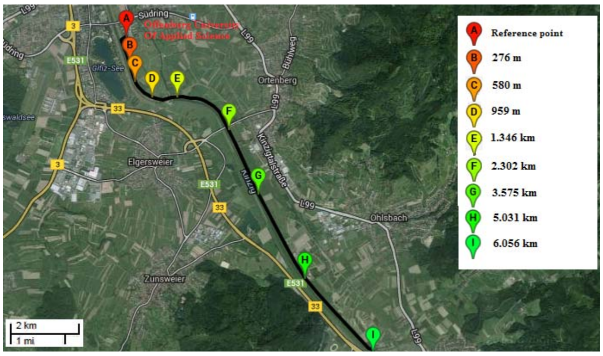

Figure 4. Short range measurement area

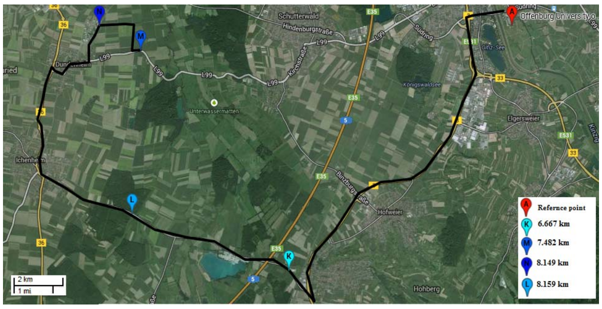

Figure 5. Long range measurement area

In our measurements, two test cases are used both in operating frequency of 868 MHz:

A. Test Case1

The first test case is considered as typical case, using parameters values close to what could use in practical applications. Spread spectrum is used as a modulation scheme with spreading factor 10. The bandwidth value is 250 KHz and coding rate 4/6 leads to bit rate of 1627.6 bps.

B. Test Case 2

In this case we measure the behavior of the Lora device using the specification of the Wireless M-Bus according to EM13757-4 [0]. Here, Frequency Shift Keying (FSK) modulation is used with an FSK deviation value of 50 kHz and a data rate of 100 kbit / s.

V. Measurement Results

In this section, we present the measurement results. First, we show the results for test case 1. Table I shows the measurement results for payload length 10 bytes in terms of packet error rate (PER), received signal strength indicator (RSSI), and signal to noise ratio (SNR). Table II and III show the results for payload length 50 and 100 bytes respectively. For Further description Fig. 6, Fig. 7, and Fig. 8 give an overview for the RSSI measured values over the distances.

TABLE I. Measurements Results for Test Case 1 With Payload Length 10 Bytes

Meas. point	Distance (km)	Packets sent	Packets received	Valid packets	PER	RSSI mean value (dBm)	RSSI variance	RSSI std. deviation	SNR mean value
B	0.276	1000	1000	1000	0.0%	-80	0.09	0.3	>0
C	0.580	1000	1000	1000	0.0%	-83.6	0.24	0.489	>0
D	0.959	1000	1000	1000	0.0%	-91	0.24	0.489	>0
E	1.346	1000	1000	1000	0.0%	-104.6	0.24	0.489	>0
F	2.302	1000	1000	1000	0.0%	-117.2	0.56	0.748	-3.2
G	3.575	1000	1000	1000	0.0%	-123.2	1.36	1.1662	-9.2
H	5.031	1000	1000	1000	0.0%	-119	1.5	0.375	-5
I	6.056	1000	1000	1000	0.0%	-125.8	0.96	0.9797	-11.8
J	6.667	1000	1000	1000	0.0%	-125.2	0.56	0.7483	-11.2
M	7.482	500	500	500	0.0%	-126	1.84	1.356	-12
N	8.149	100	100	56	44%	-130.6	2.24	1.49	-16.6
L	8.519	100	0	n.a.	n.a.	< -150	n.a.	n.a.	n.a.

TABLE II. Measurements Results for Test Case 1 With Payload Length 50 Bytes

Meas. point	Distance (km)	Packets sent	Packets received	Valid packets	PER	RSSI mean value (dBm)	RSSI variance	RSSI std. deviation	SNR mean value
B	0.276	1000	1000	1000	0.0%	-76.833	0.19	0.436	>0
C	0.580	1000	1000	1000	0.0%	-81.9	0.09	0.3	>0
D	0.959	1000	1000	1000	0.0%	-100.11	4.765	2.183	>0
E	1.346	1000	1000	1000	0.0%	-100.375	2.7344	1.6536	>0
F	2.302	1000	1000	902	9.8%	-115.667	30.88	5.5577	-3.22
G	3.575	1000	1000	995	0.5%	-124.9	2.49	1.5779	-10.9
H	5.031	1000	1000	737	26.3%	-127.6	5.84	2.4166	-13.4
I	6.056	1000	1000	869	13.1%	-127.9	1.49	1.22	-13.9
K	6.667	1000	1000	941	5.9%	-126.22	5.76	2.4	-12.22
M	7.482	600	600	482	19.67%	-129.75	14.187	3.766	-15.75
N	8.149	100	100	6	94.0%	-130.67	1.22	1.104	-16.67
L	8.519	100	0	n.a.	n.a.	< -150	n.a.	n.a.	n.a.

TABLE III. MEASUREMENTS RESULTS FOR TEST CASE 1 WITH PAYLOAD LENGTH 100 BYTES

Meas. point	Distance (km)	Packets sent	Packets received	Valid packets	PER	RSSI mean value (dBm)	RSSI variance	RSSI std. deviation	SNR mean value
B	0.276	1000	1000	1000	0.0%	-85	0.21	0.458	>0
C	0.580	1000	1000	1000	0.0%	-82.3	0.21	0.458	>0
D	0.959	1000	1000	1000	0.0%	-94	0.19	0.436	>0
E	1.346	1000	1000	1000	0.0%	-102.5	0.25	0.5	>0
F	2.302	1000	1000	1000	0.0%	-118.5	2.65	1.6278	-4.5
G	3.575	1000	1000	997	0.3%	-120.3	1.41	1.87	-6.3
H	5.031	1000	1000	1000	0.0%	-120.3	2.41	1.5524	-6.3
I	6.056	1000	1000	1000	0.0%	-120.9	0.29	0.5385	-6.9
J	6.667	1000	1000	927	7.3%	-126.8	0.56	0.7483	-12.8
M	7.482	500	500	378	24.4%	-128.3	0.4	0.632	-14.3
N	8.149	500	0	n.a.	n.a.	< -150	n.a.	n.a.	n.a.

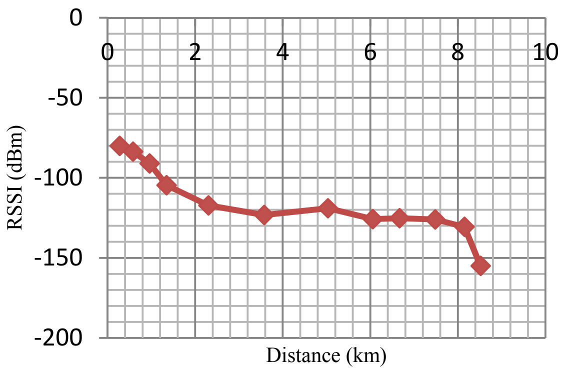

Figure 6. RSSI measurement values for test case 1 with payload length 10 bytes

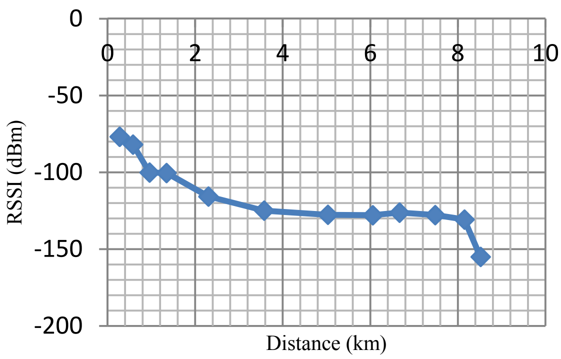

Figure 7. RSSI measurement values for test case 1 with payload length 50 bytes

Considering Fresnel zone aspect, Fig. 9 shows an approximate Fresnel zone area for measurement point at distance 3 km from the transmitter. From (2), the Fresnel zone radius will be 32.2 meter. This will be very difficult in our case to guarantee area with radius 32.2 meter to be free from obstructions, as there are some buildings and our route is not flat. Moreover, the antennas at the transmitter and the receiver are not at the same height. For test case 2, the measurements results are shown in table IV and V for payload length 16 and 64 bytes respectively.

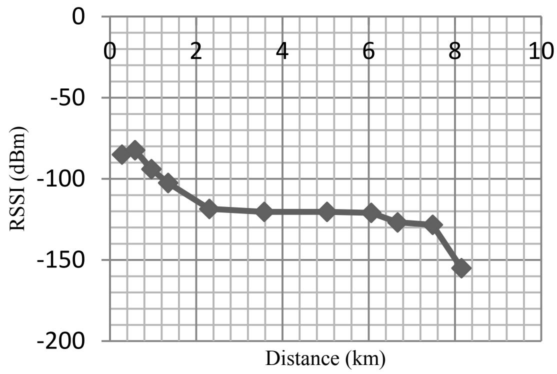

Figure 8. RSSI measurement values for test case 1 with payload length 100 bytes

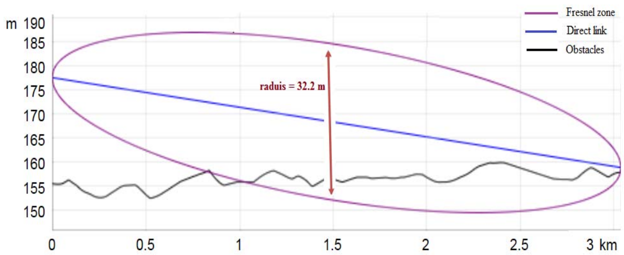

Figure 9. Approximation Fresnel zone area for our measurement at distance 3 km.

TABLE IV. MEASUREMENTS RESULTS FOR TEST CASE 3 WITH PAYLOAD LENGTH 16 BYTES

Meas. point	Distance (km)	Packets sent	Packets received	Packet loss	RSSI mean value (dBm)	RSSI variance	RSSI std. deviation
B	0.276	1000	1000	0.0%	-65.3	0.96	0.979
C	0.580	1000	992	0.8%	-86.3	3.16	1.77
D	0.959	1000	596	40.4%	-109.85	32.00	5.656
D*	1.059	1000	433	56.7%	-110	33.22	5.763
E	1.346	1000	39	96.1%	-105.65	1.102	1.05

TABLE V. MEASUREMENTS RESULTS FOR TEST CASE 3 WITH PAYLOAD LENGTH 16 BYTES

Meas. point	Distance (km)	Packets sent	Packets received	Packet loss	RSSI mean value (dBm)	RSSI variance	RSSI std. deviation
B	0.276	1000	1000	0.0%	-66.5	0.95	0.974
C	0.580	1000	990	1.0%	-88.25	3.71	1.926
D	0.959	1000	643	35.7%	-111.05	28.97	5.382
D*	850	1000	323	67.7%	-108.75	29.41	5.423
E	1.346	1000	13	98.7%	-107.55	22.62	4.75

VI. DISCUSSION

Although short range wireless communication explicitly targets local and very regional applications, range continues to be an extremely important issue. The range directly depends on the so called link budget, which can be increased by the choice of modulation and coding schemes. Especially, the recent transceiver generation comes with extensive and flexible support for Software Defined Radio (SDR). The SX127x family from Semtech Corp. is a member of this device class and promises significant benefits for range, robust performance, and battery lifetime compared to competing technologies.

VII. REFERENCES

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