ANALYSES AND OPTIMIZATION OF LEE PROPAGATION MODEL FOR LORA 868 MHZ NETWORK DEPLOYMENTS IN URBAN AREAS

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Preliminary Communication

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In the recent period, fast ICT expansion and rapid appearance of new technologies raised the importance of fast and accurate planning and deployment of emerging communication technologies, especially wireless ones. In this paper is analyzed possible usage of Lee propagation model for planning, design and management of networks based on LoRa 868MHz technology. LoRa is wireless technology which can be deployed in various Internet of Things and Smart City scenarios in urban areas. The analyses are based on comparison of field measurements with model calculations. Besides the analyses of Lee propagation model usability, the possible optimization of the model is discussed as well. The research results can be used for accurate design, planning and for preparation of high-performance wireless resource management of various Internet of Things and Smart City applications in urban areas based on LoRa or similar wireless technology. The equipment used for measurements is based on open-source hardware.

Keywords: Outdoor radio propagation, Path loss, Lee propagation model, LoRa technology, Open-source hardware, Smart cities.

INTRODUCTION

In the past decade few technologies such as Wireless Sensor Networks (Nandury & Begum, 2015), Internet of Things (Zanella, Bui, Castellani, Vangelista & Zorzi, 2014), Big Data (Hashem et al., 2016) and Cloud computing (Vögler, Schleicher, Inzinger, Dustdar, & Ranjan, 2016) influenced the shaping of Smart City concept. The term "smart city" defines the new urban environment, one that's designed for performance through information and communication technologies (ICTs) and other forms of physical capital. With the effective management of resources through intelligent management, visionaries hope that cities will drive a higher quality of life for citizens, drive down waste, and improve economic conditions", (Stimmel, 2016).

According to Georgescu and Popescul (2016) the relevant goals for a smart city are:

- Smart mobility (traffic management, bike/car/van sharing, multimodal transport, road conditioning monitoring, parking system, route planning, electric car gearing services);
- Smart grid/energy (power generation/ distribution/storage, energy management, smart metering, street lightening optimization);
- Public safety (video/radar/satellite surveillance, environmental and territorial monitoring, children protection - e.g. safer home-school journeys for children, emergency solutions, waste management, smart air quality, weather data for snow cleaning);
- Smart governance (transparent decisional process, a greater involvement of citizens in legislative initiatives, public-private partnerships, online taxing systems);

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- Smart economy (high-level jobs, competitiveness, entrepreneurial spirit, innovation and research in the field) and
- Smart life (cultural and educational facilities, meaningful events, entertainment and guided tours, access to cultural sights and historical monuments, good conditions for health).

Low-Power Wide-Area Network (LPWAN) is a type of wireless telecommunication network designed to allow long range communications at a low bit rate between connected objects, such as battery operated sensors. LPWAN represents very suitable Smart City technology, enabling wireless connectivity in urban areas. LoRa and LoRaWAN™ are two of LPWAN technologies. LoRa contains only physical and link layer protocol and is perfect to be used in P2P communications between nodes. LoRa modules are a little cheaper comparing to LoRaWAN ones. LoRaWAN includes the network layer, making it possible to send the information to any base station connected to a Cloud platform, (Libelium, 2017). LoRaWAN™ is a Low Power Wide Area Network (LPWAN) specification intended for wireless battery operated units in a regional, national or global network. LoRaWAN targets key requirements of Internet of Things (and Smart City as well) such as secure bi-directional communication, mobility and localization services. LoRaWAN network architecture is typically laid out in a star-of-stars topology in which gateway is a transparent bridge relaying messages between end-devices and a central network server in the backend. Gateways are connected to the network server via standard IP connections while end-devices use single-hop wireless communication to one or many gateways (LoRa Alliance..., 2017).

Smart city environments are largely based on wireless technology. According to (Lee, Park, & Seo, 2009), the radio propagation conditions and their statistical characteristics seriously affect the operation of wireless communication systems as well as their performance. So, in preparation for the design of high-performance wireless resource management, it is crucial to understand the characteristics of wireless communication channels. One of the most important characteristics of wireless channels is the channel gain which is determined by three factors: path loss, shadowing, and multipath fading. Path loss represents the decay of signal power dissipated due to radiation on the wireless channels, so it is determined by the channel's physical characteristics of signal propagation and modeled as a function of the distance between the transmitter and receiver.

A number of researches are performed in order to analyze and possibly optimize path loss propagation models in urban, suburban and open space environments. The number of propagation models such as: Okumura-Hata, COST231, Stanford University Interim (SUI), Ericsson 9999, ECC-33, Winner II, Egli, etc; are analyzed for different usage scenarios (Seybold, 2005; Parsons, 2000). Those researches are mainly focused on mobile communications (Alim, Rahman, Hossain, & Al-Nahid, 2010) and WiMAX (Alshami, Arslan, Thompson, & Erdogan, 2011) technologies. Furthermore (Al Salameh et al., 2015) focused his research on mobile communications in urban areas; while Armoogum, Soyjaudah, Mohamudally and Fogarty (2007) focused their research on Digital Television Broadcasting in Mauritius using the same propagation model. Evans, Joslin, Vinson and Foose (1997), dealt with optimization and application of Lee propagation model in the 1900 MHz frequency band. Galvan-Tejada and Duarte-Reynoso (2012) and Galvan-Tejada, Duarte-Reynoso and Flores-Leal (2013) analyzed usability of Lee propagation model in vegetation environments. Rivera et al. (2015) discussed about applicability of Lee propagation model in university campus environments.

There is an evident lack of similar researches for alternate technologies applicable in Smart City environments. This research represents the analyses of usability of Lee propagation model (Lee & Lee, 2000; Lee, 2006; Lee & Lee, 2010; Lee & Lee, 2014) in design, planning and management of wireless networks in urban areas based on LoRa technology for possible Smart City scenarios in small city environments. In addition, the possible optimization of the same model is discussed.

This paper is structured as follows. After the short introduction, Lee propagation model is described. The experiment and results are presented in the following sections. At the end, the conclusion and further work are presented.

LEE PROPAGATION MODEL

The Lee model was originally developed for use at 900MHz and has two modes: area-to-area and point-to-point (Seybold, 2005). This model is used to predict a path loss over flat terrain. If the actual terrain is not flat, e.g., hilly, there will be large prediction errors (Stüber, 2002). Area-to-area model uses reference path loss L_0 for one mile or 1.6 km, slope of path loss curve γ in dB and adjustment factor F_0. Propagation path loss is calculated with formula:

$$L_{50}(dB) = L_0 + \gamma \cdot log_{10}(d) - 10 \cdot log_{10}(F_0) \quad (1)$$

Distance between transceiver and receiver d is in km. The reference values for median path losses are given in Table 1.

Table 1: Reference Median Path Loss for Lee's Model

Environment	L_0 (dB)	γ
Free space	85	20
Open (rural) space	89	43.5
Suburban	101.7	38.5
Urban areas		
Philadelphia	110	36.8
Newark	104	43.1
Tokyo	124.0	30.5

The adjustment factor F_0 is calculated with formula:

$$F_0 = F_1 \cdot F_2 \cdot F_3 \cdot F_4 \cdot F_5 \quad (2)$$

Where F_1 is *base station antenna height correction factor* and h_b is base station antenna height in meters.

$$F_1 = \left(h_b(m)/30.48\right)^2 \quad (3)$$

Base station antenna gain correction factor is:

$$F_2 = \left(G_b/4\right) \quad (4)$$

G_b is base station antenna gain relative to a half-wave dipole [dBd]. dBd compares the gain of an antenna to the gain of a reference dipole antenna, while dBi is a measurement that compares the gain of an antenna with respect to an isotropic radiator (a theoretical antenna that disperses incoming energy evenly over the surface of an imaginary sphere.). The difference is 2.15 dB. To convert dBi to dBd or vice versa: the following formula is used: dBd = gain in dBi - 2.15 dB.

Further, F_3 or *mobile antenna height correction factor* is calculated like this:

$$F_3 = \left(h_m(m)/3\right)^2 \text{ if } h_m(\text{m}) > 3 \quad (5)$$

$$F_3 = \left(h_m(m)/3\right) \text{ if } h_m(\text{m}) < 3 \quad (6)$$

Mobile antenna height correction factor depends on h_m or mobile antenna height in meters. Two different formulas are used, one for antenna height above 3 m, and other for antenna heights bellow 3m.

The *frequency adjustment factor* is:

$$F_4 = \left(f/900\right)^{-n} \text{ where } 2 < n < 3 \text{ and } f \text{ is in MHz} \quad (7)$$

Mobile antenna gain correction factor with G_m (mobile antenna gain) in dBd is:

$$F_5 = G_m/1 \quad (8)$$

Another form of formula for Lee propagation is as follows, (Stüber, 2002):

$$\mu\Omega_p = \mu\Omega_p(d_0) \cdot \left(\frac{d_0}{d}\right)^{\beta} \cdot \left(\frac{f_c}{f}\right)^{n} \cdot \alpha_0 \quad (9)$$

Where $\mu\Omega_p(d_0)$ is power at 1 mile or 1.6 km (reference distance d_0); and β is path loss exponent. Parameters for formula (9) are given in Table 2. Those parameters are determined with empirical measurements.

Table 2: Reference Median Path Loss for Lee's Model variant 2

Environment	$\mu\Omega_p(d_o)$	β
Free space	-45	2
Open (rural) space	-49	4.35
Suburban	-61.7	3.84
Urban areas		
Philadelphia	-70	3.68
Newark	-64	4.31
Tokyo	-84	3.05

The adjustment or correction factor α_0 is calculated with formula like in (2):

$$\alpha_0 = \alpha_1 \cdot \alpha_2 \cdot \alpha_3 \cdot \alpha_4 \cdot \alpha_5 \quad (10)$$

α_1 is *base antenna height correction factor*,

$$\alpha_1 = \left(h_b(m)/30.48\right)^2 \quad (11)$$

Where h_b is the base station antenna height expressed in meters, like in the previous case. For α_2 or *mobile antenna height correction factor* following formula is used with h_m as mobile antenna height.

$$\alpha_2 = \left(h_m(m)/3\right)^2 \text{ if } h_m(\text{m}) > 10 \text{ m}, \quad (12)$$

$$\alpha_2 = \left(h_m(m)/3\right)^3 \text{ if } h_m(\text{m}) < 3 \text{ m}. \quad (13)$$

Two different formulae are used, one for antenna height above 10 m, and other for antenna heights bellow 3m.

Mobile antenna gain correction factor is:

$$\alpha_3 = \left(\frac{P_t}{10(W)}\right)^2 \quad (14)$$

P_t is base station transmitter power in Watts. *Base antenna gain correction factor* is:

$$\alpha_4 = \left(\frac{G_b}{4}\right) \quad (15)$$

Where G_b is base station antenna gain with respect to λ/2 dipole. Finally, α_5 is different antenna gain correction factor of mobile station.

Path loss $L_p(dB)$ is difference between transmitted and received field strengths, and it is calculated as:

$$L_p = \mu\Omega_p[dB](d_0) - \mu\Omega_p[dB] \quad (16)$$

According to the presented, formulae for path loss calculations are:

$$L_p = 96.92 + 20.0 \cdot log_{10} d + 10 \cdot n \cdot log_{10}\left(\frac{f}{900}\right) - \alpha_o \text{, for free space} \quad (17)$$

$$L_p = 82.16 + 43.5 \cdot log_{10} d + 10 \cdot n \cdot log_{10}\left(\frac{f}{900}\right) - \alpha_o \text{, for open area} \quad (18)$$

$$L_p = 99.86 + 38.4 \cdot log_{10} d + 10 \cdot n \cdot log_{10}\left(\frac{f}{900}\right) - \alpha_o \text{, for suburban area} \quad (19)$$

$$L_p = 108.49 + 35.8 \cdot log_{10} d + 10 \cdot n \cdot log_{10}\left(\frac{f}{900}\right) - \alpha_o \text{, for Philadelphia} \quad (20)$$

$$L_p = 101.20 + 43.1 \cdot log_{10} d + 10 \cdot n \cdot log_{10}\left(\frac{f}{900}\right) - \alpha_o \text{, for Newark} \quad (21)$$

$$L_p = 123.77 + 30.5 \cdot log_{10} d + 10 \cdot n \cdot log_{10}\left(\frac{f}{900}\right) - \alpha_o \text{, for Tokyo} \quad (22)$$

EXPERIMENT

Experiment is made with the support of open-source hardware. Both transceiver (mobile station) and receiver (base station) are built around Arduino platform. The transmitter is built upon Arduino MEGA development board, with Libelium multiprotocol shield and Libelium LoRA SX1272 communication module (Libelium, 2017). LoRa module uses 868MHz omni-directional antenna with 4.5 dBi gain. The receiving station is similar, with the difference of using Arduino UNO instead of Arduino MEGA. In order to increase the range of receiver, the LoRa communication module is attached to external yagi antenna with 9 dBi gain and 60° radiation angle. Antenna is located outdoor, mounted on the antenna holder on the 4th floor of the residential building. Experiment is made in Zrenjanin, a city with about 76,511inhabitants (SBRS, 2011) and it covers area of 1,324.0 km2, with density of population around 93.2/km2. The measurements are made on 17 locations, and the measurement results are presented in Table 3, while the location positions, receiver central position and antenna radiation angle are shown in Figure 1. Table 3 gives additional data for the location such as: number of packets sent and received, packet error rate (PER) in %, mean Received Signal Strength Indicator (RSSI) in dBm, mean Signal-to-noise ratio (SNR) in dBm, latitude and longitude of measurement position and its distance from central position.

Table 3: The data for measurement locations

	Pkts. Sent	Pkts Rcvd	PER (%)	RSSI	SNR	Lat (°)	Lon (°)	Distance (m)
Loc_01	530	528	99.44	-113.85	-3.28	45.383548	20.390999	1,260
Loc_03	510	510	100.00	-110.39	-1.25	45.379156	20.399343	1,938
Loc_05	527	455	86.34	-127.23	-16.23	45.374981	20.415552	3,282
Loc_12	577	530	91.85	-126.20	-15.20	45.391463	20.429713	4,402
Loc_13	558	557	99.82	-119.03	-8.03	45.382182	20.432261	4,486
Loc_14	560	558	99.64	-120.18	-9.18	45.37308	20.438386	5,072
Loc_21	512	271	52.93	-129.76	-18.77	45.390669	20.392298	1,633
Loc_22	512	512	100.00	-124.52	-13.52	45.392665	20.398479	2,159
Loc_23	509	419	82.32	-121.95	-10.95	45.386243	20.400182	2,012
Loc_24	511	509	99.61	-121.71	-10.71	45.38313	20.400116	1,963
Loc_25	515	482	93.59	-116.81	-5.81	45.383218	20.408157	2,591
Loc_26	511	511	100.00	-106.20	0.13	45.381003	20.396207	1,664
Loc_32	519	330	63.58	-128.29	-17.29	45.388763	20.38815	1,246
Loc_33	510	363	71.18	-127.73	-16.73	45.388319	20.395374	1,721
Loc_35	506	272	53.75	-128.31	-17.31	45.387327	20.401455	2,137
Loc_36	508	507	99.80	-124.52	-13.52	45.387327	20.401455	2,137
Loc_37	513	468	91.23	-123.68	-12.68	45.377506	20.393265	1,528

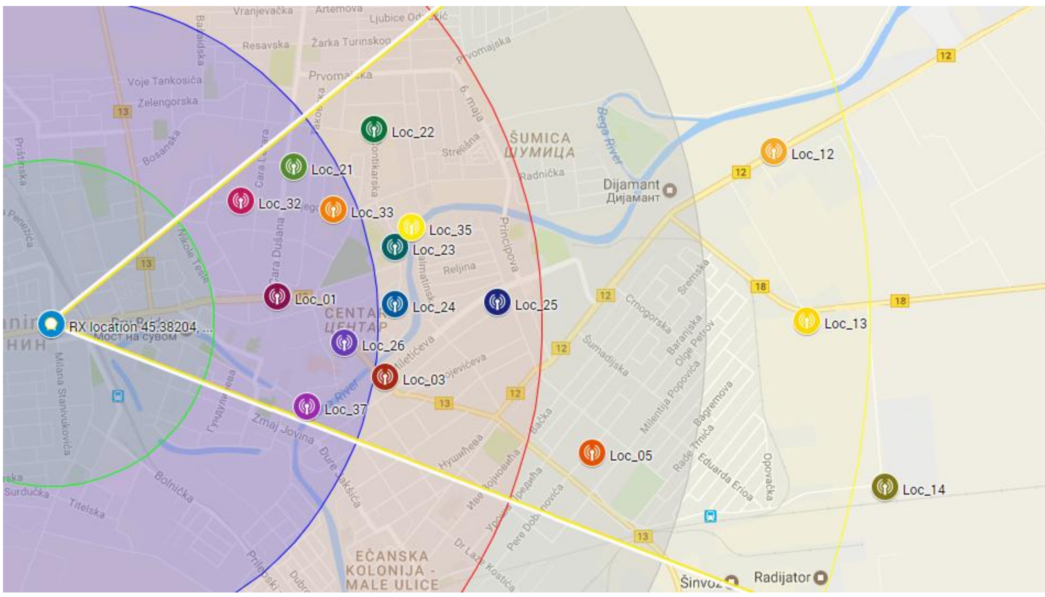

Figure 1: Locations used in LoRa 868MHz measurements (image is made in Google maps)

RESULTS ANALYSES

Calculations needed for propagation loss are made according to the formula for received power calculation. Received power calculation or link budget may be calculated with (23) and it is based on the authors experience in previous research for ZigBee and 868MHz indoor propagation (Dobrilovic, Odadzic, & Stojanov, 2016) and ZigBee and LoRa outdoor propagation. The link budget is a calculation of all the gains and losses for the link that are added in order to arrive at the mean signal level at the receiver, (Anderson, 2003; Dobrilovic et al., 2016).

$$P_{rx}=P_{tx}+G_{tx}-L_{tx}-L_{pl}-L_{m}+G_{rx}-L_{rx} \qquad (23)$$

P_{rx} is received power (dBm). P_{tx} is transmitter output power (dBm) which represents the time-average power of the link transmitter on the transmission channel. The power level is given in dB relative to one milliwatt, dBmW, or dBm; G_{tx} is transmitter antenna gain (dBi) and it depends on the antenna type (mostly its cross section or aperture size) and is obtained from the antenna manufacturer. The antenna type and its gain is one of the link system elements the design engineer can easily change to improve link performance. L_{tx} is transmitter losses (dB) represent losses in transmission line connecting the transmitter as well as the losses in connectors. L_{pl} is propagation loss or path loss (dB) and it is calculated with various propagation models formula. L_m represents miscellaneous losses (fading margin, body loss, polarization mismatch, other losses...) (dB) G_{rx} is receiver antenna gain (dBi) and L_{rx} is receiver losses (coax, connectors...) (dB) are the same as G_{tx} and L_{tx}, but on the receiver side. Effective radiated power (dBmW) or ERP is the sum of the transmitter power and transmit antenna gain minus the transmitter losses, (Anderson, 2003).

In this research with usage of LoRa 868 MHz modules based on SX1272 (Libelium, 2017), and accompanied equipment, the P_{tx} is 18 dBm, G_{tx} is 9 dBi and G_{rx} is 4.5 dBi. The P_{tx} and G_{tx} are cumulative included in formula (4). L_{tx}, L_{rx} and L_m are very low and therefore disbanded. Also, since the calculations will use formula (1) for prediction of signal strength, and since the Gtx, Grx and Ptx are inserted in formulas (2), (4) and (8) the formula for path loss calculation that is used in this research is:

$$P_{rx} = -L_{pl} \qquad (24)$$

where L_{pl} is calculated with (1). The calculated predicted signal strengths are given in Figure 2, for urban areas of Philadelphia, Newark, Tokyo and sub-urban, rural and free space areas. On the same figure measurement results from the experiment for 17 locations are shown as blue circles.

In order to analyze the accuracy of Lee propagation model, and its usability in design, planning and management of wireless network in urban environments, especially for the city of Zrenjanin, the MSE (Mean Square Error) and RMSE (Root Mean Square Error) are calculated (Al Salameh, 2015; Chrysikos, Georgopoulos, Kotsopoulos, & Zevgolis, 2010). The MSE and RMSE are given in Table 4. The minimal MSE and RMSE are for Tokyo variant of formula, with mean 6.71731 dB difference, with next best matches for Philadelphia (15.0949 dB) and Newark (19.5495 dB) and Suburban area (22.5351 dB). This analyses shows that Zrenjanin area and LoRa measurements have best mach with Lee propagation model and Tokyo parameters. The low value of difference between calculated and measured results for Tokyo model variant shows that Lee propagation loss model can be highly applicable in Zrenjanin and similar urban areas for 868 MHz LoRa technology.

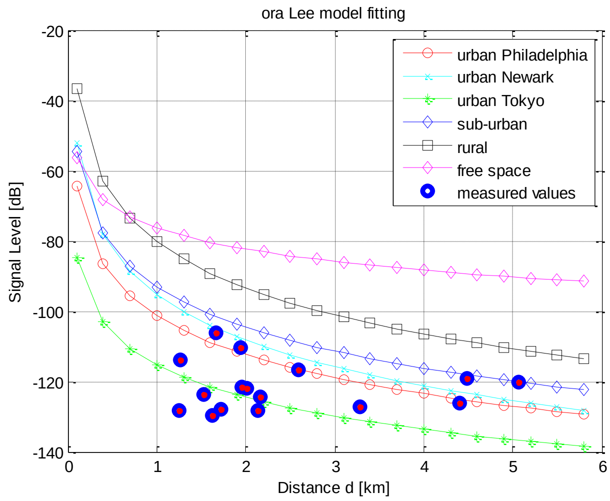

Figure 2: Comparison of Lee propagation model and LoRa 868MHz measured results

Table 4: Comparison of Lee propagation model fitting for different environments and measured results

Area	MSE (dBm)	RSME(dBm)
Philadelphia	227.858	15.0949
Newark	382.181	19.5495
Tokyo	45.1222	6.71731
Suburban	507.833	22.5351
Rural	1,153.43	33.9622
Free Space	1,778.43	42.1714

CONSLUSION AND FURTHER WORK

After the experiment and experiment result analyses as it was described in previous chapters, the applicability of Lee propagation model is proven to be efficient enough for design, planning and management of wireless networks based on LoRa technology in urban areas. The minimal RMSE is calculated for Tokyo model variant, with mean 6.71731 dB difference, with next best match for Philadelphia (15.0949 dB) and Newark (19.5495 dB). Those analyses show that Lee propagation model is accurate enough and that results can be used as a strong base for further research. Further research should be pointed towards a comparison of more measurement results with the Lee model, the comparison of Lee model accuracy with other propagation loss models and finally in the direction of tuning and optimization of Lee model with finding L_0 and γ values for Zrenjanin.

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ANALIZA I OPTIMIZACIJA LEE MODELA PROPAGACIJE ZA POSTAVLJANJE LORA 868 MHZ MREŽE U GRADSKOM PODRUČJU

U skorijem periodu, brza ekspanzija IKT i ubrzano pojavljivanje novih tehnologija su povećale važnost brzog i tačnog planiranja i razvoja tehnologija u nastajanju, posebno onih bežičnih. U ovom radu je izvršena analiza moguće upotrebe Lee modela propagacije za planiranje, dizajn i upravljanje mrežama baziranim na LoRa 868 MHz tehnologiji. LoRa je bežična tehnologija koja se može postaviti u različitim okruženjima Interneta stvari (Internet of Things) i Smart City scenarijima u gradskim područjima. Analize su bazirane na poređenju merenja na terenu sa proračunima dobijenim modelom. Pored analize upotrebljivosti Lee modela propagacije, razmatrana je i moguća optimizacija. Rezultati istraživanja se mogu iskoristiti za tačan dizajn, planiranje i za pripremu za upravljanje bežičnim resursima visokih performansi različitih aplikacija za Internet stvari i pametne gradove (Smart City) u gradskim područjima koje su bazirane na LoRa ili sličnoj bežičnoj tehnologiji. Oprema koja je korišćena za ovaj eksperiment je bazirana na open-source hardveru.

Ključne reči: Radio propagacija na otvorenom prostoru, Gubitak usled prostiranja, Lee model propagacije, LoRa tehnologija, Open-source hardver, Pametni gradovi.