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Development of an Empirical Path-Loss Model for Street-Light Telemetry at 868 and 915 MHz

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Abstract—**This paper presents an initial empirical path-loss propagation model for communication links operating at street-light/roof-top heights over the ranges of 100 m to 10 km in urban and suburban environments. The statistical path-loss model presented uses data taken from a significant number of deployed street-light telemetry systems transmitting in the licence-exempt/ISM bands at 868 and 915 MHz. This propagation model provides a valuable tool for network planning where typical cellular propagation models might not be appropriate.**

Keywords - empirical model, path loss, propagation, street light, telemetry, UHF, 868 MHz, 915 MHz, ISM, licence-exempt, urban, suburban

I. INTRODUCTION

Telensa Ltd. operate a network of street-light telemetry systems for a variety of customers (e.g. local and county councils) for control and monitoring of street lights. This capability is becoming desirable for energy efficiency and for service maintenance; for example, to switch off unnecessary lighting and/or to identify failing lights.

The telemetry systems transmit at low power in the European licence-exempt band at 868 MHz or the North American 915 MHz ISM band using Ultra-Narrow Band (UNB™) technology developed by Plextek. Ranges in excess of 10 km are achieved depending on local terrain and clutter.

Numerous path-loss models have been developed by others for link-budget calculations. However, these are predominantly suited to cellular-type applications where the link is between a high base station and low mobile station in urban, suburban or rural environments (e.g. Hata [1], COST 231 Walfisch-Ikegami [2]) or to broadcast and microwave links where both transmit and receive antennas are elevated from nearby obstructions (e.g. Irregular Terrain Model [3]). None of these propagation models optimally represent the UNB system where both ends of a link are typically mounted at heights of 5-8 m, and link obstruction due to housing and vegetation is highly probable.

This paper presents the development of an empirical path-loss model for street-light telemetry and similar applications using measurements obtained directly from a number of deployed systems that operate in the United Kingdom at 868 MHz. Furthermore, the street-light telemetry system exhibits 'mobile' fading characteristics, despite both ends of a link being fixed, because the environment is moving (i.e. nearby vehicles), as observed in the spread of received signal strength indication (RSSI) measurements. Typical fading characteristics are Rician in nature, with significant numbers showing Rayleigh fading.

II. TELEMETRY SYSTEM AND RSSI MEASUREMENTS

A. *Overview of Telemetry System*

The UNB telemetry system operates in either the 868 or 915 MHz (licence-exempt/ISM) bands and consists of high-performance base stations (BS), each supporting up to a few thousand low-cost outstations (OS). The link budgets for the downlink (BS-to-OS) and uplink (OS-to-BS) are comparable; however, the BS has a higher effective isotropic radiated power (EIRP) and transmits a wider bandwidth signal. This analysis uses measurements for the uplink obtained from deployed systems in towns and cities around the UK during September and October 2010.

B. *Telemetry Uplink*

The OS conducted transmit power is ~ +14 dBm and the nominal antenna gain is 0 dBi. The transmit modulation is Gaussian-filtered frequency-shift keying (GFSK) with a bit rate of 62.5 bps. The BS uses an omni-directional collinear antenna with a gain of +8 dBi and has a receive sensitivity of −136 dBm. The total available link budget is about 158 dB. The RSSI for each demodulated uplink message is recorded.

III. DETERMINATION OF EMPIRICAL MODEL PARAMETERS

A. *Path-Loss Calculation*

For each individual uplink, the mean RSSI level is determined; the difference between the mean and median RSSI levels is generally small. The corresponding mean path loss L_P is calculated from:

$$L_P(\mathrm{dB}) = P_{OS}(\mathrm{dBm}) + G_{OS}(\mathrm{dBi}) + G_{BS}(\mathrm{dBi}) - P_{RSSI}(\mathrm{dBm}), \quad (1)$$

where P_{OS} is the OS transmit power, G_{OS} is the OS antenna gain, G_{BS} is the BS antenna gain and P_{RSSI} is the mean RSSI level of the OS at the BS.

B. *Least-Squares Fit to Mean Path-Loss*

On a log-range scale, a straight-line fit to the uplink mean path-loss measurements is made for each BS by using a least-squares approximation. To prevent excess bias of the least-squares approximation, measurements were only considered if the range was greater than 100 m to reduce the effect of position measurement errors and exclude data where alternative propagation models are better suited (e.g. two-ray line-of-sight model). Also, a given uplink was only included if the minimum RSSI exceeded −130 dBm, thereby removing marginal links from the analysis.

The least-squares approximation results in a log-normal shadow-fading model that is given by [4]:

$$PathLoss_{dB} = A + 10\gamma \log_{10}\left(d / d_0\right) + \chi \,, \tag{2}$$

$$A = 20 \log_{10}\left(4\pi d_0 / \lambda\right) , \tag{3}$$

where A is the free-space path loss at range d_0 (the range at which the least-squares approximation intersects the free-space path-loss curve), λ is the operating wavelength, γ is the path-loss exponent, d is the range variable and χ is the fading error. Typically, χ has a log-normal distribution with standard deviation σ_χ.

IV. ANALYSIS RESULTS

A. *Results for Example BS*

Figure 1 shows an example of a measured mean path-loss data set together with its least-squares approximation ($d_0 = 64$ m and $\gamma = 3.44$). The associated fading-error distribution has log-normal characteristics with $\sigma_\chi = 9.0$ dB, as shown in Figure 2. The spread of RSSI measurements for each uplink of this example BS is shown in Figure 3 and provides a measure of the fading characteristics, which are generally Rician, although some uplinks exhibit Rayleigh fading due to multipath propagation.

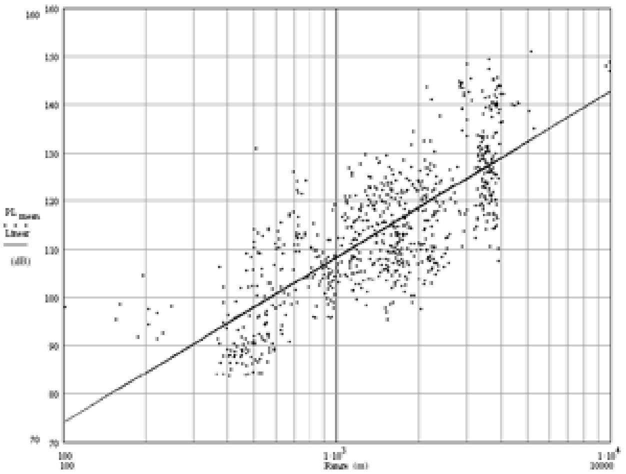

Figure 1. Example BS mean path-loss measurements and linear fit

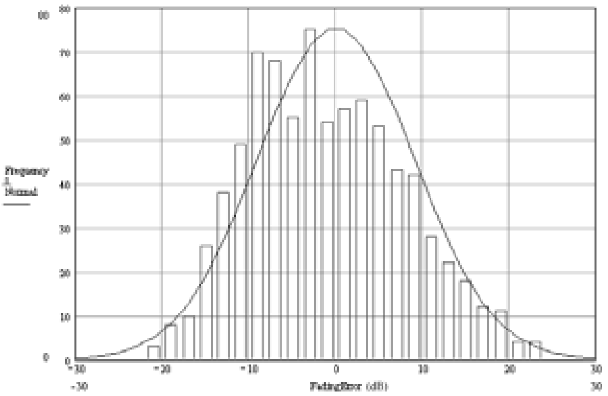

Figure 2. Distribution of measured fading error for example BS

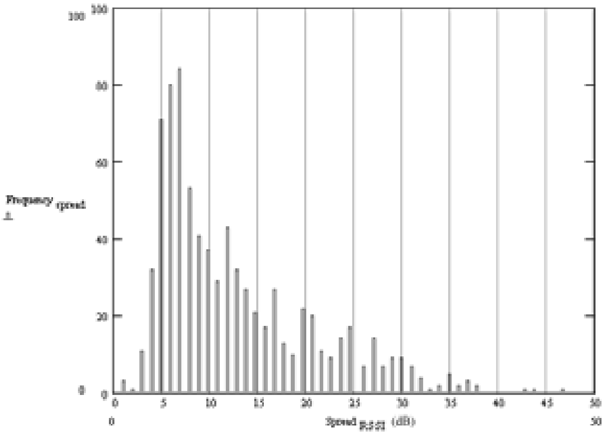

Figure 3. Spread of RSSI measurements for example BS

B. *Results for All BS Analysed*

The least-squares approximation of the mean path loss for 10 BS data sets analysed are shown in Figure 4. For reference, the free-space path loss is shown as a dashed line. The minimum and maximum OS ranges from their respective BS is given by the start and stop range of each linear-fit curve.

Six of the ten data sets have a path-loss exponent in the range of 3.3-4.3 (mean of 3.68), which are values typically observed for cellular-type communications in urban/suburban environments [5]. The associated d_0 vary between 7-104 m (mean 54.9 m). For reference, an empirical model for cellular networks at 1.9 GHz has $d_0 = 100$ m ($A = 78$ dB) [6].

The remaining four data sets show much lower path-loss exponents from 1.68-2.08. Closer inspection of the data indicates that the least-squares approximation is not meaningful because the OS density is too low at certain ranges. Assuming a higher OS density is achieved over all ranges of interest, a path-loss exponent comparable to that of the previous six is expected. The least-squares approximations for most of the data sets have similar path-loss values over link ranges of 1-5 km, which shows consistency amongst the measurements.

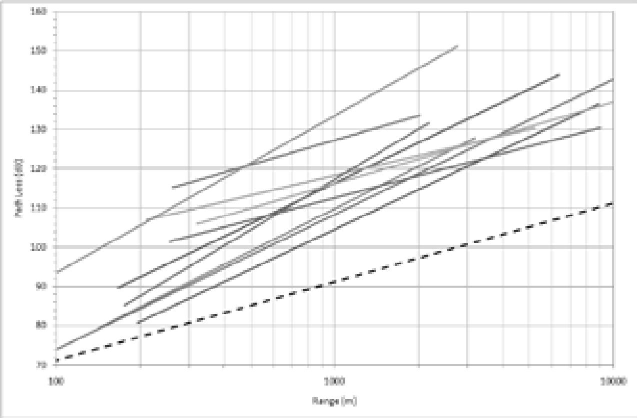

Figure 4. Least-squares approximation of mean path loss for all BS analysed (free-space path loss shown as dashed line)

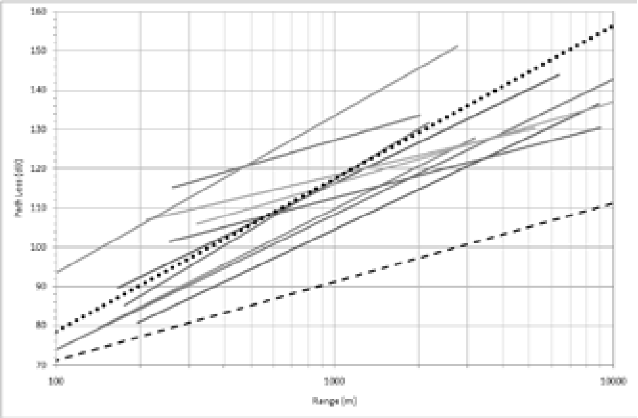

Figure 5. Comparison of Hata model (dotted line) with least-squares approximation of mean path loss for all BS analysed (free-space path loss shown as dashed line)

The fading-error standard deviation for all ten data sets lies between 6-11 dB (mean 7.8 dB) and are comparable to those observed for cellular systems. For example, measurements at 1.9 GHz gave σ_χ in the range of 5-16 dB [6], whereas measurements for broadband wireless systems at 3.5 GHz gave σ_χ in the range of 4-11 dB [7].

Knowledge of the fading-error standard deviation allows a fade margin to be calculated for a given level of availability using, for example, combined log-normal and Rayleigh distribution curves [8]. However, any such fade margin is likely to be 'generous' because the majority of street-light telemetry links exhibit Rician-fading characteristics rather than Rayleigh, as seen in Figure 3.

In summary, the mean parameters (on the basis of six data sets) are given by:

$$d_0 = 54.9 \text{ m}, \gamma = 3.68, \sigma_\chi = 7.8 \text{ dB}$$

C. *Additional UNB Telemetry Data Sets*

Additional street-light telemetry data sets are available. However, the spread of BS-OS ranges is small, making any least-squares approximation pointless. Reassuringly, the measured mean path-loss values for individual links are consistent with those of the data sets analysed in this paper.

D. *Comparison with Hata Model*

The similarity of the measured street-light model parameters with those of typical cellular propagation models warrants further comparison. The Hata model (or Hata-Okumura model because it is derived from measurements by Okumura) is considered because of its popularity and because it covers the frequencies of interest. It is noted that the Hata model is intended for links > 1 km and for base station effective antenna heights of 30-200 m. Used for street-light telemetry, the Hata-model input parameters are out of bounds. However, a comparison for base and mobile antenna heights of 8 m is shown in Figure 5 (Hata model shown as dotted line). This indicates that the Hata model, with some refinement, might be useful for propagation planning of street-light telemetry systems, subject to further investigations.

V. FURTHER WORK

The empirical path-loss model presented here can be refined as more data sets become available for analysis, which would further improve the statistical relevance. Height and clutter parameters can also be incorporated into the model.

Additionally, repeat analysis over the course of a year would provide insight into seasonal variations owing to foliage growth. In particular, it might be possible to determine foliage attenuation characteristics.

VI. SUMMARY

The development of an empirical path-loss model for street-light telemetry systems operating at 868 and 915 MHz has been presented. The analysis is based on RSSI measurements obtained from deployed systems that operate at 868 MHz in the United Kingdom. Extension to 915 MHz is considered valid because of the relatively small frequency offset.

This model is appropriate for communications links where both ends of a link are typically mounted at heights of 5-8 m, and link obstruction due to housing and vegetation is highly probable. Typical cellular models require the base station antenna height to be clear of local clutter and, therefore, do not optimally represent the street-light telemetry system.

Although both ends of a link are fixed, analysis of the RSSI measurements show that the street-light telemetry systems exhibit mobile fading characteristics due to the environment moving (i.e. nearby vehicles). Fading is typically Rician in nature, although some links show Rayleigh-fading spreads.

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