

Estimating Radio Coverage for New Mobile Wireless Services Data Collection and Pre-processing

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ABSTRACT

New mobile wireless services (digital broadcasting, 3G, etc) stress the importance of small (pico/micro) cell urban prediction models along with tighter requirements for coverage analysis. For any route within the market, service providers must guarantee the coverage and locate the service fades. Intensive drive testing and data processing are required for checking the design and tuning the prediction tools. The paper, describes a method for field strength data collection and statistical processing for accurate coverage estimation and descriptions of routes in terms of received RF power.

I. INTRODUCTION

Despite the evolution of wireless standards from narrow band to wideband systems, service coverage is still based on continuous wave (CW) measurements. For wideband communication systems, adequate field strength does not guarantee the performance of communication links. For instance, if the receiver is not capable of retrieving the energy from the multipath components, only a fraction of the CW received power will represent the useful signal power. Knowledge of the multipath statistics (number of paths and probability density functions) helps to bring the coverage analysis back to CW measurement after including adequate short term fading margins.

In a mobile environment, the received signal (envelope or power) shows three components:

- Distance dependence
- Shadow fading (random variation of the short term mean about the distance dependence)
- Fast fading (random variation of the instantaneous power about the short term mean)

The fast fading is due to the multipath structure of the channel. A complex stationary process $\mathbf{z}(\mathbf{t})$ [1], [2] is used for modeling the received envelope when a CW signal is transmitted. According to the propagation scenario, the received envelope $\mathbf{z}(\mathbf{t})$ may be described by probability density functions such as Rayleigh, Rice, Nakagami, Suzuki, lognormal or Weibull. We will assume in the following a Rayleigh channel, with a Gamma distribution for the instantaneous received power $\mathbf{w} = |\mathbf{z}|^2/2$

$$f_w(w) = \alpha \cdot e^{-\alpha \cdot w} \quad (1)$$

The average received power α changes from location to location as a function of the distance to the transmitter (Tx) and shadow fading. Non-correlated samples are 0.38 wavelengths apart [1] for the Rayleigh channel scenario. The maximum likelihood estimator for α is given by (2), where $(w_k)_{1..n}$ are independent samples.

$$\hat{\alpha} = \frac{1}{n} \sum_{k=1}^n w_k \quad (2)$$

For a given confidence level p (3) and confidence interval $[C_1 \hat{\alpha}, C_2 \hat{\alpha}]$, larger sample sizes are required when w_k are provided by a logarithmic receiver [2].

$$p = \text{Prob}\{C_1 \cdot \hat{\alpha} \leq \alpha \leq C_2 \cdot \hat{\alpha}\} \quad (3)$$

The confidence interval in dB units $20 \cdot \log_{10}(C_2 / C_1)$ as a function of the sample size is shown in Figure 1.

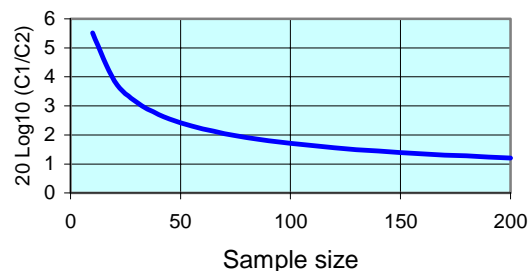


Figure 1 Confidence interval as a function of sample size

A. Distance dependence

Field strength prediction in cellular systems is currently based on Okumura-Hata empirical models, with adjusted path-loss exponents and supplementary, environment related, correction factors.

$$P_r = P_0 \cdot \left(\frac{R_0}{R}\right)^\gamma \cdot \kappa \quad ; R \geq R_0 \quad (4)$$

where P_0 – the power received at distance R_0 from the transmitter, γ – the *propagation exponent*, R – Tx-Rx distance in the 1-20 km range, κ – the correction factors to include Tx and Rx antenna height, environment, frequency, etc.

Driven by the importance of prediction models for urban pico/micro cells along with tighter requirements for coverage analysis, extensive research [3] has been conducted for finding the validity domain for diverse prediction models. It has been shown that Okumura based models can't be extended below 1 km in order to perform cell planning in metropolitan environments. 2D-raytracing and "over the roof-top" propagation models are going to become standard prediction tools for such environments. Thus, prediction results will show morphology dependence at least as important as distance dependence.

B. Shadow fading

When the fast fading (shown by the instantaneous power samples) is smoothed by averaging over a number of wavelengths n_λ , the resultant, which is called *local mean* (LM), shows a variation over a scale length on the order of 10 m. Variation of the LM from the distance dependent prediction as the mobile receiver (subscriber)

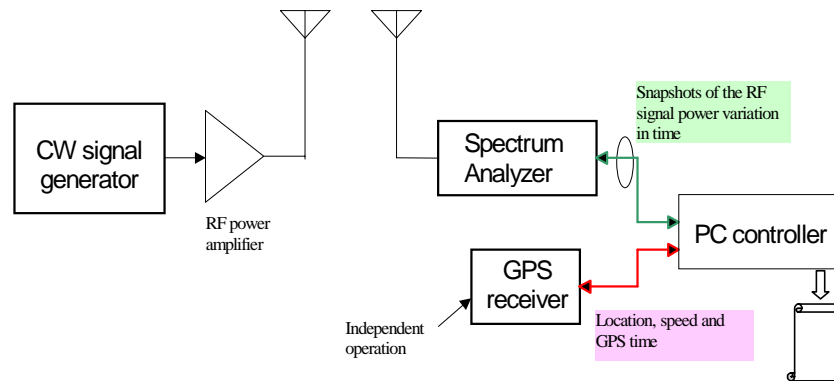


Figure 2 Equipment setup for received signal strength measurements

moves is known as *slow fading* or *shadow fading* since the scale over which it takes place is on the order of buildings' size.

For the selected channel model (1), the average received power α stands for the local mean. The sample size n_λ selection for LM-estimation is a tradeoff between accuracy (confidence interval) of the estimator and avoidance of residual terrain dependence. The average distance for LM calculation does not have to be very large such that terrain may stay out of the equation while, a small averaging distance would increase the LM estimation error. In the same time, samples considered in the averaging process must be independent. Parsons [5] recommends an averaging distance less than 40m for the VHF range and less than 25m for the UHF range.

II. THE MEASUREMENT SETUP

Two approaches are available for field strength data collection: space sampling and time sampling. The first technique provides field strength samples uniformly distributed in space, with the expense of extra hardware (the fifth wheel). The second technique acquires field

strength samples equally spaced in time, the number of samples for the same distance being a function of the receiver speed. The time sampling method does not require extra hardware and may be used for deriving statistics (probability density function, Average Duration of Fades and Level Crossing Rate) of the received envelope.

The proposed field strength measurement setup (Figure 2) uses the time sampling technique. It uses available RF equipment, is very simple to install and may operate on any frequency band. An RF signal generator, power amplifier and omni antenna are used at the transmitter side. The frequency and power of CW RF-signal on the air is known and does not change in time.

The major functional units at the receiver side are: a spectrum analyzer (SA), GPS receiver and PC-controller. The spectrum analyzer is operated in *triggered zero-span mode*. It records snapshots (traces) of time-variations of the received RF signal (Figure 3). The start time of every

trace is controlled by the PC and corresponds to the moment when the trigger command has been issued.

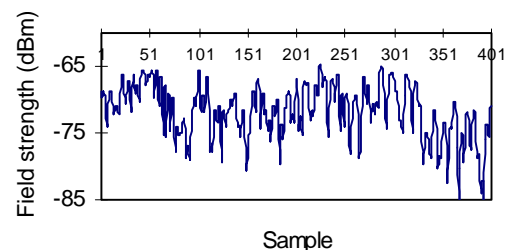


Figure 3 Trace record showing 401 samples of the instantaneous received power

The PC-controller, besides triggering the spectrum analyzer, reads GPS-data and SA-traces, attaches PC-time stamps and saves the results in a log-file (SGD-file). Basically the log-file contains two kinds of records: PV-records originating from the GPS-receiver and TR-records originating from the spectrum analyzer. The time stamp for the PV-records gives the PC-time when the data is saved while for the TR-records gives the PC-time when the controller issued the trigger command. Thus,

the sequence of records in the log-file does not follow the actual time sequence of events.

The coverage analysis and propagation parameter estimation involves two (non real time) stages: pre-processing and statistical analysis. Pre-processing creates a description of the route in terms of field strength. Each route is associated with a collection of *local means* (LM) and attached geo-location (longitude, latitude) information. Local means are derived from TR-records while geo-locations are calculated from PV-records.

Post processing uses the field strength description of the route for deriving information like: path loss exponent (meaningful only for quasi-flat terrain), standard deviation of the shadowing (σ_{LN}), coverage percentage per route (R_{cp}) and number and length of service fades.

III. PRE-PROCESSING

Pre-processing involves the following steps:

- Time smoothing and reconstruction of the time sequence of events
- Speed adaptive LM calculation
- Association of geo-location to LM with speed-adaptive interpolation

C. Time smoothing

Each GPS-record in the log-file has 2 time-fields: the PTime and the GPStime. The first one gives the time reported by the PC when the PV-record is written to the log-file. The second one (GPStime) is the time reported by the GPS-system, usually the moment when geo-location is refreshed inside GPS units. Due to the independent geo-location refreshing process inside the GPS-receiver, there is a random delay from the moment when the GPS-unit updates the geo-location information and the moment when this data is saved in the SGD-file (Figure 4). Using the crude PC-time of PV-records for calculating geo-location associated to the local means would develop large distortions in the filed strength image of the route. The time smoothing algorithm filters out the randomness by adjusting PTime according to the GPStime.

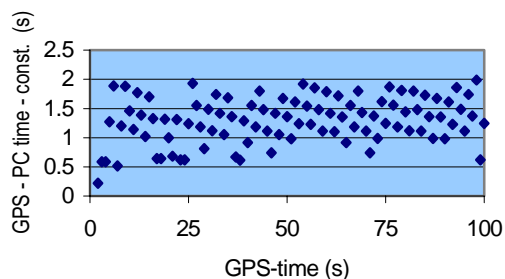


Figure 4 Randomness of the PC time for GPS data

The least-squares regression line (5) is fitted to the set of data $Y=\{PTime\}$ on $X=\{GPStime\}$, where $\{A\}$ denotes the set of data in all A -fields of the PV-records in the given log-file, $y_{ck} = Y_k - \bar{Y}$, $x_{ck} = X_k - \bar{X}$.

$$y - \bar{Y} = \left(\frac{\sum_k x_{ck} y_{ck}}{\sum_k (x_{ck})^2} \right) \cdot (x - \bar{X}) \quad (5)$$

Based on slope m and zero intercept n given by the curve fitting algorithm, PTime is updated to $PTime^*$ according to the equation (6).

$$PTime^* = m \times GPStime + n \quad (6)$$

Figure 5 shows PTime versus GPStime in a cartesian-coordinated system together with the regression line fitted to the data.

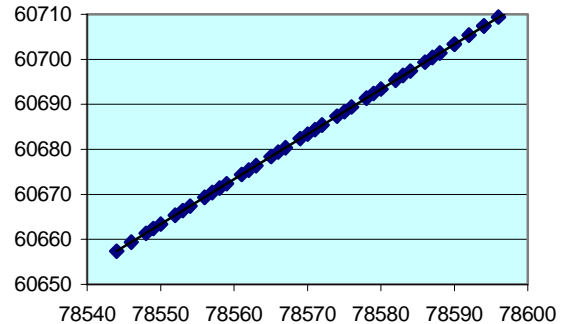


Figure 5 Straight-line fitting of $\{PTime\}$ over $\{GPStime\}$

Once the PTime fields in the PV-records are modified by the time smoothing process, all PV- and TR-records in the SGD-file are sorted in ascending order. Thus, records' order will reproduce better the time sequence of the events, helping to reduce the geo-location distortions.

D. Speed adaptive LM calculation

Based on the receiver velocity, traces are converted to one or more LM (Figure 6). Local means are calculated by averaging signal strength samples within appropriately selected distance-windows (Figure 7).

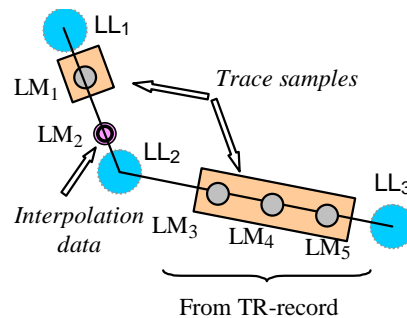


Figure 6 Example of deriving LM. LL_k are lat-long data from PV-records.

The averaging windows are fixed relative to the trace duration but never larger than 10m. This selection is in accordance with [6] where local mean are reported to show variations over a scale length on the order of tens of a meter.

According to the receiver velocity, this procedure adaptively changes the number of local means derived from each trace while keeping the LM estimator

confidence level below 2 dB. Trace samples are divided in subsets and a local mean is calculated for each subset. For the measurement setup used, each TR-record has 401 samples of instantaneous received power. The default trace duration is 1 second.

If the mobile velocity during the trace under processing is larger than a given threshold, local means derived from the current and previous traces are used to interpolate a new local mean at half the time between the current and previous traces. This adaptive interpolation

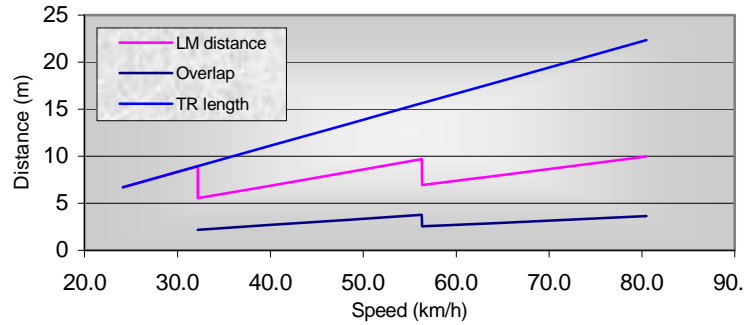


Figure 7 Speed adaptive LM calculation

Thus, for each trace, the output of the speed adaptive LM-calculation algorithm is a set of vectors (τ_k, LM_k) , where τ_k is the time of the k -th local mean LM_k . τ_k are derived from the trace start time, trace duration and local mean index (Figure 8).

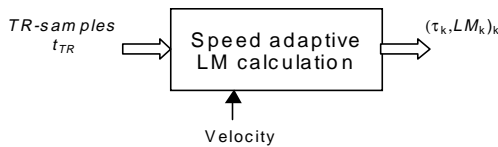


Figure 8 Speed adaptive LM calculation algorithm; t_{TR} - trace start time, LM_k - k -th local mean, τ_k - time for LM_k ,

E. Association of geo-location to LM with speed-adaptive interpolation

Once local means are derived from traces, they are geo-located. At this stage, the two PV-records flanking the current trace are used for computing the geo-location of the local means derived from it. The absolute value of the time difference between each PV-record, left or right, and the trace center must be smaller than a given time limit for performing the adaptive interpolation.

Assuming a quasi-constant receiver speed between adjacent PV-records and using linear interpolation, the geo-location for LM_k are given by (7) where, Lg_1, Lt_1, t_1 will denote the longitude, latitude and GPS-system time for the PV-record just before the current trace, while Lg_2, Lt_2, t_2 will belong to the PV-record just after the current trace.

$$Lg(\tau_k) = \frac{Lg_2 - Lg_1}{t_2 - t_1} (\tau_k - t_1) + Lg_1$$

$$Lt(\tau_k) = \frac{Lt_2 - Lt_1}{t_2 - t_1} (\tau_k - t_1) + Lt_1$$
(7)

is meant to provide LM data when traces are fairly spaced apart in time from each other.

All adjacent data records having identical geo-location or showing a low speed are averaged into a single record. Thus, all data records while the receiver is stationary are reduced to a single record.

F. Interference rejection

In the zero-span mode, the spectrum analyzer collects data on the so-called marker frequency (MkF). The collection software continuously updates the marker frequency as the frequency of the strongest signal that shows in the normal span mode. This way, possible large offsets between the transmitter and receiver frequency are eliminated. Obviously, if interference is more powerful than the test signal, the marker frequency will become the frequency of the strongest interfering signal. In such cases traces will be collected from interfering signal not from the test signal. The pre-processing algorithm continuously checks MkF and deletes all records acquired on frequencies different from that of the test frequency.

Table 1 gives a log-file excerpt after time smoothing and sorting. The second field of all records is reserved to the PC-time stamp. Starting from the third field, TR-records show only field strength (FS) samples. At this point of pre-processing, there are no geo-location information associated to the TR-records.

Using speed adaptive calculation and geo-location association pre-processing creates Table 2. Local means (LM column) are calculated from TR-records and associated to geo-location information derived from PV-records. All records showing ones in the "Intp"-field are derived by interpolation.

Table 1 SGD-file records. PV- and TR-records are not associated

	PC-time	Lat. /FS	Long. /FS	Velocity /FS	GPS time /FS
PV	60449.56	40.77072	-74.0281	38	78337
TR	60450.39	-115.93	-113.87	-114.88	-115.02
PV	60451.56	40.77087	-74.0285	40	78339
TR	60451.71	-108.67	-110.51	-112.48	-115.34
TR	60452.53	-111.2	-114.44	-118.42	-115.87
PV	60453.56	40.77102	-74.0288	39	78341

Table 2 LM and geo-location information

Long	Lat	LM	Src.	v (mph)	Intp
-74.0283	40.77081	-113.8	6	39.14	0
-74.0284	40.77084	-113.06	6	39.52	0
-74.0285	40.77087	-111.58	6	39.65	1
-74.0286	40.7709	-110.78	6	39.77	0
-74.0286	40.77094	-111.6	6	39.58	0
-74.0287	40.77097	-112.66	6	39.36	0
-74.0288	40.771	-112.76	6	39.17	0

The distance resolution improvement obtained from the speed adaptive calculation and interpolation is better emphasized using a MapInfo plot (Figure 9). Stars represent geo-location information from PV-records in the log-file. Polygons show the geo-locations calculated for LMs.

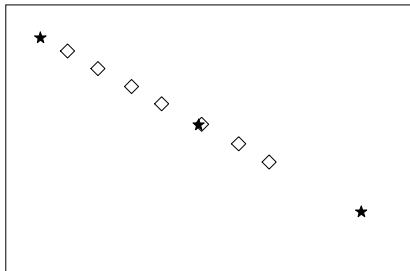


Figure 9 MapInfo plot of geo-location from PV-records (stars) and LM after speed adaptive calculation and interpolation (polygons)

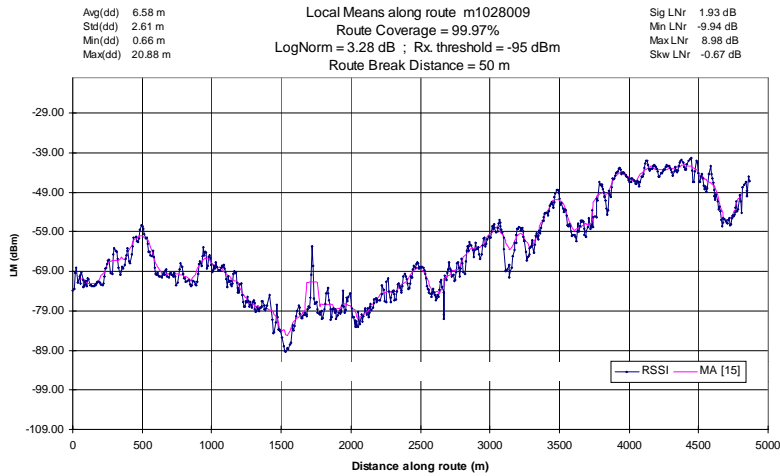
Each TR-record (Table 1) generates 2 local means (LM in adjacent rows of Table 2 having a 0 in the “Intp” column). The seventh point (the polygon that overlays the second stars) is provided by interpolation. The reduced average distance between LMs clearly illustrates

the resolution improvement in the route description given by the described method.

An example of LM along route plot is given in Figure 10. One may see how the data pre-processing highlights spikes or notches of the local mean RF power along the route. The resolution is better than 10 m. In the example, the average distance between local means is 6.58m. This is far less than the size of any major obstruction along routes that may cause quality degradation of the wireless service.

IV. CONCLUSIONS

A simple and powerful RF field strength data collection and processing is introduced. It gives the resolution and accuracy in field strength route descriptions as required by the new mobile wireless services, where small urban cells are the main concern. Tuning ray-tracing prediction tools and locating service fades demand field strength data with resolution better than 10 m. The proposed measurement setup also allows derivation of received envelope statistics like probability density functions, average duration of fades and level crossing rates.



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figure 10 Route description in terms of local means. (Dots represent local means. The smooth line shows terrain contribution only.)

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