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Empiric Characteristics of Fading Mobile Communications Channels

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Introduction

Mobile Station (MS) positioning is generally regarded to be the next big advance in mobile communications, a driver behind new application of mobile communications into our everyday lives. Rapid deployment of MS positioning, however, is held back by the lack of universally available, non-proprietary technical solution that would enable cost efficient mobile positioning along with good enough accuracy required for commercial applications. Technologies available today provide either inaccurate location at low cost (e.g. Cell ID based solutions), or high location accuracy at very high up-front investments (Angle of Arrival or Time Delay based systems) thus prohibiting deployment and adoption of location services by mass-market which has been main driver behind development of mobile communications lately.

In our previous work [1,2,3,4] we have proposed a method to improve accuracy of Cell ID based positioning systems, the least costly solution available in the market. Our research shows that proposed method improves accuracy of Cell ID based location system 2-3 times and can decrease the positioning error down to 100-150 m in typical urban environment [3]. Such positioning accuracy can already satisfy the requirements of most commercial applications at a very minor cost compared to other methods available as it does not require any modifications in customer terminals, network infrastructure equipment or software. Method is based on performing repetitive measurements and post-processing them off-network to obtain more accurate location by correlating knowledge of network configuration with results of multiple measurements. It uses fact that there is always fading present on mobile communications channels that will affect results of measurements. If MS is positioned in area where there are signals available from more then 1 Base Station (BS), likelihood of MS being attached to each BS can be expressed as exact probability given we know network configuration and radio propagation characteristics in given location.

As the method and improvements of accuracy provided by it heavily depend on fading characteristics of mobile communications channels it is very important that we use as accurate as possible information on fading properties of channels.

There are many available works that very accurately describe mobile communication channel fading characteristics in different environments. There is, however, a big problem with application of these theories in practical mobile positioning, as all of these theories assume exact knowledge of environment, accurate positions of transmitter and receiver as well as locations and properties of all obstacles between them. Of course, we cannot have all this information available on macro level. This is also a major drawback of so called “Finger-printing” location technologies based on the fact that radio propagation characteristics between any 2 points in space always have unique characteristics. Consequently, if you have measured propagation characteristics once for all possible locations, you will be able to recognize them as soon as transmission occurs from given point in future. This location method s very well described in [5]. Such approach works fine in micro-environments (such as office, warehouse) as proved by many studies, however it will not function well in macro-environments because:

- It is virtually impossible to collect required information from all possible locations;
- Even if all information was collected, there would be so much of it that storage and processing would pose a significant challenge;
- Propagation characteristics in macro-environment change constantly due to changing environment (such as car passing buy, window being opened or closed).

In our theoretical simulations we have used averaged fading characteristics – 6-12 dB with lognormal distribution, suggested by reputable sources [6,7,8] across all the area simulated.

However as it is of utmost importance for the accuracy of proposed method to know as precise as possible fading characteristics of channel in a given location, we have performed an empirical study of channel characteristics to obtain following information and it’s effects on accuracy of location model proposed by us:

- Fading characteristics for different clutters (urban, sub-urban, rural)
- Fading characteristics for line-of-sight (LOS) and no LOS environments
- Distance based fading characteristics, if any

In this paper we present method and results of our study on empiric characteristics of fading mobile communications channels.

Method

We have chosen the most simple and cost effective mobile location system based on Cell ID for our improvement efforts. The cell that the handset is connected to is the location measurement provided by the network and can be obtained at any moment by performing ATI (Any Time Interrogation) – standardized GSM procedure that causes relatively low load to network. Importantly, it is the measurement that is available without any changes to networks or handsets and allows positioning services to be offered today at no or very little extra cost. Once cell that mobile is attached to is known, operators have some knowledge of customer's location, as they know where their cell sites are located. Accuracy of this method depends on density of the cells in given area. Accuracy of predicted coverage and consequently predicted weighted center of cell coverage will be the key factor influencing measurement error.

We propose to improve the accuracy of this system by performing multiple measurements described above.

Taking into account fading, doing several measure-

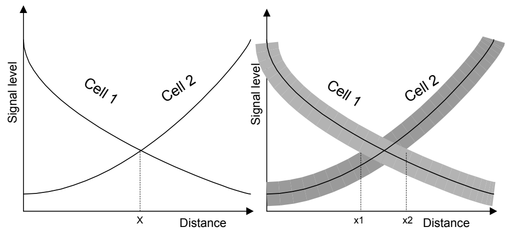

Fig. 1. Effect of fading on cell borders

ments with sufficient intervals can improve accuracy. In case fading is not present (or is static), borders between cells are strictly defined and fixed (Figure 1 – left). As soon as signal level of Cell 2 exceeds signal level of Cell 1, Cell 2 becomes serving cell of mobile in idle mode. If this was always the case, Cell ID based positioning measurement would always result in best server for the location and location error would always be equal to distance between the MS and center of the serving cell. If we take into account fading, that is a natural part of any communications system using radio waves as transmission medium, borders of cells are not strict lines any more, but become areas, where each point that happens to be within area between points x1 and x2 has a certain probability of belonging to one cell or other (Figure 1 – right). Points within the cells closer to their centers will not change cells between measurements because of fading. This is the basic principle behind our proposed method – MS that will not change cell during repeated measurements is likely to be close to the center of measured cell, MS that changes cells between measurements, is likely to be close to the border of cells returned as measurement outcomes. Knowing actual network configuration we can always obtain probability of location belonging to particular cell. Correlating actual probability obtained from repeated measurements with calculated probabilities we should be able to determine actual location of MS. Of course, subject to accuracy of theoretical coverage calculations and number of measurement repetitions we can afford to perform.

However for as accurate as possible positioning it is essential to know precise characteristics of fading channels to be able to determine probability of any location belonging to Cell1 or Cell2.

According to theory, fading in radio interface manifests itself in 3 ways:

a) long-term fading caused by obstacles in signal path (shadowing, diffraction) with period of 10-100 wavelengths with typical variation around the mean of 6-10 dB [7];
b) small-scale fading with rapid signal level changes 20-30dB in small distance < wavelength or time;
c) random frequency modulation due to varying Doppler shifts.

Long-term fading has a log normal distribution around the mean, short term fading has Rayleigh distribution in case there is no direct line of-site signal component, when line-of sight component is dominant, it will have Rician distribution. For practical system planning purposes however it is usually assumed that cumulative fading effect (long-term + short term) has a lognormal distribution that fluctuates around mean signal value. Variation depends on the type of environment.

In our simulations so far, where we were aiming to obtain generic algorithms, we always assumed that fading conditions at any test point are always equal for signals from all cells – buildings or other obstacles are not taken into account. In real life this will not be true, because probability distribution function of fading will greatly depend on availability of line of site to transmitting antenna and other factors. It is the aim of this study to find out if we can find some general empiric characteristics that could be taken into account in the positioning calculation algorithm to further improve it's precision.

For example, Aircom International, the creators of radio planning tool Asset, suggest to use log-normal fading for propagation calculations with following standard distribution as default values [9]:

Table 1. Fading parameters for different environments

Surface type	Std. Dev. (dB)
Open	10.35
Roads	12.71
Semi-Open	11.17
Water	21.67
Urban 4-6 story	13.71
Urban 2-3 story	8.82

In order to obtain sufficient information that would allow us to compare theoretical channel characteristics with actual performance in real network environment we performed a massive measurement campaign in Riga (Latvia) and its' surroundings during early 2004. Measurement campaign consisted of 2 major activities:

1) BS RF output verification - Once the measurement locations and transmitters were defined, it was important to verify that there are no defects in BS equipment or aerial systems that could influence the results of measurements and provide misleading information. All antenna/feeder systems were tested to exclude bad connections or water-seepage using

Wiltron Sitemaster equipment. BS output power was confirmed to be stable within the range of 1dB over long period of time. This ruled out any further suspicions that final results could be driven by faulty or poorly performing equipment on BS side

2) Signal level measurements with MS – we performed signal strength measurements using Rhode Schwarz portable drive test set, where MS was recording in idle mode signal values of all cells in the network it was able to see in particular moment. These are the most meaningful measurements for our project, as they actually determine how would our positioning algorithm perform in a given environment. Of course, MS is not the best measurement tool, but our application would be receiving signal level measurement inputs as measured by mobile.

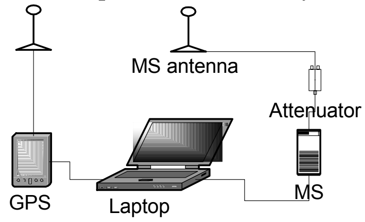

Fig. 2. Rhode Schwarz drive-test set

Actual set used for measurements consists of Laptop used for measurement data recording, GPS with outdoor external antenna (not used for those measurements performed indoors), AEG mobile station tested to have correct and stable performance across whole of the GSM frequency band, external GSM antenna (magnetic car model) and attenuator between MS and antenna. Attenuator is used in this set-up to exclude the gain of external antenna and match performance of this set with performance of handheld mobile. External MS antenna was fixed on the rooftop of the car for outdoor measurements and on top of the test-set for indoor ones (Fig.2).

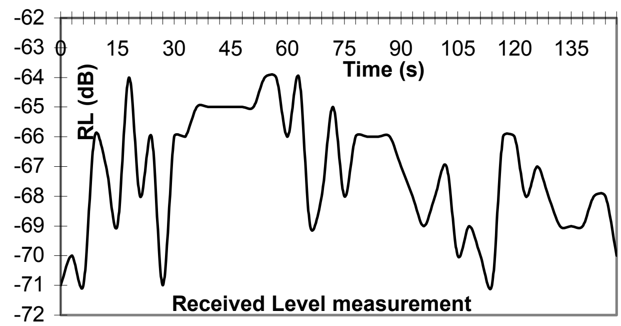

Fig. 3. Results of received level measurement

It was done in order to exclude any body effects on received signal level.

This set was used to record received signal levels in idle mode of serving cell and 6 strongest neighbour cells. Interval of data recording used was 3 seconds, as it is defined as optimum interval for our positioning algorithm [1]. Figure 3 shows typical result of signal level measurement. It must be noted that MS normally measures received level in full dB increments only. Therefore measurements performed by mobile can't fully correspond to theoretical calculations. Some sources also suggest that receiver of MS is affected by number of channels available in any particular area – e.g. more the signals available, less the sensitivity of receiver and bigger measurement delays and errors. Our experiments with comparison of data as recorded by MS and Chase GPR4000 receiver did not confirm this. Measurements of MS did not differ from Chase receiver logs more then 2 dB at a time and it has to be noted that these measurements were not perfectly synchronised, therefore minor difference was acceptable.

This study excludes fading measurements for moving objects and looks only at received signal level measurements for stationery receivers to clearly separate path-loss components from fading components.

Results

As a part of our measurements, we wanted to confirm if lognormal fading distribution used in simulations so far is applicable.

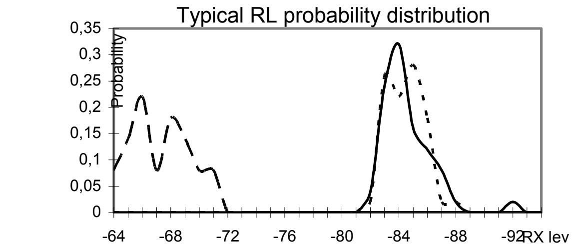

Fig. 4. Typical probability distributions measured

Some the most typical probability distributions are shown in figure 4. From the results of large number of measurements we can conclude that actual distributions are not exactly lognormal, in many cases larger right tail exists resembling Rayleigh distribution. This can be explained by the fact that in most cases fading decreases signal level from the mean. Same time obtained distributions suggests that actual channel characteristics are not significantly different from lognormal distribution; therefore we can still use it in our further simulations successfully. In case significant right side tail is present, it will only improve actual accuracy of our algorithm compared to simulation results.

Other part of our measurement focus was to compare characteristics of fading in different environments such as urban, sub-urban and rural. Our measurements failed to produce any evidence of significantly different fading characteristics in these environments. Only real difference was signal propagation over water, where standard deviation of fading was approximately 2 times bigger then in all other environments.

From our measurements we concluded that there is a clear relationship between received signal level and standard deviation of it (see Figure 5). That is – as lower the RL, the bigger the signal fluctuations.

We failed to produce clear relationship in fading characteristics and availability or lack of Line-Of-Sight (LOS) between transmitter and receiver. Although in case of LOS availability standard deviation of received signal level was slightly smaller, it is hard to distinguish between availability of LOS and just lower signal deviations due to higher received signal level (see above). We believe that both of these facts are closely interlinked – in case LOS is absent, signal level will automatically be lower and hence the influence of multi-path propagation on final results higher.

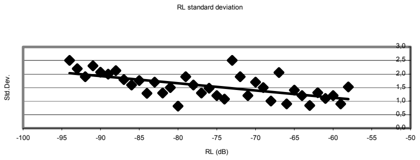

Fig. 5. Standard deviation as function of RL

Main result of our measurements though, is the fact that standard deviation of received signal level in real measurements is significantly smaller (1-3 dB) then one suggested by theory (6-12 dB) [6,7,8]. This may have a detrimental effect on efficiency of our proposed solution for improved location accuracy. Potential reason of smaller signal deviations could be the averaging of received signal level by MS but this needs to be confirmed by further investigation. At the time of measurements averaging parameter in network was set to 8 – RL provided by MS was average result of 8 measurements.

Conclusions and further work

By this measurement session we have obtained credible information that allows us to compare theoretical fading channel performance with actual performance as seen by MS, which is essential for our research.

We have concluded that there is no significant difference in fading characteristics in different environmental clutters, except water, but, instead, fading characteristics of channel are affected by path-loss and consequently propagation characteristics of environment. Finding that standard deviation of received signal level is bigger at lower signal levels, is actually beneficial for our location algorithm, as this means that signal level will fluctuate more towards the edges of cell area and less in the center of cell coverage area. This should lead to higher frequency of serving cell change on the edges of coverage thus increasing corrective characteristics of our algorithm.
Unexpected but important conclusion is that actual fading levels as seen by MS are significantly smaller then those predicted by theoretical calculations. This may be caused by signal averaging, employed in mobiles to fight negative effects of fading. However exact reason of this should still be clarified.

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Nurodoma, kad bazavimo sistema, sukurta indikatorių principu, yra pigiausia, tačiau nelabai tiksli. Siūlomas naujas algoritmas, kurį naudojant tikslumas padidėja tris kartus. Šio būdo ypatybė – tikslios fedingo nustatymo priemonės. Eksperimentiniai tyrimai atlikti Rygoje. Įrodyta, kad 2003-2004 metų tyrimų rezultatai patvirtino pasiūlyto algoritmo pranašumus. Il. 5, bibl. 9 (rusų kalba; santraukos lietuvių, anglų ir rusų k.)

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Cell ID based mobile positioning systems are generally recognised to be the most cost effective means of mobile location. However they provide poor accuracy. We have proposed an algorithm that allows to significantly (2-3 times) improve accuracy of Cell ID based location systems by utilising signal fluctuations caused by fading. To maximise improvement in accuracy provided by the proposed method, it is important that accurate fading characteristics are used. Article describes method and results of empiric fading channel properties measurements performed in Riga, Latvia in early 2004 and it's effects on proposed positioning algorithm. Ill. 5, bibl. 9 (in English; summaries in Lithuanian, English, Russian).

Р. Криевс. Эмпирические характеристики фединга каналов мобильной связи // Электроника и электротехника. – Каунас: Технология, 2004. — № 3(52). –С. 52-55.

Система позиционирования, базирующаяся на использовании идентификаторов сот считается наиболее дешёвым вариантом позиционирования мобильных объектов. Однако данный метод страдает недостаточной точностью. Мы предлагаем алгоритм, позволяющий значительно (в 2-3 раза) повысить точность определения местоположения объекта при помощи анализа идентификаторов сот используя флуктуации сигнала, вызванные фейдингом.

Для максимизации улучшения точности обеспечиваемой данным методом важно использовать точные характеристики фейдинга. В статье описаны методы и результаты практического изучения фейдинга каналов по данным измерений сделанных в Латвии, Риге в начале 2004 года и их эффект применительно к данному алгоритму позиционирования. Ил. 5, библ. 9 (на английском; рефераты на литовском, английском и русском яз.).