

# Spectrum Analyser Monitoring of Wireless Communications Networks

Claudio Narduzzi, Paolo Attilio Pegoraro, Luigi Prigol

*Dipartimento di Ingegneria dell'Informazione, Università di Padova*  
*Via G. Gradenigo, 6/b, I-35131 Padova, Italy - phone: +39 049 8277600 - fax: +39 049 8277699*  
*e-mail: claudio.narduzzi@unipd.it*

**Abstract-** The paper presents an innovative approach to the monitoring of the RF power transmitted by a mobile base station, by means of a spectrum analyser. Results account for the statistical nature of the signals, providing the means to evaluate in a more realistic way the exposition to RF fields.

## I. Introduction

Deployment of the wireless infrastructure for a mobile communication network involves a considerable amount of planning for capacity, coverage and the optimal siting of base stations. The latter may be a particularly controversial issue, as concerns about RF field strength may be voiced by residents in the neighbourhood of a base station site. Regulations referring to ICNIRP guidelines [1], or even more restrictive, are in force in most countries. Their effectiveness relies on the regular monitoring of transmitter emissions for compliance. A monitoring system should be able to perform its task independently of information provided by network operators, should produce a realistic assessment of RF field strength and total exposition levels and, finally, needs to be cheap to set-up and operate.

This paper proposes an innovative approach to monitoring, where a spectrum analyser is employed to collect statistical information on the power output of base station transmitters. Traditionally, monitoring networks are based on low-cost wide-band field strength meters, designed to be permanently installed at a selected number of sites. These have a number of shortcomings, one of the most significant being that identification of network operators on the basis of their assigned channels is hardly possible. A spectrum analyser would be an ideal choice to answer this requirement, but is generally ruled out on the grounds of high cost. However, there may be no need to place an analyser close to each monitored site. In fact, base station positions are known and assigned physical channels can be identified by the analyser through the measurement of their frequencies; therefore a single instrument equipped with a high sensitivity directional antenna could be operated, for monitoring purposes, using a limited number of locations and be moved around as the need arises.

It should be reminded that the power output from a base station transmitter is a statistical quantity that depends on the number and the spatial distribution of users connected to the station, as well as showing clear variation patterns over a daily time scale. The object of this study is to determine which kind of information statistical analysis of spectrum analyser measurements may provide, and to show how they relate to the operating parameters of a mobile system. Results presented in the paper show that a surprisingly detailed picture can be obtained by suitably interpreting measurements. This may result in an accurate assessment of the contribution of a specific transmitter to the total RF field strength at a given location, which is an important requirement from the viewpoint of both operators and environmental protection agencies.

## II. Statistical Spectrum Analyser Measurements

The initial impulse for this work was a study of potential uses of the Complementary Cumulative Distribution Function (CCDF) as an analytical tool for the characterisation of RF transmitting equipment [2]. This kind of measurement is based on the use of a spectrum analyser employed in zero-span mode, or *synchroscope*. In this mode the instrument, instead of performing a swept-frequency measurement, is permanently tuned to a selected frequency band, measuring and displaying power in that band as a function of time. Given a record of measured data, a CCDF curve displays measured values on the horizontal axis and plots the percentage of measurements whose value is larger than the corresponding abscissa. Therefore CCDF measurements by a spectrum analyser provide information on the distribution of power levels in the frequency band of interest.

The method presented in this paper has been developed with GSM systems in mind, assuming that only standard spectrum analyser functions are to be employed. It can be directly adapted to 2.5G mobile network developments, such as GPRS and EDGE. In any 2G and 2.5G mobile network, a base station may cover several cells employing different channels, suitably separated by frequency. If a spectrum analyser connected to a directional antenna is pointed towards a base station transmitter, a normal scanning measurement suffices to identify the physical channel to be monitored. Following this, the monitoring procedure can start.

The power transmitted within a channel can be considered a random process, the main causes for randomness being traffic load variations, user mobility and the adoption of dynamic power control within the system. In other words, by

acquiring a sequence of power measurements during a given time interval, an instrument in zero-span mode allows the observation of a finite portion of the realisation of a random process. Following this approach, it is possible to characterise CCDF measurements with regards to accuracy and obtain basic rules for the choice of acquisition parameters.

### A. Complementary Distribution Function

In a GSM system each physical channel, corresponding to a 200-kHz bandwidth, provides access to eight users, multiplexed by the assignment of a specific time slot within a common frame structure (time-domain multiple access, TDMA). In a GSM channel the signal ideally alternates between power-on and power-off states, the latter corresponding to unused time slots. In practice the presence of noise, interference and the effects of dynamic power control make the situation more varied. Yet, as long as the carrier-to-interference ratio of an active time slot allows for some power margin, the CCDF curve of a GSM signal evidences a plateau associated to the power threshold for active time slots. The corresponding CCDF value measures the probability that the signal power is above that threshold, i.e., that time slots in the channel are “on”, providing a direct indication of the traffic load on the base station. An example is provided in Fig. 1, where the measured CCDF of a GSM physical channel is presented.

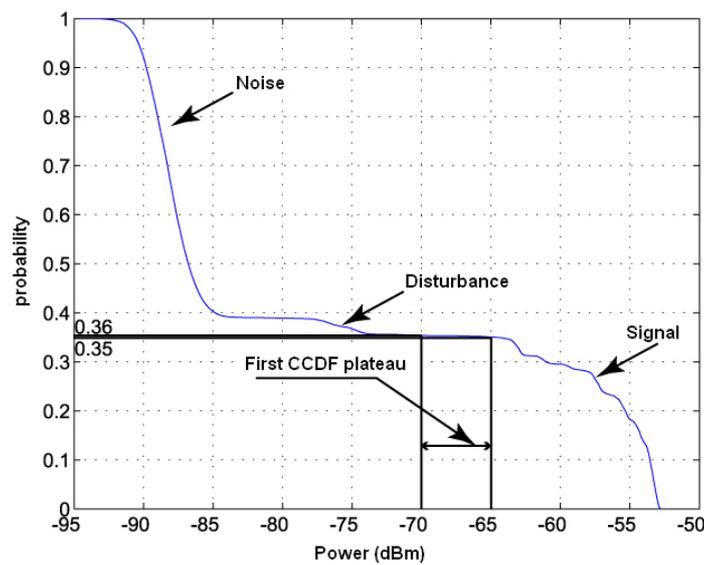


Fig. 1: measured CCDF of a GSM physical channel.

The shape of the curve is typical, being made up of a number of usually well-defined parts. The plot shows that the signal received by the spectrum analyser is above -65 dBm for 35% of the total observation time. This percentage is a measurement of the base station traffic load related to the full channel capacity. The plot also shows that, in this instance, no received signal is stronger than -53dBm at the monitoring point. Taken singly, this information is actually of minor relevance, but can be combined with information about the position of the transmitting antenna, its nominal output power, etc., to assess actual power levels within a cell. Furthermore, it allows computation of power budget wherever the contribution of several sources to the total field strength at a given point must be assessed.

A notable feature of the curve in Fig. 1 is the presence of a number of almost flat tracts, which could not be explained assuming a simple on/off model of the TDMA system. Analysis of experimental data shows that several additional effects need to be taken into account and, for this reason, statistical analysis has to be carried out, more appropriately, by the joint observation of CCDF and probability density function (PDF) curves.

### B. Probability Density Function

While CCDF measurements are well suited to determine traffic load, they are not ideal to evidence effects such as power control, since rather narrow power steps are involved. These can be better analysed if an estimate of the probability density of power, rather than its distribution, is considered. This requires arranging measured data into a histogram of power levels, rather than a CCDF curve. In this way a well defined pattern of power level probabilities is evidenced; to illustrate the point, Fig. 2 shows the PDF curve corresponding to Fig. 1.

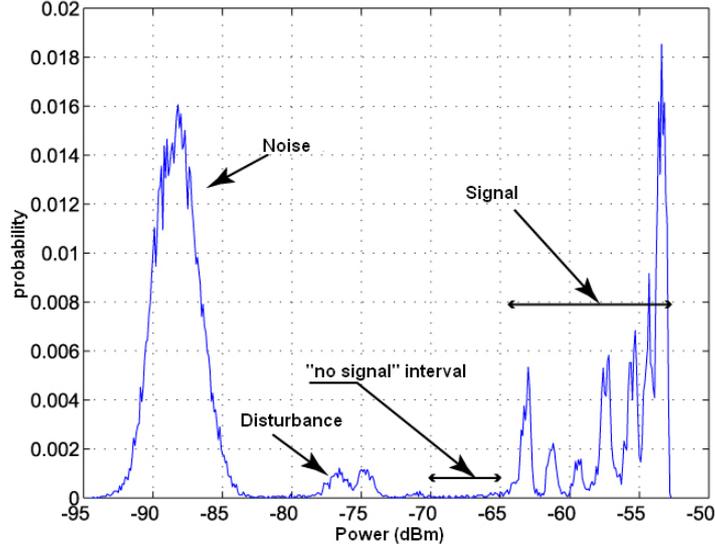


Fig. 2: PDF of the GSM channel, based on the same data of Fig. 1.

This figure readily shows most relevant features of GSM signals. The interval between -53 dBm and -65 dBm is characterised by a number of peaks, each of them separated by about 2 dBm, which mark the power levels adopted by the system for dynamic power control. Their pattern might in turn be related to the coverage provided by the analysed base station, since from its shape some rough idea about the spatial distribution of users within the cell can be inferred. Disturbances should be expected from nearby channels but, according to standards, must fall below the useful signal; in this example they concentrate in the range -70 to -78 dBm, while power levels between -65 and -70 dBm have a very low probability. The latter feature allows the unambiguous identification of a corresponding plateau in the CCDF curve, where traffic load can be read correctly.

It should be noticed that the interval between -78 and -83 dBm is also characterised by a very low probability and corresponds to a second plateau in the CCDF curve. However, the associated probability value includes the contribution to the total power distribution brought by disturbances, which do not contribute to the traffic load at all. As shown in Fig. 1, the difference between the two plateaus may be small, yet only the rightmost value is correct, whereas the second one should not be considered as it overestimates traffic load.

Finally, measurements taken while TDMA channels are off only contribute noise, which is well evidenced by the portion of the PDF curve between -83 and -94 dBm.

These preliminary results show that it is advisable to process measurement data so that both the CCDF and the PDF curves are simultaneously available, as their combined analysis can help measure the load correctly. A point worth noting is that it is preferable to calibrate the abscissae of both curves in terms of absolute power level. When CCDF curves are provided as built-in spectrum analyser functions they are more often presented with regards to relative variation from the average measured level.

### C. CCDF uncertainty analysis

CCDF measurement can be considered as the estimation of the complementary distribution function of power. Being a statistical procedure, it produces useful results only if a sufficiently large number of data have been collected. In general terms, indicating the theoretical distribution function of a random variable by  $F(x)$ , the corresponding empirical distribution function  $F_N(x)$ , obtained from a set of  $N$  samples of the random variable, is defined by the expression:

$$F_N(x) = \frac{1}{N} \sum_{i=1}^N I(x_i \leq x), \quad (1)$$

where  $I(A)$  is the indicator function of the event  $A$  and  $x_i$  is a sample in the set. CCDF is simply  $1 - F_N(x)$ , therefore all the results given below for  $F_N(x)$  also hold for CCDF.

Analysis of the statistical properties of  $F_N(x)$  shows that it is an unbiased estimator and converges in probability to  $F(x)$  as  $N$  grows to infinity; its variance is given by the expression:

$$\text{var}[F_N(x)] = \frac{F(x) \cdot [1 - F(x)]}{N} \quad (2)$$

More importantly, for large (but finite) values of  $N$  and assuming that  $F(x)$  is continuous, bounds on uncertainty can be derived, based on theorems due to Kolmogorov and Smirnov (see, e.g., [3] and [4]). Specifically, the uncertainty  $U_F$  on

the estimate of  $F(x)$  is given, with a level of confidence  $(1-\alpha)$ , by:

$$U_F = \frac{\lambda_\alpha}{\sqrt{N}}, \quad (3)$$

where  $\lambda_\alpha = 1.3581$  for  $\alpha = 0.05$ . The same expression obviously holds for the CCDF.

Expression (3) suggests that large data records would be preferable to obtain good estimates. On the other hand, ergodicity of the random process needs to be assumed, since CCDF is obtained by actually measuring a time series. Therefore, while a sufficiently large statistical sample must be collected, it must also be ensured that the analysed signal retains the properties of a stationary (hence, ergodic) random process during the observation time, thus placing an upper bound on the size of the data record. In addition, acquisition time must be short enough to avoid that daily trends and other variations characterised by longer time scales are averaged out. For these reasons, the monitoring instrument must be equipped with a reasonably fast sampler and a suitably large trace memory. These features are usually found in modern spectrum analysers, which can produce fairly large data records in a comparatively short time. With instruments having a smaller trace size, construction of the CCDF curve from a set of traces may be considered.

In detail, it has been found experimentally that a good tradeoff is represented by the acquisition of  $N_T = 20$  samples per time-slot; given that the length of a GSM time slot is about  $577 \mu\text{s}$ , this corresponds to a "video" sampling rate of no more than 35 kHz, which is achievable by most spectrum analysers. This, together with the size of the spectrum analyser trace, determines in turn the total acquisition time (which corresponds to the sweep time setting, although there is no sweep in zero-span mode). Trace size may vary from a few hundred to thousands of points; applying (3), it follows that, for  $N = 2000$ ,  $U_F = 0.03$  with a level of confidence of 95%. For the purposes of this work, this degree of uncertainty was considered acceptable and results in a sweep time of just about 60 ms.

### III. Experimental results

Experimental validation of the proposed approach was made by measuring GSM systems, which are of course readily at hand. The approach discussed in the previous section was developed into a specific LABVIEW virtual instrument, which has been tailored to measurements on mobile base stations. Data processing requirements for statistical analysis are limited and the acquisition procedure can be implemented with any kind of spectrum analyser, provided the final record of samples is large enough. Implementation details will not be discussed in this paper, as the most significant aspects have already been dealt with in [5].

An example of results is shown in Fig. 3, where a GSM channel at 937.6 MHz has been measured. The CCDF plot shows a channel traffic load of 59% (with a calculated uncertainty of  $\pm 3\%$ ), while the PDF plot evidences that about 12 different power levels are employed by the base station for dynamic power control.

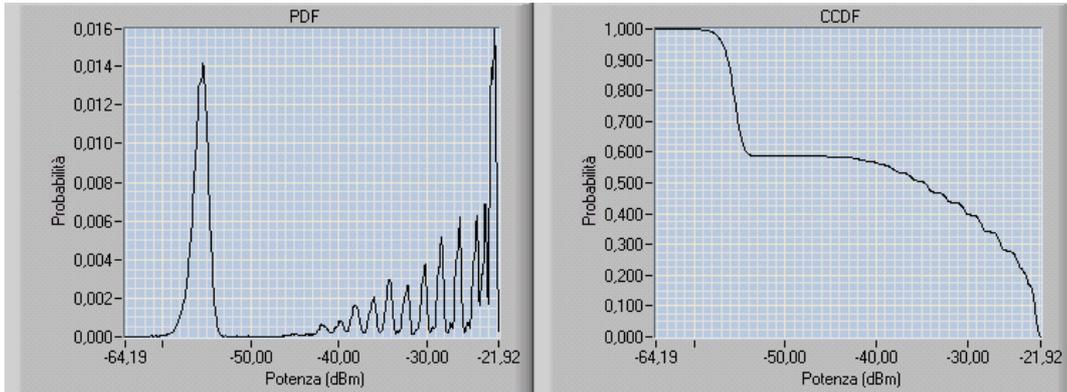


Fig. 3: CCDF and PDF measurement of a GSM channel.

The pattern associated to power control at the right side of the PDF curve can be related to the distribution of users within a cell. Under ideal conditions, power level can be assumed to depend on the distance of the user from the base station transmitter, so that boundaries between levels are represented by arcs of concentric circumferences with increasing radius. If users are uniformly distributed within the covered area, the probability that a given power level is employed will be proportional to the area between two adjacent boundaries, normalised by the total covered area. A straightforward geometrical analysis shows that the normalised area increases as a function of distance, suggesting that a similar pattern is followed by the PDF for power levels. Experimental data roughly agree with this simple model; the actual result is of course influenced by the features of the cell under analysis and it is worth noting that monitoring at a single point may allow to infer information about the whole cell. The different modulation format employed by EDGE systems would result in an almost continuous PDF curve of power which, however, would in general follow a similar pattern.

The CCDF measurement of Fig. 3 refers to a channel characterised by a very clean signal. In practice, a variety of situations may be found where disturbances and interference may occur. In these cases the use of the PDF plot becomes essential to discriminate the different parts of the CCDF plot. An example is presented in Fig. 4, where the measurements refer to a channel at 956.8 MHz. The time-domain plot reported in Fig. 4.a shows that time slots are seemingly characterised by two distinctly different ranges of power levels. In this case interference from an adjacent channel occurs, but it is rather difficult to positively identify this effect as such. The use of the PDF plot makes the effect easily recognisable, since power levels are very well separated. This allowed to place a marker at the -53.4 dBm level in Fig. 4.b, where probability falls down to zero. The marker position on the PDF plot is coupled to that of the CCDF plot, which readily shows that the probability of exceeding the -53.4 dBm power level is 28.6%. This value measures the relative traffic load of the monitored channel.

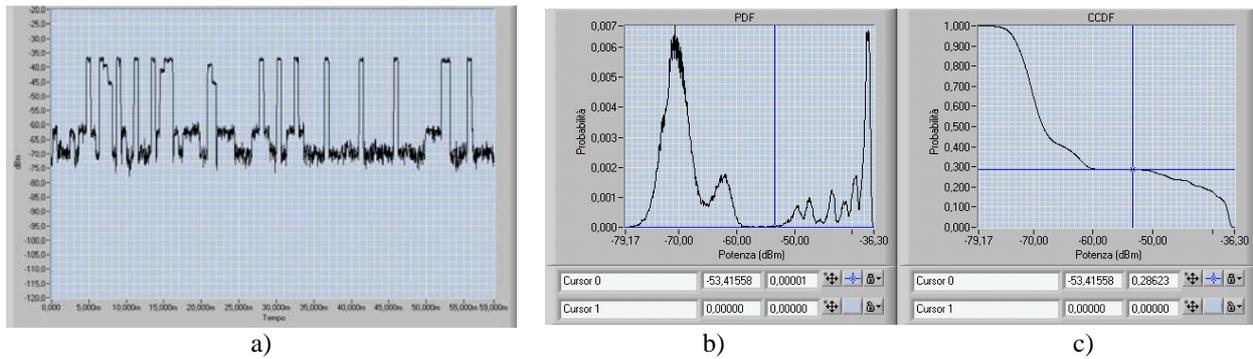


Fig. 4: measurement on a GSM channel with adjacent channel interference: a) time domain; b) PDF; c) CCDF.

The analysis has been applied to a variety of experimental conditions, showing that both adjacent channel and co-channel interference do not in fact prevent accurate assessment of traffic load. The PDF plot usually allows to correctly separate interference effects from actual signal levels, so that accurate monitoring information can be obtained.

Another aspect that required investigation was the assumed stationarity of the monitored signal. Data collection was launched over a 24 hour time span to assess the actual variability of traffic (and, consequently, of average power) on a daily basis. Considering the length of time involved, new measurements were taken every ten minutes. The plot of Fig. 5 spans the interval from 9:50 a.m. to the same hour in the next day. The daily cycle is quite apparent but, in this case, daytime load remains roughly constant, with measured values always falling between 40% and 70%. On average, traffic appears to be slightly higher in the morning hours, but the 5% difference is only just significant in comparison with the 3% uncertainty. As noted above, the instrument can acquire a large enough data record in a rather short acquisition time. New information cannot be obtained continuously, since post-processing of data requires a certain amount of time; however, the rate at which plots are updated can reach a few traces per minute, effectively allowing to repeat the study over much shorter time scales. Since Fig. 5 shows that some peaks do also occur, shorter-term variability may in fact need to be investigated further.

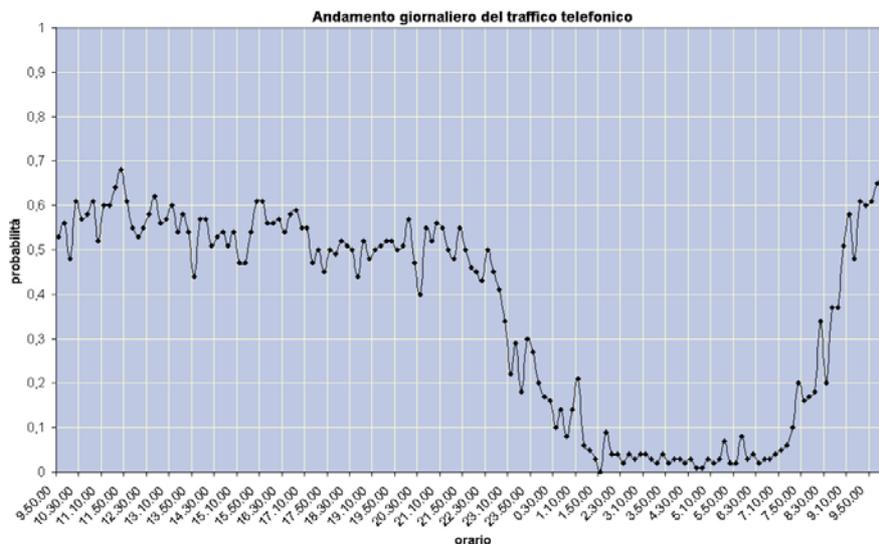


Fig. 5: daily variation of traffic load in a monitored GSM channel.

#### IV. Conclusions

Statistical analysis of power in a wireless channel allows considerable insight into the operation of base station transmitters in current mobile networks. Results obtained by using a spectrum analyser as a monitoring device provide an accurate measurement of the traffic load in a cell, as well as of the range of power levels actually employed by the base station transmitter to ensure coverage. This probabilistic information can be useful, among other things, to obtain a more accurate assessment of potential exposition to RF fields, since measurements are no longer based on a worst-case approach and allow the determination of the actual field strength.

The proposed method may help both network operators and environmental protection agencies when analysing compliance with relevant regulations. Furthermore, it gives operators a tool to obtain system relevant information which are independent of the supervisory systems within their network and could be compared to operation data from other sources for troubleshooting and network tuning.

Measurements considered in this work rely on basic spectrum analyser functions, which are well suited to 2G and 2.5G mobile systems. However, the evolution towards newer systems may be less straightforward. It should be reminded that, in 3G systems, channels are separated by code, rather than by frequency and measurement requires functions that actually turn a spectrum analyser into a dedicated measuring receiver. Therefore, extension to UMTS may be only partial, or require a different and more specialised instrument.

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