Stochastic Processes in Radiation Emissions of Cellular Base Station

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ABSTRACT

Studies have shown that radiation activities around cellular base stations, at distinct applied frequencies, have well defined profiles within boundaries of statistical fluctuations, despite expected random nature of interactions between users and serving base station, thus enabling build-up of prediction tools. It is found that causal stochastic processes of a cellular base station radiation power are quasi-stationary in nature. It is also demonstrated that processes of the total radiating power may be well represented by decomposition into fast quasi-stationary processes and slowly changing pseudo-deterministic radiation profiles. This typical behaviour is immanent in cellular frequencies, while strongly diminishing at non-cellular sources.

INTRODUCTION

During the last years, the use of cellular and other RF communication systems in urban and rural zones has become an intense phenomenon characterized by exponential growth. Public awareness to the potential effects of RF radiation raised several critical issues, among which the call for systematic independent tracking system of radiation communication profiles, especially around base stations. In the present study, time-domain of 45 days measurements sampled at $1/60$ Nyquist rate for each radiating frequency f of tested base station has been sliced into 2880 $\{k\}$ processes specified by the stochastic tensor $(f,\{k\})$. This way, the continuously measured data has been transformed via data synchronisation and regularization modules to simultaneous multiple stochastic processes. Statistical analysis has shown that for the operative radiation power at frequency f, the causal stochastic processes $x_{kf}(t)$ appear as quasi-stationary variables, where auto-correlation functions $R_{kf}(t,\tau)$ are independent of reference time t, whereas they show dependent on relative time displacement τ only. Also similar features appear at cross-correlation function between close spectral lines of the examined base station. This behaviour is found to be typical and immanent in cellular radiating frequencies, while strongly diminishing at non-cellular radiating sources.

Systematic measurements have indicated that stochastic processes of electromagnetic fields' power $x_{kf}(t)$ may be decomposed into quasi-stationary processes $\eta_{kf}(t)$ and characteristic pseudo-deterministic profile of processes $\alpha_{kf}(t)$, approximately, reflecting the nature of communication services' consumption by the end-users. This fields' behaviour in the vicinity of a base station has a clear impact on integrated fields strength signals and their contribution structure at remote distances in spite of their fast decay and the relative increasing components of other sources and noise presence.

STATISTICAL ANALYSIS

The database of the spectral activity of the studied cellular base station is composed of 41x45x2880 3rd order matrix, sampled at various distinct operating frequencies in the range of 820-1000 MHz, applying 4.5 MHz resolution, thus generating the (f_k, d, t_j) ensembles of stochastic processes $\{x_{kf}\}$ for each f_k operating frequency, d the day of measure and t_j the sampling instant [1]. Correlation levels between distinct stochastic processes $\{x_{k_1f}(t)\}$ and $\{x_{k_2f}(t)\}$ within single operation frequency f_k have been determined through numeric calculation of the *Autocorrelation Function* $R_{k_1f,k_2f}(t,t+\tau)$,

$$R_{X_{k1f}X_{k2f}}(t,t+\tau) = \int x_{k1f}(t)x_{k2f}(t+\tau)\ dx_{k1f}(t)dx_{k2f}(t+\tau) \quad k = 1,...,2880 \quad ;f, \qquad (1)$$

whereas *Cross-correlation Function* $R_{k_1f_1,k_2f_2}(t,t+\tau)$ has been used to evaluate levels of correlation between processes $\{x_{k_1f_1}(t)\}$ $\{x_{k_2f_2}(t)\}$ of different spectral lines $f^1{}_{k1,} f^2{}_{k2}$. The approximated numeric calculations of *Autocorrelation Functions* [2] for finite group of elements $\{x_{kf}\}$ of measured $(f_k\ ,\ d,\ t_j)$ ensembles has been derived by

$$R_{x_{kf}x_{kf}}(t_1,t_1+\tau)\approx\frac{1}{N}\sum_{i=1}^{N=45}x_{kf,i}(t_1)x_{kf,i}(t_1+\tau)\qquad k=1,...,2880;f. \tag{2}$$

Calculations have been done for various radiating frequencies in 820-1000 MHz band. Attention has been given to frequencies: 851.5, 856, 878.5, 887.5 and 950.5 MHz, where some spectral lines are cellular base-station working frequencies and others are not [3].

QUASI-STATIONARY STOCHASTIC PROCESSES

In studying the generated group of stochastic processes of active frequencies of the studied cellular site, it has been found that their calculated autocorrelation functions are invariant under time displacement τ so that:

$$R_{X_{k1f}X_{k2f}}(t,t+\tau)=R^{\tau}{}_{X_{k1f}X_{k2f}}=\int x_{k1f}\,x^{\tau}{}_{k2f}\;dx_{k1f}\;dx^{\tau}{}_{k2f}\,. \tag{3}$$

This has been verified in the calculation of the autocorrelation functions performed for $f_k = 887.5MHz$, a central working frequency of the base station, using (2). Time displacements by $\tau=-15\min$ and $\tau=+15\min$ around time parameter t yields nearly the same levels of autocorrelations' profile. In Fig. 1 it is shown that around *t* = 30 min the calculated autocorrelation functions, at $t=30-\tau=15\,min$ and $t=30+\tau=45\,min$, yield almost the same envelop of profiles, thus revealing a quasi reflection-symmetry in reference to *t* = 30 min, despite the high number of processes (2880).

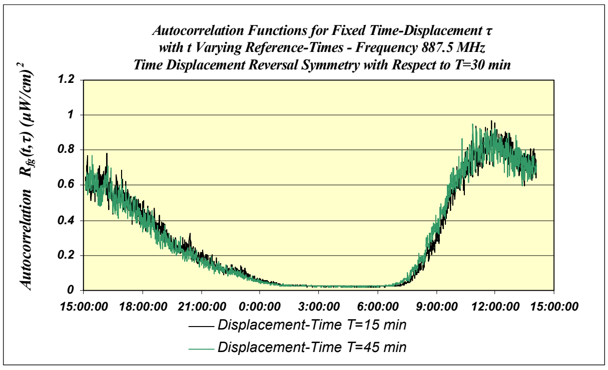

Fig. 1

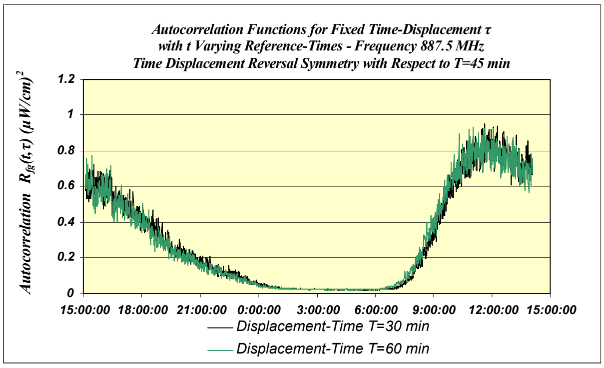

Fig. 2

The same phenomenon is found for other reference-time parameter *t* = 45 min, for time displacements $\tau=\pm15\,min$, when autocorrelation functions have been calculated at $t=45-\tau=30\,min$ and $t=45+\tau=60\,min$. The results are presented in Fig 2.

When autocorrelation functions for $f_k = 887.5MHz$ are calculated for varying time-displacement parameter τ, relative to fixed processes at 03:00, 21:00 and 15:00 reference-time parameters *t*, then the correlation profiles and the calculated values are strongly dependent on displacement-time parameter τ as presented in the following Fig. 3. Autocorrelations are relatively high for reference-time 15:00, weakened for reference-time at 21:00 and even weaker for reference-time at 03:00. Such behaviour clearly indicates the strong dependence of the autocorrelation functions of stochastic processes on τ for the examined working frequency $f_k = 887.5MHz$ of the cellular site. The same has been found for other working frequencies of the cellular site, such as $f_k = 883MHz, 878.5MHz$.

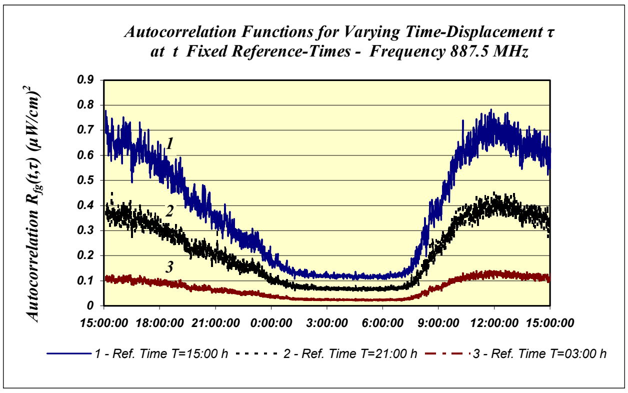

Fig. 3

Also, cross-correlation functions between different working frequencies of radiating cellular site perform similar results, indicating the concurrent site activity at the various frequency channels. For radiating sources at frequencies that are outside of the working frequency band, the calculated autocorrelation functions do not show clear response to changes in τ , and as well no significant relative variation with respect to t have been established in these calculations. See for e.g. results of study for $f_k = 856MHz$ in Fig 4.

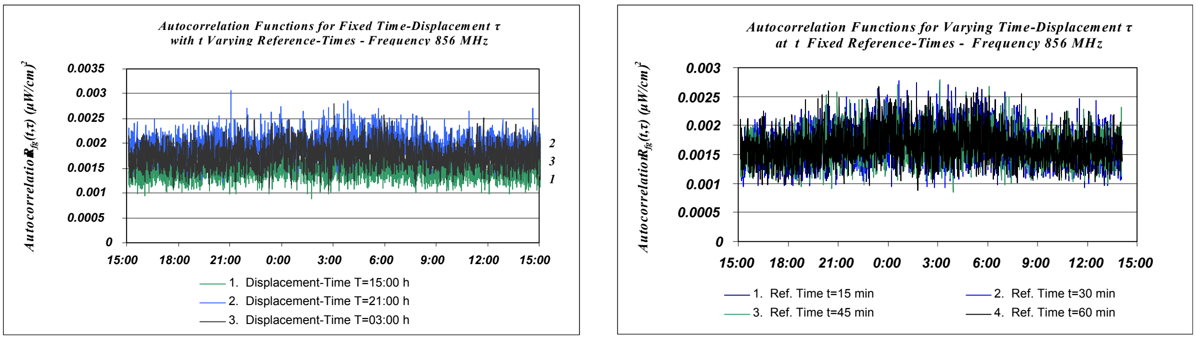

Fig. 4

The combined findings shown in Figs 1-3 for the autocorrelation functions at $f_k = 887.5MHz$ are consistent with (3), indicating their independence of t while being dependent on τ , leading to the conclusion that stochastic processes of radiating power of working frequencies of cellular site are fairly quasi-stationary processes.

LINEAR DECOMPOSITION MODEL FOR STOCHASTIC PROCESSES

In this study it has been found that stochastic processes $x^d_{k,f}(t)$ of radiating power in cellular site at f_k can approximately be decomposed into quasi-stationary processes $\eta^d_{k,f}(t)$ and characteristic pseudo-deterministic envelops of processes $a^d_{k,f}(t)$

$$\{x^d_{kf}(t)\} = a^d_{kf}(t) + \{\eta^d_{kf}(t)\} \qquad k = 1,\dots,2880; d = 1,\dots,45; f. \tag{4}$$

These approximations result from the fact that working-cycle of characteristic cellular site at f_k is bounded by upper and lower envelopes of typical radiation levels. Thus, radiation profiles reflect consistent envelops of processes $a^d_{k,f}(t)$ that could be estimated by various methods.

In applying smoothing moving average (61 values), a fairly appropriate working cycle for various days of the week has been established. Quasi-stationary processes $\eta^{d}_{k,f}(t)$ have been calculated by applying (4) approximation. The results for two complete weeks have shown remarkable consistency, confirming the assumption, which lies in the approximation of (4). See Fig. 5 of that comparison. Detailed presentations of day-by-day comparison between the two examined weeks have proven this assumption.

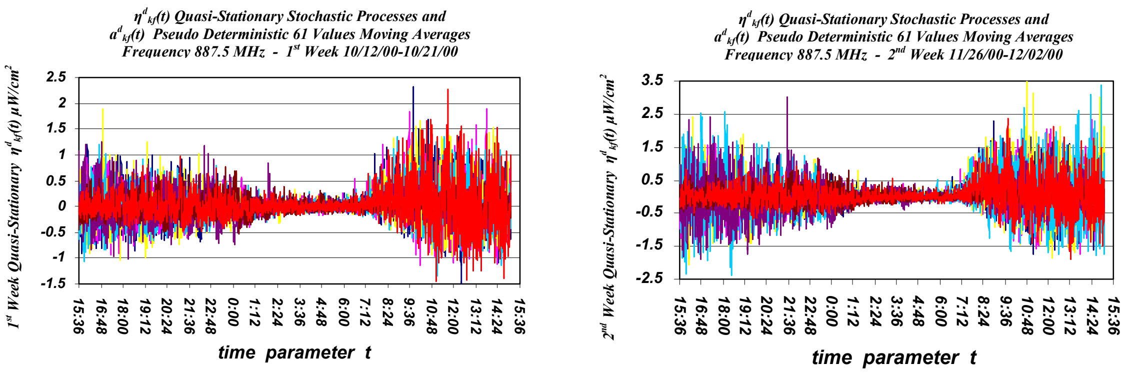

Fig. 5

Therefore, we can conclude that stochastic processes of cellular radiating site at f_k are stochastic processes that can be separated into distinct parts of the pseudo deterministic radiating activity profile and the quasi-stationary processes.

References

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[2] Random Data Analysis and Measurement Procedures, Julius S. Bendat and Allen G. Piersol, 3rd Ed., *2000.* John Wiley & Sons, Inc.

[3] Analyssis of Electromagnetic Compatibility Between Radar Stations and *4* GHz Fixed-Satellite Earth Stations, F.H. Sanders, R.L. Hinkle and B.J. Ramsey, U.S. Department of Commerce, NTIA Report 94-313, July 1994.