The applications of automated systems for real time monitoring of the electromagnetic field

Paul BECHET
LAND FORCES ACADEMY "NICOLAE BALCESCU" SIBIU

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Abstract of the habilitation thesis

This habilitation thesis presents the most important research and contributions of the author after receiving his doctoral degrees in 2001. The PhD thesis had the title “Research and development of frequency synthesiser structures for special applications”, in the Electrical Engineering domain. The supervisor was prof. univ. dr. ing. Radu Ioan MUNTEANU and it was handed in at the Technical University of Cluj-Napoca.

In the first chapter of the habilitation thesis the main cornerstones of the professional evolution of the candidate alongside with the main contributions and their impact are presented.

Chapter two highlights the major scientific research results obtained by the candidate.

A procedure for evaluating, with high accuracy, the human exposure to the electromagnetic waveform emitted by wireless devices in wireless local area networks (WLAN) is presented in the first part.

The main problem with evaluating the WLAN electromagnetic field is that the emitted signals are short time impulses spread over a large frequency bandwidth. The proposed procedure aims at improving the accuracy of the measurements while using swept-based measurement systems for representative WLAN signal quality scenarios. The most important parameter for such a measurement system in the case of evaluating burst-like signals is the swept time (SWT). The minimum active duration of the signal needs to be taken into consideration when computing the SWT. A SWT value lower than the active duration of the signal will lead to overestimation, whereas a lower value will lead to subestimation. In the WLAN case, this active duration is not fixed, which complicates the problem in selecting a good SWT value.

The procedure proposes to take into consideration two cases: the minimum duration of the signal with the largest amplitude (representing the beacon) and the minimum duration of the acknowledgement frames (ACK). The advantage is that these signals have a constant duration. To validate this hypothesis, the obtained measurements were compared to the ones yielded by a real-time vector based frequency analyzer.

In subchapter 2.1.2, a procedure for the accurate evaluation of the human exposure to the GSM (Global System for Mobile Communications) electromagnetic waves is presented. The original aspect is that the system builds the temporal distribution of the traffic over each of the 124 GSM channels.

The evaluation of the whole GSM downlink spectrum is than realised by integrating every channel. This way, the contribution of every channel can be identified, thus improving the accuracy. The traffic for every base station belonging to any operator is independent. The procedure analyzes the electromagnetic field distribution for the two channel types representative for GSM: BCCH (Broadcast Control Channel) and TCH (Traffic Channel). In addition, any information from the operators regarding the traffic is not needed. To validate this hypothesis, the obtained measurements were compared to the ones yielded by a real-time vector based

frequency analyser (which was controlled by a MATLAB based software developed for this purpose).

In subchapter 2.2, a non-contact method to detect humans is presented. The interest of scientists towards measuring the human pulse or breath using the continuous wave Doppler radar has lead to the implementation of efficient radio-frequency architectures as well as the improvement of signal processing algorithms. The most used architectures are based on the quadrature reception. Due to the additional reflections and the offset, the imperfections between the I and Q signals are needed to be compensated.

The research was aimed at implementing a signal processing algorithm based on MUSIC (Multiple Signal Classifcation), in order to the accurately evaluate the pulse frequency.

The testing system measures the s_{21} phase parameter with the help of a VNA (Vector Network Analyser). The algorithm optimised for acquisition durations within 8 to 30 s. The algorithm validation is done by computing the medium error of the pulse frequency for simultaneous measurements of multiple subjects, in case of both non-contact and direct setup.

The innovative aspect of the procedure is that high accurate estimations of the pulse frequency are obtained over short distances and in low signal noise ration conditions. For measuring the pulse a continuous wave Doppler radar was implemented using a VNA R&S ZNB4. The measurements were performed on the 2.4GHz frequency, by varying the s_{21} phase parameter. The estimation was obtained by post-processing performed in MATLAB. In order to validate the signal, a Vernier pulse measurement system in a direct contact with the subject was used.

In the 2.3.1 subchapter, the TETRA (Terrestrial Trunked Radio Standard) signal detection is investigated (using probability detection and false alarm in order to estimate the power distribution). The proposed measurement system fulfils the functions of a digital radiometer using a swept-based spectrum analyser. The main parameters of a radiometer (W - bandwidth to be analysed; T - integration period) can be comprehended by a spectrum analyzer (during the experimental phase a R&S FSH3 instrument was used). The collected data are later processed using specific MATLAB software.

In chapter 2.4.1 a HF channel estimation algorithm is presented. The algorithm is based on OFDM wave types, and it was researched and developed within the research project “Predictions for ionospheric propagations and wide band communications using HF SDR sensors in emergency cases data transmission in Romania”.

The algorithm is evaluating the SNR using OFDM waveforms. This technique allows for the estimation of other channel parameters alongside with the SNR. Its main advantages are:

- ✓ The extraction of the useful signal from the noise or the interference signals, by using an OFDM setup with 64 subcarriers.
- ✓ In order to evaluate the SNR for different channels, the frequency spacing between the subcarriers is varied.
- ✓ The OFDM method enables the SNR evaluation for every individual subchannel, thus permitting for the identification of subchannels affected by interferences.

The main disadvantage is that the power division over the number of subcarriers leads to a decrease of power of the useful signal for every sub-band. In comparison to an unmodulated single carrier system, in the OFDM system's case, the SNR is lower with a magnitude equal to the number of used subcarriers. In order to compute the SNR, it is mandatory to separate the useful signal from the noise and interfering signals. By means of spectral analysis (since the OFDM shape and the subcarrier frequency spacing are known) and by using a good resolution value, the useful signal power can be found.

In subchapter 2.4.2, the possibility of increasing the data rate for HF transmissions using OFDM is investigated. NI USRP SDR platforms, controlled via GNU radio based applications, have been used for both the transmitter and the receiver.

Data acquisition, SNR calculations and packet reception were performed in GNU radio applications. The monitoring period was 1 minute (215 transmitted packets), in real time, over a bandwidth of 16 kHz. Statistical analysis of the received data was performed in MATLAB. The SNR represents the difference between the measured power of the desired channel with a bandwidth of 4 kHz and the noise power from the adjacent 4kHz channel. Before the SNR calculations, it was checked that no other transmissions took place in the two channels. Two edge cases of the ionospheric channel from the SNR's point of view are of interest: increasing the SNR in order to go from lost packet to successfully received packet and vice-versa (decreasing the SNR in order to go from successfully received packet to lost packet). For both cases, the edge SNR values for successful transmission are important. It was shown that for a SNR under 10 dB, for a 64 subcarrier OFDM transmission over a 3 kHz HF channel, the transmission is completely broken.

Chapter 3 presents the conclusions and future research directions.

The following conclusions can be drawn:

- ✓ The author has leaded multiple successful research projects, as the project manager or partner project responsible. Together with the colleagues from the Land Forces Academy of Sibiu, they have formed a competitive research team.
- ✓ The author contributed to the strengthening of the research infrastructure within the Land Forces Academy of Sibiu. For this purpose he collaborated successfully with vendors (for modern communications equipments) as well as other chairs within the academy. It is worth mentioning the collaboration with the Romanian branch of Rohde & Schwarz, which lead to the development of automated measurement and control systems and to the organisation of events in the domain of RF measurement and control systems. The benefits of such a collaboration are: presentation and testing of cutting edge measurement systems, identifying of new collaboration projects, access to cutting edge technologies for didactical and research purposes which attract and support students with their theses (bachelor, master or PhD).
- ✓ The author collaborated with other universities for both research and didactical purposes. As example, the master program "Integrated communications systems for special applications" with Technical University of Cluj is worth mentioning. The second example is the book "Electromagnetic compatibility in radio communication backgrounds" which was publicised by the Romanian Academy Publisher and which has been awarded the "Gheorghe Cartianu" by the Romanian Academy in 2010.

- ✓ The author has participated and organised different military communication applications, some of which have had a pioneering aspect in Romania.
- ✓ The author has encouraged and promoted bachelor, master and PhD students in finishing their dissertation work. Some of them have also been integrated in the research teams of ongoing research projects.
- ✓ The author has collaborated with specialists from other institutions, which resulted in publications and in joint research projects. Worth mentioning is the joint collaboration with the Technological Institute of Crete, Greece, in the Archimedes III project. The main goal was the implementation of an automated system for measuring the electromagnetic field (the partners from Greece were in charge of the applications controlling the antenna, and our group from the AFT was in charge of the applications controlling the spectral analyser to be used).

Finalising the research project "Predictions for ionospheric propagations and wide band communications using HF SDR sensors in emergency cases data transmission in Romania" represents our immediate priority. The innovative proposed system for monitoring the ionospheric channel integrates three methods for probing the channel (oblique probing, passive probing and TEC measurements - Total Electron Content based on GPS). The system is based on configurable SDR platforms. The obtained results include information regarding the ionospheric parameters (foF2, foF1, hmF, hmE, foE) and the received signal quality (attenuation, Bit Error Rate - BER, Error vector Magnitude - EVM etc).

The development of electromagnetic field monitoring systems remains an important concern for future research projects. Thus, one objective is to build a SDR based system capable of measuring the electromagnetic field with the purpose of evaluating the human exposure to the electromagnetic radiations emitted by wireless devices compliant to 3G, 4G and 5G standards.

The SDR platform enables a more diverse way for measuring the exposures in comparison to the existing studies. The real time data acquisition (followed by post-processing) aids in measuring the exposure and the channel parameters (like the technology used, traffic density, location and time of measurement, transfer rate, modulation type, etc). Different statistical studies regarding the building of representative electromagnetic profiles are made possible.

The research in the area of SDR represents an ideal frame for master and PhD students to work on their dissertation thesis. Furthermore, this reason constitutes an additional reason for the author to obtain the habilitation thesis in order to consolidate a research group where young researchers can get involved.