A Model of Signal Processing in Software Defined Radio Communication Systems

Borislav Bedzhev* and Dilyan Dimitrov**

*NMU “V. Levski”, Faculty of Artillery, Air-Defense and CIS, 9700
Shumen, Bulgaria, e-mail: bedzhev@abv.bg

** NMU “V. Levski”, Faculty of Artillery, Air-Defense and CIS, 9700
Shumen, Bulgaria, e-mail: dilyaniv@abv.bg

Introduction

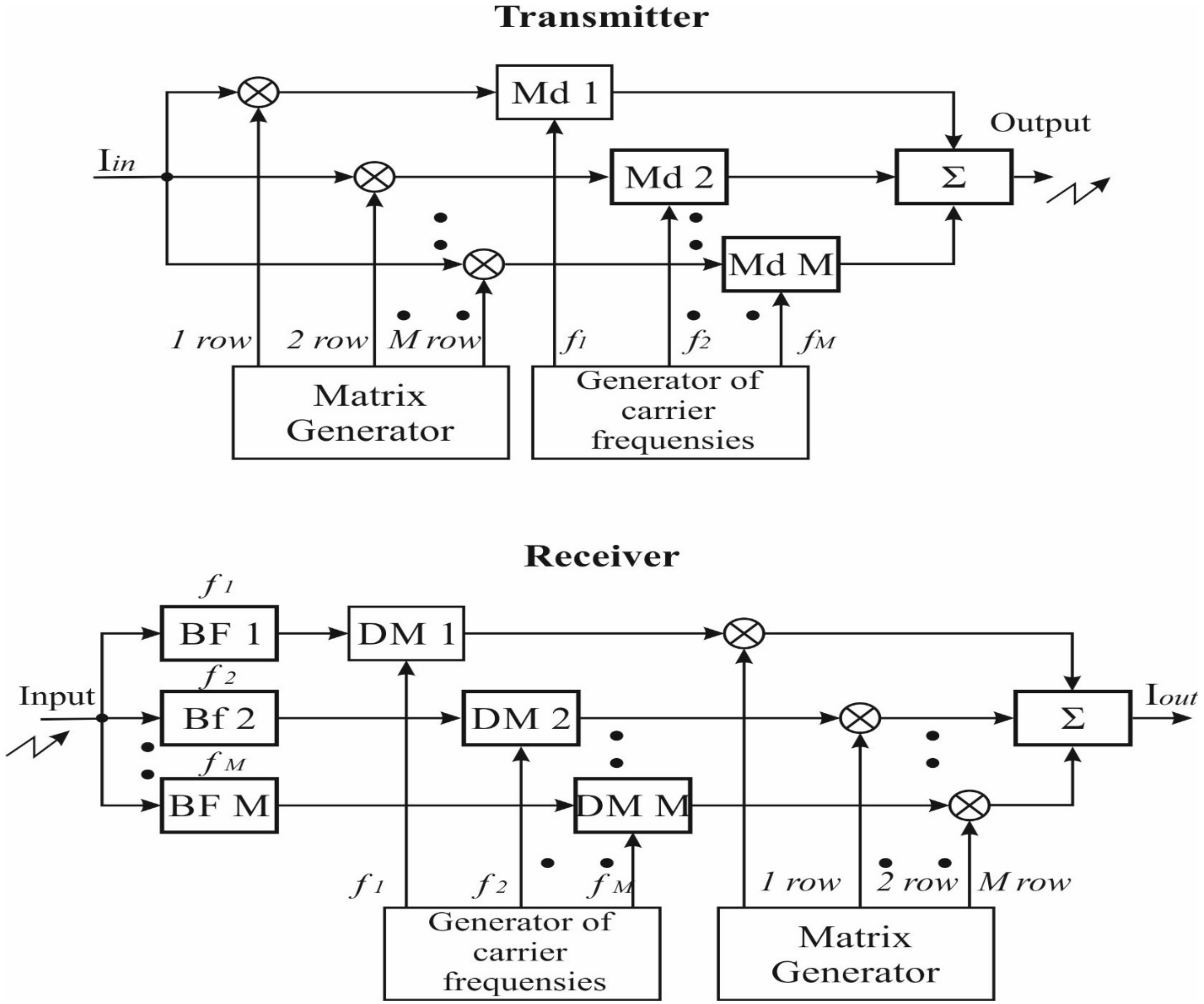
Modern wireless technologies are widely used in manufacturing, autonomous vehicles, distributed control systems, unmanned aerial vehicles, communication and announcement systems, civil defense, police, radio navigation systems, control, rescue and others. As a result, it is necessary to elaborate the approaches for coexistence and more efficient use of different wireless systems while maintaining quality of service (QoS) requirements, thereby providing maximum density of the radio frequency spectrum.

Basics of the Software Defined Radio Communication Systems

The SDRCSs consist of software-controlled firmware that can be configured to an arbitrary frequency band and to receive various types of signals. As a result, SDRCSs most often are used as secondary communication systems (SCSs), which exploit the frequency resources, given to some primary communication systems (PCSs), without to disturb the work of the authorized (primary) users. Due to this reasons, the SDRCSs have the structure, presented on fig. 1, where the following abbreviations are used:

Md-modulator, DM-demodulator, BF-frequency band filter.

Basics of the Software Defined Radio Communication Systems-fig. 1



Basics of the Software Defined Radio Communication Systems

The class of channels, which are partially loaded by the primary users (Pus), could be reused by the secondary users (Sus) by the available division and multiplexing (TDM) and/or complex phased antenna arrays (PAA) techniques so that the interferences, caused by the transmitters of SUs on the receivers of PUs, do not decrease the rate of information transmission of the PUs below the normatively defined level. For the PUs the maximal information transmission rate of every channel $I_{r_{ch}}$ is defined by the relation: $I_{r_{ch}} = \Delta f \log_2\left(1+\frac{P_{recPU}}{P_{n0}\Delta f}\right) = = \Delta f \log_2\left(1+\frac{P_{0recPU}}{P_{0n}}\right)\left[\frac{b}{s}\right].$ (1)

Basics of the Software Defined Radio Communication Systems

In (1) $P_{recPU} = P_{0recPU}\Delta f\ [W]$ and $P_{0recPU}\ [\frac{W}{Hz}]$ are respectively the power and the spectral power density of the signals, incoming by the respective channel to the input of the PU receiver, and P_{0n} is the spectral power density of the additive white Gaussian noise (AWGN).

If $I_{r_{ch}} > I_{r_{PU}}$, where $I_{r_{PU}}$ is the normatively defined level of the information transmission rate of PUs, then SUs can reuse the channel by the means of signals with spectral power density P_{0sSU}, defined by the condition:

$$I_{r_{PU}} = \Delta f \log_2\left(1 + \frac{P_{0recPU}}{P_{0n}+P_{0sSU}}\right)\ [\tfrac{b}{s}]. \quad (2)$$

A Model of Signal Processing in Software Defined Radio Communication Systems, Providing Effective Reuse of the Frequency Fesources

The output signals of n-th SU demodulators (fig. 1) can be presented in the following compact polynomial form:

$$F_n(x) = \sum_{k=0}^{N_{sl}-1} \begin{bmatrix} g_{1n}\mu_{1n}(k) \\ g_{2n}\mu_{2n}(k) \\ \cdots \\ g_{M_l n}\mu_{M_l n}(k) \end{bmatrix} x^k \qquad (4)$$

In (4) the following notations are used.

First, $\mu_{mn}(k)$ is the complex envelope of the symbol, sent in the k-th clock interval ($k = 0, 1, \dots, N_{sl} - 1$), by the means of m-th channel ($m = q_{l1}, q_{l2}, \dots, q_{lM_l}$).

A Model of Signal Processing in Software Defined Radio Communication Systems, Providing Effective Reuse of the Frequency Fesources

Besides, the complex numbers g_{mn}, $m = 1, 2, \ldots, M_l$, formed by the matrix generators (fig. 1), manage the adaptation of channels to the restrictions, imposed by their moment loading (which is a result of the activity of PUs).

Second, without loss of generality it can be accepted that analog parts of the demodulators are adjusted to equalize the magnitudes of the incoming signals.

A Model of Signal Processing in Software Defined Radio Communication Systems, Providing Effective Reuse of the Frequency Fesources

Third, the polynomial $F_n(x)$ is the so-called generating function or Hall polynomial, associated with the sequence of signal vector-columns:

$$\begin{bmatrix} g_{1n}\mu_{1n}(k) \\ g_{2n}\mu_{2n}(k) \\ \cdots \\ g_{M_l n}\mu_{M_l n}(k) \end{bmatrix}, k = 0, 1, \ldots, N_{sl} - 1. \ (5)$$

Such polynomials form a ring over the M_l dimensional complex Hilbert vector space, using the algebraic operations the bit-wise summation and subtraction of vectors, as well as the ordinary scalar product of vectors.

A Model of Signal Processing in Software Defined Radio Communication Systems, Providing Effective Reuse of the Frequency Fesources

As the information transmission rate among SUs can be increased only by the means of some kind of cooperative signal processing, in the sequel it is accepted that the complex numbers g_{mn}, $m = 1, 2, \ldots, M_l$, $n = 1, 2, \ldots, M_l$ are the entries of some unitary orthogonal matrix G. This means that all entries of G have unit magnitude and its columns and its rows are orthogonal, i.e.:

$$\begin{bmatrix} g_{1n_1} \\ g_{2n_1} \\ \cdots \\ g_{M_l n_1} \end{bmatrix} \otimes \begin{bmatrix} g^*_{1n_2} \\ g^*_{2n_2} \\ \cdots \\ g^*_{M_l n_2} \end{bmatrix} = C_{n_1} \otimes C^*_{n_2} = \begin{cases} M_l, n_1 = n_2, \\ 0, n_1 \neq n_2. \end{cases} \qquad (6)$$

A Model of Signal Processing in Software Defined Radio Communication Systems, Providing Effective Reuse of the Frequency Fesources

As i-th and n-th SUs exploit the same subclass of channels $\{q_{l1}, q_{l2}, \ldots, q_{lM_l}\}$, the output of the receiver of the n-th SU during the current time slot can be presented by the following mathematical model:

$$F_i(x)F_n^*(x^{-1}) = \left[\sum_{k=0}^{N_{sl}-1} \mu_i(k) C_i x^k\right] \times \\ \times \left[\sum_{k=0}^{N_{sl}-1} \mu_n^*(k) C_n^* x^{-k}\right] = \sum_{r=-N_{sl}+1}^{N_{sl}-1} P_{in}(r) x^r \qquad (7)$$

In (7) $F_n^*(x)$ is the polynomial, associated with the vector-columns of the MF in the receiver of n-th SU, and $P_{in}(r), r = -N_{sl}+1, -N+2, \ldots, -1, 0\ ,\ 1, 2, \ldots, N_{sl}-1$ are the samples of the cross-correlation function (CCF) of the signal of the i-th SU and the reference signal of n-th SU.

A Model of Signal Processing in Software Defined Radio Communication Systems, Providing Effective Reuse of the Frequency Fesources

It should be noted that if the number of SUs, exploiting the same subclass of channels $\{q_{l1}, q_{l2}, \dots, q_{lM_l}\}$, is smaller or equal to M_l, then SUs can exchange information among each other without any multi access interferences (MAIs). Indeed, all products in (8)

$$\{\mu_i(k+\lceil r\rceil)\mu_n^*(k)\}[C_i \otimes C_n^*] = 0 \qquad (9)$$

are zeros as $C_i \otimes C_n^* = 0$, according to (6). Consequently, the communications of SUs, exploiting the same subclass of channels are influenced only by the self-interferences (SIs).

A Model of Signal Processing in Software Defined Radio Communication Systems, Providing Effective Reuse of the Frequency Fesources

In the analysis of SIs it should be accounted the fact that they are produced by the multipath spreading of electromagnetic waves. Due to this reason in (7) and (8) it should be substituted $i = n$. As a result, $C_n \otimes C_n^* = M_l$ (according to (6)) and (8) simplifies to

$$P_{nn}(r) = \begin{cases} M_l \sum_{k=0}^{N_{sl}-1-\lceil r \rceil} \mu_n(k+\lceil r \rceil)\mu_n^*(k), \\ M_l \sum_{k=0}^{N_{sl}-1-r} \mu_n(k)\mu_n^*(k+r). \end{cases} \qquad (10)$$

A Model of Signal Processing in Software Defined Radio Communication Systems, Providing Effective Reuse of the Frequency Fesources

In situations when the n-th SU is a radar sensor $\mu_n^*(k) = [\mu_n(k)]^*, k = 0, 1, 2, \dots N_{sl} - 1$ (14) is the radar probe signal. After accounting (10) and (14) in (7) the result is:

$$\begin{aligned} F_n(x)F_n^*(x^{-1}) &= \left[\sum_{k=0}^{N_{sl}-1} \mu_n(k) C_n x^k\right] \times \\ &\times \left[\sum_{k=0}^{N_{sl}-1} \mu_n^*(k) C_n^* x^{-k}\right] = M_l \sum_{r=-N_{sl}+1}^{N_{sl}-1} P_{\mu\mu}(r) x^r, \end{aligned} \tag{15}$$

where $\sum_{r=-N_{sl}+1}^{N_{sl}-1} P_{\mu\mu}(r) x^r$ is the generating function (Hall polynomial), associated with the autocorrelation function (ACF) of the sequence $\{\mu_n(k)\}_{k=0}^{N_{sl}-1}$.

A Model of Signal Processing in Software Defined Radio Communication Systems, Providing Effective Reuse of the Frequency Fesources

Hence, in the output of the MF an amplified copy of the ACF $\{P_{\mu\mu}(r)\}_{r=-N_{sl}+1}^{N_{sl}-1}$ of the sequence $\{\mu_n(k)\}_{k=0}^{N_{sl}-1}$ is obtained, i.e. the SNR is improved M_l times. As a result:

1) the range of the radar surveillance zone R_{sz} increases $\sqrt[4]{M_l}$ times;

2) the object resolution and measurement accuracy of spatial coordinates of the tracked objects can be significantly increased if complementary phase manipulated signals are used as probe pulses.

Conclusion

In the paper a model of signal processing in SDRCSs, which are capable to manage flexibly the frequency resources among their users, is proposed. The model allows the performance of the SDRCSs to be described in a more compact form as well as new approaches for electromagnetic spectrum reuse to be substantiated.

The results, obtained in the paper, could be useful in the process of development radar sensor networks, which can exploit very effectively the limited natural resource - the electromagnetic spectrum.