New Technologies for UAV Communication

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Abstract

The purpose of this work is to consider the UAV-communication channel multiplexing in the case of nonorthogonal frequency-division multiplexing (N-OFDM) .

Keywords: UAV, orthogonal frequency-division multiplexing (OFDM), nonorthogonal frequency-division multiplexing (N-OFDM), fast Fourier transform (FFT).

The majority of known approaches to the improvement of transmission capacity of communication channels consist in expanding their spectral band. In turn it leads to a number of problems such as the electromagnetic compatibility of heterogeneous equipment and the deficiency of frequency resources in the most extensively used ranges of the electromagnetic spectrum. This situation can be improved if the processing of UAV communication signals is performed based on their super-Rayleigh resolution.

The purpose of this work is to consider the UAV-communication channel multiplexing in the case of nonorthogonal frequency-division multiplexing (N-OFDM). The reference point of our investigation is the known method of orthogonal frequency-discrete multiplexing (OFDM), which in the last few years has been widely used, for example, in WiMAX systems and in digital television (DVB-T).

The processing principle suggested below has much in common with OFDM (Fig. 1) and differs in a denser packing of the carrying signals in the transmitter (Fig. 2) oriented to their further super-Rayleigh resolution, which must not reduce the reliability of the information.

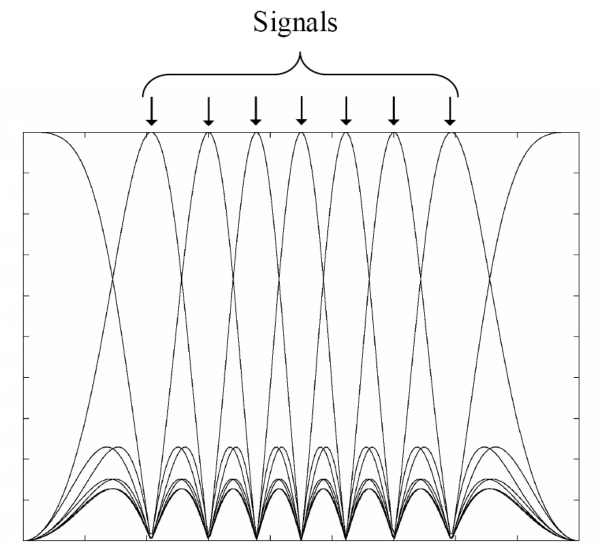

Fig. 1. OFDM

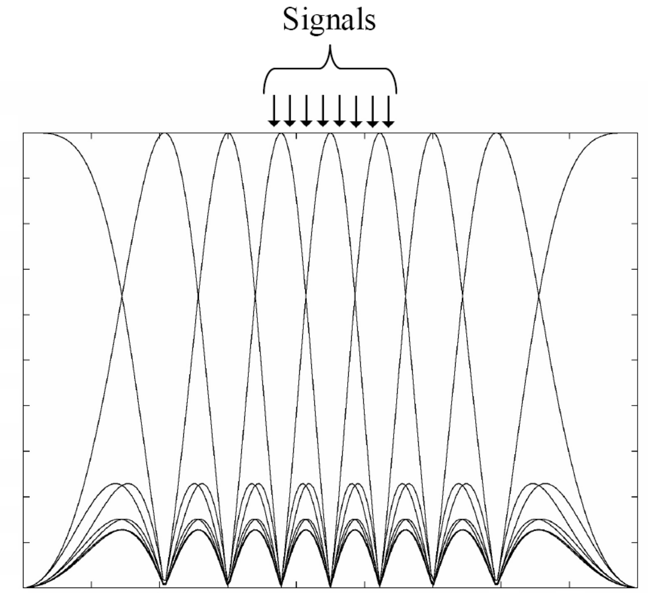

Fig. 2. N-OFDM

Provided that the frequency coding is accompanied by amplitude-phase modulation of the carrier frequencies, the estimates of quadrature components of signals in the receiver can be obtained from the voltages of frequency filters synthesized by the fast Fourier transform (FFT). In the case of deterministic interpretation of the signal mixture in the absence of Doppler's shifts of frequency, the respective relationships have the form [1]

$$\widehat{a}_m^{c(s)} = \frac{\det_m^{c(s)}}{S \times \det}; \quad m = 1,2,\ldots,M \,, \tag{1}$$

where S is the dimensionality (number of points) of the FFT operation;

$\det_m^{c(s)}$ is a partial determinant obtained from the determinant

$$\det = \begin{vmatrix} f_1(w_1) & f_1(w_2) & \cdots & f_1(w_M) \\ f_2(w_1) & f_2(w_2) & \cdots & f_2(w_M) \\ \vdots & \vdots & \cdots & \vdots \\ f_M(w_1) & f_M(w_2) & \cdots & f_M(w_M) \end{vmatrix}$$

by replacing the respective column by the vector of free terms $\left[\mathrm{B}^{c(s)}\right] = \left[\mathrm{U}_1^{c(s)} \quad \mathrm{U}_2^{c(s)} \quad \cdots \quad \mathrm{U}_M^{c(s)}\right]^T$, where $U_j^{c(s)}$ - are quadrature components of the complex response of the yth FFT-filter;

$f_j(w_m) = \dfrac{\sin S \times \left[j \times \dfrac{\pi}{S} - w_m \right]}{\sin\left[j \times \dfrac{\pi}{S} - w_m \right]}$ is the value of the amplitude-frequency response (AFR) of the yth frequency filter synthesized by means of FFT; and w_j, w_k and w_m are known carrier frequencies among the totality of the prescribed frequencies expressed in segments of the whole width of the AFR main "lobe" of the FFT-filter.

Relation (1) was derived after solving a system of equations composed by the response voltages of the frequency filter without taking noise into account:

$$\mathrm{U}_j^{c(s)} = \sum_{m=1}^{M} a_m f_j(w_m), \quad j = 1,\ldots, M.$$

To make the treatment of real-valued signals easier, their analog-to-digital conversion has to be performed with the period of sampling multiple to an odd number of quarters of the period of the information packet central frequency. Then the partition of 2S samples, obtained from ADC (2S> M), into those with even and odd ordinal numbers makes it possible to easily form the quadrature components of voltages for subsequent operation of the S-point FFT.

In the most demanding applications, generation of the quadratures from real-valued signals can be performed by means of the discrete Hilbert transformation, which is realized in the sliding window conditions over a given number of ADC samples dictated by the Hilbert filter order. In this case the overall number of ADC samples formed on the measurement sample interval must exceed the dimensionality of the FFT procedure by the doubled interval of the transient process of the Hilbert filtering [2].

To make the most use of the signal energy and to estimate optimally the amplitude components by the least-square method, the denominator of relation (1) must contain the determinant

$$\det = \begin{vmatrix} S & f_{12} & \cdots & f_{1M} \\ f_{12} & S & \cdots & f_{2M} \\ \vdots & \vdots & \cdots & \vdots \\ f_{1M} & f_{2M} & \cdots & S \end{vmatrix}, \qquad (2)$$

while the numerator of (1) is a partial determinant $\det_m^{c(s)}$ obtained from (2) by replacing the respective column by the vector of free terms [1]

$$\left[B^{c(s)}\right] = \left[\sum_{j=o}^{S-1} U_j^{c(s)} f_j(w_1) \quad \sum_{j=o}^{S-1} U_j^{c(s)} f_j(w_2) \ldots \sum_{j=o}^{S-1} U_j^{c(s)} f_j(w_M)\right]^T,$$

where $\mathrm{U}_{\mathrm{j}}^{\mathrm{c(s)}}$ are quadrature components of the complex response of the yth FFT-filter,

$f_j(w_m) = \dfrac{\sin S \times \left[j \times \dfrac{\pi}{S} - w_m \right]}{\sin \left[j \times \dfrac{\pi}{S} - w_m \right]}$ is the value of AFR of frequency filters synthesized by FFT, and $f_{jk} = \dfrac{\sin S \times (w_j - w_k)}{\sin(w_j - w_k)}$.

The potential accuracy of measurement of quadrature components comprising the signals in a multifrequency packet depends first of all on the signal-to-noise ratio at the outputs of the frequency channels synthesized, and second on the spacing between the carrier frequencies in the spectral domain. The increase in traffic capacity may take the form of a denser arrangement of carriers, or compression of the accumulation interval used for creating FFT-filters, which leads to an expansion of their passband.

An example illustrating the operability of the procedures suggested represents an approbation of a similar set of operations over a multifrequency packet [3] as applied to the measurement of amplitude-frequency responses of a radio system.

The practical implementation of the approach suggested is as follows. In the receiver of information messages we use a digital signal processor or a programmable matrix of logic elements (produced by the "Xilinx" company, for instance) involved into processing of ADC samples in conformity with the above formulas. For ADC one can take high-speed converters. At the transmitting side, to generate the multisignal mixture, it is appropriate to employ a digital signal processor and a DAC produced, for example, by the "Analog Devices" company.

The next Technologies for UAV Wireless Links are a Multi-User MIMO with using N-OFDM signals and convergence MIMO-technology with MIMO-Radar on Base of one Same Equipment of the Base Station.

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