New Multiple Access Method for Wireless Mobile Systems

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Abstract - Using an Orthogonal Frequency Division Multiple Access (OFDMA) system to achieve good parameters can prove to be an arduous task due to the effects of the Doppler Shift and delays. Here, favorable conditions for orthogonality utilization are diminished. In addition, problems exist in synchronization in the uplink from the receiver, placed inside a car, which is traveling within the confines of a modern city. This article offers proposals for necessary modifications to help decrease the negative influences of using an OFDMA system.

1. Introduction

Multipath propagation has always presented a significant challenge in radio communication systems when used with a mobile transmitter or mobile receiver. One of possible options used to overcome the difficulties in multipath propagation is the OFDMA method of data transmission [1]. It provides rather good performance for the point-to-multipoint transmission in systems without considerable Doppler frequency offset. However, increasing use of the frequency band and steady traffic growth place the influence of the Doppler shift at a greater than ever point in radio modems design.

The Digital Audio Broadcasting (DAB) system seems to present a possible solution for this problem by means of differential modulation. However, this does not prove to be the case in Quadrature Amplitude Modulation (QAM) modulation.

In OFDM systems, we may use pilot signals on some additional carriers, such as in Terrestrial Digital Video Broadcasting (DVB-T) systems, but this is not effective in the case of OFDMA systems. Implementing OFDM in DVB-T has three problems at least. Namely, different sources make use of different carriers, pilot signals are great part of common information and pilot signals amplitudes and phases do not provide reliable information due to noise and interferences influence. The Doppler shift poses a major difficulty for DVB-H. Consequently, multipath propagation in conjunction with the Doppler shift is proving to be a growing problem in modern communication systems.

Here we propose a principally new method of multiple access, namely, Frequency Bank Signal (FBS) [2, 3, 4]. FBS combines the following ideas:

- The phase shift compensation used in the PAL-TV system
- The OFDMA principle
- The spread spectrum with the aid of Walsh functions.

This method eliminates both the influence of the Doppler shift and multipath propagation, and delays rapid changes.

2. FBS method generating principles

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There are three generating ideas, which gave birth to the FBS method.

The first generating idea is the phase shift compensation method widely used in PAL-TV systems. Here follows a brief explanation of using this method. Before transmission of the color signal, its components phases are turned off every other line from ψ to $-\psi$ (see Fig. 1, where $\psi = 45^0$ and φ – represent the phase changing in time). In decoder, the phase sign returns from $(-\psi + \varphi)$ to $(\psi - \varphi)$ and is being summed with the phases of the neighboring lines (which are not changing). As a result the phase changes are compensated.

The second generating idea is concerned with today's well-known OFDM and OFDMA methods of digital modulation [1]. There are two major advantages of using the OFDMA method. First of all, because of its high frequency efficiency, which is attributed to the orthogonality of the OFDMA signal components. Secondly, the OFDMA eliminates the influence of multipath propagation, since the symbol time exceeds the maximum reflection delay. The residual reflection influence is removed with the help of choosing the relevant value of the guard interval.

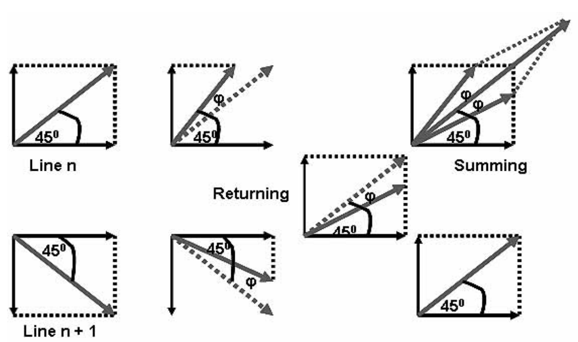

Fig. 1. Phase changing compensation in PAL principal.

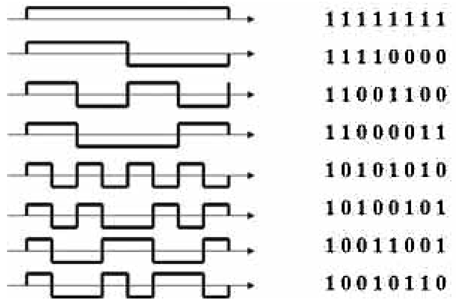

Fig. 2 Walsh function example for N = 8

The third generating idea consists in the implementation of signal distribution with the aid of the Walsh function. The proposed FBS method merges these three generating ideas.

3. FBS method principals

Let us consider the OFDMA system, which consists of N sub carriers with the MPSK modulation of each one. In FBS, the same N sub carriers are also implemented. Each component of the data is being transmitted on all N sub carriers. Thus, the same phase is transmitted N times, and the phase sign changed according to the Walsh function. Therefore, we can transmit all sub signals on all sub carriers without mutual influence.

The Walsh functions set for N = 8 is shown in Fig.2. There are N pattern of Walsh functions in total, so we can transmit N information symbols on N sub carriers. Sign of the phase i (+ or -) corresponds to 1 or 0 in the Walsh functions (see Fig. 2).

To simplify the explanation, let N = 4. Each symbol of each signal is transmitted four times on four carriers. If we implement PSK (BPSK, QPSK, 8PSK etc.) modulation, all four signals are transmitted in the same sub-carriers with respect to orthogonal conditions.

It can be shown, that any signal can be received without another signal influence. If we desire to receive signal number 2, by implementing the FFT in the receiver, this modification causes the received phases to correspond to the second pattern of Walsh functions. In other words, the signs of the phases at frequencies f2 and f4 are changed to opposite values (see Fig. 3 Receivers section). After phase changing, the sum of phases on all four frequencies does not depend on the phases of signals S1, S3, and S4. Therefore, these phases are compensated. Similarly, any N signals can be transmitted on the N sub carriers, where N is a power of two.

Corresponding to the FBS principle one symbol of l^{st} FBS signal can be described as:

$$s_{(kl),FBS} = E_l \sum_{k=0}^{N-1} e^{j[2\pi f_k t + (-1)^{W_{kl}} (\theta+\beta_i)]}, \qquad (1)$$

Where

- $0 \le t < T$
- E_l is component magnitude,
- θ is arbitrary phase, which we choose for certain system. For example, it is 30^0 or another,
- β_i *is* information symbol of the l^{st} FBS signal (BPSK or QPSK representation), i.e. $\beta \in \{+1,-1\}$ for BPSK or $\beta \in \{+1+j,-1+j,1-j,-1-j\}$ for QPSK,
- $f_k = f_0 + k\Delta f$ *is* FBS carrier frequencies, $k = 0,\dots, N-1$,
  where $\Delta f = \left| f_k - f_j \right| = 1/T$,
- W_{kl} is sequence of phases of the l^{st} FBS carrier pattern. In case of N = 8 this is l line in table on Fig. 2.

The symbol duration T is chosen to fulfill the orthogonality requirement. In the transmitted signal, the symbol duration is equal to T + τ (τ represents the guard interval duration) [1]. The demodulation will be processed with the symbol duration T.

For the signal number 4 ($S_{(k4)}$) W_{kl} pattern corresponds to l= 4. A total of 8 signals can be transmitted with l from 0 till 7 on the same 8 frequencies.

Receiver reduces the guard interval, performs FFT and changes the phases according to the used l, or multiplies by $(-1)^{W_{kl}}$

The complex l^{st} FBS signal, defined by (1), is obtained as inverse fast Fourier transform, or

$$s_{i,l(t)} = \Im^{-1}(s_{i(kl)FBS}), \qquad (2)$$

In a general case, each transmitter in the neighboring cells can transmit several signals with *l from* l_P *till* l_Q. Therefore, each symbol of the FBS signal can be described as

$$s_{i,(P\div Q)FBS}(t) = \sum_{l=l_P}^{l=l_Q} \Im^{-1}(s_{i,k,(P\div Q)FBS}), \qquad (3)$$

and in the same frequency band we can transmit signals in the neighboring cells. This fact provides, in principle, the solution to the problem of the soft handover.

4. Phase shift influence in FBS

The difference between frequencies in the FBS signal, such as frequencies found in OFDM signals, is constant and is equal to *1/T*. In reality, the Doppler shift influence exists in very high frequencies – hundreds of megahertz and higher. However, the frequency difference between sub-carriers in the OFDMA and in the FBS is very small (approximately kilohertz). For this reason, one can assume that phase changes on all sub-carriers are identical.

An example of phase changes (Δ) in the case of FBS-8 is illustrated in Fig.4.
It is evident that the sum of phase shifts before and after phase changing in the receiver is zero.

After phase changing in the receiver, the sum of phase shifts (ΣΔ) of useful signal and of all signals received together with this signal is zero (See Fig. 3).

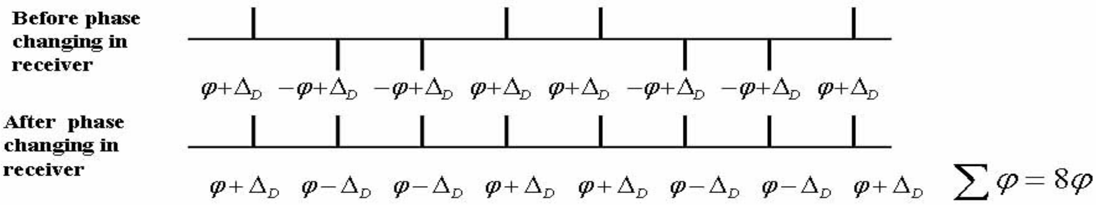

Fig. 3 Summary phases shift in FBS-8 signal.

The rigorous mathematical justification of the FBS-method can be done using the properties of the Walsh functions. We omit the proof due to the restrictions in the size of the paper. It is shown that the algorithm restores the exact value of the original phase, also in the presence of the phase shifts. The compensation of the phase shifts does not require information about the shift value, which makes the method applicable in real signal transmitting systems.

5. FBS Simulations results

The following typical system model enables connection of the FBS and OFDMA systems. A receiver is placed in the center of a zone (cell) with a diameter of 10 km. The receiver picks up signals from three transmitters located on the border of the zone. The first transmitter approaches or moves away at a speed of 120 km/h. Assuming a reflection signal with a maximal delay of 5 km (since the deflection signal is greater than the direct signal by 5 km), for example, maximal delay equals T = 10 µs. If we take a symbol duration of 100 µs, the frequency difference between sub carriers will be Δf = 1/T = 10 kHz. The first moving transmitter causes a phase shift and Doppler shift. The central carrier frequency is 10^9 Hz. Thus, the phase shift per symbol time due to a delay will be 3.6^0. The Doppler shift under these conditions can be 1% of *Δf*.

The simulation model was created in the MATLAB environment. Following every ten symbols, all three transmitters transmit test signals with maximal amplitudes and known phases. Each symbol phase of signal number one (S_1) changes

by 3^0. For Doppler shift simulation, frequencies of each symbol of a signal number change according to a Gaussian distribution with dispersion 5% of Δf.
In the case of OFDMA (Fig.4a), phase compensation was used in the decoder model for decoding of S_1 corresponding to the pilot (test) signal. Pilot symbols were transmitted after ten symbols with E_b/N_0 equals 16 dB.
FBS signal (results in Fig. 4b) was transmitted without pilot signals. OFDMA and FBS modulation were based upon: the same frequency band; the same power; and the same bit rate. The modulation method used in OFDMA was Quadrature Phase Shift Keying (QPSK). The modulation method used in FBS was 16QAM.

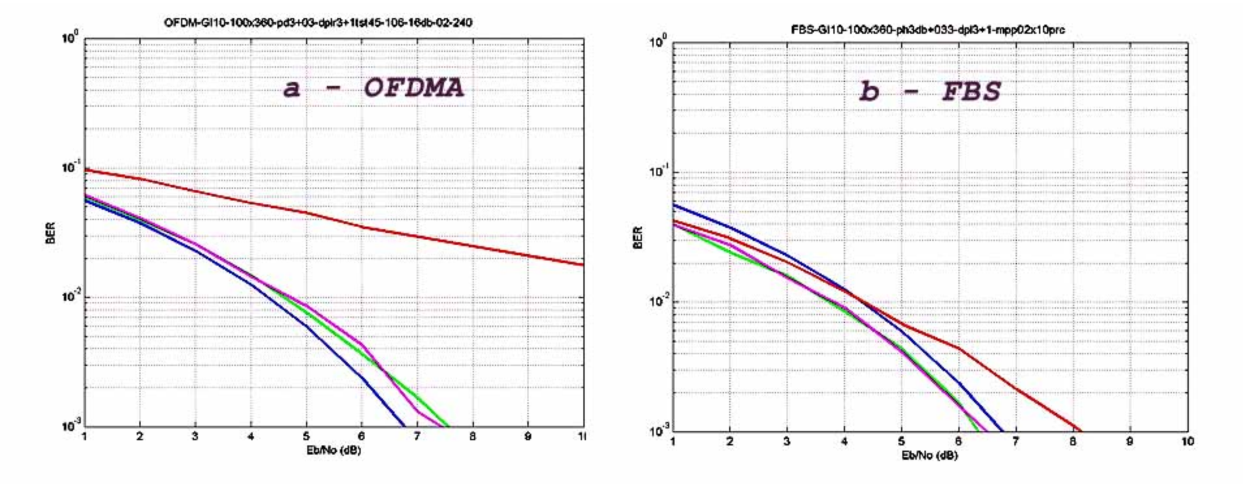

Figure 6 Simulation results. a – OFDMA, b – FBS.

Theoretical calculations ——— S_1 ———
S_2 ——— S_3 ———

These results make clear that despite the occurrence of phase shift compensation after ten symbols, the OFDMA method is not effective under these circumstances. The findings also prove that when using the FBS method without pilot signals, neither the Doppler shift nor delays had any influence upon the receiving quality.

6. Conclusion.

Proposed FBS method allows:
- Decreasing Doppler shift, delays, reflections and fading influence,
- Reducing output power density,
- Decreasing narrow band interference influence,
- Using soft hand over.

FBS does not need any test or pilot signals or equalizing process.
There is one more advantage of the FBS signal. It can be transmitted with random frequencies changing. Thus, it will be impossible to determine Doppler shift presence or whether the signal source is moving or not.
All the above features are obtained without frequency-band and power increasing.

References:

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