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New coded modulation for the frequency hoping OFDMA system

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Abstract. In this paper we consider reciever design for frequency hopping orthogonal frequency-division multiple access system [2]. We propose new demodultaion algorithm that can increase the number of simultaneous transmissions with the same bit error rate. This algoritm can use any statistic that can test equality of emprical distribution funcions. We have used Kolmogorov-Smirnov statistic in this paper. Computer simulation showed that the demodulator proposed can support more simultaneous transmissions than the ones known.

1 Introduction

Frequency hoping OFDMA is a multiuser communication system. In [2] it was described for 10 users and a base station. In this paper we will use FH OFDMA in an ad-hoc communication system with several hundreds of transmitters. The main problem was to increase the number of simultaneous transmissions with bit error rate of the inner decoder output below 0.05. This allows us to use an outer code with rate 0.5.

2 Frequency hoping OFDMA

In FH OFDMA network each user pseudorandomly selects a sequence of q subchannels and uses of them to transmit energy. The receiver knows this sequence and thus can understand which symbol was transmitted. Each transmitter selects its subchannel sequence independently. The probability of intersection of these sequences being nonzero is described in [2]. As we want to increase the number of simultaneous transmissions we should find a way to deal with errors and erasures that come from such intersections.

We propose the following coded modulation: each user transmits T copies of each symbol. Different transmitters might have neither block nor symbol synchronization. On the receiver the power of signals from different transmitters can vary greatly. We will describe several demodulators for this coded modulation.

To make demodulator algorithms easier to describe, we will first make some transformations of the received signal. Let π_i denote the pseudorandom frequency sequence selected by transmitter. Let $\mathbf{M}$ denote the signal received, where each column is an OFDM symbol. We will construct matrix $\mathbf{R}$ so that $R_{it} = M_{\pi_i t}$. All the demodulator described below map $\mathbf{R}$ to a number $i : 1 \leq i \leq q$. We will also ignore the phase of the complex signal received so that all elements of $\mathbf{R}$ are absolute values.

A naive approach is to use energy sum demodulator:

$$D_{energysum}(\mathbf{R}) = \arg\max_i \sum_{t=1}^{T} \mathbf{R}_{it} \tag{1}$$

This demodulator is very simple to implement, but its error correction efficiency is not so good. In the next two sections we will propose two other algorithms.

3 Using fast frequency hoping frequency shift keying demodulators

Fast Frequency Hoping Frequency Shift Keying is a lot like single user FH OFDMA. The transmitter uses M-FSK modulation and then makes a pseudorandom permutation. Receiver makes the inverse permutation and then calls a demodulator. A lot of the demodulators are described in [1]. We will consider only one of them: the Order Statistics-Normalized Envelope Detection Based Diversity Combining (OSN), as it shows the best results in FFH FSK environment.

The OSN demodulator is described with the following algorithm. First we sort the rows of $\mathbf{R}$. Then

$$D_{OSN}(\mathbf{R}) = \arg\max_{i=\overline{1,q}} \sum_{t=1}^{T} \frac{\mathbf{R}_{it}}{c_t}, \tag{2}$$

where $c_t = \sum_{i=1}^{q} \mathbf{R}_{it}$.

4 The proposed demodulation algorithm

Both demodulators described above rely on the value of the energy received. We propose a demodulator that deals only with energy ranks. Let us construct rank matrix $\mathbf{X}, \mathbf{X}_{it} = |A_{it}|$, where $A_{it} = \{(m,n) : m = \overline{1,q}, n = \overline{1,T}, \mathbf{R}_{mn} < \mathbf{R}_{it}\}$. Let us describe the demodulation algorithm.

Let $K(\vec{x}, \vec{y})$ be some metric of the difference between the empirical distribution functions of the samples $\vec{x}$ and $\vec{y}$. Let $\vec{r^i}$ denote the i-th row of $\mathbf{R}$. The the demodulator can be expressed as

$$D_{proposed} = \arg\max_i K(\vec{r^i}, \mathbf{R}) \tag{3}$$

There are several metrics that can be used as $K(\vec{x}, \vec{y})$ and that can be expressed as functions of ranks. In this paper we use Kolmogorov-Smirnov metric $K_{KS}(\vec{x}, \vec{y}) = \max_z |F_x(z) - F_y(z)|$, where $F_x(z)$ and $F_y(z)$ are empirical distribution functions of the samples $\vec{x}$ and $\vec{y}$ respectively.

Let us describe $K_{KS}(\vec{r^i}, R)$ as a function of $\mathbf{X}$. First we sort the elements of $\vec{r^i}$. Let $F(x)$ and $F_i(x)$ denote empirical cdfs of $\mathbf{R}$ and $\tilde{\mathbf{r}}^{\mathbf{i}}$ respectively. Let us first note, that $F(\mathbf{R}_{it}) = \mathbf{X}_{it}/qT$ and $F_i(\vec{r^i_t}) = t/T$. The maximum of $K_{KS}(\vec{r^i}, R)$ can only be reached at $\mathbf{R}_{it} - 0$ and $\mathbf{R}_{it}$. So,

$$K_{KS}(\vec{r^i}, R) = \frac{1}{qT} \max_t \max(|\mathbf{X}_{it} - tq|, |\mathbf{X}_{it} - 1 - t(q-1)|)$$

5 Simultaion results

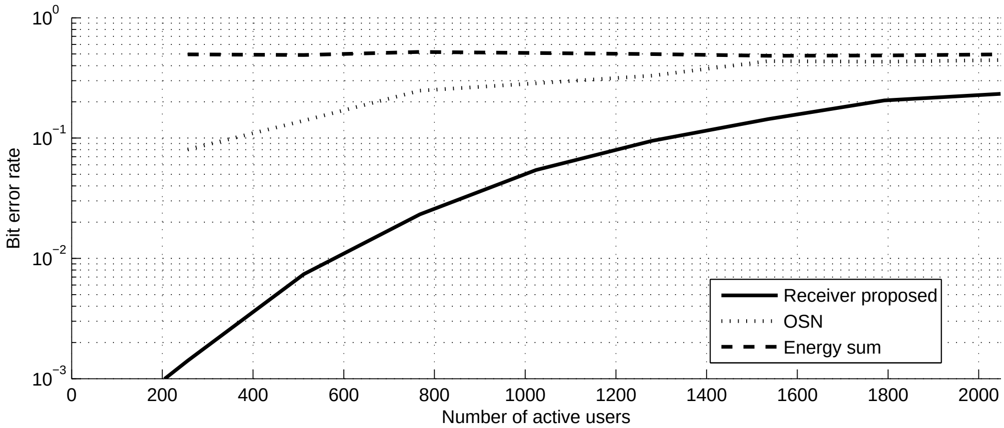

Figure 1: Simulation result in semilogy scale

To compare the demodulators described we have developed a computer simulation system. The following parameters were chosen:

- $q = 256$
- $T = 8$
- $Q = 2048$
- Signal to noise ratio 20 dB.
- Path loss was proportional to d^{-3}.

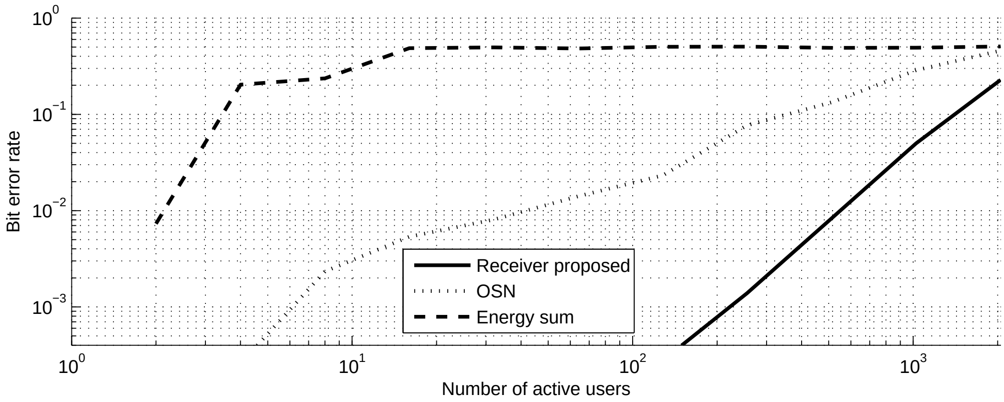

Figure 2: Simulation result in loglog scale

To simulate uniform distribution of the transmitters of the available space, we have placed i-th interfering transmitter at range $\sqrt{\frac{N}{2i}}$ from the receiver, where N is the total number of interfering transmitters. The distance between the right transmitter and the receiver was 1.

Simulation results are shown at the fig. 1 and 2. They display results for the same parameters but different scales. These figures show that it is possible to have about 1000 simultaneous transmissions with the demodulator proposed.

6 Conclusion

In this paper we considered an ad-hoc FH OFDMA communication system with many incoherent transmitters. In order to increase the number of simultaneous transmissions we proposed a coded modulation and several demodulators. One of the demodulators was based on the existing FFH FSK demodulator called OSN. We also proposed new demodulator based on Kolmogorov-Smirnov metric. Computer simulation showed that we can achieve 1000 simultaneous transmissions with ber below 0.05.

References

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[2] V. Zyablov and D. Osipov. On the optimum choice of a threshold in a frequency hopping ofdma system. *Problems of Information Transmission*, 44:91–98, 2008. 10.1134/S0032946008020026.