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Abstract	A subcarrier based polling mechanism is proposed for the 802.16ab OFDM air interface.
Purpose	Aid in the evaluation of competing PHY layer proposals.
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Subcarrier Based Polling for 802.16ab OFDM PHY

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1. Introduction

According to 802.16 MAC protocol, subscriber stations use a slotted random access technique to convey bandwidth requests. This technique incurs a non-negligible overhead on the MAC layer. To overcome, an alternative mechanism for bandwidth requests is proposed. The mechanism uses on-off keying over OFDM to provide a multiple access scheme. With the proposed scheme, several subscriber stations can request bandwidth simultaneously. Thus, the random access mechanism is not needed, and the efficiency of the air protocol is improved.

2. The Proposed Mechanism

In the proposed mechanism, the BS allocates an uplink time slot dedicated to SBP transmission. Within this slot, subscriber stations are assigned specific allocations in time and frequency. More specifically, stations are given a set of OFDM symbols and a set of subcarriers within which they can transmit. A station requests bandwidth by energizing the allocated subcarriers. When no bandwidth requests are needed, the station does not energize the subcarriers, and no transmission is performed. The transmissions are detected by the BS, which may grant the request by assigning transmission slots.

Detection is performed by collecting the energy from the subcarriers of a single station, and comparing to a predetermined threshold. In section 3, it is shown that this detection scheme provides good performance, in terms of mis-alarms and false-detection. Thus the proposed mechanism fits well within existing mechanisms of the PHY layer, both in the SS and BS, and incurs no additional complexity.

The basic allocation unit is set of equally spaced subcarriers of one OFDM symbol. The number of subcarriers in a basic allocation N_{sc}, and the number of basic allocations in an OFDM symbol, N_a, is given in is given in Table 1. Refer also to Figure 1.

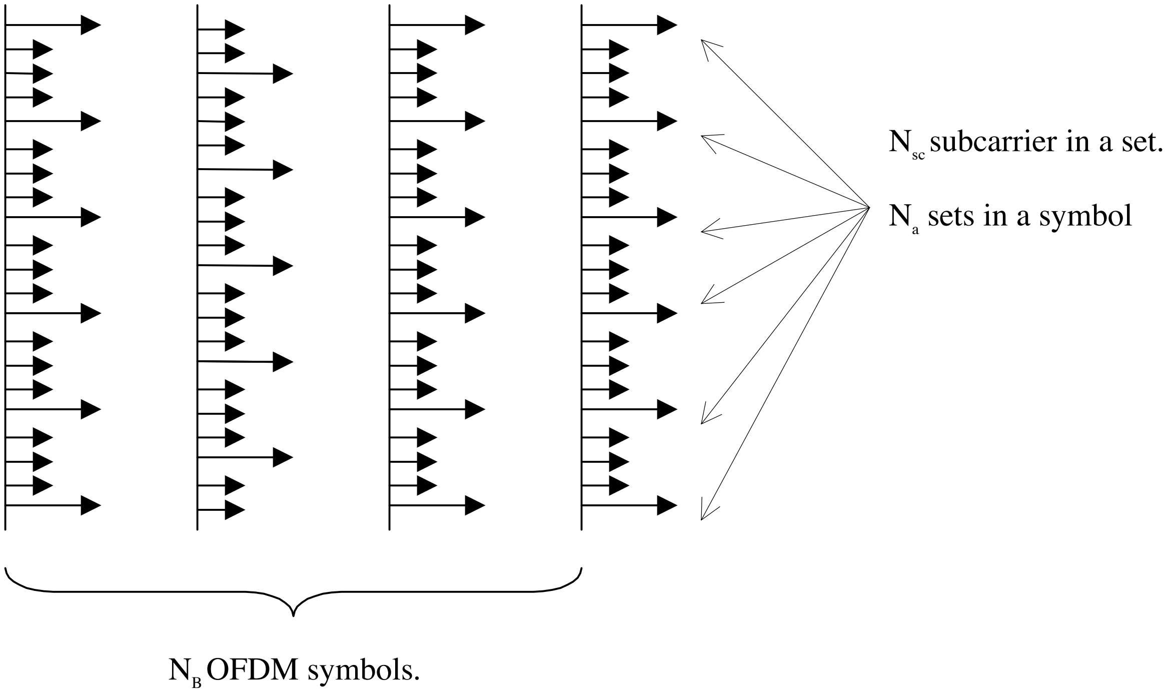

Figure 1 Basic allocations and parameters

FFT size	Number of subcarriers per allocation	Number of allocation in an OFDM symbol
	N_{sc}	N_a
64	4	13
256	8	25

512	8	49

Table 1 Basic allocations

The BS allocates a number of OFDM symbols for SBP. Let N_B denote this number. The maximum number of stations is $N_{maxSS} = N_B * N_a$

To avoid fades, the subcarrier assignment is randomly varied from poll to poll. This is performed as follows. At registration, the BS assigns to each SS a number SSID in the range 0... NmaxSS-1. Then, with each multicast polling, the BS broadcasts a random number R in the same range. An SS uses these values to determine the frequency allocation, and the symbol allocation according to:

$n = (R + SSID) \bmod N_{maxSS}$

where n is the allocation number. The allocation number determines the OFDM symbol and the frequency set within it, according to:

OFDM symbol number = $\text{floor}(n / N_a)$

Frequency set number = $n \bmod N_a$.

The relative phases of the subcarriers are set so the resulting transmitted peak to average power ratio will be small. This helps reducing non-linear distortion in the transmit chains. This also increases the immunity of the system against a single station transmitting at an excessive power level. However, since the received signal is a superposition of many signals, the PAPR of the composite signal is not low.

The subcarrier loading for $N_{sc}=4$ is given by: {1 1 -1 1}
The subcarrier loading for $N_{sc}=8$ is given by: { 1 1 -1 1 -1 -1 -1 1}

Since in each transmitted waveform only a fraction of the subcarriers are used, the overall transmitted power is also a fraction of the transmitted power of the full OFDM. Signal fact maybe used to 'bust' the signal, thereby increasing the performance. Typical busting vaules maybe in the range of 3…6 dB. However th e maximum busting level is $10\log_{10}N_a$.

3. Performance Analysis

3.1. System model

For performance analysis, let us consider an idealized subcarrier-based-polling system, as depicted in Figure 2. For simplicity the system is modeled at base-band.

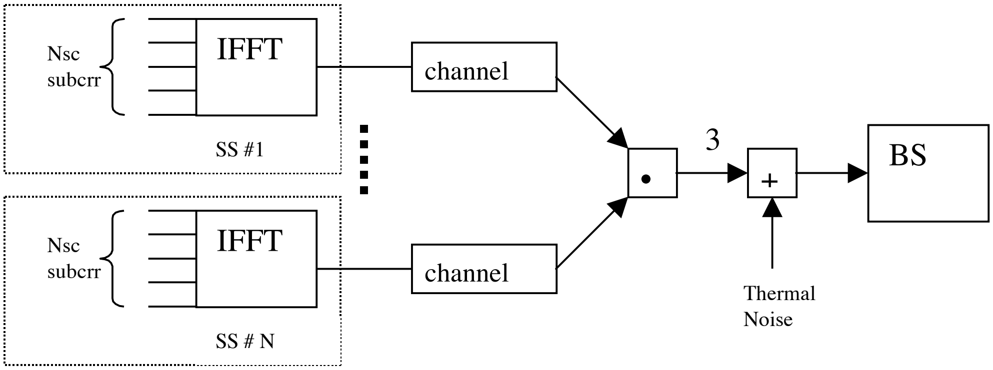

Figure 2 Model of as idealized SBP system

The system consists of N transmitting SSs and one receiving BS. Each SS unit is modeled by an IFFT unit, where only N_{sc} of the subcarriers are energized. The transmitted signal is passed through a multipath channel and received at the BS with the presence of white Gaussian noise. At the BS, the received signal is transformed to frequency domain and analyzed.

The system is idealized because no imperfections, such as frequency and timing error are modeled.At the above conditions, the system can be broken to N independent communications systems. Each such system is shown in

Figure 3.

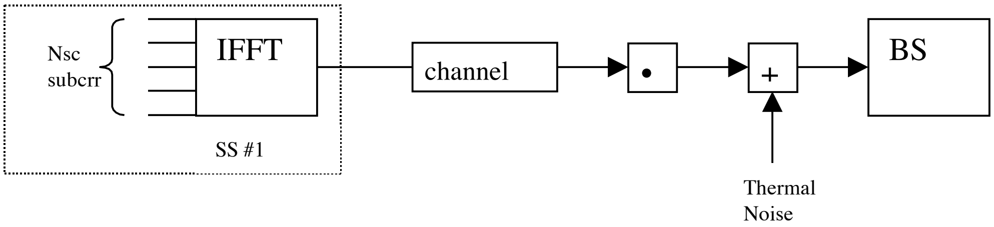

Figure 3 A single link of the SBP system

Let r_n, $n=1\ldots N_{sc}$, denote the set of received subcarrier at the BS side. Let us denote by:

A - The amplitude of the transmitted subcarriers.

v_n – The complex Gaussian noise element at the received side.

c_n – The complex channel response of subcarrier n.

Then r_n can be written as

$$r_n = \begin{cases} Ac_n + v_n & '\mathit{on}'\text{–}\mathit{transmission} \\ v_n & '\mathit{off}'\text{–}\mathit{tranmission} \end{cases} \qquad (1)$$

The random variables v_n are taken from complex Gaussian distribution with zero mean and σ^2 variance per dimension.

Let us define the Signal to Noise Ratio (SNR) at the FFT output to be:

$$SNR = \frac{|A|^2 E\{|c_n|^2\}}{2\sigma^2} \qquad (2)$$

Where E{} is the expectation operator. Here we have assumed that the statistics of c_n does not depend on n.

Detection is performed by summing the energies of the received subcarriers. The sum of energies is then compared to a predefined threshold.

Let *th* denote the predefined threshold and let Y denote the sum of envelops of the subcarriers, namely

$$Y = \sqrt{\sum_{n=1}^{N_{sc}} |r_n|^2} \qquad (3)$$

In the following we shall be interested in the false alarm (FA), denoted by P_{FA} and misdetection probability P_{MD}. The probabilities are given by:

P_{FA} = Prob ($Y > th$ | *'off'- transmission*) (4)

P_{MD} = Prob ($Y < th$ | *'on'- transmission*) (5)

The FA probability can be readily computed. For the 'off transmission' we have:

$$Y = \sum_{n=1}^{Nsc} |v_n|^2 . \qquad (6)$$

Thus, Y is a centric chi-square with $2N_{sc}$ degrees of freedom. Thus

$$P_{FA} = e^{-th^2/2\sigma^2} \cdot \sum_{k=0}^{N_{SC}-1} \frac{1}{k!}\left(\frac{th^2}{2\sigma^2}\right)^k . \qquad (7)$$

3.2. Performance in AWGN

For the AWGN case, we assume $c_n = \exp(j\phi_n)$, where ϕ_n is uniformly distributed between 0..2π.

For the on transmission:

$$Y = \sum_{n=1}^{N_{sc}} |Ac_n + v_n|^2 . \qquad (8)$$

Thus Y is non-centric chi square with $m=2N_{sc}$ degrees of freedom. The CDF of Y is given by:

$$F_Y(y) = 1 - Q_m\left(\frac{s}{\sigma}, \frac{y}{\sigma}\right) \qquad (9)$$

Where $Qm(\ ,\ )$ is the generalized Q function (cf. [1]) and s is given by :

$$s = \sqrt{\sum_{n=1}^{N_{Bc}} |A|^2} = \sqrt{N_{sc}|A|^2}\ . \qquad (10)$$

Therefore:

$$P_{MD} = 1 - Q_m\left(\frac{\sqrt{N_{sc} \cdot |A|^2}}{\sigma}, \frac{th}{\sigma}\right) \qquad (11)$$

Or alternatively:

$$P_{MD} = 1 - Q_m\left(\sqrt{2 \cdot Nsc \cdot SNR}, th\right) \qquad (12)$$

A plot of P_{MD} vs. SNR is shown in Figure 4. Here the threshold was set so $P_{FA}=10^{-3}$.

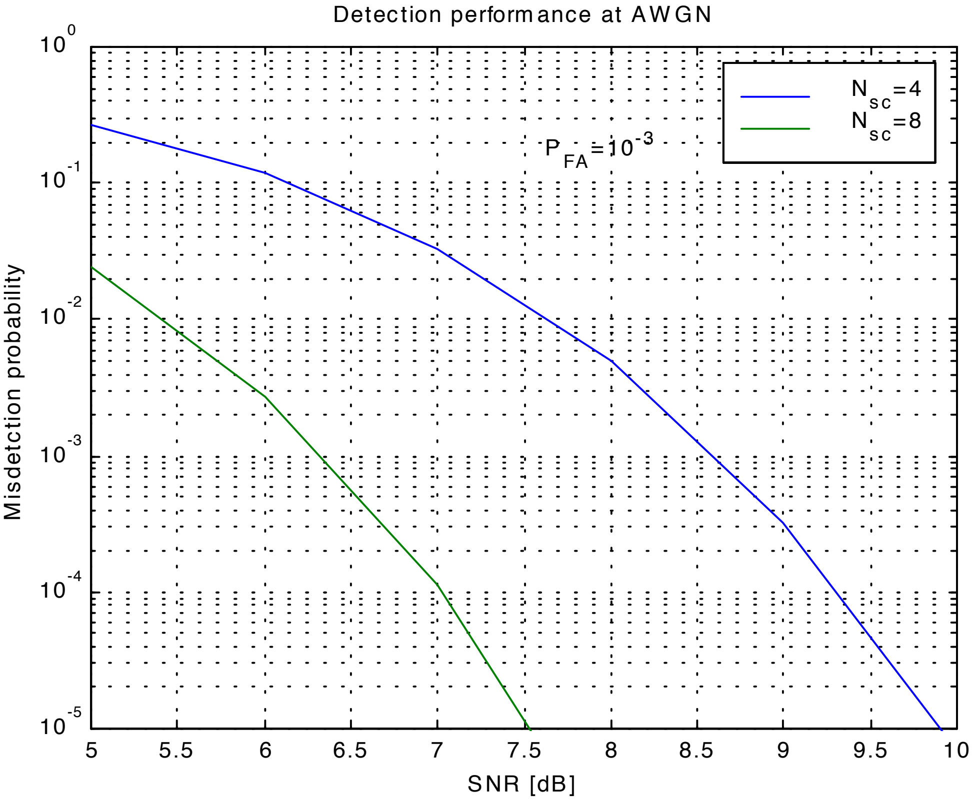

Figure 4 Detection performance at AWGN

When busting is applied the detection performance are improved by 3 dB. This is shown in Figure 5.

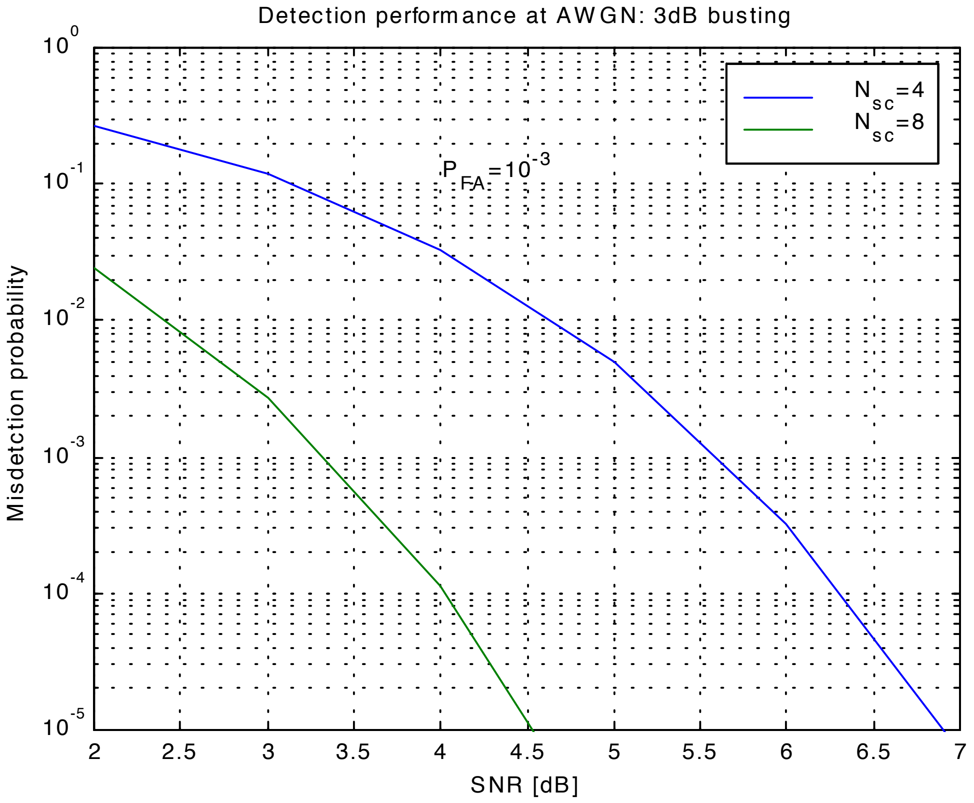

Figure 5 AWGN performance with 3 dB busting

3.3. Performance in Rayleigh fading

To evaluate the effect of fading and multipath on the system, we assumed a Rayleigh fading statistics, with independent fades at each sub-carrier. This corresponds to a deep NLOS situation with a long impulse response.

Let c_n be modeled as a zero mean complex Gaussian random variable with $E\{c_n c_m^*\}= \delta_{n,m}$, where $\delta_{n,m}= 1$ iff n=m.

In this case for the 'on-transmission' we have that r_n is the sum of two zero mean complex Gaussian random variables, and the sum is also a zero mean Gaussian variable with variance per dimension given by:

$$\sigma_r^2 = 0.5\,|A|^2+\sigma^2 = (½\,SNR + 1)\,\sigma^2, \qquad (13)$$

and the MD probability is given by:

$$P_{MD} = 1 - e^{-th^2/2\sigma_r^2} \cdot \sum_{k=0}^{2N_{sc}-1} \frac{1}{k!}\left(\frac{th^2}{2\sigma_r^2}\right)^k \qquad (14).$$

Equation (14) was used to plot the misdetection probabilities, as shown in Figure 6.

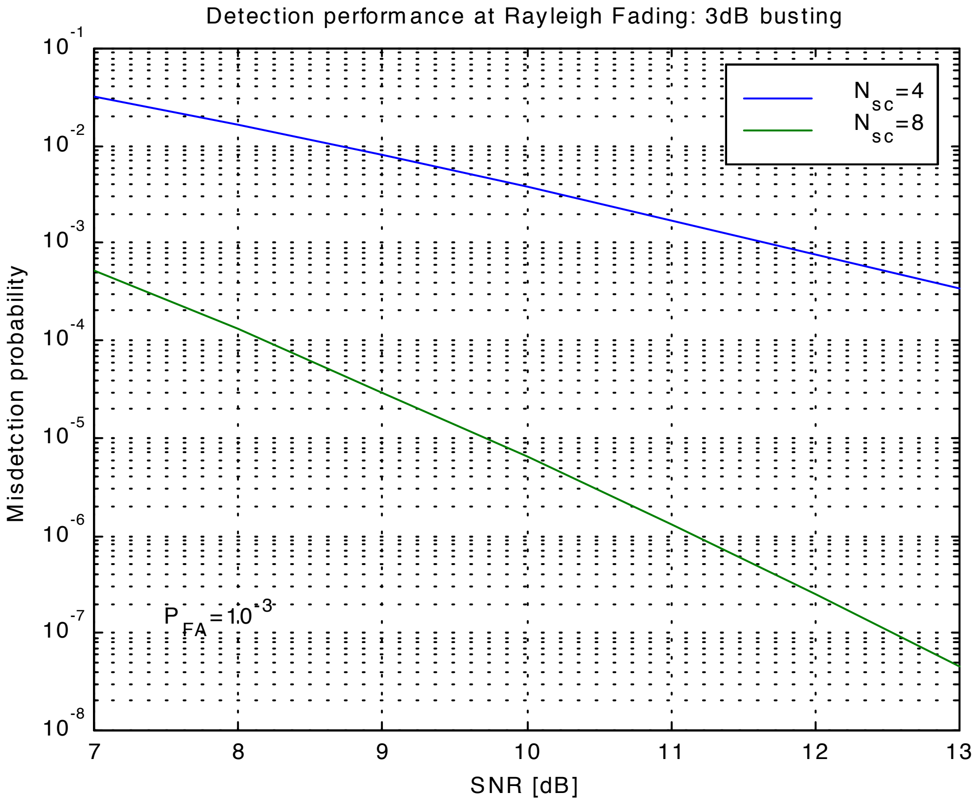

Figure 6 Performance at Rayleigh fading

4. Conclusions

A subcarrier based polling mechanism was proposed for 802.16ab OFDM air interface. The mechanism improves the performance of the MAC protocol, while fitting well with existing elements in the PHY layer. It performances well in terms of mis-detection and false alarm both under AWGB and Rayleigh fading.

5. References

[1] J.G Proakis: Digital Communications systems