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TITLE:

Comparison of Differential and Coherent RACH Preamble Detection

SOURCE:

Motorola

ABSTRACT:

This contribution compares conventional coherent detection of the RACH preamble with a differential approach as a function of Doppler spread. Coherent detection is found to be superior at speeds up to about 200 km/h at a carrier frequency of 2 GHz..

1.0 Introduction

Two methods of RACH preamble detection have been studied. The first consists of coherently summing the preamble symbols, squaring the result, and comparing with a threshold. In [1] an alternative approach based on differential detection is proposed. This approach is claimed to have significantly superior performance in channels with multipath fading and frequency offset. The performance of these approaches was compared in [2]. This contribution presents simulation results which further compare these approaches. The comparison is based on the probability that a transmitted preamble is detected for a fixed false alarm probability. This differs from [2] where the preamble with the largest metric is compared with the transmitted preamble to determine a detection probability.

2.0 Signal Model

Figure 1: illustrates the model used for the comparison. The transmitted signal consists of the length 16 preamble sequence, $\mathbf{p} = \begin{bmatrix} p_0 & p_1 & \cdots & p_{15} \end{bmatrix}^T$ spread by a length 256 spreading code. The channel consists of multipath fading and additive noise. The fading is assumed to be constant over the duration of a single preamble symbol, 256 chips, and distributed as complex Gaussian random variables, i.e., independent real and imaginary Gaussian distributed components with equal variance. Denote the random vector of fading values across the preamble as $\mathbf{f} = \begin{bmatrix} f_0 & f_1 & \cdots & f_{15} \end{bmatrix}^T$. The correlation between these values is assumed to follow the classical Jakes spectrum:

$$E\{ f_k f_{k-l}^* \} = J_0\left(\frac{512\pi v T_c l}{\lambda}\right) \tag{1}$$

where v is the vehicle speed and λ is the carrier wavelength.The additive thermal noise has two-sided density $N_0/2$ The $T_c/2$ spaced received signal $r(k)$ is first matched filtered with the length 256 spreading code. The result is the 16 element vector $\mathbf{y} = \begin{bmatrix} y_0 & y_1 & \cdots & y_{15} \end{bmatrix}^T$:

$$\mathbf{y} = M\sqrt{E_c}\mathbf{f} \bullet \mathbf{p} + \mathbf{n} \tag{2}$$

where $\bullet$ denotes Schur or element by element product and $\mathbf{n} = \begin{bmatrix} n_0 & n_1 & \cdots & n_{15} \end{bmatrix}^T$ is a vector of independent complex Gaussians random variables with variance (real + imaginary part) MN_0, E_c is the energy per chip, and $M = 256$.

Coherent Detection

The coherent detection statistic, decision z_c, is calculated as

(3)

$$
\begin{aligned}
z_c &= \left| \sum_{l=0}^{15} y_l p_l^* \right|^2 \\
&= \left| \sum_{l=0}^{15} M\sqrt{E_c} f_l + p_l^* n_l \right|
\end{aligned}
\tag{4}
$$

Differential Detection

The differential detection decision statistic, z_d, is calculated as

$$
\begin{aligned}
z_d &= \sum_{l=0}^{14} \mathrm{Re}\{ y^*_l y_{l+1} p_l p^*_{l+1} \} \\
&= \sum_{l=0}^{14} \mathrm{Re}\{ (M\sqrt{E_c} f_l^* + p_l n_l^*)(M\sqrt{E_c} f_{l+1} + p^*_{l+1} n_{l+1}) \}
\end{aligned}
\tag{5}
$$

For both methods the decision statistic is compared with a threshold to determine the presence of

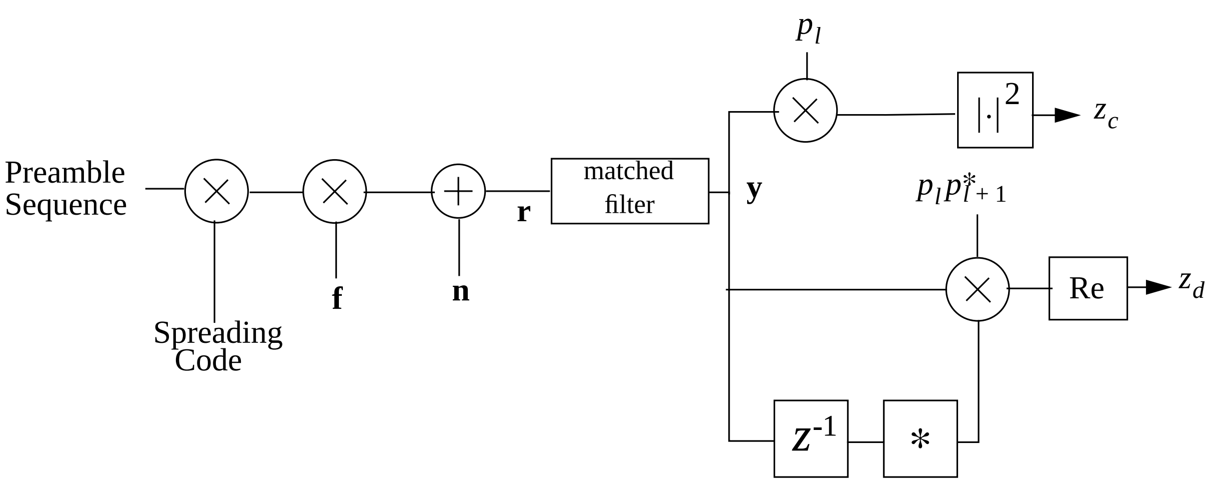

Figure 1: Signal Model

the preamble.

3.0 Simulation Results

The signal model above was simulated to obtain the probabilities of detection and false alarm. Figures are plots of detection probability vs. E_c/N_0 (SNR) for various speeds. The false alarm probability is fixed at 2.3×10^{-5} for both methods. Figure 2 shows the expected superiority of coherent accumulation at slow speeds: differential detection is approximately 2 dB worse. As a point of reference, the -21 dB Ec/Ior value corresponds to an Eb/No of 5 dB for SF=128 (data rate $\approx 10kbps$). Figures 3 through 5 show the degradation of coherent accumulation with increased speed. Note that coherent detection outperforms differential detection through 200 km/h. Only at 300 km/h does differential detection offer improved detection. At approximately 380 km/h coherent detection suffers the same 2 dB degradation that differential detection incurs at slow speeds.

4.0 Conclusion

The simulation results presented in this contribution show little reason to modify the preamble sequences for differential detection. The 2 dB degradation in performance at slow speeds could only be justified if even greater degradation would occur at high speeds with the coherent approach. Although such degradations do occur at speeds greater than 380 km/h, the occurrence of such speeds in fully scattered environments, as was assumed here, would be quite rare. In addition it is likely that the channel estimation algorithms used on the preamble message will be optimized for speeds much lower than 380 km/h; the result being that the message error rate will tend to be high at speeds above 380 km/h anyway. The reduced sensitivity of coherent detection at these speeds will compensate for this effect.

[1] Tdoc SMG2 UMTS-L1 620/98, “Random Access Preamble Detection in the Presence of Doppler”, Interdigital

[2] Tdoc SMG2 UMTS L1 2x99-011, “Random Access Preamble Detection in Doppler; Performance in ITU Channel Model”. Interdigital.

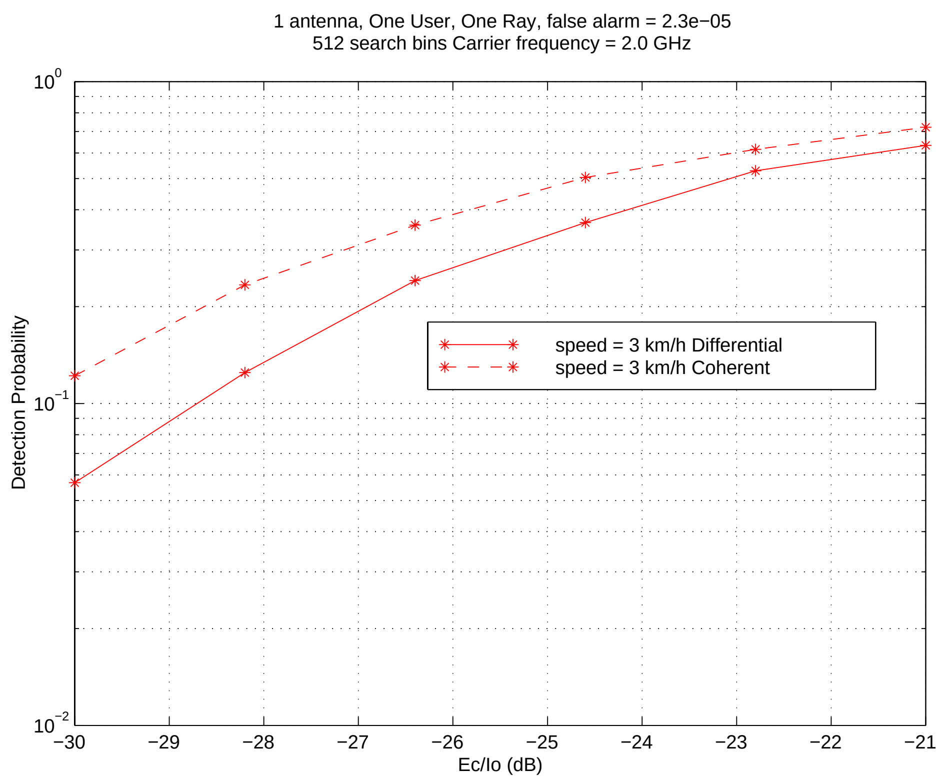

Figure 2: 3 km/h

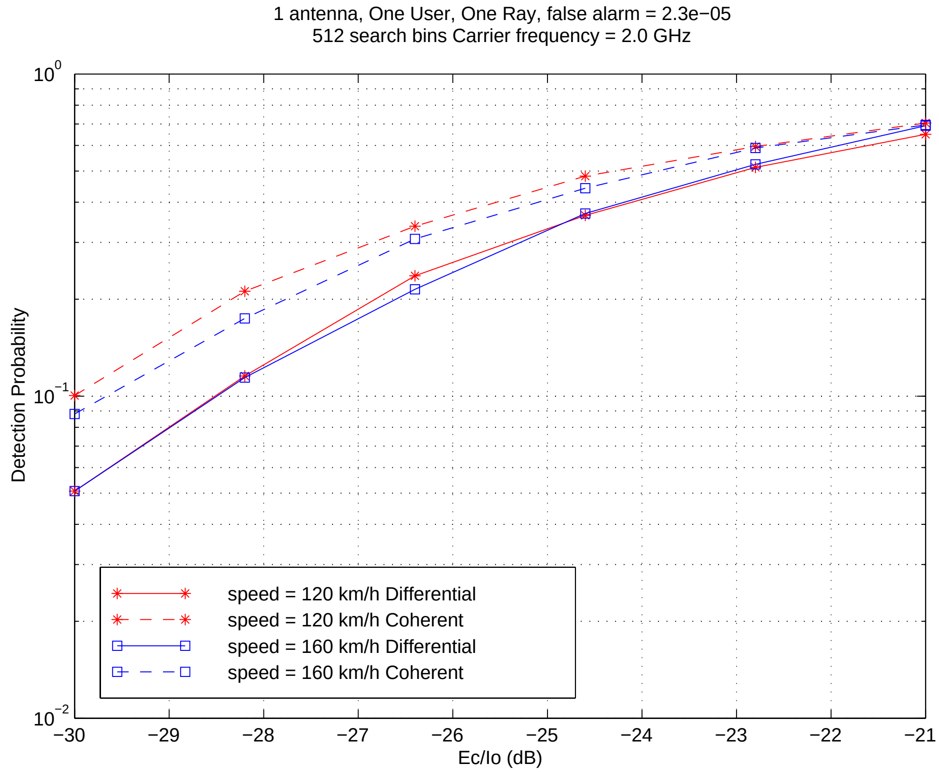

Figure 3: 120 and 160 km/h

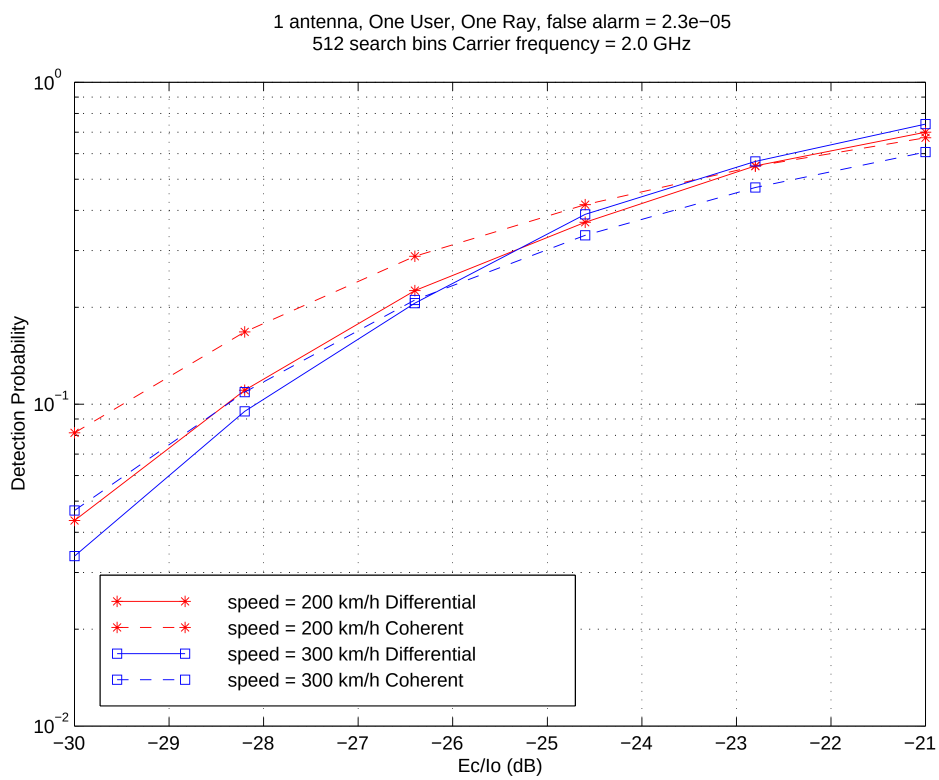

Figure 4: 200 and 300 km/h

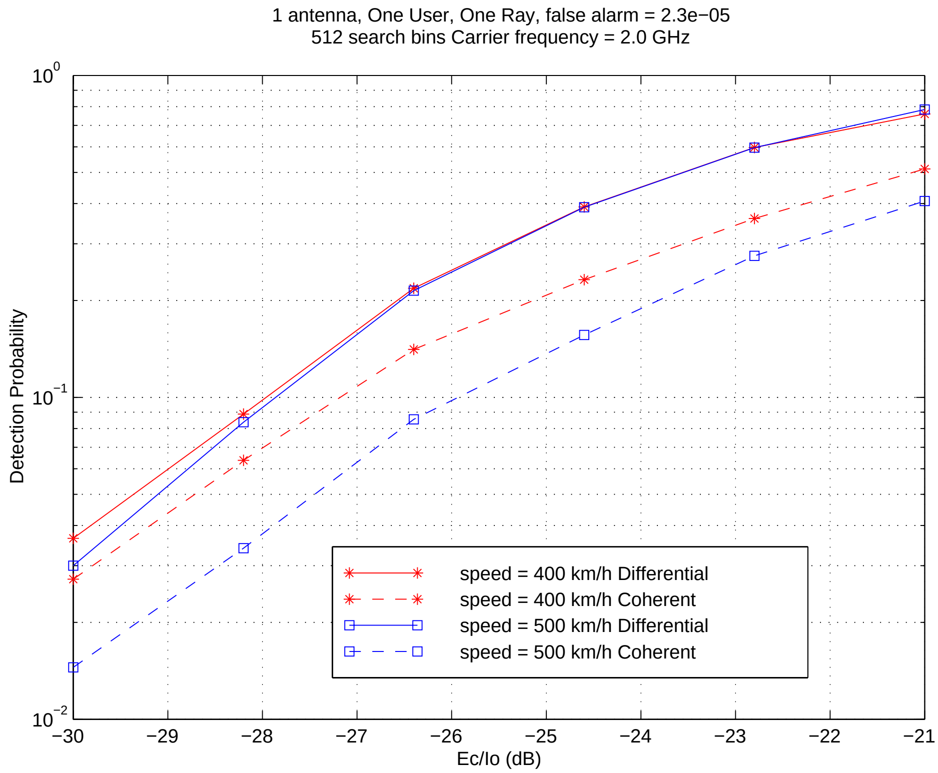

Figure 5: 400 and 500 km/h