Path-Based Frequency Offset Estimation for Acoustic OFDM Systems

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Description:

This poster presents a path-based frequency offset estimation in the context of a single input multiple output orthogonal frequency division multiplexing (OFDM) system. We address scenarios in which the multipath channel exhibits different Doppler shifts on different propagation paths, and such channel can be found in practical applications, including underwater acoustic communications. The proposed algorithm first isolates the multipath signals and then estimates the frequency offset per path. The Doppler compensated signals from multiple paths are subsequently recombined, and differentially coherent detection is applied, keeping the receiver complexity at minimum. The performance is demonstrated through simulation, showing excellent results in terms of data detection mean squared error (MSE) and bit error rate (BER).

Signal and Channel Models

Transmitted signal:

$$s(t) = \mathrm{Re}\left\{\sum_{k=0}^{K-1} d_k e^{j2\pi f_k t}\right\}, \quad t \in [-T_g, T]$$

- OFDM sys. with K carriers and bandwidth B
- f_0: first carrier frequency
- Δf: carrier spacing
- $T = 1/\Delta f$: symbol duration
- b_k: unit amplitude PSK data symbols
- $d_k = b_k d_{k-1}$: differentially encoded symbols

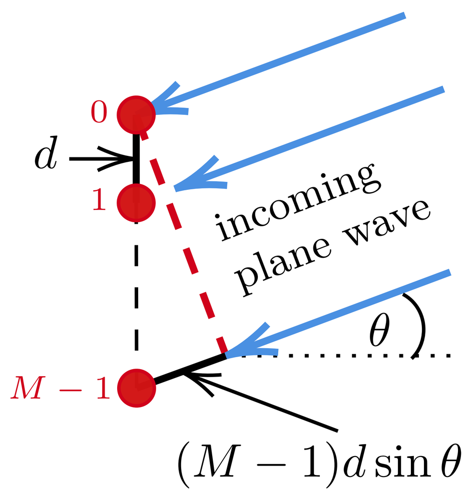
Channel: P propagation paths

$$h_m(\tau, t) = \sum_{p=0}^{P-1} h_p^m(t)\delta(\tau - \tau_p^m(t))$$

Received signal: M receivers

$$\tilde{\mathbf{v}}(t) = \sum_{k=0}^{K-1} d_k \mathbf{H}_k(t) e^{j2\pi k \Delta f t} + \tilde{\mathbf{w}}(t), \quad t \in [-T_g, T]$$

$$\mathbf{H}_k(t) = \sum_{p=0}^{P-1} e^{j\beta_{p,k} t} h_p e^{-j2\pi f_k \tau_p^0} \mathbf{s}_M(2\pi f_k \Delta\tau_p)$$



$$\mathbf{s}_M(\varphi) = \begin{bmatrix} 1 \\ e^{-j\varphi} \\ \vdots \\ e^{-j(M-1)\varphi} \end{bmatrix}$$

$$\Delta\tau_p = \frac{d}{c}\sin\theta_p$$

Algorithm

1. **Multipath angle identification:**

$$S(\theta) = \sum_k \left| \mathbf{s}'_M(2\pi f_k \Delta\tau) \tilde{\mathbf{V}}_k \right|^2$$

$$\hat{\theta}_p = \mathrm{peaks}_\theta \{S(\theta)\}, \quad p = 0, \ldots, P-1$$

2. **Null-steering and Beamforming:**

$$\mathbf{w}_{k,p} = \hat{\mathbf{S}}_k \left[\hat{\mathbf{S}}'_k \hat{\mathbf{S}}_k\right]^{-1} \mathbf{e}_p$$

$$V_{k,p} = \mathbf{w}'_{k,p} \tilde{\mathbf{V}}_k, \quad p = 0, \ldots, P-1$$

$$v_p(t) \approx e^{j2\pi\beta_p t} c_p \sum_{k=0}^{K-1} d_k e^{-j2\pi k \Delta f \tau_p^0} e^{j2\pi k \Delta f t}$$

3. **Frequency offset estimation:**

$$y_{k,p}(\hat{\beta}_p) = \int_0^T e^{-j\hat{\beta}_p t} v_p(t) e^{-j2\pi k \Delta f t} dt$$

$$\hat{b}_{k,p}(\hat{\beta}_p) = \frac{y_{k-1,p}^*(\hat{\beta}_p) y_{k,p}(\hat{\beta}_p)}{|y_{k-1,p}(\hat{\beta}_p)|^2}$$

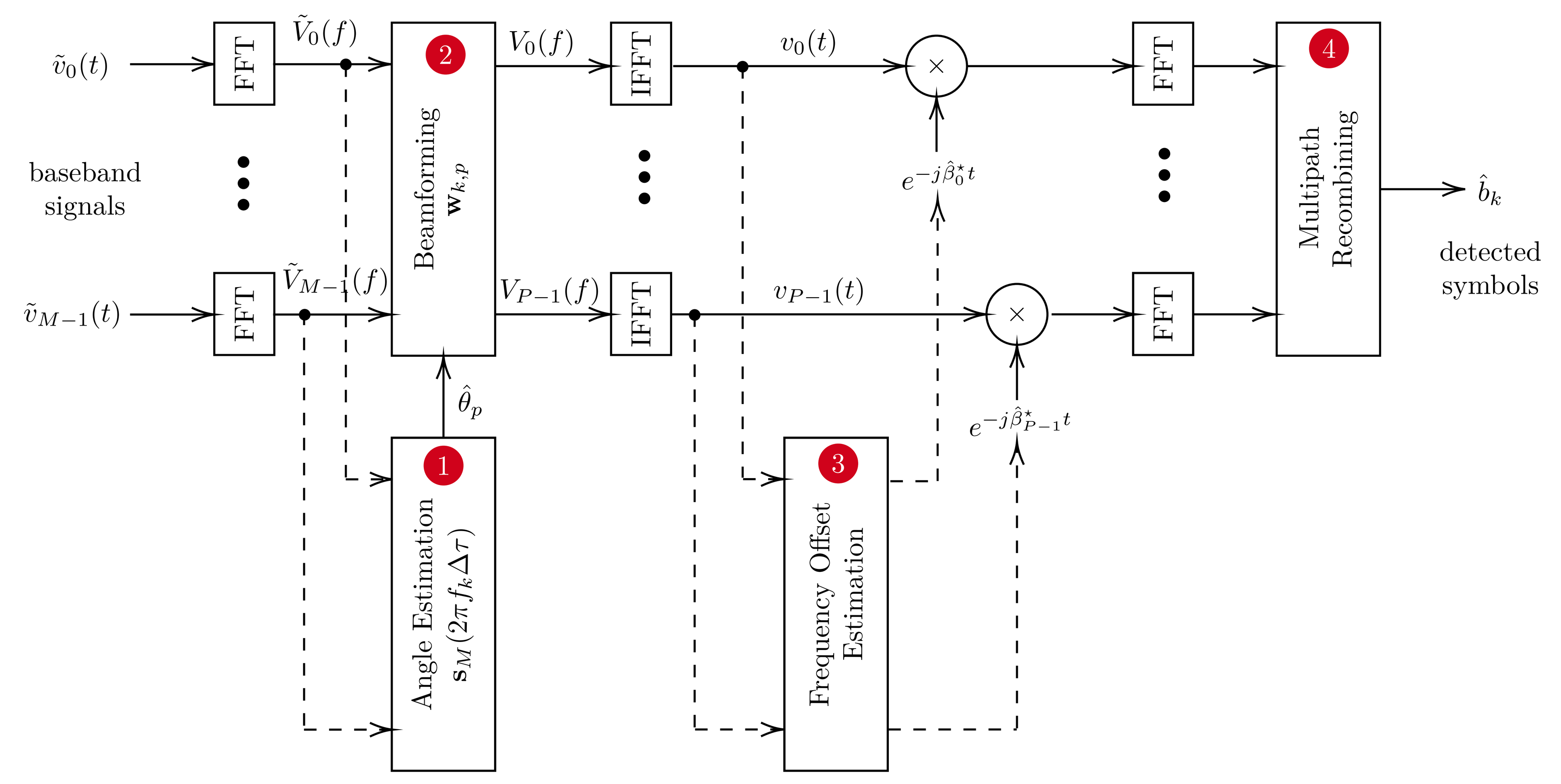
$$E[\hat{\beta}_p] = \sum_{k \in \mathcal{K}_p} \left| b_k - \hat{b}_{k,p}(\hat{\beta}_p) \right|^2$$

$$\hat{\beta}_p^\star = \arg\min_{\hat{\beta}_p} E[\hat{\beta}_p]$$

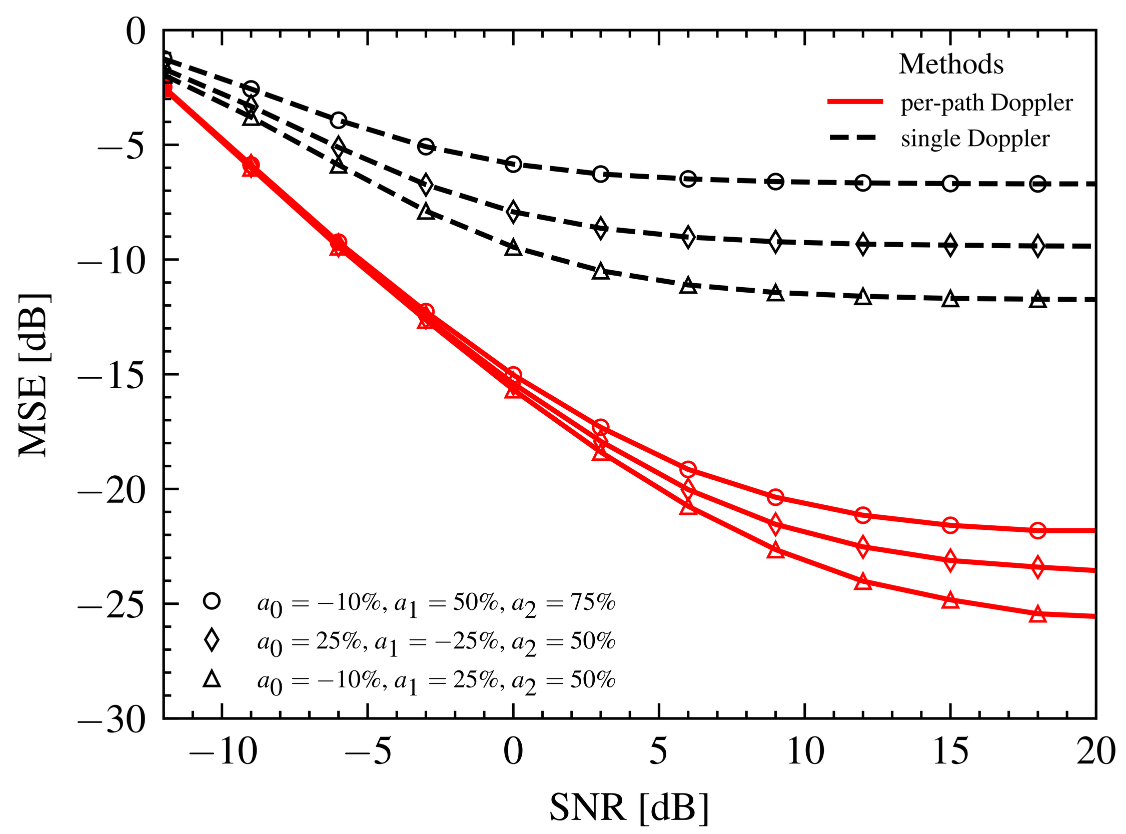
4. **Data detection:**

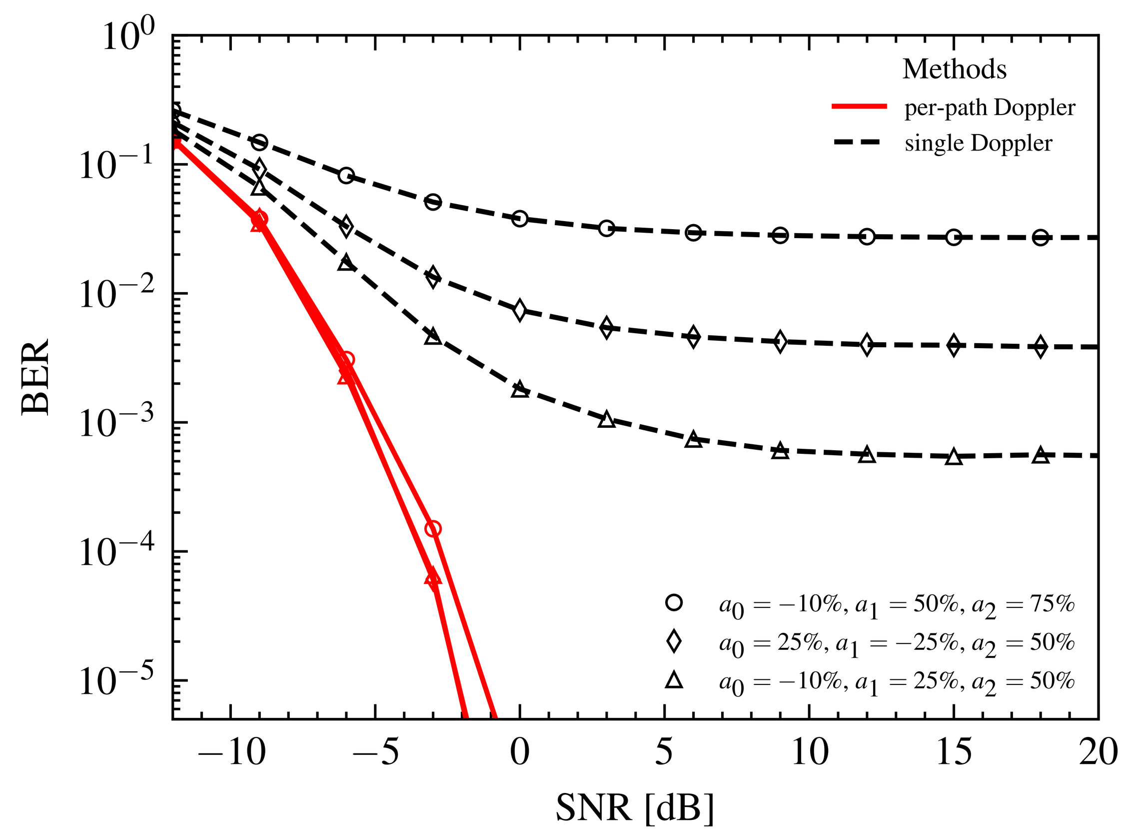
$$\hat{b}_k = \frac{\sum_{p=0}^{P-1} y_{k-1,p}^*(\hat{\beta}_p^\star) y_{k,p}(\hat{\beta}_p^\star)}{\sum_{p=0}^{P-1} |y_{k-1,p}(\hat{\beta}_p^\star)|^2}$$

Diagram



Results: Mean squared error (MSE) and bit error rate (BER)





Simulation parameters

Parameter	Value
Bandwidth (B)	5 kHz
First carrier freq. (f_0)	10 kHz
Number of carriers (K)	1024

scenario	Doppler rate
1	$\{-10\%, 50\%, 75\%\}\Delta f/f_c$
2	$\{-10\%, 50\%, 75\%\}\Delta f/f_c$
3	$\{-10\%, 50\%, 75\%\}\Delta f/f_c$

Received Constellation