Maximum Likelihood Synchronization for DVB-T2 in Unknown Fading Channels

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Introduction

✓ We consider the time delay and carrier frequency offset (CFO) estimation problem for the digital video broadcasting-second generation terrestrial (DVB-T2) signals over an unknown fading channel.

✓ The special preamble, i.e., P1 symbol, designed for fast synchronization of the DVB-T2 frames is exploited.

✓ Our proposed schemes can jointly estimate the delay and CFO by maximum likelihood (ML) methods.

Structure of the P1 symbol

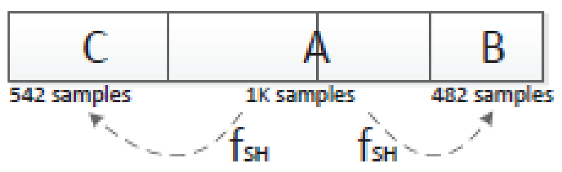


Fig. 1. Time domain structure of the P1 symbol.

Each DVB-T2 frame starts with a P1 symbol of duration 2048 (2K) samples. As shown in Fig. 1, the 2K samples are divided into three parts: A, B, and C.

❖ Part A: Generated by applying a 1024-point inverse Fourier transform on the signaling vector (similar to the OFDM symbol); only 384 specific sub-carriers are active, while the other sub-carriers carry zero symbols (null carriers).

❖ Part B: Repeat the last 482 samples of Part A with a frequency shift of f_{SH}.

❖ Part C: Repeat the first 542 samples of Part A with a frequency shift of f_{SH}.

Therefore, the P1 symbol can be formulated as

$$\mathbf{s}_{P1} = \mathbf{ETPd}.$$

where **d** is the signaling vector in the frequency domain, **P** is the active carrier pattern matrix, **T** is the inverse Fourier matrix, and **E** is the frequency shift matrix.

Problem Formulation

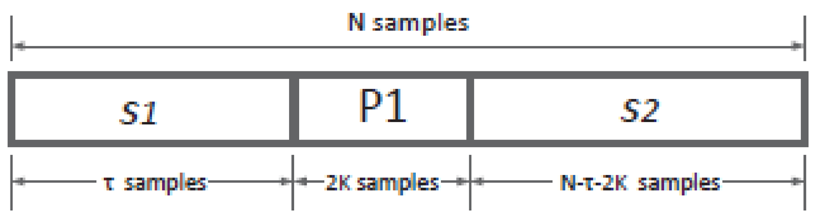


Fig. 2. Transmitted signal during the observing window.

N (N > 2048) consecutive samples are collected in a column vector **x** (see Fig. 2) for each estimation procedure, where one P1 symbol is captured.

$$\mathbf{x} = \alpha\mathbf{s} \odot \mathbf{e} + \mathbf{w}$$

$$\mathbf{s} = [s(0), s(1), \ldots, s(N-1)]^T$$

$$s(n) = \begin{cases} s_1(n), & n \in [0, \tau - 1] \\ s_{P1}(n-\tau), & n \in [\tau, \tau + 2N_a - 1] \\ s_2(n - \tau - 2N_a), & n \in [\tau + 2N_a, N - 1] \end{cases}$$

$$\mathbf{e} = [1, e^{j2\pi\Phi}, \ldots, e^{j2\pi\Phi(N-1)}]^T$$

$$\mathbf{w} = [w(0), w(1), \ldots, w(N-1)]^T \sim \mathcal{CN}(\mathbf{0}, \eta\mathbf{I}_N)$$

where α denotes the unknown coefficient regarding the channel gain, τ is the delay in the unit of samples, Φ is the normalized CFO, and η is the noise power. The problem of interest is to jointly estimate the time delay and CFO from the observations **x** by means of ML methods.

Proposed Approaches

1. Model the transmitted signal **s** as zero-mean complex Gaussian distributed (Central Limit Theorem).

SML, ASML

DISTRIBUTION

$$\mathbf{x} \sim \mathcal{CN}(\mathbf{0}, \mathbf{R}_x)$$
$$\mathbf{R}_x = \mathbf{K}(\Phi)\mathbf{Q}\mathbf{K}(\Phi)^H$$
$$[\mathbf{K}(\Phi)]_{p,p} = e^{j2\pi\Phi(p-1)} \text{ for } p = 1, 2, \ldots, N$$
$$\mathbf{Q} = \eta_s\mathbf{R}_s(\tau) + \eta\mathbf{I}_N$$
$$\mathbf{R}_s(\tau) = \begin{bmatrix} \mathbf{I}_\tau & \mathbf{0}_{\tau\times 2N_a} & \mathbf{0}_{\tau\times N'} \\ \mathbf{0}_{2N_a\times\tau} & \mathbf{R} & \mathbf{0}_{2N_a\times N'} \\ \mathbf{0}_{N'\times\tau} & \mathbf{0}_{N'\times 2N_a} & \mathbf{I}_{N'} \end{bmatrix}$$
$$\mathbf{R} = E\{\mathbf{s}_{P1}\mathbf{s}_{P1}^H\} = \mathbf{ETPP}^H\mathbf{T}^H\mathbf{E}^H$$

MAX LLF

$$\Lambda(\eta_s, \tau, \Phi) = -\frac{\Gamma_2(\tau)}{\eta_s + \eta} - (N - 2N_a)\ln(\eta_s + \eta) - N\ln\pi$$
$$- \mathbf{x}_{P1}(\tau)^H\mathbf{K}_{P1}(\tau, \Phi)\mathbf{B}^{-1}\mathbf{K}_{P1}(\tau, \Phi)^H\mathbf{x}_{P1}(\tau)$$
$$- \ln|\mathbf{B}|,$$
$$(\bar{\eta}_s(\tau), \bar{\Phi}(\tau)) = \arg\max_{\eta_s, \Phi} \Lambda(\eta_s, \Phi|\tau)$$
$$\hat{\tau} = \arg\max_{\tau} \Lambda(\bar{\eta}_s(\tau), \tau, \bar{\Phi}(\tau))$$
$$\hat{\eta}_s = \bar{\eta}_s(\hat{\tau}) \quad \text{and} \quad \hat{\Phi} = \bar{\Phi}(\hat{\tau})$$

2. Model the transmitted signal **s** as deterministic but unknown.

DML

DISTRIBUTION

$$\mathbf{x} = \mathbf{s} \odot \mathbf{e} + \mathbf{w} = \mathbf{K}(\Phi)\mathbf{s} + \mathbf{w}$$
$$\mathbf{x} \sim \mathcal{CN}(\mathbf{K}(\Phi)\mathbf{s}, \eta\mathbf{I}_N)$$

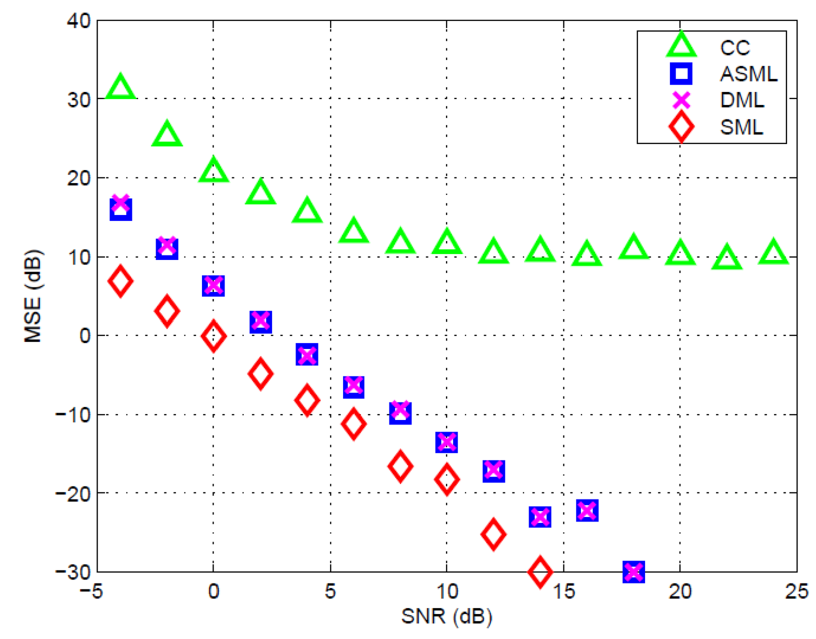
MAX LLF

$$\Lambda(\mathbf{s}, \tau, \Phi, \eta) \triangleq \ln f(\mathbf{x}|\mathbf{s}, \tau, \Phi, \eta)$$
$$= -\frac{\Delta}{\eta} - N\ln\eta - N\ln\pi$$
$$(\hat{\mathbf{s}}, \hat{\tau}, \hat{\Phi}, \hat{\eta}) = \arg\max_{\mathbf{s}, \tau, \Phi, \eta} \Lambda(\mathbf{s}, \tau, \Phi, \eta)$$
$$(\hat{\mathbf{s}}, \hat{\tau}, \hat{\Phi}) = \arg\min_{\mathbf{s}, \tau, \Phi} \Delta(\mathbf{s}, \tau, \Phi)$$
$$\hat{\eta} = \frac{\Delta(\hat{\mathbf{s}}, \hat{\tau}, \hat{\Phi})}{N}$$

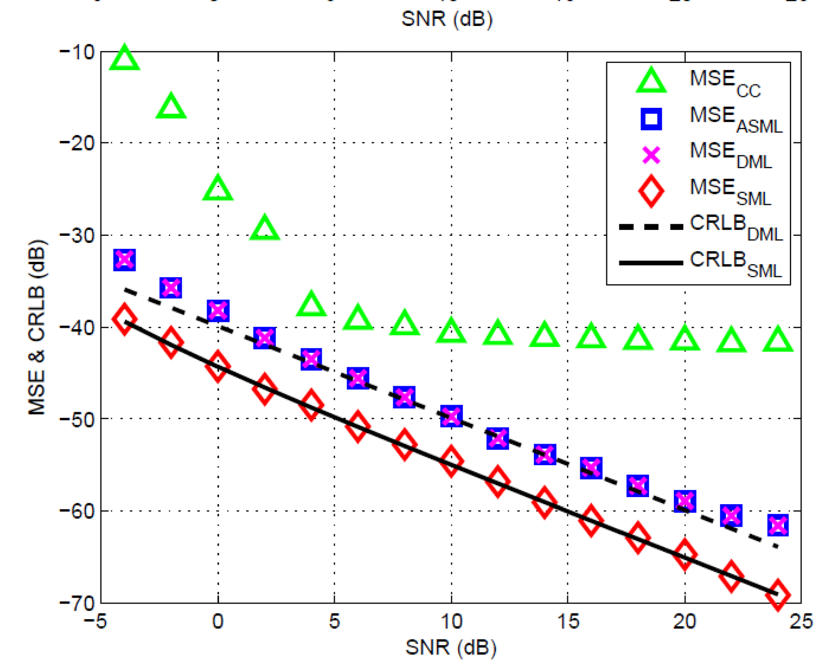
Simulation Results

$N = 6N_a$	M	ϕ	Φ	τ	η
6144	384	0.45	$\frac{0.45}{1024}$	100	1

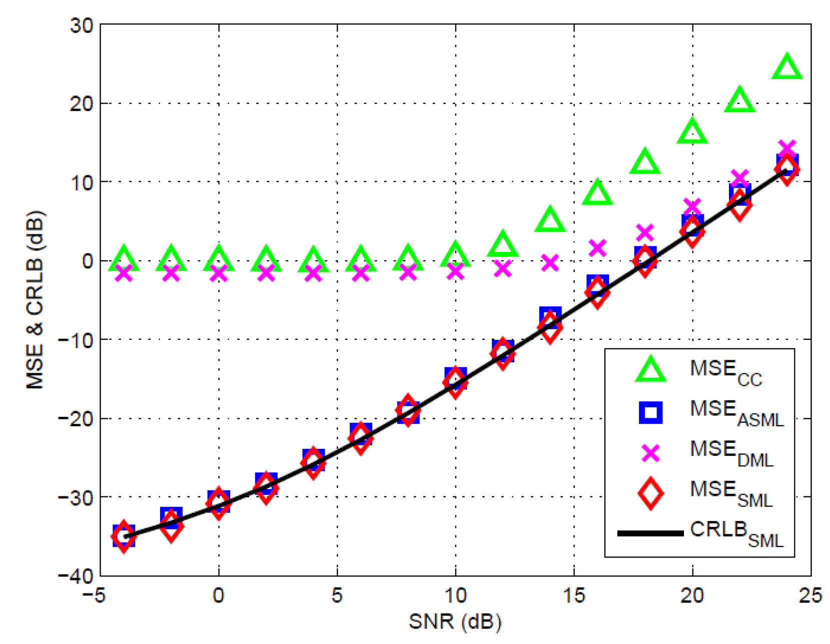
Delay



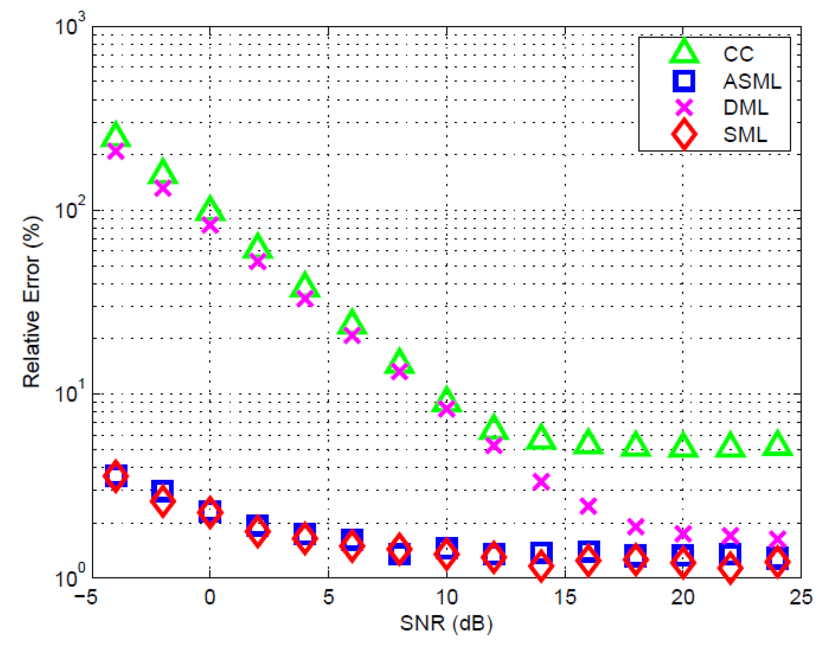
CFO



s Power



s Power



Conclusion

❖ Unlike previous studies, we consider a more general channel environment where the channel coefficient is unknown.

❖ Stochastic Model => SML, ASML.

❖ Unknown Deterministic Model => DML.

❖ CRLB = SML ≥ ASML ≥ DML > CC.

❖ DML is more flexible and has a lower complexity.