Estimation of Channel Parameters in UWB Impulse Radio Communication
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1 Signal Model and problem formulation

In Impulse-Based Ultra-Wideband (IR-UWB) communication, signaling is commonly realized by transmitting very short duration pulses on the order of sub-nanoseconds [1]. The transmitted signal consists of a train of such pulses at baseband, where each transmitted pulse is generally a Gaussian pulse derivative. The received signal at the receiver in the frequency domain is given by [2],

$$y(\omega) = s(\omega) \sum_{l=1}^{L} \alpha_l e^{-j\omega\tau_l} + b(\omega) \tag{1.1}$$

where $y(\omega)$ is the received signal, $s(\omega)$ is the transmitted pulse, α_l is the gain and τ_l is the delay of the l^{th} path. $b(\omega)$ is the zero-mean Additive White Gaussian noise.

The discretized received signal can be written as:

$$y_n \stackrel{\text{def}}{=} y(w_n) = s_n \sum_{l=1}^{L} \alpha_l e^{jw_n\tau_l} + b_n, \quad k = 0, ..., N-1 \tag{1.2}$$

where $s_n \stackrel{\text{def}}{=} s(w_n)$ and $b_n \stackrel{\text{def}}{=} b(w_n)$ with $w_n = w_0 k$ and where $w_0 = \frac{2\pi}{N}$. Let $\mathbf{y} \stackrel{\text{def}}{=} (y_0, \ldots, y_{N-1})$ and $\mathbf{b} \stackrel{\text{def}}{=} (b_0, \ldots, b_{N-1})^T \sim \aleph(0, \sigma^2\mathbf{I})$ be two vectors containing the N samples of y_n and b_n, respectively. From (1.1), we have

$$\mathbf{y} = \mathbf{S}\mathbf{A}_\tau\boldsymbol{\alpha} + \mathbf{b} \tag{1.3}$$

where $\boldsymbol{\alpha} \stackrel{\text{def}}{=} (\alpha_1, \ldots, \alpha_{L-1})^T$ is a vector formed by the L channel gains, $\mathbf{S}$ is a diagonal complex matrix of dimension $(N \times N)$, whose elements are the DFT of the transmitted signal, $\mathbf{A}_\tau$ is a matrix of dimension $(N \times L)$ defined by the delay-signature vectors (i.e., harmonic components) associated to each arriving delayed signal (path),

$$\mathbf{A}_\tau = (\mathbf{a}_0, \ldots, \mathbf{a}_{L-1})$$

where $\mathbf{a}_k \stackrel{\text{def}}{=} \mathbf{a}_{\tau_k} = (1, e^{-jw_0\tau_k}, \ldots, e^{-jw_0(N-1)\tau_k})^T$.

With the above problem formulation, we assume that the signal s is deterministic and is the 2^{nd} derivative of Gaussian pulse given by [3],

$$s(t) = E_0 \left[1 - 4\pi \left(\frac{t - t_0}{\Delta t}\right)^2\right] exp\left\{-2\pi \left(\frac{t - t_0}{\Delta t}\right)^2\right\} \tag{1.4}$$

where E_0 is the peak amplitude at the time $t = t_0$, and Δt is a nominal duration which can be chosen to adjust the pulse width.

Furthermore, the channel is assumed to be time varying Rayleigh channel (i.e., the gains are zero-mean complex circular Gaussian but with the delays constant during the observation period) and the number of paths (i.e., L) is known.

Now we note that $\boldsymbol{\theta} \stackrel{\text{def}}{=} (\boldsymbol{\tau}, \boldsymbol{\alpha})$ is to be estimated from $\mathbf{y}$ where $\boldsymbol{\tau} \stackrel{\text{def}}{=} (\tau_1, \ldots, \tau_L)^T$.

Since the path gains of the channel are assumed stochastic with covariance matrix $\mathbf{R}_\alpha$ of Rank equal to L, the principle of the classical Multiple Signal Classification (MUSIC) algorithm can be applied because the Rank of the subspace signal is $L = Rank(\mathbf{R}_\alpha) = Rank(\mathbf{S}\mathbf{A}_\alpha\mathbf{R}_\alpha\mathbf{A}_\alpha^H\mathbf{S})$, where we have used the fact that the matrix $\mathbf{A}_\alpha$ has full column rank.

Therefore, the auto-correlation of the received signal $\mathbf{R}_y$ is estimated at the receiver from the Q snapshots of the received signal. The noise sub-space is formed by the $N - L$ eigenvectors corresponding to the $N - L$ smaller eigenvalues of auto-correlation matrix $\mathbf{R}_y$. The L peaks of the MUSIC spectrum correspond to the respective delays. The MUSIC spectrum is given by,

$$F(\tau) = \frac{1}{\hat{\mathbf{y}}(\tau)^{\mathbf{H}}\mathbf{U_n}\mathbf{U_n^H}\hat{\mathbf{y}}(\tau)} \tag{1.5}$$

where $\mathbf{U_n}$ is the N x $(N - L)$ matrix associated with the $N - L$ smaller eigenvalues.

The path gains α are estimated from the MAP estimation algorithm, which is expressed as:

$$\hat{\alpha} = \arg\max_{\alpha} \quad p\left(\alpha/\mathbf{y}\right) \tag{1.6}$$

where $p\left(\alpha/\mathbf{y}\right)$ is the a posteriori probability of α. The above equation 1.6 can be equivalently expressed as:

$$\hat{\alpha} = \arg\max_{\alpha} p\left(\alpha/\mathbf{y}\right)\ p(\alpha) \tag{1.7}$$

where $p(\alpha)$ is the a priori density function of α.

Monte Carlo simulations need to be done to obtain the mean-square error (MSE) on the path gain and delay parameters.

2 Objective

The main objective of this project is to estimate the UWB Channel parameters, namely path gains and delays, in a Rayleigh fading channel. The deterministic path delays are first estimated using MUSIC algorithm and then the path gains are estimated by applying the Maximum Aposteriori Probability estimation (MAP) technique.

References

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