Multiresolution Time-of-Arrival Estimation from Multiband Radio Channel Measurements

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Introduction

In radio communications, the time-of-arrival (TOA) estimation starts with the estimation of the underlying non bandlimited multipath channel from bandlimited observations of communication signals.

Modeling the channel impulse response (CIR) as a sparse sequence of Diracs pulses, the TOA estimation becomes a problem of parametric spectral inference from observed bandlimited signals.

To increase resolution without arriving at unrealistic sampling rates, we consider a multiband sampling approach, and propose: (i) a practical multiband receiver for the acquisition and (ii) an algorithm for multiresolution TOA estimation based on the ESPRIT algorithm.

Multiband Sampling of the Radio Channel

The multipath radio channel model assuming $K$ propagation paths is

$$\tilde{h}(t) = \sum_{k=1}^{K} \tilde{a}_k e^{-j\omega_k t}$$

where $\tilde{a}_k$ represent the gain and time-delay of the $k$th resolvable path.

Multiband sampling approximates probing of the channel (1) by a wideband sensing signal $\tilde{s}(t)$ defined by

$$\tilde{s}(t) = \sum_{k=1}^{K} \tilde{s}_k e^{-j\omega_k t}$$

where $\tilde{s}_k$ represent the gain and time-delay of the $k$th resolvable path.

The multiband receiver downconverts the received signal to baseband and performs lowpass filtering and sampling of $\tilde{s}(t)$.

The channel model is

$$h(t) = \sum_{k=1}^{K} a_k e^{-j\omega_k t}$$

where $a_k$ represents the gain and time-delay of the $k$th resolvable path.

Discrete-time model: Assuming that $x_i(t)$ has a finite duration $T$, and it satisfies conditions for Nyquist sampling, the data model in the frequency domain is

$$X_i[\omega] = H[\omega]X_i[\omega] + N_i[\omega]$$

where $X_i[\omega]$ is the frequency response of the $i$th receiver chain, $H[\omega]$ is the bandwidth of the $i$th sub-band, and $N_i[\omega]$ is the bandlimited white Gaussian noise.

Numerical evaluation

• A standard outdoor UWB channel model with eight dominant multipath components (DPCs) is considered with $t_{\text{delay}} = 8 \text{ ns}$.

• The continuous time is modeled using a 3 GHz grid, where the channel tap delays are spaced at 333.33 ps.

• The Root Mean Square Error (RMSE) is used as a metric for evaluation, which is taken to be $10^3$ independent Monte Carlo runs.

Channel sampling and reconstruction:

Numerical evaluation

A standard outdoor UWB channel model with eight dominant multipath components (DPCs) is considered with $t_{\text{delay}} = 8 \text{ ns}$.

The continuous time is modeled using a 3 GHz grid, where the channel tap delays are spaced at 333.33 ps.

The Root Mean Square Error (RMSE) is used as a metric for evaluation, which is evaluated over $10^3$ independent Monte Carlo runs.

Conclusions

• The block Hankel matrix formed from multiband radio channel samples has a multiple shift invariance structure.

• The invariance structure of a single sub-band provides coarse parameter estimates, while the invariance structure of the lowest against the highest frequency sub-band provides high-resolution, but phase wrapped estimates.

• The multiresolution TOA estimation from multiband channel samples increases the resolution of TOA estimates while it reduces the spectral occupancy and sampling costs.