ABS-1-1

Investigation of Performance Improvement of EAMVs in Diffuse Scattering Channels

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1 Introduction

In order to reuse a channel model, it is requisite to separate the channel model from its measurement system and estimation procedures. For this purpose, the concept of a parametric channel model is introduced. Considering direction of arrival (DOA) estimation, a traditionally used signal model in a parametric channel model, which is a plane wave model, can be reasonable if and only if a measurement system has sufficient resolution to resolve multipaths. This condition is not the case in diffuse propagation channels, where a number of very close multipaths are incident at a measurement antennas with limited number of antenna elements. In terms of parameter estimation, the model mismatch between the resulting perturbed and expected signal models leads to the error in the estimated nominal DOAs of clusters in cluster scenarios. While in terms of signal reconstruction of the received signal, which can be more important than nominal DOA estimates in some applications, this model mismatch causes high residual power after the reconstructed signals are removed from the input signal. To deal with these problems, the application of the extended array mode vectors (EAMVs) based on the first and the second-order Taylor series expansion has been proposed [1][2]. In this paper, based on one- and two-cluster scenarios, the EAMVs' performances from both viewpoints are investigated in the framework of successive interference cancellation (SIC) -based Maximum Likelihood Estimation (MLE), also known as SAGE with SIC [3][4].

2 Signal Model and Concept of EAMVs

In K-cluster scenarios with D_k scatterings, the output $\mathbf{x}(t)$ can be written as $\mathbf{x}(t) = \sum_{k=1}^{K} \mathbf{v}_k s_k(t) + \mathbf{n}(t)$, where $\mathbf{v}_k$ is the spatial signature (SS) of the kth cluster, $s_k(t)$ and $\mathbf{n}(t)$ denote the k th baseband and noise signals, respectively. Given the nominal azimuth DOA $\phi_{0,k}$ and the angle deviation of the dth scattered multipath $\tilde{\phi}_{d,k}$, $\mathbf{v}_k$ is

$$\mathbf{v}_k = \sum_{d=1}^{D_k} \beta_{d,k} \mathbf{a}\left(\phi_{0,k} + \tilde{\phi}_{d,k}\right), \qquad (1)$$

Depending on the order of the Taylor series applied for modeling $\mathbf{a}\left(\phi_{0,k} + \tilde{\phi}_{d,k}\right)$ [2][5][6], three types of approximated $\hat{\mathbf{v}}_k$ are presented as follows,

$$\begin{aligned} \hat{\mathbf{v}}_{1,k} &= \gamma_k \left\{ \mathbf{a}(\phi_{0,k}) + \xi_k \mathbf{d}(\phi_{0,k}) \right\}, & (2) \\ \hat{\mathbf{v}}_{2,k} &= \gamma_k \mathbf{a}(\zeta + \jmath \xi_{\mathrm{i}}), & (3) \\ \hat{\mathbf{v}}_{3,k} &= \gamma_k \left\{ \mathbf{a}(\phi_{0,k}) + \xi_k \mathbf{d}(\phi_{0,k}) + \eta_k \mathbf{f}(\phi_{0,k}) \right\}, & (4) \end{aligned}$$

where $\mathbf{d}(\phi_{0,k}) = \frac{\partial \mathbf{a}(\phi)}{\partial \phi}\big|_{\phi=\phi_{0,k}}$, $\gamma_k = \sum_{d=1}^{D_k} \beta_{d,k}$, $\xi_k = \xi_{\mathrm{r}k} + \jmath \xi_{\mathrm{i}k} = \frac{\sum_{d=1}^{D_k} \beta_{d,k} \tilde{\phi}_{d,k}}{\gamma_k}$, $\zeta = \phi_{0,k} + \xi_{\mathrm{r}k}$, $\mathbf{f}(\phi_{0,k}) = \frac{\partial^2 \mathbf{a}(\phi)}{\partial \phi^2}\big|_{\phi=\phi_{0,k}}$, and $\eta_k = \eta_{\mathrm{r}k} + \jmath \eta_{\mathrm{i}k} = \frac{\sum_{d=1}^{D_k} \beta_{d,k} \tilde{\phi}_{d,k}^2}{2\gamma_k}$. $\hat{\mathbf{v}}_{1,k}, \hat{\mathbf{v}}_{2,k}$, and $\hat{\mathbf{v}}_{3,k}$ are referred to as the first-order, simplified first-order, and second-order EAMVs, respectively.

3 Numerical results

Table 1 shows the simulation conditions for one- and two-cluster scenarios. The scattered multipaths are assumed to be incident at a 6-element ULA. The antenna spacing for ULA is 0.487 wavelength (λ). Based on 2000 simulations, Fig. 1 depicts the root mean square error (RMSE) randomly distributed around the given nominal DOA as a function of Δ_1, in the one-cluster scenario. As can be seen for both ULA, the nominal DOA estimation is only somewhat improved by the simplified first-order EAMV compared with the conventional array mode vector (CAMV) based on the single plane wave assumption. Conversely, great improvements are easily noticeable for the first- and the second-order EAMVs. This emphasizes the adverse effect of the oversimplification in Eq. (3). Comparing with the first-order EAMV, the second-order EAMV does not affect

Table 1　Simulation Parameters

	One cluster	Two-cluster	
cluster index	♯1	♯1	♯2
nominal DOA (degrees)	0	0	-40
SNR (dB)	20	20	5
azimuthal power spectrum	Uniform $(-\Delta/2, +\Delta/2)$		
Δ_k (degrees)	1-10	10	
the number of scatters	30		
Estimation Algorithm	SIC-based MLE		
the number of time samplings	100		

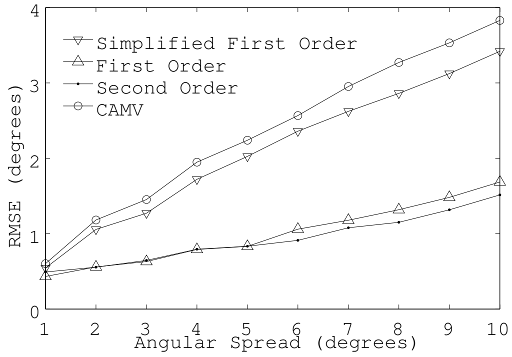

Fig 1　RMSE of estimated nominal DOA.

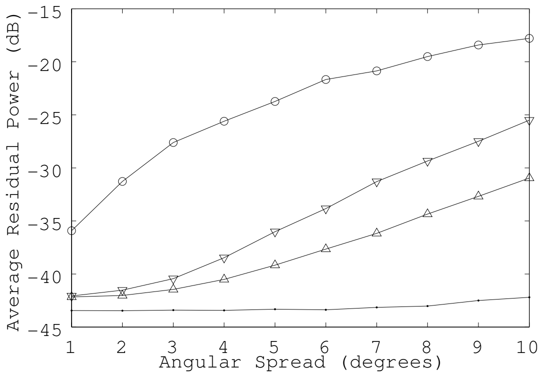

Fig 2　Median of average residual power.

the DOA estimate much, up to 10 degrees of angular spread. To investigate performances on the signal reconstruction, the residual power of each antenna is first calculated by removing reconstructed signal from the input signal of the algorithm (averaged by the number of time samplings). Then, the average residual power values are obtained by averaging over 6 antenna elements and their medians are shown in Fig. 2. As in the case of nominal DOA estimates, the average residual power is improved as the order of EAMV increases. However, in contrast to the parameter estimation, the signal reconstruction is significantly improved by using the second-order approximation. It can be concluded from the figure that up to 10 degrees of angular spread in Uniform APS scenarios, the second-order EAMV can almost perfectly model the signal variations over ULA. In Figs. 3 and 4, 200 simulations of the average residual power for the two-cluster scenarios are plotted for Cumulative Distribution Functions (CDFs). Good performance of signal reconstruction is confirmed for the EAMVs, especially for the second-order EAMV, with 7-dB improvement from the first-order EAMV.

4 Conclusion

We investigated the performance improvements in terms of the nominal DOA parameter estimation and signal reconstruction when the EAMVs based on first and second-order approximation of the CAMV are applied to the SIC-based MLE. The performance of EAMVs and CAMV was verified via numerical simulations under the one- and two-cluster scenarios. Comparing performance improvement in both aspects, the second-order EAMV was shown to have more notable impact in the signal reconstruction aspect.

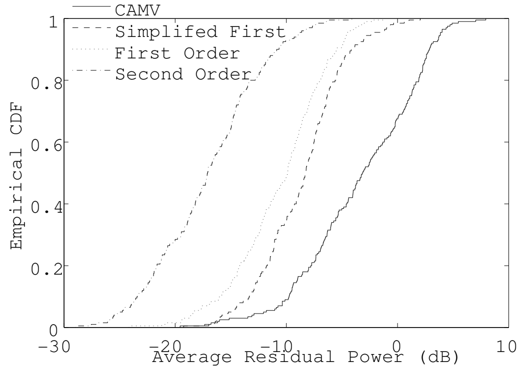

Fig 3　CDFs of average residual power in the two-cluster scenario for ULA.

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