Channel Parameters Estimation in V2V Networks

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Abstract

In this paper, we propose an online expectation maximization (EM) algorithm to estimate the channel parameter even with a few measurements. We address the issue of the online EM initialization by employing the distributed compressed sensing-simultaneous orthogonal matching pursuit (DCS-SOMP) algorithm. The results reveal that the proposed scheme can be applied with low complexity beam tracking algorithm for vehicular networks.

I. Introduction

The vehicle to vehicle (V2V) communication technology has grasped considerable attention in recent years. Considering the number of sensors embedded in the vehicles, ultra-high data rates communication between vehicles is required [1]. Hence, the millimetre wave (mmWave) band is a viable option due to the large underutilized bandwidth available at the mmWave spectrum [2].

The use of the mmWave band requires the estimation of the channel parameter in other to design efficient beamformers between the target vehicles and the connected vehicles. Due to the number of parameters to be estimated and the high complexity involved in the V2V scenario, the maximum likelihood (ML) estimation may not be feasible, thus we proposed an online expectation maximization (online-EM) algorithm [3].

II. System Model

Consider a V2V scenario where K connected vehicles communicate with a target vehicle over the mmWave band. We assume that the K connected vehicles are equipped with N_r uniform linear array (ULA) antennas with only one RF chain, while the target vehicle is equipped with N_t ULA antennas with N_{RF} chains enabling it to simultaneously communicate with the K connected vehicles. In each beam training period, the target vehicles transmit M_t beams sequentially at different spatial directions. Each of the connected vehicles estimates the channel and select the precoding matrix using the estimated channel information. Thereafter, the selected precoding matrix is feedback to the target vehicle. At the end of the beam training period, the target vehicle transmits the precoded data to the connected vehicles during the data transmission phase.

At the n-th training period, the received signal at the k-th connected vehicle can be expressed as

$$\mathbf{y}_k = \mathbf{H}_k \mathbf{W} \mathbf{x} + \mathbf{n}_k, \tag{1}$$

where $\mathbf{y}_k \in \mathbb{C}^{N_r \times \mathbf{1}}$ is the received signal, $\mathbf{H}_k \in \mathbb{C}^{N_r \times N_t}$ is the channel matrix between the target vehicle and the k-th connected vehicle, $\mathbf{W} = [\mathbf{w}_1, \mathbf{w}_2, \dots, \mathbf{w}_{M_t}] \in \mathbb{C}^{N_t \times M_t}$ is the transmit beamforming matrix, $\mathbf{x} = [x_1, x_2, \dots x_{M_t}]^T \in \mathbb{C}^{M_t}$ is the transmitted signal and $\mathbf{n}_k \in \mathbb{C}^{N_r}$ is the k-th connected vehicle receiver noise. We assume only the line of sight path (LOS) exist, hence, channel can be modelled as

$$\mathbf{H}_k = \sqrt{N_r N_t}\,\alpha_k e^{j2\pi \upsilon n T_s} \mathbf{a}(\theta_k)\mathbf{a}(\phi_k), \tag{2}$$

where α_k is the complex channel gain, θ_k and ϕ_k are the angle of arrival (AOA) and angle of departure (AOD) respectively and $\mathbf{a}(\theta_k)$ and $\mathbf{a}(\phi_k)$ are the steering vectors. The steering vector is defined as

$$\mathbf{a}(\theta_k) = \frac{1}{\sqrt{N_r}}[1, e^{-j\pi \sin\theta_k}, \dots, e^{-j\pi(N_r-1)\sin\theta_k}], \tag{3}$$

and the steering vector $\mathbf{a}(\phi_k)$ can be obtained as (3).

III. Proposed EM based Parameter Estimation

Due to high mobility in V2V scenario, the Online EM algorithm is employed in leaning and estimating the channel parameters. Specifically, in each iteration, the EM algorithm produces a sequence of $\boldsymbol{\eta}_k^l = 1, 2, \dots$, and each iteration consist of the expectation step (E-step) and maximization step (M-step), where $\boldsymbol{\eta}_k = [\theta_k, \phi_k, \alpha_k]$.

The Online EM algorithm requires parameter initialization. Hence, we adopt the DCS-SOMP algorithm for the initialization [4].

To this end, we obtain the maximum a-posteriori channel estimation for the l-th iteration as

$$f(\mathbf{y}_k|\boldsymbol{\eta}_k) = \frac{1}{D(\pi\sigma^2)^{M_t}} \sum_x \exp\left(\frac{1}{\sigma^2}(\mathbf{y}_k - \mathbf{m}_k)^H(\mathbf{y}_k - \mathbf{m}_k)\right), \tag{4}$$

where D is the total possible values of transmitted symbols and $\mathbf{m}_k = \mathbf{H}_k \mathbf{W}\mathbf{x}$. The $(l+1)$-th iterative estimate can be obtained by iterating between the following two steps until convergence is realized.

- *E-Step*: compute the expectation of the log-likelihood function $L(\boldsymbol{\eta}_k|\mathbf{y}_k) = \ln f(\mathbf{y}_k|\boldsymbol{\eta}_k)$ as

$$Q^{l+1}(\boldsymbol{\eta}_k) = Q^l(\boldsymbol{\eta}_k) + \gamma_{l+1}(\mathbb{E}_{\hat{\boldsymbol{\eta}}_k}[L(\boldsymbol{\eta}_k^{l+1}|\mathbf{y}_k^{l+1})] - Q^l(\boldsymbol{\eta}_k)). \tag{5}$$

- *M-Step*: find the parameters of the next iteration

$$\hat{\boldsymbol{\eta}}_k^{l+1} = \arg\max_{\boldsymbol{\eta}} Q^{l+1}(\boldsymbol{\eta}_k). \quad (6)$$

The convergence criterion is determined by $|L(\boldsymbol{\eta}_k^l) - L(\boldsymbol{\eta}_k^{l+1})| = \epsilon$, where ϵ is the convergence threshold.

Table 1: Summary of simulation parameters

Parameters	Values	Parameters	Values
Frequency	28 GHz	Antenna size	16
Codebook size	16	Transmit power	30 dBm
Pathloss exponent	2.75	Number of Vehicles	3

IV. Result and Discussion

In this section, we present the results to show the performance of the proposed online EM algorithm channel parameter estimation. In the simulation, three vehicles are deployed in an area of 100 by 100 meters area with an average speed of 20~27 m/s. The vehicles consist of one target vehicle and two connected vehicles operating the millimeter wave band. The simulation parameters are summarized in Table 1.

In Fig. 1, it is observed that the proposed scheme achieves better performance when compared with the DCS-SOMP scheme. The performance gap is attributed to the fact that the DCS-SOMP algorithm is limited by the grid system and hence may fail to estimate the AOA correctly if the actual AOA does not coincide with the grid. On the other hand, the proposed online EM achieves a better estimate iteratively with a single received signal at the k-th vehicle.

In Fig. 2, the estimated AOD in each time slot is plotted for two connected vehicles and a single target vehicle. The figure reveals that the performance of the online EM scheme can achieve a good estimate of multiple vehicles in a high mobility scenario. Hence, the online EM algorithm can be combined with other tracking algorithms to estimate and track vehicles in a high mobility scenario. Also, with multiple sensors embedded in vehicles, the proposed scheme can be adopted for sensor information fusion to improve situational awareness vehicle tracking.

V. Conclusion

In this paper, we study the implementation of the online EM algorithm for channel parameter estimation in a V2V scenario. Due to high mobility, the channel changes rapidly, hence, the existing compressed sensing techniques cannot be employed to estimate the channel parameters. The proposed online EM algorithm is shown to achieve a good estimate of the rapidly changing channel and can be adopted with low complexity tracking algorithms for beam tracking in a V2V mobile environment. Our future research is to apply the proposed method in the study of situational awareness communication in vehicular networks.

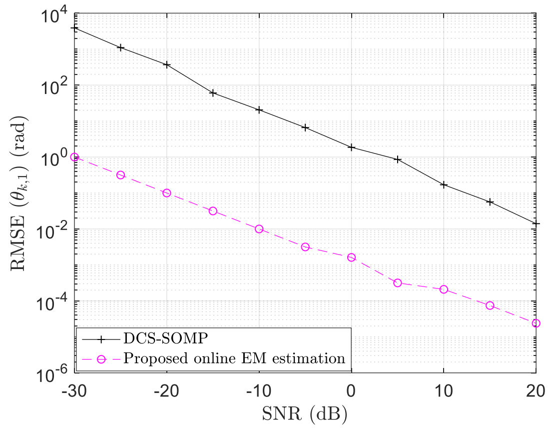

Fig. 1. Comparison of the RMSE of proposed online EM and the DCS-SOMP

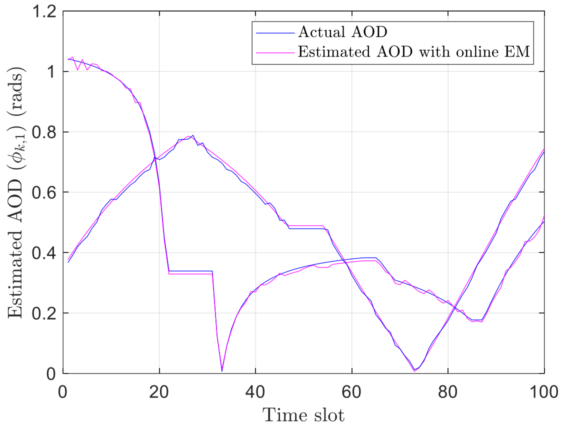

Fig. 2. Online EM based AOD estimation per time slot of two connected vehicles and a target vehicle

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