Hybrid Maximum Likelihood Modulation Classification Using Multiple Radios

Onur Ozdemir, *Member, IEEE*, Ruoyu Li, and Pramod K. Varshney, *Fellow, IEEE*

***Abstract*—The performance of a modulation classifier is highly sensitive to channel signal-to-noise ratio (SNR). In this paper, we focus on amplitude-phase modulations and propose a modulation classification framework based on centralized data fusion using multiple radios and the hybrid maximum likelihood (ML) approach. In order to alleviate the computational complexity associated with ML estimation, we adopt the Expectation Maximization (EM) algorithm. Due to SNR diversity, the proposed multi-radio framework provides robustness to channel SNR. Numerical results show the superiority of the proposed approach with respect to single radio approaches as well as to modulation classifiers using moments based estimators.**

***Index Terms*—Modulation classification, data fusion, ML estimation, EM algorithm**

I. Introduction

Modulation classification (MC) deals with determining the modulation type of a noisy communication signal. It plays an important role in many civilian and military applications, e.g., adaptive cognitive radios for satellite communications [1]. A thorough review of MC methods can be found in [2], [3]. Here, we focus on amplitude-phase modulations and consider the *hybrid maximum likelihood (HML)* approach. The performance of an MC system using a single radio depends highly on the channel quality, i.e., fading and background noise. In addition, some nuisance parameters, such as signal-to-noise ratio (SNR) and phase offset, are usually unknown which further complicates the classification problem. Receiver diversity is a common technique used in wireless communication systems to alleviate channel fading effects for demodulation/symbol detection. Similarly, it is natural to argue that using multiple radios for modulation classification, i.e., collaborative MC, has the potential for improving classification performance compared to a single radio especially in the low to mid signal-to-noise (SNR) regimes. Inspired by this reasoning, collaborative MC approaches have been proposed in [4], [5], [6], [7], [8], [9]. Most of these works are based on the distributed detection framework [10], where each radio makes a local (hard or soft) classification decision and then these decisions are fused at a fusion center (FC) to make a global decision [6], [7], [8]. To the best of our knowledge, there are only two centralized likelihood based approaches proposed in the literature [4], [9]. In [9], signals from different radios are linearly added to generate a combined signal, which is then used for modulation classification. Linear combining is optimal only if the phase and time information is perfectly known at each radio. In [4], an antenna array is used to receive the unknown signal. The authors adopt the HLRT framework and use moments based estimators to estimate the unknown signal parameters to simplify the estimation problem. As a result, the estimates in [4] are obtained by ignoring the coupling (due to common received constellation symbols) between different antenna elements which results in sub-optimality.

O. Ozdemir is with ANDRO Computational Solutions, 7902 Turin Road, Rome, NY 13440. R. Li is with the School of EEE, Nanyang Technological University, Singapore. P. K. Varshney is with Department of EECS, Syracuse University, Syracuse, NY 13244. This material is in part based upon work supported by the Government under Contract No. W15P7T-12-C-A040. Email: oozdemir@androcs.com, rli11@syr.edu, varshney@syr.edu.

In this paper, we propose a centralized fusion approach where raw data from local radios as in [4], [9] are fused at a fusion center to make the global classification decision. Although the proposed centralized data fusion approach is expected to improve the performance, the resulting MC problem is computationally more complex to solve than a single radio based MC. In order to alleviate this issue, we propose to use the Expectation-Maximization (EM) algorithm [11], which significantly simplifies the MC problem along with its nice convergence properties. In an earlier work [12], the EM algorithm was used for the MC problem using a single radio under flat fading channels corrupted by Gaussian mixture noise. Our proposed framework along with the problem formulation for centralized fusion based MC is different from the problem considered in [12] even though the EM algorithm is suitable for both. Due to SNR diversity, the proposed centralized data fusion framework significantly improves the MC performance compared to single radio approaches. Furthermore, our numerical results show that the proposed EM based solution provides superior performance compared to the moments based solution proposed in [4] with only a small increase in computational complexity.

II. Problem Formulation

Consider a radio/sensor network with L sensors observing the same communication signal with a block of N constellation (information) symbols that undergo flat block fading. These sensors are located more than half wavelength apart so that they experience independent fading. We assume that timing and frequency offsets have been perfectly estimated and the pulse-shaping filter is known. Under these assumptions, the received baseband observation sequence at sensor l is

$$r_{l,n} = a_l e^{j\theta_l} I_n + w_n, \tag{1}$$

where $l = 1, \ldots, L$, $n = 0, \ldots, N-1$, I_n is the n^{th} complex constellation symbol of the block, w_n is the additive complex zero-mean white Gaussian noise with variance N_0, and a_l and θ_l are the channel gain and the channel phase at sensor l,