A Practical Multi-Packet Reception Technique with Joint Detection for Wireless Ad Hoc Networks

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Abstract

In this letter, a practical multi-packet reception technique is proposed for wireless ad hoc networks in which concurrent transmissions generally occur. We propose a suboptimal asynchronous joint detection (SAJD) technique, which yields better performance than that of the successive interference cancellation (SIC) technique which successively decodes a packet with the strongest signal and cancels a decoded packet from multiple received packets.

Index Terms: Multiple packet reception, time and frequency offset, SIC

I. INTRODUCTION

To enhance the performance of medium access control (MAC) protocols, multiple packet reception (MPR) techniques have been proposed in [1]–[3], where timing and frequency offsets among received packets were assumed to be perfectly pre-compensated. In practice, however, this assumption is not feasible because of the decentralized nature of wireless ad hoc networks. Several techniques have been proposed for practical implementation of MPR considering this timing and/or frequency offset. In [4], the successive interference cancellation (SIC) technique was used for decoding collided packets. Other techniques including [5]–[7] have adopted similar interference cancellation techniques for decoding the randomly arriving packets.

In this paper, we propose a practical MPR technique for asynchronous ah hoc networks where the timing and frequency offsets are not pre-compensated before transmission. When all the received packets have different timing and frequency offsets, the detection performance of the conventional single user detection (SUD) technique degrades significantly due to the inter-symbol interference (ISI) resulting from the practical pulse-shaping filters. To solve the asynchronous problem and to reduce the computational complexity of the optimal asynchronous joint detection (OAJD), we propose a suboptimal asynchronous joint detection (SAJD) technique based on the log-likelihood ratio (LLR).

II. SYSTEM MODEL

We assume that K users transmit their packets simultaneously to a common receiver. Each packet may be asynchronous in the symbol level. In the frequency domain, there is also frequency offset due to local oscillator mismatch. The receiver is assumed to perfectly estimate both frequency and timing offsets of the K transmitters. At an arbitrary time m, the received signal $y[m]$ is given as

$$y[m] = \sum_{k \in \mathcal{K}} h_k e^{if_k m} \sum_{n=-N}^{N} s[m - nT - \tau_k] x_k[n] + w[m], \tag{1}$$

where h_k is a one-tap channel coefficient for the k-th packet and is assumed to be unchanged within a packet transmission and $s[m]$ is the combined transmitter and receiver pulse shaping filter. Moreover, $x_k[n]$ represents the transmitted symbol with index n of the packet k. Each packet consists of $(2N+1)$ symbols. The received signal in (1) contains both frequency and timing offsets for each packet. Let f_k and k denote the frequency offset [rad/sec] and the timing offset [sec] of the k-th packet, respectively. $w[m]$ denotes the additive white Gaussian noise at time m with noise variance of σ^2. In this paper, we consider a practical pulse-shaping filter.

III. MULTIPACKET RECEPTION WITH JOINT DETECTION

In order to reduce the complexity of the OAJD technique to a practical level, we propose a SAJD technique. The proposed SAJD technique utilizes a fact that the impulse response of RC filter $s[m]$ is close to zero when $|m|$ is greater than several multiples of T. We assume that only Δ neighboring symbols contribute to the current received sample $y[m]$. The proposed SAJD algorithm is described in Algorithm 1. The receiver first estimates the timing and frequency offsets for the K number of arriving packets and initializes the LLRs for all the symbols from all the packets to zeros.

input : A set of samples,
$\mathbf{y} = \{y[m_1], \cdots, y[m_L]\}$ // $L \geq 2N+1$
A set of frequency offsets $\mathbf{f} = \{f_1, \cdots, f_K\}$
A set of timing offsets $\boldsymbol{\tau} = \{\tau_1, \cdots, \tau_K\}$
output: K sets of packet LLRs,
$\overline{\boldsymbol{\Lambda}}_k = \{\overline{\Lambda}_{k,-N}, \cdots, \overline{\Lambda}_{k,N}\}$ for $k = 1, \cdots, K$

Initiation;
$\overline{\Lambda}_{k,n} \leftarrow 0$ for $k = 1, \cdots, K$ and $n = -N, \cdots, N$

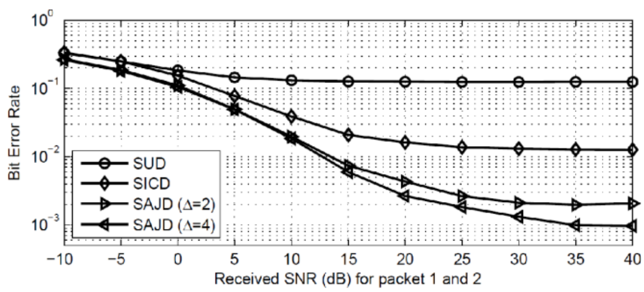
Iteration for LLR computation;
for $l \leftarrow 1$ **to** L **do**
  Calculate $\mathcal{N}_k = \left\{ n \,\middle|\, \frac{|m_l - nT - \tau_k|}{T} < \frac{\Delta}{2} \right\}$
    for all $k = 1, \cdots, K$
  for $k \leftarrow 1$ **to** K **do**
    for $n \in \mathcal{N}_k$ **do**
      Calculate $\Lambda_{k,n}$
      $\overline{\Lambda}_{k,n} \leftarrow \overline{\Lambda}_{k,n} + \Lambda_{k,n}$ // update LLR
    end
  end
end

Algorithm 1. LLR computation algorithm for the proposed suboptimal asynchronous joint detection

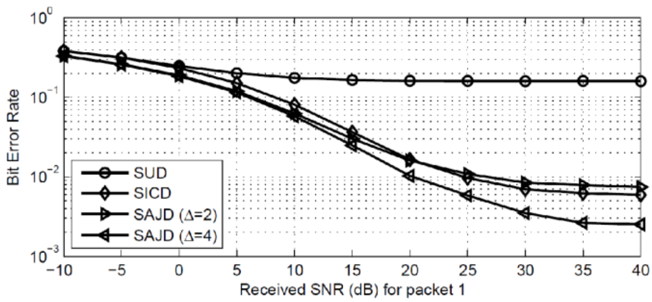
Then, it calculates the neighbor symbol set N_k for all packets and calculate partial LLRs for the neighboring symbols. Finally, the receiver updates the final LLRs by the partial LLRs and turns to the next received sample.

IV. NUMERICAL EXAMPLES

In our simulations, two users transmit their own BPSK-modulated packets of length of $N = 600$ to a common receiver. Lack of timing and frequency synchronization among the three nodes is modeled as $\{\tau_1, \tau_2\}$ and $\{f_1, f_2\}$, and they are assumed to be random and uniformly distributed with intervals $\tau_k \in [0, T)$ and $f_k \in [-10^4, 10^4]$, respectively. T is set to 10^{-6} sec and the roll-off factor is set to a typical value of 0.35. We set $L = 2N + 1$. The wireless channel coefficients are assumed to be independent Rayleigh distributed and unchanged during a packet reception.



(a) Symmetric channel environment $\left(\mathrm{E}\left[\|h_1\|^2\right]=\mathrm{E}\left[\|h_2\|^2\right]\right)$.



(b) Asymmetric channel environment $\left(\mathrm{E}\left[\|h_1\|^2\right]=10\mathrm{E}\left[\|h_2\|^2\right]\right)$.

Fig. 1. BER performance of the SAJD technique the conventional techniques for varying received SNR.

In Fig. 1(a), the proposed SAJD scheme outperforms SIC and SUD in all SNR ranges. Note that the BER of SAJD for $\Delta = 2$ is roughly a tenth of that of the SIC at maximum. Moreover, the BER of SAJD $(\Delta = 4)$ is less by a half of that of the SAJD for $\Delta = 2$ at the high SNR. Fig. 1(b) shows the BER performance in an asymmetric channel environment. The SIC achieves low BER compared with the previous symmetric channel environment because the BER of decoding the stronger packet is generally good enough to perfectly reconstruct the transmitted stronger packet. The SIC achieves even better performance than the SAJD for $\Delta = 2$ when the SNR is greater than 20 dB. However, the SAJD for $\Delta = 4$ still achieves the best BER for all observed SNR ranges.

V. CONCLUSION

We propose a novel and practical joint detection technique for distributed ad hoc networks in which the timing and frequency offset cannot be pre-compensated. The proposed SAJD technique works well for practical pulse-shaping filters such as the RRC filter with a reasonable complexity of $O(MK)$ at the receiver. We also derived an analytical model and an algorithm to compute accurate bit LLR values for multiple packets. The numerical results show that the proposed SAJD technique outperforms the conventional SUD and SIC techniques in terms of the BER at receiver.

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