Timing Synchronization for Cooperative Wireless Communications

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Outline of presentation

- Motivation
- Problem statement
- Questions to be answered
- What we attempted
- Contributions
• Cooperative wireless communication is one of the expected key radio technologies for next generation wireless system.

• Cooperative communication has the ability to realize performance gains of MIMO wireless networks consisting of single antenna devices.

• Cooperative communication can improve capacity, symbol error rate and energy efficiency.
Motivation

As a radio technology cooperative communication is applicable in:

- Mobile communications
- Nationwide deployment of future wireless networks
- Body-area communications
- Satellite communications
- Defence
- Low-power communications
- Green communications
- Underwater communications
Problem statement

- Perfect timing is assumed by various researchers for analyzing the performance of cooperative communication.

- However, perfect timing represents a very strong and unrealistic assumption due to the distributed nature of the cooperative communication.
Why do we need timing synchronization?

- Timing synchronization performance is critical to system performance where a large amount of design time, receiver area and power is spent.

- Relevance of timing synchronization is increasing due to a number of factors including
  - Decreased transmit distances use low transmit power, and therefore, receiver power begins to dominate.
  - The wireless channel is more frequency selective at higher transmissions speed which require increased timing synchronization functionality.
Why do we need timing synchronization

Fig. 1: Timing error in the received signal

τ is the timing error to be estimated

Optimum time instant

Received Signal

Fig. 1: Timing error in the received signal
Fig. 2: Receiver structure with timing recovery
Cooperative communication

Fig. 3: Single link and two-hop communications
Fig. 4: Cooperative Communications
Questions to be Answered

- What is the effect of timing synchronization errors on wireless communications over a fading channel? Can we quantify the effect in terms of performance degradation?

- Can we design a timing estimator with low computational complexity that will work for AWGN channel and for fading channels with different statistical characterizations? Can we find the theoretical performance bounds of the timing estimator?

- What is the effect of timing synchronization errors on cooperative communications? Can we quantify the performance degradation due to timing synchronization errors?
Questions to be Answered

• Can we design a timing estimator that can be applied to cooperative communication over a variety of flat slow fading conditions?

• Can we find a timing estimator that is robust to change of fading conditions including fast flat-fading channels, modulation schemes with larger signal constellations and diversity combining methods?

• What is the effect of power allocations and timing errors on the quality of service in power constrained cooperative communication?
Overview of what was attempted

- NDA-NML Timing Estimation for Single Link Transmission with Timing Error
- Theoretical Performance for Single Link Transmission with Timing Error
- Timing Estimation Techniques for 3-Node Cooperative Communications in Slow Fading Channels
- Timing Synchronization for 3-Node Cooperative Communications in Fast Fading Channels with Larger Signal Constellations
- Effect of Timing Synchronization on Power Allocation in 3-Node Cooperative Communication
- Timing Synchronization for Multinode Cooperative Communications
- Theoretical Performance for Cooperative Communications in Presence of Timing Errors
- Thesis Preparation

Fig. 5: Flowchart of attempts
NDA-NML timing estimator for single link

• Develop a non data aided near maximum likelihood (NDA-NML) timing estimator with low computational complexity.

• Derive probability distribution of timing estimates.

• Derive probability distribution of maximum energy.

• Derive Cramer Rao bound (CRB) and modified CRB (MCRB) for the NDA-NML timing estimator for AWGN channel

• Evaluate the performance of the NDA-NML timing estimator in terms of bit-error-rate for AWGN channel and for fading channels with different characterizations.
• Characterize bit error probability (BEP) for static timing error for AWGN channel using raised cosine pulse shaping.

• Derived closed form expression for conditional BEP with static timing errors for BPSK over Rayleigh fading channel for NRZ pulse shaping.

• Expressions for average BEP are found for dynamic timing errors assuming timing error has either a Gaussian distribution or a Tikhonov distribution.
Timing synchronization for 3-node cooperative communication

- Extend NDA-NML estimation to be applied to 3-node cooperative communication.

- Develop data-and-channel aided timing estimation for cooperative communication.

- Derive a CRB for asymptotically low SNR for NDA-NML estimator.

- Timing complexity of NDA-NML estimator is derived and compared to known DA-ML estimator.
Fig. 6: Timing complexities for NDA-NML estimator and correlator based DA-ML estimator
Fig. 7: Effect of static timing error on BER performance of cooperative communication
Fig. 8: BER with timing estimation and correction for various combining methods
DCA-ML estimation for cooperative communication

Fig. 9: Performance of DCA-ML estimator applied in 3-node cooperative communication operating in Weibull fading channels.

Weibull fading channel
Scale parameter, $a = 1.0$
Shape parameter, $b = 0.7$

Fig. 9: Performance of DCA-ML estimator applied in 3-node cooperative communication operating in Weibull fading channels.
• We consider selection combining, sub-optimal selection combining and sub optimal maximal ratio combining.

• The low complexity NDA-NML estimator performs well for larger signal constellations in fast fading channels.

• Both the estimators perform better in fast fading with constant modulus constellations.
• The paradigm shift towards green communication for developing power efficient communication system has attracted many stakeholders.

• Our results show that power allocations at the source and relay nodes for transmissions and related timing errors at relay and destination nodes have some considerable effect on the power constraint cooperative communication.
Cooperative techniques for saving transmit power

**Fig. 10:** BER for cooperative communication for various power allocations and timing errors

- $P_i/N_0 = 10$ dB
- $P_2/P = 1 - P_1/P$
- $T/T_s = 15$

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Applied Signal Processing Series Seminar Presentation

Thursday 23rd Sept 2010
Multi-node cooperative communication

- Decode-and-forward relaying with linear block code.

- We propose switch-and-stay combining (SSC) and switch-and-examine combining (SEC) for multi-relay cooperative communication.

- We consider various cooperative architectures with equal gain combining, maximal ratio combining, selection combining, SSC and SEC with different fading conditions.
Multi-node cooperative communication

• Performance gains of various orders of cooperative diversity, with various combining methods are realized using NDA-NML timing estimation.

• Performance degradation with synchronization errors increases with increasing diversity.

• Decode-and-forward relaying with a simple coding scheme performs better than detect-and-forward relaying.
• Performance could deteriorate if more relays are used in a multi-hop link

Fig. 11: Cooperative communication architecture with one parallel multi-hop branch, two relays for the multi-hop branch and source to destination transmission – $C(1,2,0,1)$
- MRC could be inferior to SC if there is a timing error in MRC.

Fig. 12: Performance of $C(1,1,0,1)$ cooperative communication architecture operating in Rayleigh fading channels with various combining techniques with and without synchronization.
• Derive analytical expressions for bit error probability (BEP) with timing synchronization errors for amplify-and-forward and detect-and-forward cooperative communication.

• BEP expressions are derived both for static timing errors and dynamic timing errors assuming timing error has a Gaussian distribution.

• BPSK modulation, Rayleigh fading channels, rectangular pulse shaping and maximal ratio combining method are considered.
• It is found that for large timing errors, whether static or dynamic, cooperative communication performs worse than single link transmission with exact timing.

• BEP performance using detect-and-forward relaying performs better than that of amplify-and-forward relaying strategy both for perfect and imperfect timing.
Analytical performance of cooperative communication with timing synchronization errors

Fig. 13: BEP of amplify-and-forward and decode-and-forward cooperative communications.
Summary:

2 Journal Articles Published
1 Journal Article Accepted
1 Journal Article Submitted
1 Journal Article is in Preparation
4 Conference Paper Published
3 Conference Papers are planned to prepare
(If I get time after thesis writing)
Thank You!

Questions?