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Estimating Timing and Frequency Offset along with Channel in Multi-Relay Cooperative Networks Using Amplify and Forward Network

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Abstract: Orthogonal synchronization has been a major problem in Cooperative Orthogonal Frequency Division Multiplexing (CO-OFDM) under the influence of both carrier frequency offset and timing offset with unknown channel gains. CO-OFDM network performance can be improved by employing Amplify-and-Forward (AF) relay strategy. The OFDM network comprises of many sub-carriers which requires an adjustment of transmit frequencies in order to avoid Inter-Carrier-Interference (ICI) which would otherwise destroy the orthogonality of subcarriers and lead to severe performance degradation. Symbol timing offset between transmitter and receiver due to multipath propagation that exist in cooperative channels often cause erroneous decoding and Inter-Symbol-Interference (ISI). Multi-relay cooperative networks affected by Multiple Carrier Frequency Offsets (MCFO's), Multiple Timing Offsets (MTO's) and unknown channel gains are estimated by Maximum-Likelihood (ML) estimation and Maximum Ratio Combining (MRC). Simulation results show that, through the ML decoding method, cooperative system results in significant improvement in Symbol Error Rate (SER).

Key words: Cooperative Networks · Timing Offset · Frequency Offset · Amplify and Forward

INTRODUCTION

In the past decades, wireless communication has benefited from a variety of technology advancements and it is considered as the key technique for innovative future consumer products. In order to satisfy the requirements of various applications from generation to generation, many kinds of innovations in wireless technologies and devices have been developed and utilized in our daily life. In future, significantly technical achievements are required to ensure that wireless communications have appropriate architectures suitable for supporting a wider range of services and higher speed data transmission delivered to the users.

In the foreseeable future, the large-scale deployment of wireless devices and the requirements of high bandwidth applications are expected to lead to tremendous new challenges in terms of efficient exploitation of the achievable spectral resources. The coming wireless personal communication systems are expected to provide ubiquitous, high-quality and high-rate mobile multimedia transmission. However, in order to achieve this objective, various technical challenges need to be overcome. Signal fading due to multi-path propagation is one of the major impairments to meet the demands of next generation wireless networks for high data rate services. To mitigate the fading effects, time, frequency and spatial diversity techniques or their combinations can be used.

Among different types of diversity techniques, spatial diversity is of a special interest as is does not incur the system losses in terms of delay and bandwidth efficiency. Spatial diversity has been studied intensively in the context of MIMO system. It has been shown that utilizing MIMO systems can significantly improve the system throughput and reliability. However, MIMO gains hinge on the independence of the paths between transmit and receive antennas, for which one must guarantee antenna element separation several times the wavelength, a requirement difficult to meet with the small-size terminals. To overcome this problem and to benefit from the performance enhanced by MIMO systems, cooperative diversity schemes for the relay transmission have been introduced. Recently, the research on

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cooperative communication is extremely active. In Europe, the Enhanced Wireless Communication Systems Employing cooperative diversity is a famous international project, which includes a lot of state of the art on the cooperative communication research.

Among the existing air-interface techniques, OFDM is a promising technique for high-bit-rate wireless communications. It possesses the advantages of frequency parallel transmission, high speed communication and efficient spectrum usage. By introducing OFDM transmission into the cooperative communication domain, the gains from both sides are combined. When transmitted through the multipath channel, OFDM can help that cooperative communication gain from multipath diversity.

Frequency offset introduces interference among the multiplicity of carriers in the OFDM signal leading to loss of orthogonality. Imperfect timing synchronization between transmitter and receivers in a practical cooperative network often cause erroneous decoding and Inter Symbol Interference is generally in robust OFDM based systems. Synchronization is crucial in OFDM systems. Signal diversity resulting from cooperative communication, makes joint compensation absolutely necessary. Cooperative diversity is a lucrative alternative to achieve spatial diversity when the multiple antenna structure is not an option. By adopting the cooperative relay nodes to forward information, we can mitigate the fading effects, increase the capacity, lower the bit-error rate, increase the achievable transmission range and without sacrificing time and bandwidth efficiency.

OFDM is a popular multicarrier modulation technique in the modern wireless communications, since it possesses the advantages of parallel transmission, high speed communications and efficient spectrum usage. Cooperative communications generally assume perfect timing synchronization among the cooperative nodes and frequency offsets are compensated for or vice-versa. This implies that the transmission from different cooperating nodes reach the destination in orthogonal time slots. In practice, due to imperfect synchronization, orthogonality among different node signals at the destination can be lost, causing ISI or ICI. To carry out joint estimation of timing and carrier frequency offset in a cooperative multi relay network by employing amplify and forward ML decoding and MRC combining.

Related Works: Relaying is a key technology to assist in the communication between two user terminals, especially when there are large transmission distances between them. Unidirectional (one way) relaying supports communication from a source user to a destination user. On the other hand, TWRNs allow for more bandwidth efficient use of the available spectrum since they allow for simultaneous information exchange between the users with the assistance of an intermediate relay node. Thus, compared with one way half-duplex relaying, bidirectional relaying is a spectrally more efficient relaying protocol. Both AF and DF protocols have been developed for TWRNs. In contrast to the DF protocol, the AF protocol is widely adopted, as it requires minimal processing at the relay node [1]. Also considering relay node that purely amplifies and forwards, which is also known as the repeater [2].

Cooperative communications is an attractive low cost solution to combat fading in wireless communications, where multiple single antenna relay terminals receive and cooperatively transmit the source information to the destination. In cooperative networks, MCFOs and MTOs originate due to multiple distributed nodes [3]. However, such an idealistic assumption does not hold in practical cooperative systems, where the channel gains, MCFOs and MTOs need to be jointly estimated. This fact is highlighted in [2], where joint ML estimation of MCFOs, MTOs and channel gain for DF cooperative systems is investigated. However, the ML estimator in [2] is very computationally complex. The improvement in spectrum efficiency in TWRN is achieved by applying self-interference cancelation at each source node and extracting the desired information from the received network-coded messages [4].

During the two phase communication in AF TWRNs, the two users first transmit their information to the relay node. The relay broadcasts its received signal to both users in the second phase. However, the two users' signals at the relay node undergo different propagation and may not be aligned in time and frequency. Consequently, the superimposed signal broadcasted from the relay node is affected by multiple impairments, e.g., channel gains, timing offsets and carrier frequency offsets [5]. CRLBs and different techniques for estimating MCFOs and MTOs are addressed in [3]. A low complexity and low overhead semi-blind channel estimation algorithm helps the signal detection in AF TWRNs [6]. To realize channel estimation of individual links and to decompose the bidirectional link into MAC phase and BC phase and conducted the channel estimation in each phase is discussed in [4].

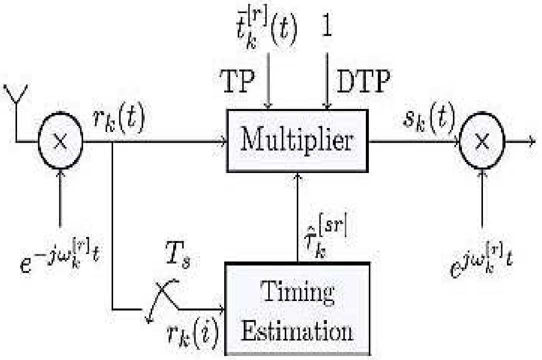

Fig. 1: Block diagram for AF kth relay transmitter

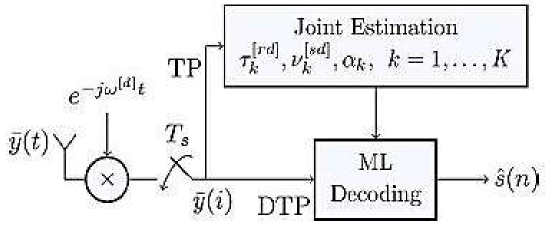

Fig. 2: Block diagram for AF destination receiver

Training and data transmission methods for both DF and AF relaying multi relay cooperative networks affected by MCFOs and MTOs and unknown channel gains [7]. Next, ML approach is proposed to decode the received signal at the destination for both DF and AF systems [3] (i.e.) Estimation and compensation algorithms have been proposed to counter these impairments in unidirectional relaying networks.

System Design

AF-Relaying Cooperative Network: The block diagram for the AF transceiver at and AF receiver at are depicted in Fig.1 and Fig.2, respectively. The proposed training and data transmission methods for the TP and DTP are outlined in the following two subsections.

Training Period: The received signal at is down converted by oscillator frequency and then over sampled by the factor *Q*. The sampled received signal at the input of the timing estimation block, is given by eqn. (1).

$$(n)\ g(i - nT - T) + (i) \qquad (1)$$

where is the carrier frequency offset, normalized by the symbol duration, between S and, denotes the unknown channel gain from S to that is assumed to not change over a frame but to be distributed as from frame to frame, is the normalized fractional unknown timing offset of the sampler at, is the sampling time period such that, *g(t)* is the transmitter pulse shaping function, L is the length of the source training signal (TS) and is the zero-mean complex baseband AWGN at with variance, i.e.,) Without loss of generality, it is assumed that the noise at all relays have the same variance, i.e.,

In order to ensure synchronous transmission and successful cooperation for AF networks, a timing detector at the kth relay estimates the corresponding timing offset,, using schemes available for point-to-point SISO. The timing offset estimate is used as an input to the multiplier to ensure that the kth relay's unit amplitude training signal, is multiplied by the received signal at the appropriate time. The training signal used for AF relaying here is given by for, where is in between and denotes the phase of the nth symbol of the kth relay's training signal, where, for. The output of the analog multiplier,, as shown in Fig.1, is given by

☻ (2)

where is the timing estimation error between *S* and and is the analog frequency offset between *S* and. The received signal at D for AF relaying, is affected by the timing offset from the kth relay to the destination, for. Thus, the sampled received signal is given by,

☻ (3)

where

- denotes the complex unknown channel gain from To D that is assumed to be distributed as) from frame to frame.
- satisfies the kth relay's power constraint.
- is the sum of CFOs from S - -D
- is the normalized CFO from to.
- .
- is the AWGN at D and has been used in place of since denotes the AWGN and its statistics are not affected by the sampling time.
- ;
- is a
- ;
- and
- Note that has the same statistical properties as, for, due to the assumption of unit-amplitude training signals.

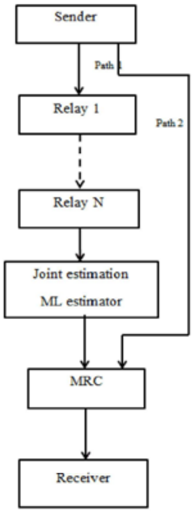

Fig. 3: Flow chart

Data Transmission Period: Modulated data symbol Vector is transmitted from source to the relays. As shown in Fig.1, after performing timing correction using timing offset estimates obtained in the TP, forwards the received signal to D. The received signal at D inthe DTP can be written as

☻ (4)

Where and Fig. 3 summarizes the proposed transceiver structure at for AF relaying.

RESULTS AND DISCUSSION

In this section, the SER performance of AF, DF and point–to- point communication using OFDM subcarriers in a cooperative network with single relay, two relay and multi-relay between Source and Destination is presented. Randomly generated timing and frequency offsets are introduced in all signal pathways, i.e., Source to destination, source to relay1, relay1 to relay2, relay2 to relay3 and relay3 to destination. The signal strength to error performance comparison before and after compensation for the estimated offsets is shown graphically.

- AWGN noise is added to signal from source to relay, relay to destination and source to destination (such that length compensates the input signal length).
- Average channel gain is finally added to the input signal and transmitted from the source.
- Maximum Ratio Combining technique is used at the receiver.

Table 1: Simulation Scenario

Parameters	Value
No. of symbols	10^6
Total transmitted power	1
Protocol used	AF, DF
Modulation technique	QPSK
Channel	AWGN
Fading	Rayleigh fading
Software	MATLAB

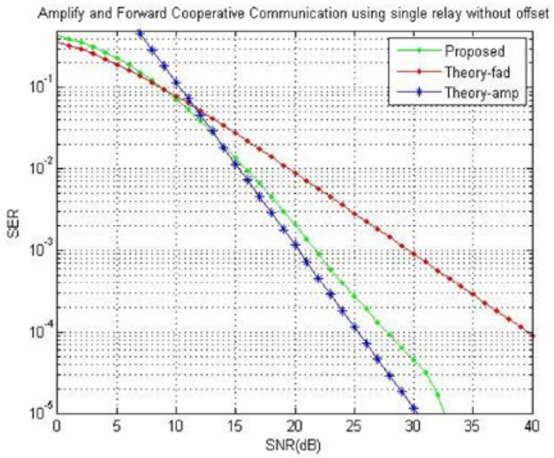

Fig. 4: Amplify and forward using single relay network without offset

The comparison of the SNR vs. SER for single relay, two relay and multi-relay network using AF protocol was shown below. The simulation compares the SER with theoretical Rayleigh fading, AWGN channel and AF channel.

SER of AF using single relay gives 32.5dB of SNR when compared to theoretical result of AF, AWGN and fading channel. For a SER of 10^{-3} the theoretical results in Fig. 4 gives SNR of 20dB. The simulation result of the proposed AF gives a SNR of 22dB for SER of $10^{-3.}$

SER of AF using two relay gives 40dB of SNR when compared to theoretical result of AF, AWGN and fading channel. In Fig. 5 the theoretical results show SNR of 26dB for SER of 10^3 simulated results gives SNR of 17.5dB for SNR of 10^{-1}.

In Fig. 6 the theoretical results gives a SNR of 26.5dB for SER of 10^2 the simulated result of proposed AF shows a SNR of 35dB for SER of 10^{-2}.

The simulation result of the proposed AF in Fig.7 shows a SER of 10^{-3} for SNR of 20dB and the theoretical calculations also shows a SNR of 20dB for a SER of 10^{-3}. Hence, the theoretical and simulated results are almost same.

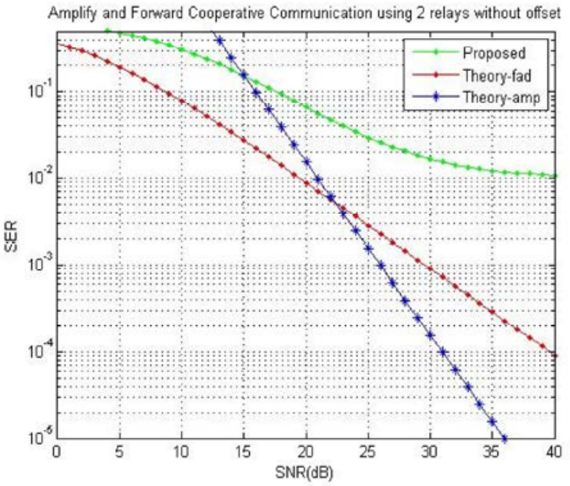

Fig. 5: Amplify and forward using two relay without offset

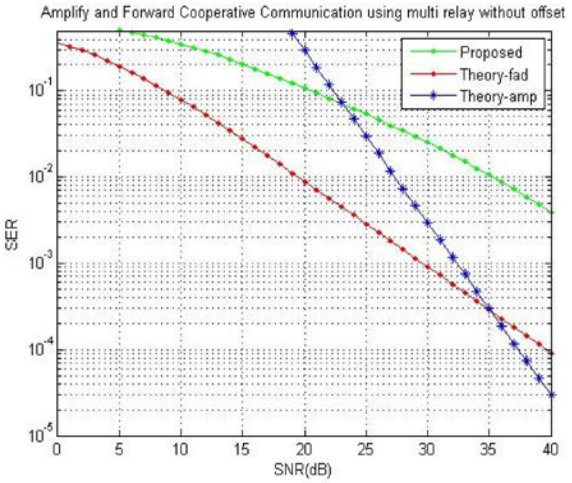

Fig. 6: Amplify and forward using multi relay without offset

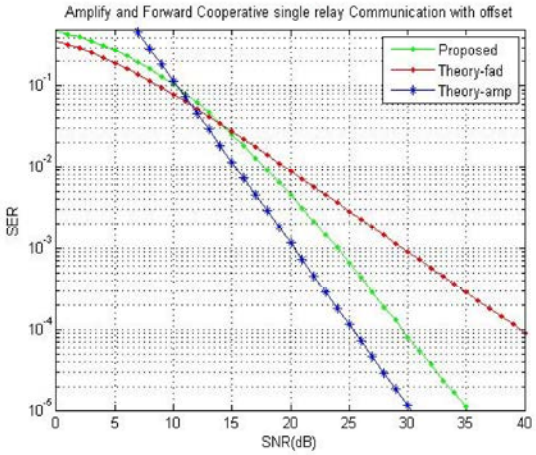

Fig. 7: Amplify and forward using single relay with offset

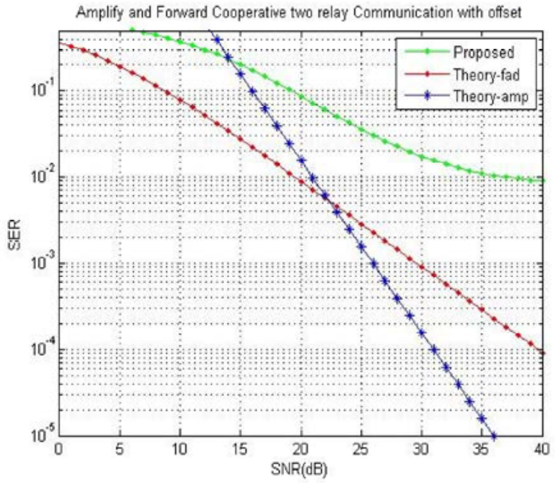

Fig. 8: Amplify and forward using two relay with offset

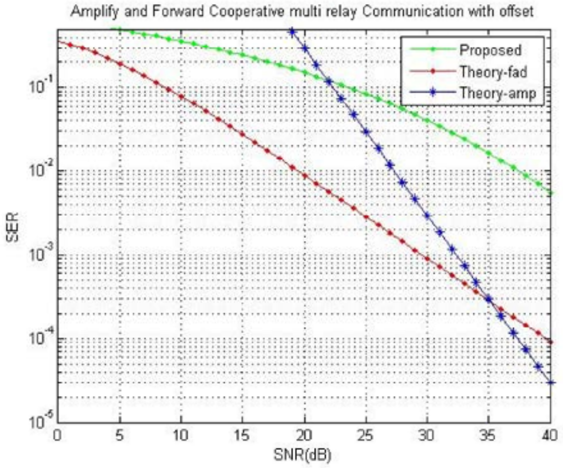

Fig. 9: Amplify and forward using multi-relay with offset

The simulated results in Fig. 8 shows a SNR of 20dB for corresponding SER of 10^{-1} while the theoretical results gives SNR of 16dB for SER of 10^{-1}.

The simulated results in Fig. 9 shows a SNR of 33dB for SER of 10^{-2} and theoretical results shows a SNR of 27dB for SER of 10^{-2}.

Above results shows that the proposed AF with and without offset highly advantageous in single relay system and shows better result when compared to other methods, but doesn't show any significant improvement in multi relay networks.

CONCLUSION

Multi-relay co-operative networks affected by MCFO, MTO and unknown channel gain were estimated by ML estimator. The performance of the AF using multiple relaying strategies was analyzed with and without offset. A better correlation to theoretically calculate values after the joint compensation for timing and carrier frequency offsets with multi-relay cooperative networks was performed. The AF using single relay network shows a SER of 10^{-3} for SNR of 22dB. AF using two relay shows SER of 10^{-3} for SNR of 17.5dB. AF using multi-relay network shows a SER of 10^{-2} for SNR of 35dB. A similar performance analysis for two-way relay network in a cooperative OFDM can be implemented for better bandwidth efficiency. We also intend to develop a hybrid relaying strategy involving both the AF and DF relaying protocols.

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