Performance Evaluation of Outage Behaviour Of Cooperative Diversity In Wireless Networks

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ABSTRACT:

Cooperative communication systems have emerged as a significant concept to improve reliability and throughput in wireless systems. Some existing cooperative diversity protocols are shown to increase the diversity order, allowing single-antenna nodes to cooperate and achieve performance like a real MIMO system. In this paper we focus on the outage probabilities of both fixed and adaptive strategies of the cooperative communication protocols and combined protocols of Compress and Forward (CF) protocol like Amplify and Forward (AF) with CF and Decode and Forward (DF) with CF protocol are proposed and their performance is compared with other relaying techniques in terms of their outage behaviour.

Keywords: Cooperative communication, Outage behaviour, Relaying techniques

I.INTRODUCTION

Communication in a wireless network can be improved by letting the terminals cooperate. Cooperation helps providing diversity, can enable higher transmission rates and offer a better coverage. These promises of cooperation have drawn a lot of interest and research in recent years; contributions most related to this paper are [1]–[3].

Three relaying techniques are at the core of cooperative communication. The first typical approach is to make the relay decode, re-encode and forward the signal; this is the so-called Decode-and-Forward (DF) strategy. The second approach consists in making the relay simply amplify the signal it receives and forward it to the destination; this is the Amplify-and-Forward (AF) technique. And finally, in the third approach the relay compresses the signal it receives, then encodes compressed version and sends it to the destination; this is termed Compress-and-Forward (CF).
II. SYSTEM MODEL

We consider a simple wireless relay network consisting of a source terminal, a relay and a destination as in fig. 1. Transmissions suffer from frequency-flat block-fading and additive noise, which is deemed appropriate for a narrow-band low-mobility scenario [4].

The relay operates in half-duplex mode, to get round the technical difficulty of receiving and transmitting at the same time in the same frequency band. Moreover, in order to keep the receiver at the destination simple, we allocate orthogonal channels to the source and the relay. Bandwidth and time are equally shared out among these.

Figure 1: Simple Cooperative Communication Network

In phase 1, the source broadcasts its information to both the destination and the relay. The received signals $y_{s,d}$ and $y_{s,r}$ at the destination and the relay, respectively, can be written as

$$y_{s,d} = \sqrt{P} h_{s,d} x + n_{s,d}$$

$$y_{s,r} = \sqrt{P} h_{s,r} x + n_{s,r}$$

in which $P$ is the transmitted power at the source, $x$ is the transmitted information symbol, and $n_{s,d}$ and $n_{s,r}$ are additive noise. In (1) and (2), $h_{s,d}$ and $h_{s,r}$ are the channel coefficients from the source to the destination and the relay, respectively. They are modeled as zero-mean, complex Gaussian random variables with variances $\delta_{s,d}^2$ and $\delta_{s,r}^2$, respectively. The noise terms $n_{s,d}$ and $n_{s,r}$ are modeled as zero-mean complex Gaussian random variables with variance $N_0$.

In phase 2, the relay forwards a processed version of the source’s signal to the destination, and this can be modelled as

$$y_{r,d} = h_{r,d} q(y_{s,r}) + n_{r,d}$$

where the function $q(\cdot)$ depends on which processing is implemented at the relay node.

III. OUTAGE PROBABILITY OF COOPERATION PROTOCOLS

There may exist many different relaying computations. These differences depend on the required complexity or knowledge at the relay. The relative benefits and merits of the four relaying schemes. They are as follows:

**Fixed protocols**

- *Amplify and forward (AF):* The AF scheme requires no particular computation for relaying, and amplifies the noise in the receiving period during the relaying period.

With the knowledge of the channel coefficients of the Rayleigh fading channel the mutual information of AF protocol is given by

$$I_{AF} = \frac{1}{2} \log(1 + \gamma_1 + \gamma_2)$$

Where

$$\gamma_1 = \frac{P|h_{s,d}|^2}{N_0}$$
The outage probability with spectral efficiency $R$ can be obtained by averaging over the exponential channel gain distribution, as follows:

$$P_r[I_{AF} < R] = E_{h_{s,d},h_{r,d},h_{s,r}} \left[ \frac{1}{2} \log \left( \left( 1 + \frac{|h_{s,d}|^2}{|h_{r,d}|^2} \right) \left( \frac{1}{\Gamma} \right)^{2-1} \right) \right]$$

Calculating the above integration, the outage probability at high SNR is given by

$$Pr[I_{AF} < R] \approx \left( \frac{\sigma_{s,d}^2 + \sigma_{r,d}^2}{2\sigma_{s,d}^2 \sigma_{r,d}^2} \right) \left( \frac{2^{R-1} - 1}{\Gamma} \right)^2$$

- **Decode and forward (DF):** The relay first decodes both messages from source and destination nodes then it independently encodes both decoded messages [5]. The DF scheme requires the full codebooks and huge computation power at the relay $r$.

The mutual information for decode-and-forward transmission in terms of the channel fades can be given by

$$I_{DF} = \frac{1}{2} \min \{ \log (1 + \Gamma |h_{s,r}|^2), \log (1 + \Gamma |h_{r,d}|^2) \}$$

where the min operator in the above equation takes into account the fact that the relay only transmits if decoded correctly, and hence the performance is limited by the weakest link between the source–destination and source–relay [6].

- **Compress and forward (CF):** The relay performs something between DF and AF. It compresses (or quantize) the received signal [7]. The relay requires the quantizing codebooks or output distribution at the relay.

The event $C$ of correct decoding is given by

$$C: R \leq \log_2 (1 + \gamma_{s,d})$$

The event $D$ of correct decompression is written as

$$D: R \geq \log_2 \left( 1 + \frac{1 + \gamma_{s,r}}{\gamma_{s,d}} \right)$$

If both $C$ and $D$ occur, the achievable spectral efficiencies for the cooperative transmission are those satisfying

$$R \leq \frac{1}{2} \log_2 \left( 1 + \gamma_{s,d} + \frac{\gamma_{s,r}}{1 + N_o} \right) \leq I_{CF}$$

The outage probability of the with spectral efficiency $R$ and known $\gamma_{s,r}$, where $\gamma_{s,r} = \left|h_{s,r}\right|^2 P$, is given as

$$Pr[I_{CF} < R] = 1 - \exp \left( -\frac{1}{\sigma_{s,d}^2} \left( 2^{R} - 1 - \frac{\gamma_{s,r}}{1 + N_o} \right) \right)$$

**Adaptive cooperation strategies**

**Selective DF relaying**

In a selective DF relaying scheme, if the signal-to-noise ratio of a signal received at the relay exceeds a certain threshold, the relay decodes the received signal and forwards the decoded information to the destination [8]. On the other hand, if the channel between the source and the relay suffers a severe fading such that the signal-to-noise ratio falls below the threshold, the relay idles.

The mutual information for selective DF relaying is given by
The outage probability for selective relaying can be derived as follows. Using the law of total probability, conditioning on whether the relay forwards the source signal or not, we have

\[
I_{SDF} = \begin{cases} \\
\frac{1}{2} \log \left( 1 + 2G |h_{s,d}|^2 \right), & |h_{s,r}|^2 < g(G) \\
\frac{1}{2} \log \left( 1 + G |h_{s,d}|^2 + G |h_{r,d}|^2 \right), & |h_{s,r}|^2 \geq g(G) \\
\end{cases}
\]

where \( g(G) = \frac{2^{2R-1}}{G} \).

The outage expression at high SNR is given by

\[
(11)
\]

\[
\frac{1}{2} \log \left( 1 + |h_{s,d}|^2 \right), & |h_{s,r}|^2 < g(G) \\
\frac{1}{2} \log \left( 1 + |h_{s,d}|^2 + |h_{r,d}|^2 \right), & |h_{s,r}|^2 \geq g(G)
\]

Incremental relaying

For incremental relaying, it is assumed that there is a feedback channel from the destination to the relay. The destination sends an acknowledgement to the relay if it was able to receive the source’s message correctly in the first transmission phase, so the relay does not need to transmit. This protocol has the best spectral efficiency among the previously described protocols because the relay does not always need to transmit, and hence the second transmission phase becomes opportunistic depending on the channel state condition of the direct channel between the source and the destination. The outage probability can be calculated as follows:

\[
Pr[I_{IR} < R] = \frac{1}{2} \log \left( 1 + |h_{s,d}|^2 + |h_{r,d}|^2 \right) \left( \frac{2^{2R-1}}{G} \right)
\]

(12)

For large SNR we have

\[
Pr[I_{IR} < R] \simeq \left( \frac{1}{\sigma^2_{s,d} + \sigma^2_{r,d}} \right) \left( \frac{2^{2R-1}}{G} \right)
\]

(13)

IV. PROPOSED PROTOCOLS

In this paper we propose the combination of AF and DF protocols with CF protocol. The outage probabilities of these protocols are also analyzed and compared.

This section introduces a protocol for two alternately transmitting relay nodes of which one relay node is transmitting while the other relay is listening. We apply a mixed approach where one relay supports the source using CF and one node employs DF/AF. The major bottleneck in such a network is the inter-relay interference, which can, however, be exploited if the destination uses the CF transmission to decode not only the source but also the DF-relay transmission. Nonetheless, we still face the problem that the DF relay is interfered by the CF relay, which we mitigate using the previously introduced regular encoding approach, i.e., both DF/AF relay and the destination decode the transmission of the CF relay but use different side information [8]-[10].

Figure 2: Phase 1 of combined protocols

\[
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Figure 3: Phase 2 of combined protocols
The outage probability for DF&CF protocol is given as
\[ P_{R_{DCF}}[I_{DCF} < R] = 1 - \exp \left( \frac{1}{\sigma_{s,d}^2} \frac{2^{2R-1}}{1+N_0} \right) \] (14)
Similarly the outage probability for AF&CF protocol is given as
\[ P_{R_{ACF}}[I_{ACF} < R] = \exp \left( \frac{-1}{\sigma_{s,d}^2} \frac{\gamma r_d}{(2^{R-1})N_0-1} - 1 \right) \] (15)

V. SIMULATIONS AND DISCUSSION
We compared the performance of fixed, adaptive and combined protocols in terms of their outage probabilities using Matlab simulation. In figure 4, the SNR loss of orthogonal transmit diversity with respect to unconstrained transmit diversity is intended to indicate the cost of the half-duplex constraint, and the loss of our cooperative diversity protocols with respect to the transmit diversity bound indicates the cost of both imposing the half-duplex constraint and employing repetition-like codes. Figure 5 shows the outage probability curves based on the exact and approximate formulae. The curves clearly show that the performance of AF&CF protocol is better than others. It is also interesting that amplify-and-forward and selection decode-and-forward have the same high-SNR performance.

Figure 4: SNR loss cooperative diversity protocols and orthogonal transmit diversity bound relative to the transmit diversity bound.

Figure 5: Comparison of the outage probabilities of cooperative protocols.

VI. CONCLUSION AND FUTURE WORK
This paper presented the performance evaluation of different cooperative communication protocols in terms of their outage behaviour and compared them. For practical implementation of such schemes in a network environment, it is necessary to investigate several other issues, like full duplex operation of relays, relay selection and power optimization.

VII. REFERENCES


