Some New Adaptive Protocols for the Wireless Relay Channel *

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Abstract

The AWGN capacity is given for several adaptive relaying schemes. A constraint is imposed that requires the source and relay to transmit orthogonally through time division duplexing, which divides each transmission into two time slots. During the first slot, the source always transmits. During the second slot, either the source will continue to transmit or the relay will forward using either a decode-forward or amplify-forward rule. The criterion used to select which node transmits during the second slot and the relaying rule is what distinguishes the various protocols.

1 Introduction

The relay channel comprises a source, a destination, and a relay [1]. The destination receives both the direct signal from the source and an indirect signal forwarded by the relay. This is in contrast to multi-hop, where all transmissions pass through the relay and the destination does not receive the source's direct signal. Relaying has received renewed interest due to its ability to achieve distributed spatial diversity in a manner analogous to a fixed antenna array [2].

To achieve the unconstrained capacity of the relay channel, the source and relay must transmit coherently to create a beamforming effect [1]. However, this is not practical due to the difficulty of appropriately synchronizing the phases of the source and relay. A more practical approach is to use time division duplexing (TDD) to orthgonalize the source and relay transmissions. The message is transmitted over two slots. During the first slot, the source transmits. In traditional (non-adaptive) protocols, the second slot is reserved for the relay, which will either amplify the message (without decoding it) and retransmit (*amplify-forward: AF*) or it will decode the message and forward if decoding was successfully (*decode-forward: DF*). However, it is sometimes advantageous to instead let the source continue its transmission during the second slot. This is true, for instance, when the source-destination SNR is better than the relay-destination SNR. Also, in the case of decode-forward relaying, the source could occupy the second slot whenever the relay failed to decode the source's initial transmission. An alternative adaptive protocol is to always use the relay during the second slot, but switch between decode-forward and amplify-forward relaying.

2 Capacity of Adaptive Relaying

Table 1 describes the various protocols studied in this paper and their capacities in AWGN. The source-relay SNR is γ_{sr}, source-destination SNR is γ_{sd}, and relay-destination SNR is γ_{rd}. α is the fraction of time spent in the first slot, while $\bar{\alpha} = 1 - \alpha$ is the fraction spent in the second slot. R is the overall rate of the combined code transmitted by source and relay. If repetition coding is used, $\alpha = \frac{1}{2}$, the same code word is transmitted during both slots, and the destination performs diversity-combining (the SNRs add). If incremental redundancy is used, then α may be any arbitrary value, a single code word is transmitted over the two slots (a different portion over each slot), and code-combining performed at the destination (the capacities add).

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Table 1: Description of relaying protocols and their capacities, where $C(\gamma) = \frac{1}{2}\log_2(1+\gamma)$

name	combining rule	relay if...	capacity
DF-MRC	diversity-combining	always (nonadaptive)	$\min\{\frac{1}{2}C(\gamma_{sd}+\gamma_{rd}), \frac{1}{2}C(\gamma_{sr})\}$ if $\gamma_{sd} < \gamma_{sr}$ $\frac{1}{2}C(\gamma_{sd})$ otherwise
DF-CC	code-combining	always	$\min\{\alpha C(\gamma_{sd}) + \bar{\alpha}C(\gamma_{rd}), \alpha C(\gamma_{sr})\}$ if $\gamma_{sd} < \gamma_{sr}$ $\alpha C(\gamma_{sd})$ otherwise
AF	diversity-combining	always	$\frac{1}{2}C\left(\gamma_{sd} + \frac{\gamma_{rd}\gamma_{sr}}{\gamma_{rd}+\gamma_{sr}}\right)$
RA	adaptive	always	$\max\left\{\min\left\{\frac{1}{2}C(\gamma_{sd}) + \frac{1}{2}C(\gamma_{rd}), \frac{1}{2}C(\gamma_{sr})\right\}, \frac{1}{2}C\left(\gamma_{sd} + \frac{\gamma_{rd}\gamma_{sr}}{\gamma_{rd}+\gamma_{sr}}\right)\right\}$
SA-MRC	diversity-combining	$\gamma_{sr} \geq 2^{4R}-1$	$\frac{1}{2}C(2\gamma_{sd})$ if $\gamma_{sr} < 2^{4R}-1$ $\frac{1}{2}C(\gamma_{sd}+\gamma_{rd})$ otherwise
SA-CC	code-combining	$\gamma_{sr} \geq 2^{2R/\alpha}-1$	$C(\gamma_{sd})$ if $\gamma_{sr} < 2^{2R/\alpha}-1$ $\alpha C(\gamma_{sd}) + \bar{\alpha}C(\gamma_{rd})$ otherwise
SB-MRC	diversity-combining	$\gamma_{sr} \geq 2^{4R}-1$ and $\gamma_{rd} > \gamma_{sd}$	$\frac{1}{2}\max\{\min\{C(\gamma_{sd}+\gamma_{rd}), C(\gamma_{sr}\}, C(2\gamma_{sd})\}$
SB-CC	code-combining	$\gamma_{sr} \geq 2^{2R/\alpha}-1$ and $\gamma_{rd} > \gamma_{sd}$	$\max\{\min\{\alpha C(\gamma_{sd}) + \bar{\alpha}C(\gamma_{rd}), \alpha C(\gamma_{sr}\}, C(\gamma_{sd})\}$

The first three protocols in Table 1 are non-adaptive and thus the relay always transmits during the second slot, if possible (with DF, the relay only forwards if it can decode; with AF it always forwards). These protocols and adaptive protocol SA-MRC have been previously studied in the literature [2]. With the relay-adaptive protocol (RA), the relay always transmits during the second slot. However, RA switches between DF and AF modes: If $\gamma_{sr} \geq 2^{4R}-1$, the relay can decode the source's transmission and thus DF mode is used with incremental redundancy / code-combining; otherwise it will use AF and diversity combining. The last four protocols are all based on DF and adaptively select the node that transmits during the second slot. The first pair (SA) uses a policy based only on the source-relay SNR: If the SNR is insufficient for the relay to properly decode, then the source occupies the second slot. Like the SA protocols, the last pair of protocols (SB) will let the source occupy the second slot if the relay is in an outage. However, even if the relay can decode the source's message it does not always transmit. Rather, the relay will only forward if it both decodes the source transmission *and* has a higher SNR to the destination than the source does.

The various protocols can be compared in terms of their outage event regions [2], which are the values of the three SNRs that cause the destination to be in an outage. The outage regions for the two SA protocols are entirely contained within the region for the corresponding DF protocols. Likewise, each SB protocol is entirely contained within the corresponding SA protocol. Thus, we can conclude that SB performs better than SA, which in turn is better than DF.Comparing code-combining with diversity combining, we find that each X-CC protocol has an outage region that is entirely contained within the corresponding X-MRC protocol. Comparisons between DF and AF are a little harder to make, although the RA protocol always performs better than either.

References

[1] T. M. Cover and A. A. El Gamal, "Capacity theorems for the relay channel," *IEEE Trans. Inform. Theory*, vol. 25, pp. 572–584, Sept. 1979.

[2] J. N. Laneman, *Cooperative diversity in wireless networks: Algorithms and architectures.* PhD thesis, Massachusetts Institute of Technology, 2002.