Outage Probability Analysis of Correlated Sources Transmission over Fading Channels with Line-of-sight Component

Shen Qian (1210021)
School of Information Science
Japan Advanced Institute of Science and Technology

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Abstract: Cooperative communications, recognized as being one of the most important techniques in designing power-and-spectrally-efficient wireless communication networks, have been proposed and studied intensively in the last several years. In cooperative communications scenarios, nodes (i.e., base stations, mobile devices, stationary devices) form *virtual antenna array* to cooperate with each other for better overall network performance, without requiring strict constraints in deployment or high hardware complexity, compared with *fixed* multiple-input multiple-output (MIMO) techniques.

Our research team has been focusing on creating of new concepts and technologies for next generation wireless communication systems, including this very hot topic. The most outstanding achievement made by our team is that the network, in general, can be seen as distributed coding system, as a whole, even though some of the nodes contain errors. Some valuable results achieved based on the considerations, have proven that these techniques can significantly improve performances of the wireless cooperative communication networks compared to the conventional technologies.

In a simple cooperative transmission system which has three nodes, denoted as source 1 (S_1), source 2 (S_2) and destination (D), the role of the D is to reconstruct the information

transmitted from S_1, with the help of information transmitted from S_2. The destination receives two sequences, one from the S_1 and the other from the S_2. S_1 and S_2 can be seen as two sensors, for example, which are located near each other observing the same target, hence the information of S_1 and S_2 are correlated with each other. One can easily find that the relaying is straightforward application of the this transmission system and the correlation between S_1 and S_2 can be regarded as source-relay link (intra-link) error in relaying system. With the technique shown in previous achievements obtained by our research team, the Slepian-Wolf theorem is applied to exploit the correlation knowledge between the information sequences sent from two sources. Hence it exemplifies a Slepian-Wolf correlated sources transmission system.

The relationship between the Slepian-Wolf correlated sources transmission and the relaying has been exploited in various ways. Information theoretic outage probability bound is derived and the optimal relay location is evaluated. A practical, simple coding and its iterative decoding technique are proposed. It is then further extended to the correlated sources transmission over multiple access channel (MAC).

The results achieved by the previous research are all based on the assumption that the variations of the links all follow the Rayleigh distribution which is composed of only non-line-of-sight (NLOS) components. The impact of the line-of-sight (LOS) component is not considered. However, in real transmission environment, either the Channel 1 connecting S_1 to D or Channel 2 connecting S_2 to D, or the both, are often suffer from fading variation having different statistical properties. In relay systems, it is quite reasonable to assume that the Channel 2 has LOS component, resulting in the channel being Rician distributed. Moreover, we extend the problem to more generic and practical case, where fading variation follows the Nakagami-m distribution which is an empirically derived distribution through measurement data gathered in real fields.

In this thesis, the outage probabilities of correlated sources transmission systems are analyzed. The primary goal of this work is to derive theoretical limit for correlated sources transmission which utilize the source correlation, and to establish theoretical bases for wireless cooperative communications system design utilizing the correlated sources transmission concept. We focus on the problems that correlated sources are transmitted via channels having different statistical properties, and analyze how significant influent the differences of the statistical channel characteristics makes on the system outage.

First of all, in this thesis, the outage probability of a system having two correlated sources transmitted to common destination through Rayleigh and Rician fading channels is derived. The outage probability can be expressed by double integrals with respect to the probability density functions (PDF) of the instantaneous signal-to-noise power ratios (SNRs) of each channel, where the range of the integration is determined by the Slepian-Wolf theorem. This work identify the effect of the Rician factor K on the outage probability, where the K factor denotes the average power ratio of the line-of-sight (LOS) component power-to-non-line-of-sight (NLOS) components. We first define the outage event and theoretically derive the outage probability expressions which can be evaluated by numerical techniques. The ***new*** result found by this work is that the outage curve exhibits sharper decay than that with $2nd$ order diversity if two sources are fully correlated. Another ***new*** outcome is that in the case the sources are not fully correlated, the outage curves exhibit very sharp decay at relatively low average SNR region, and then they asymptotically converge in to that with $1st$ order diversity as the average SNR increases. To verify the consistency between the theoretical and practical results, we apply the technique to a Slepian-Wolf correlated sources transmission system where bit-interleaved coded modulation with iterative detection (BICM-ID) scheme is used. Performance comparison between the theoretical outage and the frame-error-rate (FER) shows that FER curves exhibit the same tendency as the theoretical results.

Moreover, we investigate the optimal power allocation for minimizing the outage probability with the condition that the total transmit power of the two sources is kept constant. The analytical results show that, so far as two sources are not fully correlated, lower outage probability can not always be achieved by increasing the transmit power ratio allocated to the source which transmit the signal via the channel have LOS component.

We then investigate the outage probability of a system having two correlated sources transmitted to common destination via Rayleigh and Nakagami-m fading channels, where the Nakagami-m fading channel model is known to more accurately represent the distribution of fading variations of the channel having LOS component than Rician fading channel model. The Nakagami-m distribution well represents the channel variations because it is derived from the measurement data gathered in real fields. The same analytical techniques as the one that are used in the Rician fading case is applied to calculate the outage probability. The most significant contribution of this work is the derivation of a closed-form expression for outage probability in several extreme cases. Furthermore, the asymptotic decay of the outage curves are derived theoretically. This thesis theoretically reveal that the decay of the outage curve is sharper than the $2nd$ order diversity when the m factor value of Nakagami-m fading increases (namely fading variation become milder).

In the main body of this thesis, we analyze the outage probability of a Slepian-Wolf correlated sources transmission system over Rayleigh and Rician fading channels, as well as over Rayleigh and Nakagami-m fading channels, respectively. Rician fading model can well be approximated by the Nakagami-m fading model by adjusting the factor K in Rician fading model and the factor m in Nakagami-m fading model. Hence, it is quite meaningful to identify the impact difference on outage performance. We investigate Kullback-Leibler distance (KLD), which is a measure of the difference between two probability distributions, between the Rician and Nakagami-m distributions. We then evaluate the impact of the KLD on the outage performance. In this work we find theoretically that when the variation of Rician and Nakagami-m fading become milder, the outage performance with Rician fading is well matched to the outage with Nakagami-m fading in the low average SNR region, but there is a difference in the decay of the curves in terms of the diversity order as the average SNR increases. However, again the difference of outage performance becomes small when the channel variation due to Rician and/or Nakagami-m fading further reduces. It can be concluded that the difference between the Rican and Nakagami-m distributions need to be considered when accurately designing and/or evaluating the techniques for wireless communication systems, of which some of the coverage have LOS propagation components.