

BUFFER-AIDED RELAYING IN DF COOPERATIVE NETWORKS

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BHARTI SCHOOL OF TELECOMMUNICATION
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by

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**BHARTI SCHOOL OF TELECOMMUNICATION TECHNOLOGY
AND MANAGEMENT**

Submitted

in fulfillment of the requirements of the degree of Doctor of Philosophy
to the



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Dedicated to

My parents & wife

Certificate

This is to certify that the thesis entitled “**Buffer-Aided Relaying in DF Cooperative Networks**” being submitted by **Manoj B. R.** to the Bharti School of Telecommunication Technology and Management, Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy** is the record of the bona-fide research work carried out by him under our supervision. In our opinion, the thesis has reached the standards fulfilling the requirements of the regulations relating to the degree. The results contained in this thesis have not been submitted either in part or in full to any other university or institute for the award of any degree or diploma.

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Abstract

Cooperative communication has drawn a lot of attention due to its ability to extend network coverage and increase the reliability and effective transmission rates of wireless communication. Data transmission from a source to a destination can be achieved through cooperative diversity or multi-hop relaying using various relay selection techniques which are shown to be efficient in using system resources. In a conventional relaying network, the relay, without employing a data buffer, typically assumes a prefixed schedule for reception and transmission. However, the prefixed scheduling of the data reception and the transmission at the relay does not guarantee that the best of the source-to-relay and the relay-to-destination links is utilized when a fading environment is present. In recent years, for cooperative networks, equipping data buffers at relay nodes has been proven to offer flexible scheduling of data reception and transmission, and higher gain in terms of system throughput and diversity. Therefore, in this thesis, we present a detailed performance analysis of various buffer-aided relay selection techniques which are proposed for cooperative networks with decode-and-forward (DF) relays. We have adopted a Markov chain approach to analyze the state transition matrix that models the evolution of the relay buffer status.

To begin with, we propose, for a dual-hop link with buffer-aided DF cooperative networks, a relaying scheme which is based on giving a priority to the status of buffers along with the highest channel gain of wireless links. We derive analytical expressions for the outage probability and the average bit error rate. Expressions for the steady-state distribution are also obtained, and through these expressions, it is shown that states with the same probabilities can be clustered, thus reducing the size of the state transition matrix. We propose a state-clustering-based method to obtain the reduced

state transition matrix, which in turn reduces the computational complexity in obtaining the steady-state distribution. Numerical results demonstrate that the proposed scheme has better performance gain over the existing max-link scheme.

Multi-hop relaying is an important strategy for improved link performance and increasing the range of communication, while the data buffers at the relays improve the diversity advantage of the system. Thus, we analyze the performance of a buffer-aided multi-hop relaying system using the max-link relay selection scheme for DF cooperative networks. A generalized Markov chain approach is proposed to model the evolution of buffer status for more than one cluster of relays. Closed-form expressions for the outage probability and the average packet delay are derived. We also obtain analytical expressions for the steady-state probability vector for a three-hop buffer-aided system. Through these expressions, we observe that states with the same probabilities can be clustered, thus reducing the size of the state transition matrix. Furthermore, we propose a state-clustering-based method to obtain the reduced state transition matrix, which is further used to derive an analytical expression for the outage probability with reduced computational complexity. Numerical results are provided to investigate the performance of buffer-aided multi-hop relaying networks.

The drawback with the existing max-link scheme in buffer-aided multi-hop relaying networks is that the end-to-end average packet delay increases with increase in the buffer size and the number of relays. To overcome this limitation, we propose, for multi-hop DF cooperative networks, a novel virtual full-duplex relaying scheme, referred to as center-partition max-link relaying, by using buffer-aided half-duplex relays. In this scheme, we aim to select two independent available links for data transmission in the same time slot, which, in turn, improves the overall performance of the system. The performance of the system is analyzed in terms of outage probability and average packet delay. The state transition matrix of the Markov chain is constructed and its steady-state distribution is obtained to derive the outage probability. Numerical results demonstrate that the proposed scheme provides significant outage performance with reduced average packet delay as compared to that of buffer-aided multi-hop DF relaying networks using the conventional max-link scheme.

सार

सहकारी संचार ने नेटवर्क कवरेज का विस्तार करने और वायरलेस संचार की विश्वसनीयता और प्रभावी ट्रांसमिशन दरों को बढ़ाने की अपनी क्षमता के कारण बहुत ध्यान आकर्षित किया है। एक स्रोत से गंतव्य तक डेटा ट्रांसमिशन सहकारी विविधता या मल्टी-हॉप रिलेइंग के माध्यम से विभिन्न रिले चयन तकनीकों का उपयोग करके हासिल किया जा सकता है, जो सिस्टम संसाधनों का उपयोग करने में कुशल दिखाया गया है। एक पारंपरिक रिलेइंग नेटवर्क में, रिले, डेटा बफर का इस्तेमाल किए बिना, आमतौर पर रिसेप्शन और ट्रांसमिशन के लिए एक पूर्व-निर्धारित शेड्यूल होता है। हालाँकि, डेटा रिसेप्शन के पूर्वनिर्धारित शेड्यूलिंग और रिले में ट्रांसमिशन की गारंटी नहीं है कि सबसे अच्छा स्रोत-से-रिले और रिले-से-डेस्टिनेशन लिंक का उपयोग हो जब फेडिंग वातावरण मौजूद है। हाल के वर्षों में, सहकारी नेटवर्क के लिए, डेटा बफर को रिले नोड्स से लैस करने को डेटा रिसेप्शन और ट्रांसमिशन के लचीले शेड्यूलिंग और सिस्टम थ्रूपुट और विविधता के संदर्भ में उच्च लाभ प्रदान करने के लिए सिद्ध किया गया है। इसलिए, इस थीसिस में, हम विभिन्न बफर-एडेड रिले चयन तकनीकों का एक विस्तृत प्रदर्शन विश्लेषण प्रस्तुत करते हैं जो कि डिकोड-एंड-फॉरवर्ड (डीएफ) रिले के साथ सहकारी नेटवर्क के लिए प्रस्तावित हैं। हमने स्टेट ट्रांजीशन मैट्रिक्स का विश्लेषण करने के लिए एक मार्कोव श्रृंखला दृष्टिकोण अपनाया है जो रिले बफर स्थिति के क्रम-विकास को मॉडल करता है।

शुरुआत करने के लिए, हम बफर-एडेड डीएफ सहकारी नेटवर्क के साथ दोहरे-हॉप लिंक के लिए प्रस्ताव करते हैं, एक रिलेइंग योजना जो वायरलेस लिंक के उच्चतम चैनल लाभ के साथ बफर्स की स्थिति को प्राथमिकता देने पर आधारित है। हम आउटेज प्रायिकता और औसत बिट त्रुटि दर के लिए विश्लेषणात्मक अभिव्यक्तियाँ प्राप्त करते हैं। स्थिर-स्टेट वितरण के लिए अभिव्यक्तियाँ भी प्राप्त की गयी हैं, और इन अभिव्यक्तियों के माध्यम से यह दिखाया गया है कि समान संभावनाओं वाले स्टेट्स को क्लस्टर किया जा सकता है, इस प्रकार स्टेट ट्रांजीशन मैट्रिक्स का आकार कम हो जाता है। हम संक्षिप्त स्टेट ट्रांजीशन मैट्रिक्स प्राप्त करने के लिए एक स्टेट-क्लस्टरिंग-आधारित विधि का प्रस्ताव करते हैं, जो बदले में स्थिर-स्टेट वितरण प्राप्त करने में कम्प्यूटेशनल जटिलता को कम करता है। संख्यात्मक परिणाम प्रदर्शित करता है कि प्रस्तावित स्कीम का प्रदर्शन मौजूदा अधिकतम-लिंक योजना से बेहतर है।

मल्टी-हॉप रिलेइंग बेहतर लिंक प्रदर्शन और संचार की सीमा को बढ़ाने के लिए एक महत्वपूर्ण रणनीति है, जबकि रिले में डेटा बफर्स सिस्टम के विविधता लाभ में सुधार करते हैं। इस प्रकार हम डीएफ सहकारी नेटवर्क के लिए अधिकतम-लिंक रिले चयन योजना का उपयोग करके बफर-एडेड मल्टी-हॉप रिलेइंग सिस्टम के प्रदर्शन का विश्लेषण करते हैं। एक सामान्यीकृत मार्कोव श्रृंखला दृष्टिकोण रिले के एक से अधिक क्लस्टर के लिए बफर स्थिति के क्रम-विकास को मॉडल करने का प्रस्ताव है। आउटेज प्रायिकता और औसत पैकेट देरी के लिए क्लोज्ड-फॉर्म अभिव्यक्तियाँ निकाली गई हैं। हम तीन-हॉप बफर-एडेड सिस्टम के लिए स्थिर-स्टेट संभाव्यता वेक्टर के लिए विश्लेषणात्मक अभिव्यक्ति भी प्राप्त करते हैं। इन अभिव्यक्तियों के माध्यम से, हम देखते हैं कि समान संभावनाओं वाले स्टेट्स को क्लस्टर किया जा सकता है, इस प्रकार स्टेट ट्रांजीशन मैट्रिक्स के आकार को कम किया जा सकता है। इसके अलावा, हम एक स्टेट - क्लस्टरिंग-आधारित विधि का प्रस्ताव करते हैं ताकि संक्षिप्त स्टेट ट्रांजीशन मैट्रिक्स प्राप्त किया जा सके, जिसका उपयोग कम कम्प्यूटेशनल जटिलता के साथ आउटेज संभावना के लिए एक विश्लेषणात्मक अभिव्यक्ति प्राप्त करने के लिए किया जाता है। बफर-एडेड मल्टी-हॉप रिलेइंग नेटवर्क के प्रदर्शन की जांच करने के लिए संख्यात्मक परिणाम प्रदान किए गए हैं।

बफर-एडेड मल्टी-हॉप रिलेइंग नेटवर्क में मौजूदा अधिकतम-लिंक योजना के साथ दोष यह है कि बफर आकार में वृद्धि और रिले की संख्या के साथ एंड-टू-एंड औसत पैकेट देरी बढ़ जाती है। इस दोष को पार करने के लिए, हम प्रस्तावित करते हैं, मल्टी-हॉप डीएफ सहकारी नेटवर्क के लिए, एक नयी आभासी पूर्ण-द्वैध रिलेइंग योजना, जिसे केंद्र-विभाजन अधिकतम-लिंक रिलेइंग के रूप में संदर्भित किया जाता है, बफर-एडेड आधा-द्वैध रिले का उपयोग करके। इस योजना में, हम एक ही स्लॉट में डेटा ट्रांसमिशन के लिए दो स्वतंत्र उपलब्ध लिंक का चयन करना चाहते हैं, जो बदले में, सिस्टम के समग्र प्रदर्शन में सुधार करता है। आउटेज प्रायिकता और औसत पैकेट देरी के संदर्भ में प्रणाली के प्रदर्शन का विश्लेषण किया गया है। मार्कोव श्रृंखला के स्टेट ट्रांजीशन मैट्रिक्स का निर्माण किया गया है और इसकी स्थिर-स्टेट वितरण की मदद से आउटेज संभावना को प्राप्त किया गया है। संख्यात्मक परिणाम प्रदर्शित करते हैं कि प्रस्तावित योजना पारंपरिक अधिकतम-लिंक योजना की तुलना में बफर-एडेड मल्टी-हॉप डीएफ रिलेइंग नेटवर्क में कम औसत पैकेट देरी के साथ महत्वपूर्ण आउटेज प्रदर्शन प्रदान करती है।

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Abbreviations

ABER	Average bit error rate
AF	Amplify-and-forward
BER	Bit error rate
BPSK	Binary phase-shift keying
bpcu	Bits per channel use
CCU	Central control unit
CDF	Cumulative distribution function
CPML	Center-partition max-link
CSI	Channel state information
DF	Decode-and-forward
FD	Full-duplex
FSO	Free space optical
HD	Half-duplex
i.i.d.	Independent and identically distributed
i.n.i.d.	Independent and non-identically distributed
IRI	Inter-relay interference
MC	Markov chain
NOMA	Non-orthogonal multiple access
PDF	Probability density function
RF	Radio frequency
SIR	Signal-to-interference ratio
SNR	Signal-to-noise ratio
SSK	Space-shift keying