

SECRECY PERFORMANCE ANALYSIS OF THRESHOLD-BASED COGNITIVE AND COOPERATIVE RELAY SYSTEM WITH DIVERSITY RECEPTION

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DEPARTMENT OF ELECTRICAL ENGINEERING
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by

KHYATI CHOPRA

DEPARTMENT OF ELECTRICAL ENGINEERING

Submitted

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



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OCTOBER 2018

Certificate

This is to certify that the thesis entitled “**Secrecy performance analysis of threshold-based cognitive and cooperative relay system with diversity reception**” being submitted by **Ms. Khyati Chopra** to the Department of Electrical Engineering, Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy** is the record of bonafide research work carried out by her under my supervision. In my 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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Khyati Chopra

Dedicated to my parents
Dr. Praveen Chopra and Dr. Sangeeta Chopra
and
my dear husband
Chetan Arora

Abstract

In wireless networks, cooperative communication explores a new dimension of diversity to combat unfriendly environment. Cooperative diversity is incorporated in a multipath fading environment with the help of relay nodes, to improve the communication reliability and throughput. Maximal ratio combining (MRC) and selection combining (SC) are two diversity combining techniques, where the relayed signal, as well as, the signal from the source are combined to obtain the diversity gain. In this thesis, we begin by investigating the secrecy performance of decode-and-forward (DF) cooperative relay system, without considering threshold-based relaying in the system. The closed-form expressions of the outage probability are evaluated for the worst-case scenario, where MRC and SC diversity combining schemes are employed only at the eavesdropper. To address the impact of source-relay link quality on the system secrecy in a better way, further in the thesis, we propose threshold-based relaying, where, perfect decoding at the relay is only possible if the received signal-to-noise ratio (SNR) at the relay meets the particular threshold.

The growing demand for wireless spectrum has kindled the need for research on cognitive radio (CR), which has emerged as a dynamic spectrum access technique, where an unlicensed (secondary) user is allowed to simultaneously access the licensed channels. Due to the open and dynamic nature of these cognitive radio network (CRN) architecture, the licensed spectrum is opportunistically accessed by the various unknown wireless devices. This makes it extremely vulnerable to potential eavesdropping attacks and thus security becomes a major issue which is addressed in this thesis. For characterizing underlay CRN, we have used power control modeling with peak interference constraints at secondary source and relay.

The research work reported in this thesis aims at studying the effect of threshold-based relaying and diversity reception on the secrecy performance of DF cooperative relay system and underlay cognitive relay system. The relayed and the direct signal is combined at the eavesdropper and the destination. The closed-form expressions of the outage probability are evaluated for the system with either SC, or with MRC or with the combination of both, at the destination and eavesdropper, and the best possible combination for the system secrecy is determined. The secrecy outage probability is observed to be more sensitive to the direct link between source-eavesdropper than source-destination, especially at the higher secrecy rates. This makes the direct transmission link between source-eavesdropper highly crucial for the system secrecy performance. We have shown that the system secrecy performance is significantly affected by the threshold SNR, interference power, eavesdropper channel quality, required secrecy rate and diversity scheme (MRC/SC).

Further, the secrecy outage probability of optimal relay selection (OS) scheme is derived for a multi-relay system, when either the instantaneous channel state information (ICSI) or the statistical channel state information (SCSI) is available. It is shown that the secrecy performance of the OS with ICSI of the system is better than with SCSI, and also the relay selection improves the performance of multi-relay system, when the number of relays are increased. Subsequently, asymptotic and diversity gain analysis of the secrecy outage for both single relay and multi-relay system with relay selection has been presented, when average SNRs of source-relay and relay-destination links are balanced or unbalanced. It is found that the constraint on either of the source-relay and relay-destination link average SNR creates an unbalance, which can actually be a bottleneck for secure communication. However, it is shown that both the unbalance cases do not have symmetric effect on the secrecy, when threshold-based relaying is considered. While, their effect on the secrecy is identical, when threshold-based relaying is not considered. We have also shown that the channel state information (CSI) knowledge at the transmitter can improve secrecy. Moreover, the degree of improvement is more for the outage probability when the required rate is low and for low operating SNR.

Towards the end of the thesis, we use the market strategic game framework, where relay nodes use different duopoly models to trade their power to source. We have evaluated the utility of relays in various duopoly economic models with both symmetric and asym-

metric costs. We have shown that an increase in the channel gain from the relay to the eavesdropper decreases the profit of the relays. We demonstrate that the choice of the strategic variable as output or price, can have a dramatic effect on the Nash outcome. Also, it is shown that the relay will be better-off in the dynamic scenario than static. We have also proposed a scheme based on Stackelberg security game for price and power control, in threshold-based DF relay network. The source profits from the cooperative secrecy rate and the relay gets revenue for transmitting the source information. We have maximized the utility of relay and source, with allocated maximum power constraints at the relay node, using Stackelberg security game scheme. The closed-form optimal solution for price and power control is obtained, for this leader-follower security equilibrium game model, with the help of convex optimization.

सार

वायरलेस नेटवर्क में, सहकारी संचार असंगत वातावरण का मुकाबला करने के लिए विविधता के एक नए आयाम की पड़ताल करता है। संचार विश्वसनीयता और थ्रूपुट को बेहतर बनाने के लिए रिले नोड्स की मदद से मल्टीपाथ लुप्तप्राय वातावरण में सहकारी विविधता शामिल की जाती है। अधिकतम अनुपात संयोजन (एमआरसी) और चयन संयोजन (एससी) दो विविधता संयोजन तकनीकों हैं, जहां रिलेड सिग्नल, साथ ही, स्रोत से संकेत विविधता लाभ प्राप्त करने के लिए संयुक्त होते हैं। इस थीसिस में, हम सिस्टम में थ्रेसहोल्ड-आधारित रिलेइंग पर विचार किए बिना, डीकोड-एंड-फॉरवर्ड (डीएफ) सहकारी रिले सिस्टम के गुप्त प्रदर्शन की जांच करके शुरू करते हैं। आउटेज संभावना के बंद-स्वरूप अभिव्यक्तियों का मूल्यांकन सबसे खराब स्थिति परिदृश्य के लिए किया जाता है, जहां एमआरसी और अनुसूचित जाति विविधता योजनाओं को संयोजित करते हैं केवल छिपाने वाले पर ही कार्यरत होते हैं। सिस्टम गोपनीयता पर स्रोत-रिले लिंक गुणवत्ता के प्रभाव को बेहतर तरीके से संबोधित करने के लिए, थीसिस में आगे, हम थ्रेसहोल्ड-आधारित रिलेइंग का प्रस्ताव देते हैं, जहां रिले पर सही डिकोडिंग केवल तभी संभव होता है जब प्राप्त सिग्नल-टू-शोर अनुपात (एसएनआर) रिले पर विशेष दहलीज को पूरा करता है।

वायरलेस स्पेक्ट्रम की बढ़ती मांग ने संज्ञानात्मक रेडियो (सीआर) पर शोध की आवश्यकता को जन्म दिया है, जो गतिशील स्पेक्ट्रम एक्सेस तकनीक के रूप में उभरा है, जहां लाइसेंस रहित चैनलों के साथ-साथ एक लाइसेंस रहित (माध्यमिक) उपयोगकर्ता को अनुमति दी जाती है। इन संज्ञानात्मक रेडियो नेटवर्क (सीआरएन) आर्किटेक्चर की खुली और गतिशील प्रकृति के कारण, लाइसेंस प्राप्त स्पेक्ट्रम को विभिन्न अज्ञात वायरलेस उपकरणों द्वारा अवसरिक रूप से उपयोग किया जाता है। यह संभावित छिपाने वाले हमलों के लिए बेहद कमजोर बनाता है और इस प्रकार सुरक्षा एक प्रमुख मुद्दा बन जाती है जिसे इस थीसिस में संबोधित किया जाता है। अंडरले सीआरएन की विशेषता के लिए, हमने माध्यमिक स्रोत और रिले पर शीर्ष हस्तक्षेप बाधाओं के साथ पावर कंट्रोल मॉडलिंग का उपयोग किया है।

इस थीसिस में रिपोर्ट किए गए शोध कार्य का उद्देश्य डीएफ सहकारी रिले सिस्टम और अंडरले संज्ञानात्मक रिले सिस्टम के गुप्त प्रदर्शन पर थ्रेसहोल्ड-आधारित रिलेइंग और विविधता रिसेप्शन के प्रभाव का अध्ययन करना है। रिलेड और सीधा संकेत छिपानेवाला और गंतव्य पर संयुक्त होता है।

आउटेज संभावना की बंद-रूप अभिव्यक्तियों का मूल्यांकन एससी के साथ या एमआरसी के साथ या दोनों के संयोजन के साथ, गंतव्य और छिपाने के लिए सिस्टम के लिए किया जाता है, और सिस्टम गोपनीयता के लिए सबसे अच्छा संभव संयोजन निर्धारित किया जाता है। गुप्तता की संभावना संभावना स्रोत-गंतव्य की तुलना में स्रोत-बचाव के बीच सीधा लिंक के प्रति अधिक संवेदनशील होने के लिए मनाया जाता है, खासतौर पर उच्च गोपनीयता दरों पर। यह प्रणाली गुप्तता प्रदर्शन के लिए स्रोत-एवेसड्रॉपर के बीच सीधा संचरण लिंक बनाता है। हमने दिखाया है कि सिस्टम गुप्तता प्रदर्शन थ्रेसहोल्ड एसएनआर, हस्तक्षेप शक्ति, छिपे हुए चैनल की गुणवत्ता, आवश्यक गोपनीयता दर और विविधता योजना (एमआरसी / एससी) द्वारा काफी प्रभावित है।

इसके अलावा, इष्टतम रिले चयन (ओएस) योजना की गुप्तता संभावना संभावना बहु-रिले प्रणाली के लिए ली गई है, जब तात्कालिक चैनल राज्य जानकारी (आईसीएसआई) या सांख्यिकीय चैनल राज्य की जानकारी (एससीएसआई) उपलब्ध है। यह दिखाया गया है कि सिस्टम के आईसीएसआई के साथ ओएस का गुप्त प्रदर्शन एससीएसआई के मुकाबले बेहतर है, और रिले चयन बहु-रिले सिस्टम के प्रदर्शन में सुधार करता है, जब रिले की संख्या में वृद्धि होती है। इसके बाद, रिले चयन के साथ एकल रिले और बहु-रिले सिस्टम दोनों के लिए गुप्तता आउटेज का विश्लेषण प्राप्त किया गया है, जब स्रोत-रिले और रिले-गंतव्य लिंक के औसत एसएनआर संतुलित या असंतुलित होते हैं। यह पाया जाता है कि स्रोत-रिले और रिले-गंतव्य लिंक औसत एसएनआर पर बाधा असंतुलन पैदा करती है, जो वास्तव में सुरक्षित संचार के लिए बाधा बन सकती है। हालांकि, यह दिखाया गया है कि दोनों असंतुलन मामलों में गुप्तता पर सममित प्रभाव नहीं पड़ता है, जब थ्रेसहोल्ड-आधारित रिलेइंग माना जाता है। जबकि, गोपनीयता पर उनका प्रभाव समान है, जब थ्रेसहोल्ड-आधारित रिलेइंग पर विचार नहीं किया जाता है। हमने यह भी दिखाया है कि ट्रांसमीटर पर चैनल राज्य की जानकारी (सीएसआई) ज्ञान गुप्तता में सुधार कर सकता है। इसके अलावा, जब आवश्यक दर कम है और कम ऑपरेटिंग एसएनआर के लिए आउटेज संभावना के लिए सुधार की डिग्री अधिक है।

थीसिस के अंत में, हम बाजार रणनीतिक गेम ढांचे का उपयोग करते हैं, जहां रिले नोड्स स्रोत के लिए अपनी शक्ति का व्यापार करने के लिए विभिन्न डुप्लिकेट मॉडल का उपयोग करते हैं। हमने समरूप और असममित लागत दोनों के साथ विभिन्न दुविधा आर्थिक मॉडल में रिले की उपयोगिता का मूल्यांकन

किया है। हमने दिखाया है कि रिले से चैनल में बढ़ने से चैनल में वृद्धि रिले के लाभ को कम करती है। हम दर्शाते हैं कि आउटपुट या कीमत के रूप में सामरिक चर की पसंद, नैश परिणाम पर नाटकीय प्रभाव डाल सकती है। साथ ही, यह दिखाया गया है कि स्थिर गति से गतिशील परिदृश्य में रिले बेहतर होगा। हमने थ्रेसहोल्ड-आधारित डीएफ रिले नेटवर्क में मूल्य और बिजली नियंत्रण के लिए स्टैकेलबर्ग सुरक्षा गेम के आधार पर एक योजना का प्रस्ताव भी दिया है। सहकारी गोपनीयता दर और रिले से स्रोत लाभ स्रोत जानकारी संचारित करने के लिए राजस्व प्राप्त करता है। हमने स्टैकेलबर्ग सुरक्षा गेम योजना का उपयोग करते हुए रिले नोड पर आवंटित अधिकतम पावर बाधाओं के साथ रिले और स्रोत की उपयोगिता को अधिकतम किया है। उत्तल अनुकूलन की सहायता से, इस नेता-अनुयायी सुरक्षा संतुलन गेम मॉडल के लिए मूल्य और बिजली नियंत्रण के लिए बंद-फॉर्म इष्टतम समाधान प्राप्त किया जाता है।

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List of Abbreviations

AWGN	Additive white Gaussian noise
AF	Amplify-and-Forward
AN	Artificial Noise
ACDG	Adapted Cooperative Diversity Gain
BER	Bit Error Rate
CR	Cognitive Radio
CRN	Cognitive Radio Network
CSI	Channel State Information
CDF	Cumulative Distribution Function
CPS	Cyber-Physical Systems
dB	Decibel
DF	Decode-and-Forward
DWTC	Degraded Wiretap Channel
DSC	Distributed Selection Combining
DSSC	Distributed Switched and Stay Combining
DSA	Dynamic Spectrum Access
EGC	Equal Gain Combining
FCC	Federal Communications Commission
ICSI	Instantaneous Channel State Information
IoT	Internet-of-Things
LOS	Line-of-Sight
LSMIMO	Large-Scale Multiple-Input Multiple-Output
MRC	Maximal Ratio Combining
MIMO	Multiple-Input Multiple-Output
MISO	Multiple-Input Single-Output

MISOME	Multiple-Input Single-Output Multi-Eavesdropper
OS	Optimal Relay Selection
PDF	Probability Distribution Function
PLS	Physical Layer Security
PU	Primary User
QoS	Quality-of-Service
R.V.	Random Variable
SC	Selection Combining
SU	Secondary User
SCSI	Statistical Channel State Information
SNR	Signal-to-Noise Ratio
SIMO	Single-Input Multi-Output
SSSC	Secure Switch-and-Stay Combining
TAS	Transmit Antenna Selection
