

GREEN DESIGN FOR ENERGY-CONSTRAINED WIRELESS SENSOR NETWORKS

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by

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DEPARTMENT OF ELECTRICAL ENGINEERING

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Certificate

This is to certify that the thesis entitled "**Green Design for Energy-Constrained Wireless Sensor Networks**" being submitted by **Rashi Mehrotra** 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 the bona-fide 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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Rashi

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Abstract

With the increasing energy cost in modern communication systems, ‘Green communication design’ has recently become a well known and appealing concept. The advances in the very large scale technology (VLSI) has made a possibility of using thousand of sensor nodes which are as small as size of a grain of dust. As these sensor nodes forms a wireless network hence the name wireless sensor network (WSNs). These nodes consists of sensors, a processor, limited memory, and a radio. These sensors are distributed to collect information on entities of interests, e.g., they can be deployed on the ground, in the air, inside buildings, on bodies, and in vehicles to detect events of interests and monitor environmental parameters. The sensor nodes are battery driven and there is one big issue of recharging and replacement of the battery. Therefore power and energy are the critical constraints in WSNs and the need to reduce its consumption is a primarily concern of today’s engineers.

The thesis is targeted towards reducing energy consumption and providing a power optimal solution for WSNs. In WSNs, operating over short inter-node distances, the total power which depends on the computation and radio power have an impact on the battery life. To increase performance and battery life, we have used smart antenna system (SAS). We have proposed and developed a framework for optimizing power consumption in SAS. In this thesis we have evaluated the utility of SAS from a power perspective by considering the power consumed in the beamforming unit (computation power) and the power consumed in the radio unit (radio power). SAS are analyzed using iterative beamforming algorithms so as to develop green design for SAS.

As WSNs operates in short distances, a relay-based communication is an effective approach to increase energy-efficiency of the system. Hence, joint optimization of constellation size, energy allocation and relay location is proposed for decode-and-forward multi-hop relaying over Rayleigh fading channels under a constraint on average bit error rate. The proposed optimization method minimizes the total energy consumption per bit having constraints on total transmit power, assuming fixed end-to-end distance. It is observed that joint optimization using different constellation size in each hop of the multi-hop network not only performs better than equal allocation, it also outperform when link unbalance is large. By balanced link we mean identical links with equal distance and channel statistics.

One-way relaying communication suffers from spectral-efficiency loss. To overcome the loss, two-way relaying network is proposed. In this thesis, the objective is to propose energy-efficient two-way relaying network for amplify-and-forward strategy. An optimization problem is formulated for power allocation and provided an optimal solution for total transmit power as well as the transmit power at each node. The proposed power allocation solution in two-way relaying outperforms the one-way relaying communication. A relay selection scheme is also proposed which offers an advantage of requiring statistical channel state information (CSI) instead of instantaneous CSI. It also relies on only local CSI than the global CSI at each relay. Owing to the above two advantages, the proposed relay selection method can lower the implementation complexity caused by channel estimation and reduce the relay overhead in a practical power limited network.

सार

आधुनिक संचार प्रणाली में बढ़ती ऊर्जा लागत के साथ 'ग्रीन संचार डिजाइन' हाल ही में एक प्रसिद्ध और आकर्षक अवधारणा बन गया है। (वीएलएसआई) प्रौद्योगिकी की प्रगति ने हजारों संवेदक नोड्स का उपयोग करने की संभावना बना दी है, जो कि धूल के एक कण के आकार के रूप में छोटे होते हैं। ये संवेदक नोड्स एक वायरलेस नेटवर्क का निर्माण करते हैं, इसलिए इनका नाम वायरलेस सेंसर नेटवर्क (डब्ल्यूएसएनएस) हैं। इन नोड्स में सेंसर, संसाधक, सीमित मेमोरी और रेडियो शामिल होते हैं। ये सेंसर संस्थाओं की रूचि के बारे में जानकारी एकत्रित करने के लिए वितरित किए जाते हैं, उदाहरण के लिए इनको जमीन पर, हवा में, इमारतों के अंदर, शरीर पर, वाहनों में होने वाली घटनाओं में रूचि और पर्यावरणीय मानदंडों की निगरानी का पता लगाने के लिए इस्तिमाल किया जाता है। ये सेंसर बैटरी से चलाये जाते हैं, बैटरी को दोबारा से चार्ज करना और बैटरी को परिवर्तित करना एक बड़ा कार्य है, जिसके कारण बिजली और ऊर्जा डब्ल्यूएसएन में महत्वपूर्ण बाधा हैं और इसकी खपत को कम करने की आवश्यकता आज के अभियन्ता की मुख्य चिंता है।

यह शोध-प्रबंध ऊर्जा खपत को कम करने और डब्ल्यूएसएनएस के लिए बिजली का इष्टतम समाधान प्रदान करने के लिए लक्षित है। डब्ल्यूएसएनएस जो की कम अंतर-नोड दूरी पर परिचालित होता है, उसकी बैटरी का जीवन, सम्पूर्ण रूप से बिजली, जो गणना और रेडियो शक्ति पर निर्भर करती है, से प्रभावित होता है। बैटरी का जीवन और प्रदर्शन बढ़ाने के लिए, हमने स्मार्ट एन्टेना सिस्टम (एसएएस) का उपयोग किया है। हमने एसएएस में बिजली खपत की अनुकूल स्थिति बताने के लिए एक रूपरेखा प्रस्तावित और विकसित की है। इस शोध-प्रबंध में हमने एसएएस की उपयोगिता को बीमफॉर्मिंग यूनिट (अभिकलन शक्ति) में खपत होने वाली शक्ति एवं रेडियो इकाई में खपत होने वाली शक्ति को एक शक्ति परिप्रेक्ष्य के रूप में मूल्यांकित किया है। पुनरावृत्त बांफोर्मिंग अल्गोरिथम का प्रयोग करके एसएएस का विश्लेषण किया गया है ताकि एसएएस के लिए ग्रीन डिजाइन विकसित किया जा सके।

चूंकि डब्ल्यूएसएनएस कम दूरी पर परिचालित होता है, इसलिए रिले आधारित संचार प्रणाली एक ऐसा प्रभावकारी तरीका है जिससे ऊर्जा की क्षमताओं को बढ़ाया जा सकता है। इस शोध-प्रबंध में हमने, नक्षत्र आकार, ऊर्जा आवंटन और रिले स्थान को संयुक्त करके डीकोड और फॉरवर्ड बहु-हॉप रिलेयिंग के लिए किसी बाधा या समस्या को औसत बिट त्रुटि दर पर अनुकूलित करके रेलीघ फेडिंग चैनलों के लिए प्रस्तावित है। कुल संचारित शक्ति पर बाधाओं और कुल अंतराल की दूरी तय के तहत प्रति बिट की कुल ऊर्जा खपत को कम करने के लिए अनुकूलन विधि को प्रस्तावित किया है। यह देखा गया है कि बहु-हॉप नेटवर्क के प्रत्येक हॉप में अलग नक्षत्र आकार का उपयोग करने पर संयुक्त अनुकूलन सिर्फ बराबर आवंटन के

मुकाबले में ही बेहतर प्रदर्शन नहीं करता है, बल्कि यह उससे भी बेहतर है जब संपर्क असंतुलन बढ़ा है। संतुलित संपर्क से हमारा मतलब समान संपर्क के साथ समान दूरी और चैनल के आंकड़े हैं।

एक-तरफा रिलेयिंग संचार वर्णक्रमीय-दक्षता जिस हानि से ग्रस्त होता है उस नुकसान से उबरने के लिए, दो-तरफा रिलेयिंग नेटवर्क हमारे द्वारा प्रस्तावित किया गया है। इस शोध-प्रबंध में हमारा उद्देश्य ऊर्जा से भरपूर दो-तरफा रिलेयिंग नेटवर्क एम्पलीफी और फॉरवर्ड रणनीति को प्रस्तावित करना है। बिजली आवंटन के लिए होने वाली समस्या का एक अनुकूल सूत्रीकरण तैयार करके प्रत्येक संचारित शक्ति के साथ प्रत्येक नोड पर संचारित शक्ति के लिए एक सर्वोत्तरात समाधान प्रदान किया गया है। प्रस्तावित बिजली आवंटन समाधान, दो तरफ़ा रिलेइंग, एक-तरफा रिलेयिंग संप्रेषण को पीछे छोड़ देता है। अर्थात दो-तरफ़ा रिलेइंग, एक-तरफा रिलेयिंग से बेहतर प्रदर्शन करता है। एक रिले चयन योजना भी प्रस्तावित की गयी है जो सांख्यिकीय चैनल राज्य सूचना तात्कालिक चैनल राज्य सूचना (सीएसआई) से अधिक श्रेष्ठ एवं लाभकारी है। प्रत्येक रिले, सीएसआई की अपेक्षा केवल स्थानीय सीएसआई वैश्विक पर निर्भर करता है। उपर्युक्त दो लाभों के कारण प्रस्तावित रिले चयन विधि चैनल द्वारा अनुमानित कार्यान्वित जटिलता को कम कर सकती है और एक व्यावहारिक शक्ति सीमित नेटवर्क रिले में होने वाले खर्च को कम करती हैं।

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List of Abbreviations

Acronym	Meaning
AAA	Adaptive Array Antenna
ABER	Average Bit Error Rate
ADC	Analog-to-Digital Converter
AF	Amplify-and-Forward
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BF	Beamforming
BPF	Band Pass filter
BPSK	Binary Phase Shift Keying
CDF	Cumulative Distributive Function
CMA	Constant Modulus
CSI	Channel State Information
DAC	Digital-to-Analog Converter
DF	Decode-and-Forward
DOA	Direction of Arrival
EQA	Equal Allocation
EQPA	Equal Power Allocation
FS	Frequency Synthesizer
GP	Geometric Programming

ICSI	Instantaneous Channel State Information
IDFT	Inverse discrete Fourier transform
IFA	Intermediate-frequency amplifier
JOCER	Joint Optimization of Constellation Size, Energy Allocation and Relay Location
JOCR	Joint Optimization of Constellation Size and Relay Location
JOCE	Joint Optimization of Constellation Size and Energy Allocation
KKT	Karush-Kuhn-Tucker
LMS	Least Mean Square
LNA	Low Noise Amplifier
LPF	Low Pass Filter
LT	Long Term
MIMO	Multiple Input Multiple Output
MPSK	M-ary Phase Shift keying
MQAM	M-ary Quadrature Amplitude Modulation
MSE	Mean Square Error
OPA	Optimal Power Allocation
PA	Power Allocation
QoS	Quality-of-Service
RLS	Recursive Least Square
SA	Smart Antennas
SAS	Smart Antenna System
SNR	Signal-to-Noise Ratio
SIR	Signal-to-Interference Ratio
ST	Short Term
WSN	Wireless Sensor Network
VLSI	Very large Scale Integration
