

EFFICIENT TECHNIQUES FOR BROADCAST OF IN-BAND SYSTEM INFORMATION IN MASSIVE MIMO SYSTEMS

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**DEPARTMENT OF ELECTRICAL ENGINEERING
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by

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DEPARTMENT OF ELECTRICAL ENGINEERING

Submitted

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to the



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Dedicated to
My Parents

Certificate

This is to certify that the thesis entitled “**Efficient Techniques for Broadcast of In-band System Information in Massive MIMO Systems**” being submitted by **Mr. Kamal Biswas** 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 him 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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“We were but stones, your light made us stars”

–Low Light, Pearl Jam

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Abstract

Non-orthogonal broadcast of system information (SI) in massive MIMO systems is a method where beamforming of information to scheduled terminals (STs) and broadcast of SI to idle terminals (ITs) is carried out on the same time-frequency resource by signalling SI on the null-space of the space spanned by the channel vectors of the STs. In this thesis, we consider joint beamforming of data to STs and broadcast of SI to ITs on the same time-frequency resource for two different type of systems: a) multi-cell multi-user massive MIMO systems and b) single cell mmWave massive MIMO systems.

For multi-cell multi-user massive MIMO systems, we consider two different types of SI broadcast, i) synchronous broadcast of common (i.e., same) SI symbols from all cells, and ii) synchronous broadcast of cell-specific SI symbols from each cell. Through analysis we derive expressions for the achievable sum rate to STs in each cell and the rate of SI transmission to an IT for both these types of SI broadcast. We also derive expressions for the sum rate to STs and the rate to an IT for traditional orthogonal broadcast strategy (OBS) where a fraction of physical resource is reserved for broadcast of SI. Simulations reveal that, just as in the single-cell scenario, for the multi-cell scenario also, non-orthogonal broadcast of system information (NoBS) is more energy efficient than OBS.

Prior work has shown that for i.i.d. Rayleigh fading, the transmit power required to achieve a desired sum-rate to STs and a desired rate of SI broadcast to the ITs, is smaller for NoBS when compared to that for the traditional OBS where a fraction of the resource is dedicated for broadcast of SI. However, to the best of our knowledge there is no work which has studied the power advantage of NoBS over OBS for the mmWave scenarios. Therefore, in this thesis we study the performance of NoBS for mmWave massive MIMO systems in two different

scenarios: i) single cell mmWave massive MIMO system with single LoS path between base station (BS) and a user terminal (UT) with the BS having perfect knowledge of channel state information (CSI) to the STs, ii) single cell mmWave massive MIMO system with multiple channel path components between BS and a UT and the BS having imperfect CSI of STs. For the case of single LoS path between the BS and a UT, we consider Millimeter wave (mmWave) Massive MIMO systems where a large antenna array at the base station (BS) serves a few scheduled terminals. Our analysis reveals the interesting result that with a sufficiently large antenna array this non-orthogonal broadcast strategy requires significantly less total transmit power when compared to the traditional orthogonal strategy where a fraction of the total resource is reserved for broadcast of system information. Also we show that even with imperfect CSI of STs at the BS and multi-path mmWave channel, the power advantage of NoBS over OBS in mmWave massive MIMO systems can be large (around 9 dB) which makes NoBS a desirable strategy for such systems.

सार

विशाल एमआईएमओ सिस्टम सूचना (एसआई) का गैर-ऑर्थोगोनल प्रसारण पद्धति एक ऐसी विधि है जहां समान समय-आवृत्ति संसाधन में अनुसूचित टर्मिनलों (एसटी) को सूचना का बीमफॉर्मिंग और निष्क्रिय टर्मिनलों (आईटी) को एसआई का प्रसारण किया जाता है। इस पद्धति में एसटी के चैनल वैक्टर के शून्य-स्थान पर एसआई का प्रसारण किया जाता है।

इस थीसिस में, हम एसटी को डेटा के संयुक्त बीमफॉर्मिंग और एसआई को आईटी पर प्रसारित करने पर विचार करते हैं। हम दो अलग-अलग प्रकार की प्रणालियों के लिए समान समय-आवृत्ति संसाधन का विचार करते हैं: क) बहुकोशिका बहु-उपयोगकर्ता विशाल एमआईएमओ सिस्टम और ख) एक-कोशिका मिलीमीटर-तरंग (एमएमवेव) विशाल एमआईएमओ सिस्टम।

बहुकोशिका बहु-उपयोगकर्ता विशाल एमआईएमओ सिस्टम के लिए, हम दो अलग-अलग प्रकार के एसआई प्रसारण पर विचार करते हैं, १) सभी कोशिकाओं से सामान्य एसआई (यानी, समान) प्रतीक का तुल्यकालिक प्रसारण, और २) प्रत्येक कक्ष से कक्ष-विशिष्ट एसआई प्रतीकों का तुल्यकालिक प्रसारण। हमने विश्लेषण के माध्यम से प्रत्येक कक्ष में निश्चित एसटी को प्राप्य योग-दर और इन दोनों प्रकार के एसआई प्रसारण के लिए एक आईटी को निश्चित एसआई संचरण की दर के अभिव्यक्ति प्राप्त की हैं। पारंपरिक ऑर्थोगोनल प्रसारण स्ट्रेटेजी (ओबीएस) जहां भौतिक संसाधन का एक अंश एसआई के प्रसारण के लिए आरक्षित है, उस के लिए भी हमने विश्लेषण के माध्यम से प्रत्येक कक्ष में निश्चित एसटी को प्राप्य योग-दर और इन दोनों प्रकार के एसआई प्रसारण के लिए एक आईटी को निश्चित एसआई संचरण की दर के अभिव्यक्ति प्राप्त की हैं। । सिमुलेशन से पता चलता है कि, एक-कोशिका परिदृश्य की तरह, बहुकोशिका परिदृश्य के लिए भी, सिस्टम सूचना की गैर-ऑर्थोगोनल प्रसारण (एनओबीएस) पारंपरिक ऑर्थोगोनल प्रसारण की तुलना में अधिक ऊर्जा कुशल है। इस विषय पर किया गया पहले के काम से पता चला है कि स्वतंत्र तथा सदैव वितरित (आई आई डी) रेले फ़िडिंग प्रणाली के लिए, एसटी को वांछित योग-दर और आईटी के लिए एसआई प्रसारण के वांछित दर प्राप्त करने के लिए आवश्यक ट्रांसमिट शक्ति, एनओबीएस के लिए छोटा है जब इसकी तुलना पारंपरिक ओबीएस (जहां एसआई के प्रसारण के लिए संसाधन का एक अंश समर्पित है) के साथ किया जाए। हालांकि, हमारे सर्वोत्तम ज्ञान में ऐसा कोई काम प्रतिवेदित नहीं है जो मिलीमीटर-तरंग के लिए ओबीएस पर एनओबीएस के शक्ति लाभ का अध्ययन किया है। इसलिए, इस थीसिस

में हम दो अलग-अलग परिदृश्यों में एमएमवेव विशाल एमआईएमओ सिस्टम के लिए एनओबीएस के प्रदर्शन का अध्ययन किये हैं:

१) एक-कोशिका मिलीमीटर-तरंग विशाल एमआईएमओ सिस्टम जिसमें बेस स्टेशन (बीएस) और एक उपयोगकर्ता टर्मिनल (यूटी) के बीच केवल एक दृष्टिरेखा पथ हो और जिसमें बीएस के पास एसटी के चैनल स्टेट सूचना (सीएसआई) का संपूर्ण ज्ञान है, २) एक-कोशिका मिलीमीटर-तरंग विशाल एमआईएमओ सिस्टम जिसमें एक यूटी और बीएस के बीच कई चैनल पथ घटकों हो और जिसमें बीएस के पास एसटी के चैनल स्टेट सूचना (सीएसआई) का अपूर्ण ज्ञान है। हमारे विश्लेषण से दिलचस्प परिणाम का पता चलता है कि पर्याप्त रूप से बड़े एंटीना सरणी के साथ यह गैर-ऑर्थोगोनल प्रसारण रणनीति के लिए पारंपरिक ऑर्थोगोनल रणनीति की तुलना में काफी कम कुल संचार शक्ति की आवश्यकता होती है जहां कुल संसाधन का एक अंश सिस्टम सूचना के प्रसारण के लिए आरक्षित है। हम यह भी दिखाते हैं कि बीएस के पास एसटी के अपूर्ण सीएसआई के साथ भी बहु-पथ मिलीमीटर-तरंग चैनल परिदृश्यों में, ओबीएस की तुलना में एनओबीएस की संचारित शक्ति का लाभ विशाल एमआईएमओ सिस्टम में बड़े (लगभग ९ डीबी) हो सकते हैं जो बनाता है एनओबीएस ऐसी प्रणालियों के लिए एक वांछनीय पद्धति है।

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Abbreviations

3G Third Generation

4G Fourth Generation

5G Fifth Generation

AWGN Additive White Gaussian Noise

BS Base Station

CSI Channel State Information

DoF Degrees of Freedom

eMBB Enhanced Mobile Broadband

IT Idle Terminal

JBB Joint Beamforming and Broadcasting

L.H.S. Left Hand Side

LoS Line-of-sight

LTE Long Term Evolution

MIB Master Information Blockd

MMSE Minimum Mean-Square Error

mmWave millimeter wave

MIMO Multi-Input Multi-Output

MISO Multi-Input Single-Output

m-MTC Massive Machine Type Communications

MRT Maximum Ratio Transmission

MU Multi-User

MUI Multiuser Interference

NB-IoT Narrow-Band Internet-of-Things

NoBS Non-orthogonal Broadcast of System Information

NoBS-SAME-SI Non-orthogonal Broadcast of Same System Information

NoBS-DIFF-SI Non-orthogonal Broadcast of Different System Information

OA Orthogonal Access

OBS Orthogonal Broadcast Strategy

R.H.S. Right Hand Side

SI System Information

SIB System Information Block

ST Scheduled Terminal

STBC Space-Time Block Code

SU Single User

TDD Time-division Duplex

UPA Uniform Planar Array

URA Uniform Rectangular Array

URLLC Ultra Reliable Low Latency Communications

UT User Terminal

UTC Coordinated Universal Time

ZF Zero Forcing