Cairo University

PERFORMANCE EVALUATION OF A DENSE RELAY NETWORK

By

Khaled Yehia Salem Morsy Ahmed

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
ELECTRONICS AND COMMUNICATIONS ENGINEERING

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Title of Thesis:

Performance Evaluation of a Dense Relay Network

Key Words:
Relays.; Massive System ; Dense relay network ; Wireless Communications

Summary:

In this thesis, we investigated the performance of a dense relay network. We derived the SNR expression of the system, simulated and compared the system with a reference direct-transmission system, evaluated the capacity and the energy efficiency of the system. We have also derived approximations and bounds for the SNR expression of the AF case. Finally we solved for the optimum number of relays that would maximize the energy efficiency of the system.

Acknowledgments

First of all, I must thank my God for his great mercy supporting me all the way till the end. If it weren't for his help, I wouldn't have reached this point.

Second I would like to thank my supervisors Prof. Dr. Khaled Fouad and Dr. Ahmed Salah for their effort, their patience and their support during the whole period of my masters work. Also I would like to thank Dr. Ahmed Hesham Mehanna for his volunteering to advice me within the last year.

Finally I would like to thank my parents for their great effort and support on all sides of my life since my first days and until this moment.

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Accepted (to be published on Sep. 2015):

[1] Khaled Y. Ahmed, Ahmed S. Ibrahim, Ahmed Hesham Mehana and Khaled M. F. Elsayed, "Perfromance Analysis of Dense Relay Network" *IEEE 82nd Vehicular Technology Conference (VTC2015-Fall).*

List of Figures

List of Abbreviations

AF	Amplify-and-Forward
AWGN	Additive White Gausssian Noise
BER	Bit Error Rate
BS	Base Station
CSI	Channel State Information
DF	Decode-and-Forward
EE	Energy Efficiency
IE	Intermediate Equipment
IoT	Internet of Things
LTE-A	Long Term Evolution-Advanced
MIMO	Multiple Input Multiple Output
MMSE	Minimum Mean Square Error
MU-MIMO	Multi-user Multiple Input Multiple Output
PDF	Probability Density Function
PSD	Power Spectral Density
QoS	Quality of Service
RFID	Radio Frequency Identification
SINR	Signal to Noise and Interference Ratio
SISO	Single Input Single Output
SNR	Signal to Noise Ratio
UE	User Equipment

.

List of Symbols

BER	Bit error rate
C	Capacity
E	Channel estimation error
EE	Energy efficiency
$Ei(x)$	Exponential integral
$F(W)$	Lambert W-function
$_cF_d$	Generalized hyper-geometric function
$\hat{h}$	Estimated channel
h_{BS,IE_i}	Channel gain between the BS and the ith IE
$h_{IE\_i,D}$	Channel gain between the ith IE and the destination
J	Jacobian
K	Number of IE's
K_{opt}	Optimum number of relaying nodes
m_i	Matched filter of the ith IE
n_i	AWGN at the ith IE
N	Total number of receiving and relaying nodes
N_o	Noise variance
N_w	Total noise variance at the destination
P_{BS}	Transmitted power from the BS
P_{IE}	Transmitted power from the IE "relay node"
P_e	Probability of error
P_{tot}	Total power
SNR	Signal to Noise Ratio
$U(a,b,z)$	Confluent hyper-geometric function
v	AWGN at the destination
w	Total noise terms at the destination
W	Bandwidth
y_{BS,IE_i}	The received signal at the antenna of the ith IE
$y_{IE,D}$	The received signal at the destination
$ß, \alpha$	Rayleigh distribution factors
ε	Reliability factor
Γ	Gamma function
Ψ, τ	Exponential distribution factors

Abstract

Relays are important elements to provide more coverage for the communication system and also to obtain acceptable received signal strength at long distances. The deployment of a large number of relays can construct a massive distributed system which adds the advantages of the relaying system in terms of the different types of diversity. This work investigates the performance of a dense relay network using different metrics such as the Signal to Noise Ratio (SNR), the Bit Error Rate (BER), the Capacity and the Energy Efficiency (EE) of the system.

First, we derive the SNR expression for the system under certain assumptions such as having full knowledge of channel state information at the relaying nodes and separating the two stages in two different time slots. Then we study the effect of having a large number of relays on the derived expression. We validate the analytical expressions by simulating the system. We consider two relaying protocols Amplify-and-Forward (AF) and Decode-and-Forward (DF). The derivations show that the SNR changes almost linearly with the number of relays in case of the AF protocol and it is proportional to the square of the number of relays in the case of DF protocol. We also compare the system performance in terms of the BER with a simple system that uses direct transmission instead of relays. The relaying system has superiority over the reference direct-transmission system. Then, using simulations only, we study the effect of having channel estimation error on the performance of the system. We show that the relaying system has a stronger immunity to the channel estimation error than the reference system.

Second, we derive some approximation and bounds for the SNR expressions to have simpler equations that could be used in some extensions for this work such as power allocation, relay selection and other optimization problems.

Finally, we evaluate the capacity and the energy efficiency of the system. A classical tradeoff exists between improving the spectral efficiency of the system by adding more relays to the network while requiring using less relays to decrease the total power consumed in the internal circuits of the relays. The ratio between these contradicting terms is the energy efficiency of the system. So we study this interesting tradeoff between the spectral efficiency and the energy efficiency of the system. Hence

we solve the optimization problem of choosing the optimum number of relays that maximizes the energy efficiency of the system.

Chapter 1 : Introduction

In the early 60s and 70s the basic idea of relaying was first introduced and studied 1] - [3]. The relaying nodes can increase the coverage of the communication system by dividing the communication between the source and the destination into multiple hops instead of the direct transmission over a single hop. However, the distance between the source and the destination is the same in both cases, the multi-hop scheme improves the signal strength due to the fact that the summation of the pathloss over the hops is less than the pathloss of a long distance single hop. This fact is based on the non linear relation between the pathloss and the distance between the source and the destination.

Another motivation for using the relays is to make the best use of the communication channel. User equipment (UE) can only have a few number of antennas which does not make the best use of the space-time resources of the communication channel. The deployment of relays between the transmitter and the receiver with more antennas can utilize these resources.

In order to achieve the required data rates and quality of service (QoS) for modern wireless communication techniques, the Massive Multiple Input Multiple Output (MIMO) system was introduced to enhance the performance of the basic MIMO system while increasing the number of the deployed antennas to a very large value.

Establishing a massive MIMO system in a distributed form or a co-located form has several difficulties on the structure level and the operational level of the communication process [4],[5].

The Internet of Things (IoT) [6],[7] will revolutionize the architecture of communication systems by adding "things" that we use in our daily life, after equipping them with wireless transceivers or Radio Frequency Identification (RFID). These empowered "things", referred to as devices from here onwards, allow a variety of IoT applications such as transportation, healthcare, smart environment and social domains. Most of these applications require the existence of a large number of communicating nodes. The communication reliability among these nodes is vital to the success of the IoT network.

In Massive MIMO, the relaying techniques may be combined together in a system that uses a large number of relays to establish a massive distributed system [8] − [18].