IMPROVING THE CONNECTIVITY OF HYBRID BACKHAULING FOR 5G NETWORKS

By

Mohammed Hamood Mohammed Almekhlafi

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
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Title of Thesis:

Improving the Connectivity of Hybrid Backhauling for 5G Networks

Key Words:
Backhauling; Algebraic connectivity; Optical fiber; Free space optics; Radio frequency.

Summary:

This thesis aims to improve the network connectivity by adding a limited number of OF links along with the wireless connections of RF, FSO or hybrid RF/FSO backhaul links between the small cells while taking into consideration the minimum data rate, the cost, and reliability of different links. In contribution I, we aim to maximize the algebraic connectivity by inserting a limited number of links of backhauling technologies, while minimum rate per link (R) constraint must be satisfied. While in contribution II, we aim to maximize both the algebraic connectivity and nodes throughput by inserting a limited number of links of backhauling technologies.

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List of Abbreviations

5G	5th generation of cellular networks
ATM	Asynchronous Transfer Mode
BSC	Base Station Controller
BTS	Base Transceiver Station,
CAPEX	Capital Expenditure
CRN	Cognitive Radio Network
CVX	Matlab Software for Disciplined Convex Programming
D2D	Device to Device
DC-DC	Direct D2D communication with device controlled link establishment
DC-OC	Direct D2D communication with operator controlled link establishment
DR-OC	Device relaying with operator controlled link establishment
EDGE	Enhanced Data rates for GSM Evolution
FSO	Free Space Optics
GE	Gigabit Ethernet
GHZ	Giga Hertz
GSM	Global System for Mobile
H-CRAN	Heterogeneous Cloud Radio Access Network
HDTV	High Definition Television
HetNets	Heterogeneous Networks
IM/DD	Intensity Modulation / Direct Detection
IoT	Internet of Things
IR	Infrared
LED	Light Emitting Diode
LOS	line-of sight
LP	Linear Programming
LPD	Low probability of Detection
LPI	Low probability of intercept

MBS Macrocell Base-Station

MIP Mixed Integer Programming

MOP Multi-Objective Problems

MPLS Multi-protocol Label Switching

Non-LOS Non line-of sight

OF Optial Fiber

OOK On-Off Keying

OPEX Operation Expense

OWC Optical Wireless Communication

PCM Pulse Code Modulation

PMP Point-To-Multi-Point

PTP Point-To-Point

SOCP Second-Order Cone Program

QP Quadratic Programming

RF Radio Frequency

RNC Radio Network Controller

SBS Small Base Station

SDH Synchronous Digital Hierarchy

SDP Semidefinite programing

SNR Signal-to Noise Ratio

SONET Synchronous Optical Networking

STM Synchronous Transport Module-

TDM Time Division Multiplexing

UV Viable Ultraviolet

UMTS Universal Mobile Telecom. System

Wi-Fi Wireless Fidelity

WiMAX Worldwide Interoperability for Microwave Access

WMN Wireless Mesh Network

WSN Wireless Sensor Network

List of symbols

a_l	Edge vector
A	Incidence matrix
$\hat{A}$	Adjacency matrix
B	Channel bandwidth
C^F	Free space optics link capacity
C_n^2	The index of refraction structure parameter
C^O	Optical fiber link capacity
C^Ω	Radio frequency link capacity
D	Degree diagonal matrix
E	Set of edges
E_{base}	Set of pre-deployed edges in network graph
f^0	Ideal vector
G	Network Graph
I_0	Average intensity Received without turbulence
I_{th}	Threshold of the received intensity
K^O	Number of inserted optical fiber links
K^Ω	Number of inserted radio frequency links
K^F	Number of inserted free space optics links
K^T	Number of total inserted links
L	Laplacian matrix
L_{base}	Laplacian matrix of the base network graph
L^O	Laplacian matrix of OF links in graph
L^F	Laplacian matrix of FSO links in graph
L_p	Linear programming metric
L^Ω	Laplacian matrix of RF links in graph
m_c	Set of cardiants edges
n	Number of small-cells in the network
P^*	Pareto optimal Set

PF^*	Pareto front
R^F	Free space optics link rate
R^O	Optical fiber link rate
R^Ω	Radio frequency link rate
R_1	Lower tier rate threshold
R_2	Upper tier rate threshold
R_j	Node j throughput
W	Weight matrix
w^F	Free space optics link weight
w^O	Optical fiber link weight
w^Ω	Radio frequency link weight
z	Transmission distance
α	Path loss exponent
β	Altitude
γ	FSO peak to noise ratio
$\bar{\gamma}$	FSO average signal to noise ratio
λ	Optical wave wavelength
λ_2	Second eigenvalue of the Laplacian matrix
ω	Pareto optimal solution set
σ_X^2	Log-amplitude fluctuation variance
$2\pi/\lambda$	Optical number