



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
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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

\mathbf{a}_l	Edge vector
\mathbf{A}	Incidence matrix
$\hat{\mathbf{A}}$	Adjacency matrix
\mathbf{B}	Channel bandwidth
\mathbf{C}^F	Free space optics link capacity
\mathbf{C}_n^2	The index of refraction structure parameter
\mathbf{C}^O	Optical fiber link capacity
\mathbf{C}^Ω	Radio frequency link capacity
\mathbf{D}	Degree diagonal matrix
\mathbf{E}	Set of edges
\mathbf{E}_{base}	Set of pre-deployed edges in network graph
\mathbf{f}^0	Ideal vector
\mathbf{G}	Network Graph
\mathbf{I}_0	Average intensity Received without turbulence
\mathbf{I}_{th}	Threshold of the received intensity
\mathbf{K}^O	Number of inserted optical fiber links
\mathbf{K}^Ω	Number of inserted radio frequency links
\mathbf{K}^F	Number of inserted free space optics links
\mathbf{K}^T	Number of total inserted links
\mathbf{L}	Laplacian matrix
\mathbf{L}_{base}	Laplacian matrix of the base network graph
\mathbf{L}^O	Laplacian matrix of OF links in graph
\mathbf{L}^F	Laplacian matrix of FSO links in graph
\mathbf{L}_p	Linear programming metric
\mathbf{L}^Ω	Laplacian matrix of RF links in graph
\mathbf{m}_c	Set of cardiants edges
\mathbf{n}	Number of small-cells in the network
\mathbf{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