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Dissertation

OPTICAL MIMO MODULATION TECHNIQUES UNDER ILLUMINATION CONSTRAINTS

by

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"Δv - v for velocity, Δ for change. In space, this is the measure of change in velocity required to get from one place to another, thus a measure of the energy required to do it. Everything is moving already but to get something from the moving surface of the Earth into orbit around it requires a minimum Δv of 10km/s. To leave Earth's orbit and fly to Mars requires a minimum Δv of 3.6km/s and to orbit Mars and land on it requires a Δv of about 1 km/s. The hardest part is leaving Earth behind, for that is by far the deepest gravity well involved."

Kim Stanley Robinson
Red Mars (2.2.99) check reference

Acknowledgments

I would like to thank ...

Sincerely,

Pankil

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ABSTRACT

In recent years, there has been a large-scale adoption of portable computing devices like smartphones and tablets. These along with internet-of-things need ubiquitous connectivity to the internet to provide value added services, maximize their functionality and create a 'smart'-er world to live in. Cisco's visual networking index predicts wireless data consumption to increase by a cumulative rate of 61% every year. This will put additional stress on our already stressed wireless access network infrastructure creating a phenomenon called 'spectrum crunch'. Wireless access technologies in and around the 60 GHz spectrum along with carrier aggregation adopted by long term evolution (LTE) standards promise to mitigate the spectrum crunch to an extent.

On the other hand, solid state devices industry has made remarkable advances in energy efficient light-emitting-diodes (LED). The lighting industry is rapidly adopting LEDs to provide illumination in indoor spaces. If light emitted from lighting fixtures can be exploited to carry wireless data, these fixtures are then uniquely positioned to act as wireless access points. The visible spectrum (380 nm – 780 nm) is yet unregulated and untapped for wireless access. Unlike with omni-directional radio

frequency (RF) access points, directionality of light can enable creation of a grid of multiple optical access points in close proximity to each other. This provides unique opportunity to upgrade existing lighting infrastructure and create a dense grid of small cells by using this additional 'optical' wireless bandwidth. Under the above model, lighting fixtures will service dual missions of illumination and wireless data access. These can be easily set up to function within a heterogeneous system with an optical downlink and an RF uplink.

This dissertation explores different modulation techniques for an optical wireless broadcast system using intensity modulation / direct detection (IM/DD) under unique constraints imposed by IM/DD and user illumination requirements. Performance of single–input single–output (SISO) optical modulation techniques between a single optical source and a single receiver is studied. The dissertation then explores degrees of freedom provided by frequency, space and color to study performance of multiple–input multiple–output (MIMO) optical modulation techniques between multiple optical sources and multiple receiving elements. This dissertation then introduces several optical MIMO modulation schemes for spectrally efficient MIMO optical wireless communications.

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List of Abbreviations

ACO	.....	Asymmetrically Clipped Optical
APD	.....	Avalanche Photo Diode
AWGN	.....	Additive White Gaussian Noise
CIE	.....	Commission Internationale de l'Eclairage
CSI	.....	Channel State Information
CSK	.....	Color Shift Keying
DCO	.....	DC biased Optical
DMT	.....	Discrete Multi-Tone
FOV	.....	Field Of View
GCS	.....	Global Coordinate System
ICI	.....	Inter Channel Interference
IID	.....	Independent and Identically Distributed
IM/DD	.....	Intensity Modulation / Direct Detection
LED	.....	Light Emitting Diode
LOS	.....	Line Of Sight
MIMO	.....	Multiple Input Multiple Output
MM	.....	Metameric Modulation
OFDM	.....	Orthogonal Frequency Division Multiplexing
OOK	.....	On-Off Keying
PAM	.....	Pulse Amplitude Modulation
PD	.....	Photo Diode
PIN	.....	P-I-N Junction
PPM	.....	Pulse Position Modulation
PWM	.....	Pulse Width Modulation
QAM	.....	Quadrature Amplitude Modulation
RCS	.....	Receiver Coordinate System
RF	.....	Radio Frequency
RGB	.....	Red, Green and Blue
SISO	.....	Single Input Single Output
SIS	.....	Sample Indexed Spatial
SM	.....	Spatial Modulation
SMP	.....	Spatial Multiplexing
SNR	.....	Signal to Noise Ratio
SPD	.....	Spectral Power Distribution

SSK	.....	Spatial Shift Keying
SVD	.....	Singular Value Decomposition
TIA	.....	Trans-Impedance Amplifier
VLC	.....	Visible Light Communication
VPPM	.....	Variable Pulse Position Modulation
WDM	.....	Wavelength Division Multiplexing
	.....	
$\mathbb{R}^2$	.....	the Real plane