DEVELOPMENT OF A DYNAMIC FREQUENCY HOPPING CODE SYSTEM FOR OPTICAL CODE DIVISION MULTIPLE ACCESS COMMUNICATIONS

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BY

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of Requirement for the Degree of Doctor of Philosophy

July 2006

To the future of my nation

Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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July 2006

Chairman: **Associate Professor Mohamad Khazani Abdullah, PhD**

Faculty: **Engineering**

In this work, a novel method of optical code division multiple access (OCDMA) communication system is proposed. This method is based on a code changes dynamically as a function of time and frequency. Thus, the system is referred to as dynamic frequency hopping OCDMA (DFH-OCDMA). The fundamental principles are defined and described with implementation solutions for DFH-OCDMA system.

DFH-OCMDA system implementation based on tunable optical filter is found to be an effective solution. Tunable optical filter is found to be able to provide a simple, programmable, and effective solution for the encoding and decoding functions. Only one filter at the encoder and one more at the receiver are required to implement the proposed coding scheme. Special simple codes based on orthogonal sinusoidal functions are also proposed for DFH-OCDMA system. These codes are generated and used to control the tunable optical filters. The effectiveness of the new system with the proposed special codes has been verified and demonstrated using theoretical analysis and computer simulations. Theoretical analysis has been done using

MATLAB and MathCAD softwares, while Optisystem 3.0 is used for the computer simulations. A clipping scheme at the receiver is also proposed to enhance the performance of the system and reduce the multiple access interference.

The performance results of DFH-OCMDA system shows that the effect of all types of noise, specifically, multiple access interference, phase induced intensity noise, and shot noise have been reduced compared to other OCDMA systems. Thus, the signal to noise ratio and bit error rate performance parameters are improved. For example, at an error rate of 10^{-11}, DFH-OCDMA can accommodate up to 80 users, whereas for other systems, the maximum simultaneous users are 32 for spectral amplitude coding system using Hadamard code, 52 for spectral amplitude coding system using modified quadratic congruence code, 58 for spectral amplitude coding system using modified frequency hopping code, and 24 for fast frequency hopping system. The BER of the DFH-OCDMA system is increasing at a slower rate than that of the other systems, which indicates that there is a significant improvement in performance at large number of users. Indeed it is shown that the BER for DFH-OCDMA is better than any other system at any number of users of more than 50. However, for less than 50 active users, spectral amplitude coding systems gives BER better than that of DFH-OCDMA system. It should be noted that for this range of users, the error rate is too small (less than 10^{-14}).

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN SISTEM KOD LOMPATAN FREKUENSI DINAMIK UNTUK KOMUNIKASI CAPAIAN PELBAGAI PEMBAHAGIAN KOD OPTIK

Oleh

MOHAMMAD MAHMOUD NAJI AHMAD HAMARSHEH

Julai 2006

Pengerusi: **Profesor Madya Mohamad Khazani Abdullah, PhD**

Falkulti: **Kejuruteraan**

Di dalam kajian ini, suatu kaedah novel bagi sistem komunikasi optikal capaian pelbagai pembahagian kod (OCDMA) telah di perkenalkan. Kaedah yang di gunakan ini berasaskan perubahan kod secara dinamik sebagai fungsi antara masa dan frekuensi. Sistem ini dikenali sebagai Frekuensi Dinamik Hoping OCDMA (DFH-OCDMA). Prinsip asas telah di jelaskan secara terperinci beserta dengan penyelesian penggunaan bagi sistem DFH-OCDMA ini.

Pelaksanaan sistem DFH-OCDMA berasaskan penapis bolehlaras optikal dan ini di kenalpasti sebagai suatu penyelesian yang berkesan. Penapis bolehlaras optikal di kenalpasti berkeupayan menyediakan suatu penyelesaian yang mudah, tersusun dan berkesan bagi fungsi enkoder dan dekoder. Hanya satu penapis di perlukan pada enkoder dan satu pada penerima di perlukan bagi pelaksaanan skim pengkodan yang di cadangkan. Suatu kod mudah yang khas berasaskan fungsi sinusoidal yang orthogonal juga di cadangkan bagi sistem DFH-OCDMA ini. Kod yang di hasilkan ini di gunakan untuk mengawal penapis bolehlaras. Keberkesanan sistem baru ini yang di lengkapi dengan kod baru yang telah di cadangkan telah di buktikan secara

analisa teoritikal dan simulasi komputer. Analisa secara teortiikal di hasilkan mengunakan perisan MATLAB dan MathCAD dan manakala simulasi komputer menggunakan perisian Optisystem 3.0. Kami juga mencadangkan suatu skim yang di kenali sebagai skim pengetipan pada bahagian penerima untuk meningkat prestasi sistem serta mengurangkan gangguan capaian pelbagai (MAI).

Keputusan prestasi bagi sistem DFH-OCDMA dapat mengurangkan kesan yang di sebabkan oleh semua jenis ganguan hingar terutamanya adalah ganguan capaian pelbagai (MAI), hingar PIIN dan letusan berbanding dengan sistem OCDMA yang lain. Dengan ini prestasi nisbah isyarat-hingar (SNR) dan kadar ralat bit (BER) dapat di tingkatkan. Sebagai contoh, pada kadar ralat bit 10^{-11} sistem ini dapat menampung sehingga 80 pengguna, manakala sistem lain, sistem yang mengunakan keadah pengkodan amplitud spektra dan kod Hadamard hanya dapat menampung maksima 32 penguna, 52 pengguna untuk sistem menggunakan kod MQC, 58 pengguna untuk sistem menggunakan kod MFH dan 24 pengguna untuk sistem FFH. Kadar ralat bit (BER) bagi sistem. DFH-OCDMA meningkat pada kadar yang perlahan berbanding sistem lain dan ini merupakan suatu peningkatan prestasi pada kadar pengguna yang tinggi. Kadar ralat bit (BER) bagi sistem DFH-OCDMA lebih baik berbanding sistem lain pada yang melebihi 50 pengguna. Walau bagaimanapun, untuk sistem yang kurang daripada 50 pengguna kaedah pengkodan amplitud spektra memberikan kadar ralat bit yang lebih baik daripada sistem DFH-OCDMA. Pada julat pengguna ini, kadar ralat bit adalah terlalu rendah (kurang daripada 10^{-14})

الحمد لله الذي جعلني من المسلمين و يسر أمري لأتمام هذا البحث العلمي و الصلاة والسلام على رسول الله الذي أدى الأمانه وبلغ الرساله.

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Finally, I would like to express my deepest gratitude to my wife Rasha Hamarsha for her love, support, patience, and taking care of our baby Obada during the last few years.

I certify that an Examination Committee has met on 24 July 2006 to conduct the final examination of Mohammad Mahmoud Naji Ahmad Hamarsheh on his Doctor of Philosophy thesis entitled "Development of a Dynamic Frequency Hopping Code System for Optical Code Division Multiple Access Communications" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination committee are as follows:

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This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for the quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

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MOHAMMAD MAHMOUD NAJI AHMAD HAMARSHEH

Date:

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LIST OF ABBREVIATIONS

ASE	Amplified Spontaneous Emission
ASK	Amplitude Shift Keying
AWG	Array Waveguide
BER	Bit Error Rate
CDMA	Code Division Multiple access
DCF	Dispersion Compensating Fiber
DFH	Dynamic Frequency Hoping
DS	Direct Sequence
EDFA	Erbium Doped Fiber Amplifier
ERFC	Error Function Complementary
FBG	Fiber Bragg Grating
FFH	Fast Frequency Hoping
FH	Frequency Hopping
FWHM	Full Wave Half Maximum
Gbps	Giga bit per second
GF	Galois Field
IM/DD	Intensity Modulation/Direct Detection
LAN	Local Area Network
LED	Light Emitting diode
MAI	Multiple Access Interference
Mbps	Mega bit per second
MFH	Modified Frequency Hoping
MQC	Modified Quadratic Congruence

NRZ	Non Return to Zero
OCDMA	Optical Code Division Multiple access
OOC	Optical Orthogonal Code
OOK	On-Off Keying
PIIN	Phase Induced Intensity Noise
PIN	Positive Intrinsic Negative
PRBS	Pseudo Random Binary Sequence
PSD	Power Spectral Density
RF	Radio Frequency
SAC	Spectral Amplitude Coding
SLM	Spatial Light Modulator
SMF	Single Mode Fiber
SNR	Signal to Noise Ratio
SOA	Semiconductor Optical Amplifier
SONET	Synchronous Optical Network
SSC	Sine Shifted Code
TDM	Time Division Multiplexing
TDMA	Time division Multiple Access
TLS	Tunable Laser Source
TOF	Tunable Optical Filter
WDMA	Wavelength Division Multiple access