UNIVERSITI PUTRA MALAYSIA

PERFORMANCE ANALYSIS OF VARIABLE WEIGHT OPTICAL CODE DIVISION MULTIPLE ACCESS SYSTEM

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By

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Thesis Submitted to the School of Graduate Studies, University Putra Malaysia, in Fullfilment of the Requirements for the Degree of Master of Science

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DEDICATIONS

To my wife Parinaz and my mom and dad, Zakieh and Ali for their unconditional love, support, and encouragement ...

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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July 2013

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Recently, Optical Code Division Multiple Access (OCDMA) systems are among the popular choice of research areas deployed in metro networks as they could provide service differentiation for different quality of signals in such networks. In OCDMA system Quality of Service (QoS) differentiation is realized by assigning dierent code weight or length for each user or service. In actual implementation which involves ber in the transmission, the ber impairment such as dispersion and nonlinear effects can greatly reduce the performance of the system, especially when the bit rate is high. In this thesis, mathematical and simulation model is proposed to analyze the performance of a Variable-Weight OCDMA (VW-OCDMA) system.

The research was carried out by firstly developing a mathematical model for VW-OCDMA system deploying Direct Detection (DD) and AND detection techniques. In the numerical analysis the effects of phase-induced intensity noise, shot noise and thermal noise was taken into account. Subsequently, different detection schemes

i.e. DD and AND subtraction, as well as different optical sources i.e. broadband and laser were analyzed using software simulation. Three weights of 2, 4 and 6 were chosen for different services which represent voice, data and video. The simulation setup was also used to investigate the effects of fiber impairments including chromatic dispersion, self-phase modulation and four wave mixing. Various dispersion compensation techniques were then applied in VW-OCDMA system. Finally, feasibility of the proposed system was investigated using practical experimentation to compare with the system's performance in simulation environment. Three users with weight 6, 4 and 2 were used in experimental design, each transmitting data at rate of 1.25 Gbps. With reference to BER of 10^{-3}, 10^{-9} and 10^{-12} for voice, data and video respectively, VW-OCDMA deploying DD scheme supports 95 users each operating at bit rate of 1.25 Gbps. Moreover, using non-zero dispersion shifted fiber and chirped fiber Bragg grating the signals of users can be transmitted up to 150 km.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

ANALISIS PRESTASI PEMBERAT BOLEH UBAH SISTEM PEMBAHAGIAN KOD PELBAGAI CAPAIAN OPTIK

Oleh

SEYEDMOHAMMADSALEH SEYEDZADEH KHARAZI

Julai 2013

Pengerusi: Siti Barirah Ahmad Anas, PhD

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Kebelakangan ini, sistem pembahagian kod pelbagai capaian optik (OCDMA) adalah antara pilihan popular bidang penyelidikan bagi rangkaian metro kerana ia boleh menyediakan perkhidmatan yang berlainan untuk kualiti isyarat yang berbeza dalam rangkaian tersebut. Dalam sistem OCDMA, pembezaan kualiti perkhidmatan (QoS) direalisasikan dengan memberikan pemberat atau panjang kod yang berbeza untuk setiap pengguna atau perkhidmatan. Dalam pelaksanaan sebenar yang melibatkan gentian optik dalam penghantaran, kelemahan gentian optik seperti penyerakan dan kesan tak linear boleh menjatuhkankan prestasi sistem, terutamanya untuk kadar bit yang tinggi. Dalam tesis ini, model matematik dan simulasi dicadangkan untuk menganalisis prestasi sistem berbeza berat OCDMA (VW-OCDMA).

Penyelidikan ini bermula dengan membentuk model matematik bagi sistem VW-OCDMA menggunakan teknik pengesanan langsung (DD) dan pengesanan AND. Dalam analisis berangka, kesan hingar keamatan aruhan fasa, hingar das dan hin-

gar terma telah diambil kira. Berikutnya, beberapa skim pengesanan yang berbeza iaitu DD dan penolakan AND serta sumber optik berbeza seperti sumber optik jalur lebar dan laser telah dianalisa menggunakan perisian simulasi. Tiga pemberat iaitu 2, 4 dan 6 telah dipilih untuk mewakilkan perkhidmatan yang berbeza iaitu suara, data dan video. Tatacara simulasi juga digunakan untuk menyiasat kesan kepincangan gentian termasuk penyerakan kromatik, modulasi fasa diri dan pencampuran empat gelombang. Pelbagai teknik pampasan penyerakan kemudian digunakan dalam sistem VW-OCDMA. Akhirnya kebolehlaksanaan sistem yang dicadangkan telah diselidik menggunakan perkakasan eksperimen dan juga prestasi sistem dibandingkan dengan prestasi sistem yang sedia ada dalam persekitaran simulasi. Tiga pengguna dengan pemberat 6, 4 dan 2 telah digunakan dalam reka bentuk eksperimen dimana setiap pengguna memancar data pada kadar 1.25 Gbps. Dengan merujuk kepada kadar BER 10^{-3}, 10^{-9} dan 10^{-12} untuk suara, data dan video, VW-OCDMA berdasarkan skim DD dapat menyokong 95 pengguna, dimana setiap satunya beroperasi pada kadar bit sebanyak 1.25 Gbps. Tambahan pula, dengan menggunakan gentian sebar anjak bukan sifar dan parutan Bragg gentian ciap, isyarat pengguna boleh dipancarkan sehingga 150 km.

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Last but not the least, I would like to thank my wife, Parinaz, for tolerating the intolerable. Thanks for all her patience, love and care.

I certify that a Thesis Examination Committee has met on (**insert the date of viva voce**) to conduct the final examination of (**insert the student's name**) on his (or her) thesis entitled "**Title of thesis**" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the (**insert the name of relevant degree**).

Members of the Thesis Examination Committee were as follows:

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

SEYEDMOHAMMADSALEH SEYEDZADEH KHARAZI

Date: 9 July 2013

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LIST OF ABBREVIATIONS

BBS	Broad Band Source
BER	Bit Error Rate
CD	Chromatic Dispersion
CFBG	Chirped FBG
CW	Continuous Wave
DCF	Dispersion Compensating Fiber
DD	Direct Detection
DSF	Dispersion Shifted Fiber
DS-OCDMA	Direct Sequence OCDMA
FBG	Fiber Bragg Grating
FWM	Four Wave Mixing
GVD	Group Velocity Dispersion
KS	Khazani-Syed
LAN	Local Area Network
LED	Light Emitting Diode
MAI	Multiple Access Interference
MAN	Metropolitan Area Network
MW-OCDMA	Multi-Wavelength OCDMA
NLE	Nonlinear Effect

NZ-DSF	Non-Zero Dispersion Shifted Fiber
NRZ	Non-Return to Zero
OCDMA	Optical Code Division Multiple Access
OOC	Optical Orthogonal Code
OOK	On/Off Keying
PIIN	Phase Intensity Induced Noise
PMD	Polarization Mode Dispersion
QoS	Quality of Service
ROP	Received Optical Power
SAC	Spectral Amplitude Coding
SBS	Stimulated Brillouin Scattering
SIK	Sequence Inverse Keying
SMF	Single Mode Fiber
SPM	Self-Phase Modulation
SRS	Stimulated Raman Scattering
TDMA	Time Division Multiple Access
VW-OCDMA	Variable Weight OCDMA
WDMA	Wavelength Division Multiple Access
WHTS	Wavelength Hopping Time Spreading
XPM	Cross-Phase Modulation

Mathematical symbols

B	Noise equivalent electrical bandwidth of receiver
c_k	Code sequence for kth user
d_k	Information bit of kth user
D_v	Line-width of broadband source
e	Electron charge
h	Plancks constant
K_b	Boltzmanns constant
N_v	Total length of VW code
P_{sr}	Received power per chip
R	Responsivity of photodetector
R_L	Receiver load resistor
W_k	Code weight of kth user

CHAPTER 1

INTRODUCTION

1.1 Motivation and background

Optical networks have emerged as a solution to the growing demand for bandwidth and system capacity. They offer other advantages such as immunity to interference, high speed transmission and low attenuation factor, which facilitate increasing of transmission distance without amplification and signal regeneration. Moreover, the cost of manufacturing optical fiber and devices is low comparing with copper technologies. Bandwidth sharing of same medium among different users is also provided in optical networks, using multiple access techniques including Time Division Multiple Access (TDMA), Wavelength Division Multiple Access (WDMA) and Optical Code Division Multiple Access (OCDMA).

In OCDMA system all users have asynchronous access to the medium in contrast with TDMA system. Unlike WDMA, bandwidth is not wasted when some users are idle. This was achieved by assigning each particular user with a specific code signature (Prucnal, 2006). OCDMA system offers other advantages such as secure transmission, ability to support varying bit rates, busty traffic (Kwong and Yang, 2004) and increased scalability of optical networks.

OCDMA is also seen as an appropriate solution for the demand for Quality of Service (QoS) in metro networks where applications such as video streaming and Voice over IP (VoIP) require different amount of bandwidth portion. Among several coding techniques developed in OCDMA, Spectral Amplitude Coding (SAC) system has been considered as a candidate to provide QoS (Prucnal, 2006). In SAC, service differentiation for users is implemented by varying a users' code address, mainly its code weight and length (Kwong and Yang, 2004; Tarhuni et al., 2006).

Two new detection techniques has been developed for single weight SAC-OCDMA systems (Direct Detection and AND detection) which both have outperformed their conventional counter parent, complementary subtraction detection (Sahbudin et al., 2009, 2006a).

Variable Weight OCDMA (VW-OCDMA) as an optical system uses optical fiber as transmission medium; hence, in the actual implementation which involves fiber, the fiber impairments such as dispersion and Nonlinear Effects (NLE) can greatly reduce the performance of the system, especially with increase of data rate (Anas, 2010). Such effects are Chromatic Dispersion (CD), Polarization Mode Dispersion (PMD) and NLE, which include Four-Wave Mixing (FWM) and Self-Phase Modulation (SPM).

Moreover, in VW-OCDMA system each service is assigned by different code weights; therefore, fiber imprisonments and also other factors such as different detection techniques or optical sources might affect the performance of services with different weights in dissimilar ways.

1.2 Scope of research

OCDMA is generally divided into two broad categories; coherent and incoherent, based on the way a particular user's code or address is applied to an optical signal. In the coherent approach, phase encoding is applied into the optical field and recovered by phase detection, while its incoherent counterpart uses intensity modulation and direct detection. Coherent OCDMA systems are built from high cost devices and have a more complex transceiver design while implementation of incoherent system is much simpler and can be constructed from cheaper devices. Therefore, incoherent system is more appropriate for metro networks applications.

In this research, development of VW-OCDMA system will be based on incoherent system using SAC technique. Higher priority signals are achieved by assigning more wavelengths to the particular user or service using this technique (Djordjevic and Vasic, 2003; Ghafouri-Shiraz and Shalaby, 2001). The system is considered to provide three different services such as voice, data and video with the reference error rate at least equal to 10^{-3}, 10^{-9} and 10^{-12} respectively.

In the implementation of system in metro network, ring topology was used because majority of fiber networks today are based on ring and mesh topologies (Bres and Glesk, 2005).

Three approaches were carried to analyze the performance of VW-OCDMA system, which are mathematical approximation, software simulation and hardware experiment. In mathematical approximation the effects of phase-induced intensity noise, shot noise and thermal noise is considered.

In simulation and hardware implementation bit error rate and eye diagram are used to analyze the system performance with the parameters such as number of users, transmission distance, received optical power per chip and input power. Calculation of performance parameters used in the software simulation and hardware experiment is described in detail in Appendix A.

The main focus of this research is to investigate fiber impairment effect on the performance of VW-OCDMA system. There are different kinds of fiber dispersions and fiber nonlinear effects such as Stimulated Brillouin Scattering (SBS), Stimulated Raman Scattering (SRS) and other impairments. However, advanced fiber technology has solved some problems related to fiber impairments by reducing the fiber core area or polarization dispersion (DeCusatis, 2002). Here the concentration is on three kinds of fiber impairments including chromatic dispersion, polarization mode dispersion, four wave mixing and self-phase modulation which known as major fiber impairments in OCDMA systems.

The scope of research work is summarized in Figure 1.1 using a K-chart[1], with the blue colored boxes indicating the research path, while the grey boxes are the related topics in the field.

1.3 Objectives

The main objectives of this research are as follows:

1. To develop a mathematical model for VW-OCDMA system in order to investigate the efficiency of detection techniques
2. To develop a VW-OCDMA setup using SAC technique using simulation software in order to investigate the effect of fiber impairment. And to propose the suitable compensating mechanism according to the suitability of implementation.
3. To test the feasibility of the proposed system using hardware experimentation

1. K-Chart is a research planning and monitoring tool, developed for engineering and technology applications.

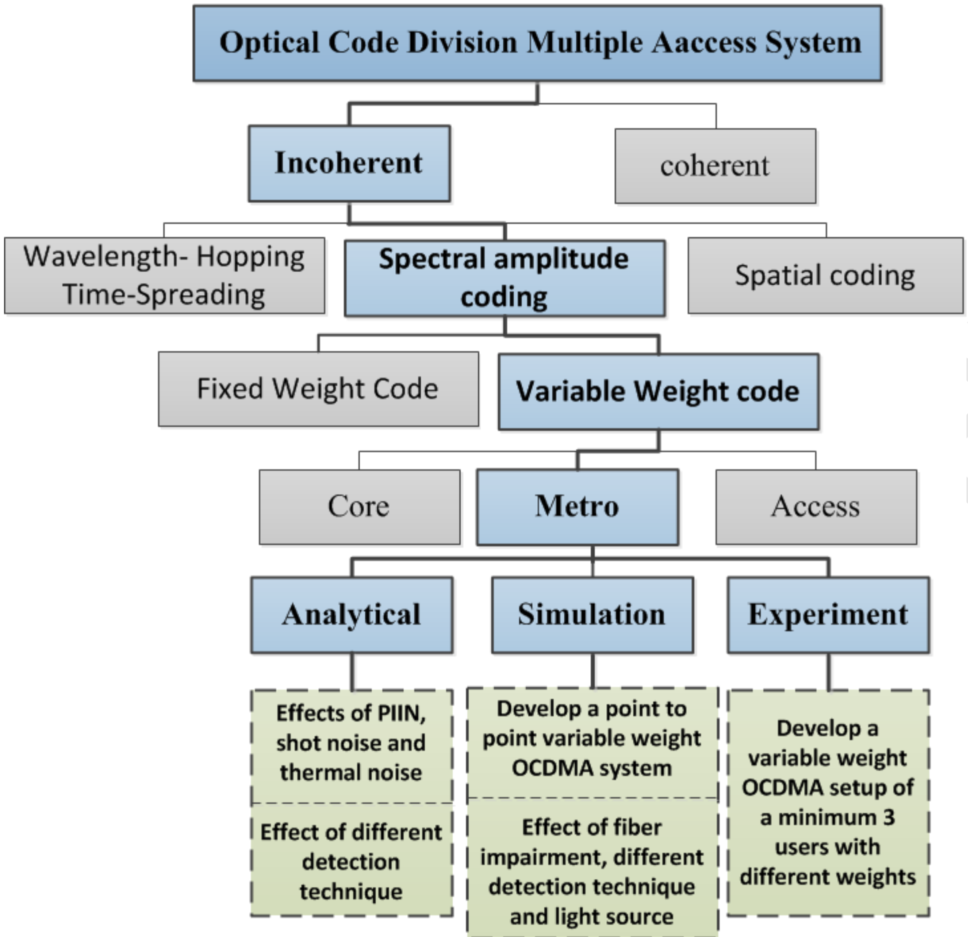

Figure 1.1: Scope of research

1.4 Methodology

Description of research methodology is as following:

1. Development of VW-OCDMA using software simulation.

   A point-to-point OCDMA system based on SAC technique is developed for variable weight (different priority) users using OptiSystem™ software.

2. Development of a mathematical model for VW-OCDMA system.

   A numerical model was developed using the method proposed by Smith (Smith et al., 1998). The numerical model was implemented using Matlab software. A new approach is proposed to analyze the performance of system using AND detection technique.

3. Investigation and analyzing the effect of fiber dispersion and non-linearities. Chromatic dispersion is first to be analyzed. Standard single mode fiber (SMF) is used without any compensation mechanism to observe the tolerance of the developed VW-OCDMA model in a dispersion-limited system by considering dispersion alone and both dispersion and non-linear effects. SPM and FWM are then analyzed in depth individually with respect to several design parameters such as chip spacing, bit rate and fiber input power.

4. Analyzing the compensating mechanism for fiber impairment and proposing the most suitable approach.
   Several CD compensation techniques is performed and compared in terms of suitability and practicality of the implementation.

5. Proof-of-feasibility hardware demonstration of fiber impairment effects to VW-OCDMA.
   VW-OCDMA setup of a minimum 3 users of unequal weights is developed. A point-to-point system connected with standard SMF within the length of metro networks is demonstrated considering the above mentioned fiber impairment effects. Dispersion compensating fiber (DCF) is also employed to mitigate the dispersion imposed by SMF.

Flowchart of research activities is shown in Figure 1.2.

OptiSystem is an optical simulation software that enables users to design, test and simulate virtually any type of optical link in the transmission layer of an optical networks from Local Area Network (LAN), Storage area network (SAN),

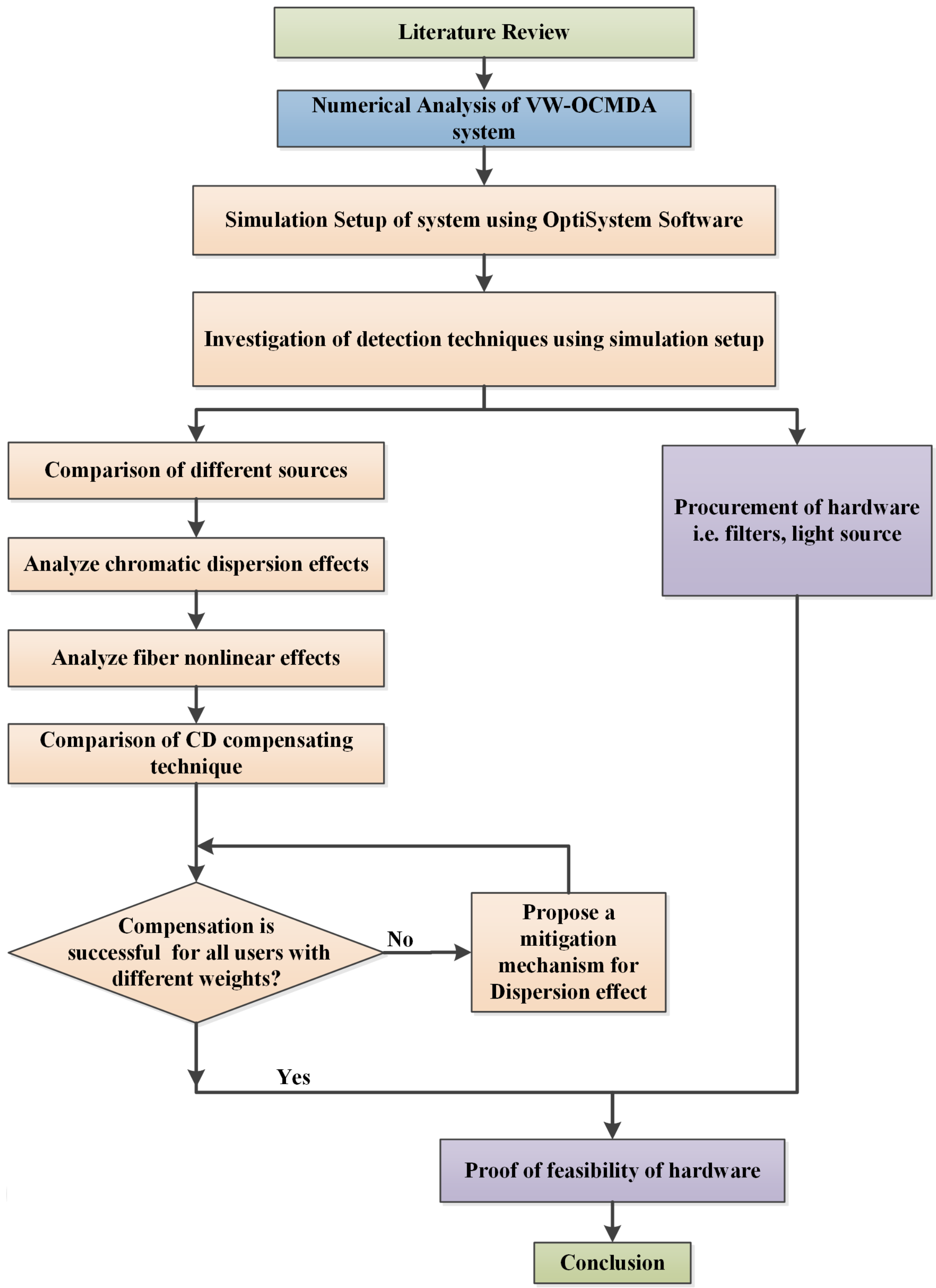

Figure 1.2: Flowchart of research activities

Metropolitan area network (MAN) to ultra-long-haul. It provide transmission layer optical communication system design and planning from component to system level, and visually presents analysis and scenarios.

1.5 Outline of thesis

This thesis is organized into six chapters. This chapter provides an introduction to service differentiation, presenting the motivation and background of the research. Moreover the scope of research and objectives is clearly defined and the research activities are presented to clarify the research methodology.

Chapter 2 continues with the overview of optical CDMA systems in term of the effect of fiber impairments including dispersion and fiber NLEs on the performance with respect to different coding techniques. This chapter also gives a brief review of service differentiation using SAC-OCDMA and the construction of variable weight codes.

Chapter 3 describes the details of detection techniques used in the system. A mathematical model is developed to analyze the VW-OCDMA system considering shot, thermal and phase induced intensity noises.

Analysis of simulation result is reviewed in chapter 4. Performance of VW-OCDMA system using different dispersion compensating approaches is evaluated and impact of fiber nonlinear effects is investigated. Chapter 5 presents the experimental setup description and results.

Finally, Chapter 6 summarizes the thesis emphasizing the major contribution of this research work. Future woks are also recommended.

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