MODELING AND SIMULATION TO EXTEND FIBRE OPTIC COMMUNICATION SIGNAL TRANSMISSION USING MICRO RING RESONATOR

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To my: Dear

Father and Mother

Thanks for your supports and for all that you have done to me.

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ABSTRACT

Long-distance communication systems use high-bit-rate optical fibre, where dispersion and distortion of the signals cause technical difficulties and problems which have to be dealt with in order to optimize the efficiency and the reliability of such systems. Applying soliton transmission is an interesting method due mainly to its potential capability to overcome the effect of fibre dispersion and to provide all optical transmission systems. Optical solitons can be formed when a balance has been established between self-phase modulation and group velocity dispersion within the regime of anomalous dispersion. The consequent governing wave equation is of the nonlinear Schrodinger (NLS) type. In this thesis, a system of microring resonators (MRRs) connected to an optical modified add/drop filter is presented as a soliton pulse generator. The system uses chaotic signals generated by a Gaussian laser pulse and bright soliton propagating inside a nonlinear MRR system. The chaotic signals can be generated via a set of microring resonators, suitable for long distance communications. The obtained results show comparison of laser and generated solitonic signals over several distances. Then, the generation of solitonic signals using add/drop filter system connected to a series of micro ring resonators is demonstrated and the output of this model is compared to various disposition of the Bit Error Rate (BER) for soliton versus laser signals over 25, 50 and 100 Km distances. Thus, these types of signals can be used in optical indoor systems such as wireless personal area networks and transmission link using appropriate components such as transmitter, fibre optics, amplifier, and receiver.

ABSTRAK

Sistem komunikasi jarak jauh menggunakan gentian optik halaju-tinggi, dimana isyarat penyebaran dan herotan yang menyebabkan masalah teknikal, memerlukan perhatian untuk memastikan kecekapan dan kebolehpercayaan suatu sistem pada tahap optimum. Penggunaan transmisi soliton pada sistem adalah satu kaedah yang menarik, disebabkan oleh kebolehan ia untuk mengatasi masalah sebaran isyarat gentian opti dan juga berkemampuan untuk keseluruhan sistem transmisi. Soliton optikal boleh terbentuk apabila keseimbangan di antara modulasi kendiri dan halaju sebaran berada pada kawasan sebaran ganjil terjadi. Natijah ini adalah berkaitan dengan persamaan gelombang jenis Schodinger tidak linear (NSL). Di dalam tesis ini, satu sistem resonator mikro (MRRs) disambungkan pada gentian optik yang telah diubahsuai sebagai penapis tambah/jatuh sebagai penjana denyut soliton. Sistem ini menggunakan janaan isyarat huru-hara oleh denyut laser Gaussian dan sinaran soliton terbiak di dalam sistem resonator mikro tidak-linear. Isyarat huru-hara ini terbentuk melalui set resonator mikro, yang sesuai dengan pengunaan komunikasi jarak jauh. Keputusan yang diperoleh menunjukkan perbandingan antara isyarat laser dengan isyarat solitonik pada jarak yang berbeza. Kemudian, isyarat generasi solitonik menggunakan sistem penapis tambah/jatuh disambungkan pada cecincin resonator mikro dihasilkan dan natijah dari model ini dibandingkan antara Kadar Ralat Bit (BER) yang berbeza dengan pancaran laser melebihi jarak 25, 50 dan 100 km. Justeru, isyarat jenis ini boleh digunakan pada sistem optikal tertutup seperti rangkaian kawasan sulit tanpa wayar and jaringan transmisi menggunakan komponon sewajarnya seperti pemancar, gentian optik, penguat dan penerima.

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LIST OF ABBREVIATIONS

Abbreviation	Meaning
BER	Bit error rate
BS	Base station
CDMA	Code Division Multiple Access
CS- SSB	Carrier Suppressed Single Side Band
CW	Continues Wave
DSL	Digital subscriber line
DWDM	Dense Wavelength Division Multiplexing
EOFA	Erbium optical fibre amplifiers
FCC	Federal Communications Commission
FDM	Frequency Division Multiplexing
FSR	Free spectral range
FWHM	Full width at half maximum
Gb/s	Gigabit per second
GHz	Gigahertz
GVD	Group-velocity dispersion
HD-TV	High-definition- television
IEEE	Institute of Electrical and Electronics Engineers
KDV	Kortewag-de Varies
MAC-SAP	Media Access Control - Service Access Point
MATLAB	Matrix Laboratory
MM	Millimetre
MRR	Micro Ring resonator
MZM	Mach-Zehnder Modulators
NLS	Non-linear Shrödinger

OADM	Optical Add-Drop Multiplexes
OFDM	Orthogonal Frequency Division Multiplexing
OFM	Optical frequency multiplication
OPT	Optical pulse train
OTDM	Optical time-division multiplexing
PAPR	Peak-to-average power ratio
PDA	Personal digital assistant
RF	Radio frequency
ROF	ROF
RoF	Radio over fibre
SMF	Single mode Optical fibre
Soliton	Self-phase modulation
TSSB	Tandem Single Side Band
VoIP	Voice over Internet protocol
WDM	Wavelength Division Multiplexing
WiGig	Wireless Gigabit Alliance
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless local area network
WPAN	Wireless personal area networks

CHAPTER 1

INTRODUCTION

1.1 Introduction

An increased care has been paid recently on the wireless network communications leading to deliver maximum distance and high capacity (Gupta & Kumar, 2000). This chapter contains a brief introduction to the researches on wireless personal area networks (WPAN). The unlicensed frequency of 60 GHz available for wireless communications worldwide has attracted much concern due to the vast bandwidth it can provide. It allows for rapid transfer of large amounts of data while also supporting a variety of new, bandwidth intensive multimedia applications. Recently, a number of option 60 GHz wireless network protocols have emerged, some of which initially targeted different applications (Jiang Jr *et al.*, 2012) but now appear to compete with one another. For instance, Wireless-HD is a standard that determines the development of technology to support the streaming of HD-TV signals within the home (Siligaris *et al.*, 2011). There is also the Wireless Gigabit Alliance and its WiGig standard, proposed initially at allowing WPAN devices to communicate at Gb/s speeds within a typical room (Emami *et al.*, 2011). Also focusing on extending the data rate transfer capabilities of WPAN networks is the IEEE 802.15 project which is defining modifications to the IEEE 802.15.3c standard provides operation in the 60 GHz frequency for extremely high throughput (Fisher, 2007). Integrating a fibre-optic signal distribution network into a 60 GHz wireless network can allow to efficiently delivering high data rate signals to numerous wireless access points with optimized radio coverage (Park *et al.*, 2008). Optical signals carrying broadband WPAN data are distributed over optical fibre from a central distribution point (connected to the external IP backbone network) to remotely placed wireless access points (Jia, 2008), which provide wireless coverage to a great number of user terminals. The high penetration loss of radio signals at 60 GHz will confine the WPAN radio coverage to smaller areas such as room environments (Guo *et al.*, 2007).

Furthermore, this chapter shows integration of WPAN and fibre-optic networks and background information about that. Based on self-phase modulation (Soliton) definition pulses will be kept within a specific range, and with no changes in their shapes, these pulses will propagate, which is suitable for our goal (Hsieh *et al.*, 2006). Ring resonators can be used in many research areas such as signal processing and fibre-optic communications in the micro/nano scale (Qiang *et al.*, 2007), where they have shown promising applications. In order to generate large bandwidth and transmit the signals over long distances (Afroozeh *et al.*, 2012), Soliton pulses that propagate in a nonlinear medium of Kerr type are used. Employing proper parameters, for example, the coupling, power at input, ring radii, and coefficients, the output signals can be generated and controlled within a numbers of micro and nano ring resonators (Yupapin & Suwancharoen, 2007).

1.2 Background of the problem

Wireless transmission is the transfer of data between two or more points that are not connected with wire. The most popular wireless technologies use electromagnetic wireless communications, such as radio (Gibson, 2012). Radio transmitters and receivers use some energy to transfer data without using wires (Armstrong, 2009). Data can be sent and received in this technique over different distances (Whitehouse *et al.*, 2007). The transmitters use radio frequency (RF) to send and receive data. RF is composed of signals, which are generated by pulses for transmitters (Helaoui *et al.*, 2008). There are many ways to generate wireless signals. In this proposal, I will examine the signals of optical solitons generated by Ring Resonator (Suwanpayak *et al.*, 2011).

Wireless data transmission is actually not a new technology (Molisch, 2010). Rather, its industrial applications are relatively new. In fact, the term "wireless" started as a convenient source of data transfer employing a dual-aim device incorporating both receiving and transmission. Heinrich Rudolf Hertz in 1888 explained the theory of electromagnetic waves (Jenkins, 2008). He showed and proved that the electromagnetic waves can be transmitting in starlight lines through space, where receivers are able to translate them electronically. Guglielmo Marconi, an Italian researcher, in 1895 conceded experimented (Falciasecca & Valotti, 2009).

Signals were sent and received throughout the Atlantic Ocean in 1901, and in the year of 1905 the first wireless signal was sent was for the application of Morse code. U.S. military used the wireless for the first time (Falciasecca & Valotti, 2009). The army used this system due to the encryption data, which makes almost impossible unauthorized access to network data. The engineering was initiated when the U.S. military commenced to send plans over enemy lines during the Second World War (Wilkins & Wilkins, 2009). Wireless proved as valuable a secure communication medium compared to wired systems. In 1971, the first wireless local area network (WLAN) was implemented (Gainey & Proctor Jr, 2012) in a research project called ALOHA net in the University of Hawaii (Schwartz & Abramson, 2009). Thereafter, wireless communication systems started their travel into universities, homes, businesses, and in the industrial factories around the world.

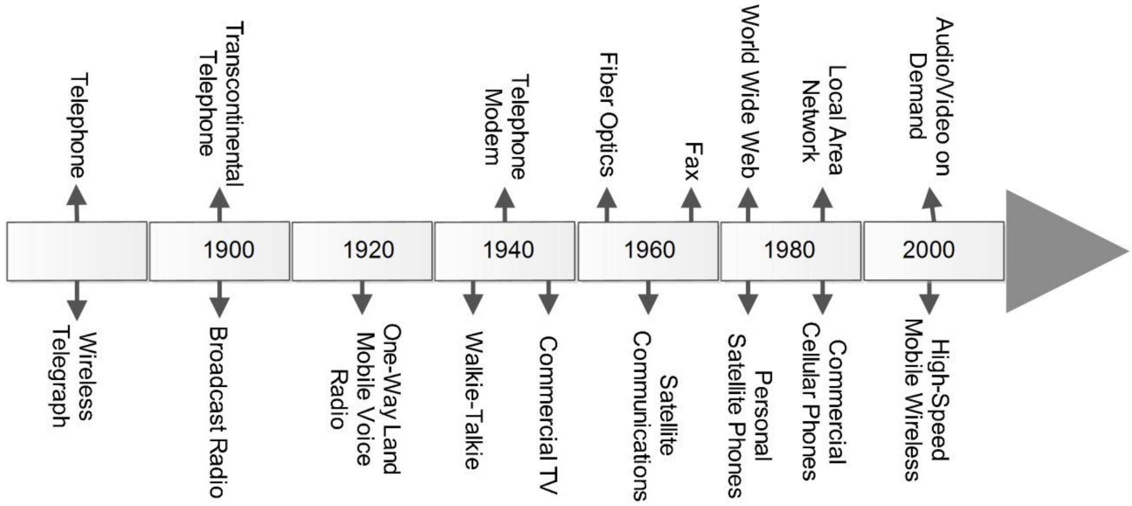

Figure 1.1 The graph shows universal telecommunications advances on the top and wireless-specific advances on the below.

In 2001, the Federal Communications Commission (FCC) assigned the 57–64 GHz band for unlicensed use (Pepe & Zito, 2011). The 60 GHz frequency band is highly promising since it offers a huge part of the unlicensed spectrum that provides extremely high throughput (Daniels & Heath). Some standardization groups and industrial consortia have been formed to specify 60 GHz transmission for WPAN applications (Park & Rappaport, 2007), where the main initiatives are IEEE 802.15.3c. The standard focuses on the indoor over Gb/s data rate wireless communication and operate at the 60 GHz frequency band (Baykas *et al.*, 2011).

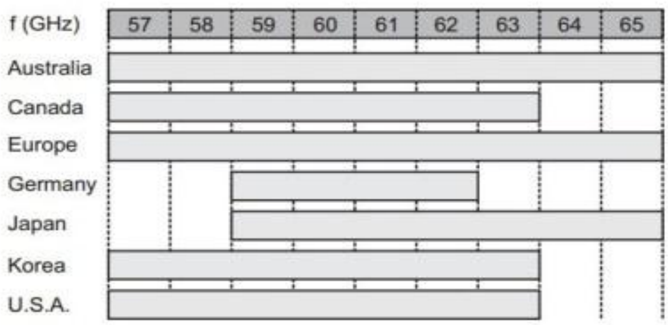

Figure 1.2 Unlicensed bandwidth around 60 GHz for different countries.

1.2.1 Optical Solitons

Optical soliton can be defined as a single self-reinforcing wave which is able to maintain the signal shapes while traveling with a stable speed. The Idea of optical soliton incorporates its nonlinearity feature and aims to eliminate and replace fibre optic (Ivancevic, 2010). Therefore, optical solitons are pulses that travel without distortion because of dispersion or other agents (Mishra & Konar, 2008). The subject of solitary waves is thus an important development in the field of optical communications. When located far apart, each of the solitons pulses is a wave travelling with relatively constant velocity and shape. When two pulses of optical soliton are brought together, they deform gradually and they will finally merge together creating a single wave (Solitons). However, this wave packet can be split into two discrete single waves with similar velocity and shape before they collided. Optical solitons are used in telecommunication via Wavelength Division Multiplexing (WDM) (Tripathi *et al.*, 2007). The historical perspectives of the solitary wave are shown in Table 1.1.

Table 1.1: Background of Optical Solitons (Musslimani *et al.*, 2008)

No	Year	Finding
01	1808-1882	John Scott Russe discovered soliton as a first scientific.
02	1965	Zabusky of Bell Lab and Kruskal from Princeton University demonstrated soliton behaviour in media subject to Kortewag-de Varies (kdv) in equation which is nonlinear partial differential equation of the third order.
03	1967	Gardner, Greene, Kruskal and Miura discovered an inverse scattering transform enabling analytical solution of kdv equation.
04	1973	Akira Hasegawa of AT&T Bell labs was the first to suggest that solitons could exist in optical fibers.
05	1991	Bell Lab research team transmitted soliton error-free at 2.5

		GB over more than 14000 kilometres, using erbium optical fibre amplifiers (EOFA).
06	1998	Thierry Georges and his team at France Telecom R&D Centre, combining optical. Solitons of different wave lengths (wavelength division multiplexing).
07	2001	The practical use of soliton became a reality when Algety Telecom deployed submarine telecommunications equipment in Europe carrying real traffic using John Scott Russell's solitary wave
08	2002	Alexander V. Buryak study on Optical solitons due to quadratic nonlinearities from basic physics to futuristic applications
09	2003	Kivshar Agrawal published a book by the title of Optical solitons : From fibres to photonic crystals
10	2004	Akira Hasegaw studied on the Effect of polarization mode dispersion in optical soliton transmission in fibers
11	2005	M. F. Ferreira worked on optical Solitons in Fibers for Communication Systems to solve a long distance transmission
12	2006	Mishra.M writing a book about Interaction of Solitons in a Dispersion Managed Optical Communication System with Asymmetric Map
13	2007	Preecha Yupapin worked on Chaotic signal generation and cancellation using a micro ring resonator
14	2010	Enhancement of FSR and finesse using add/drop filter and PANDA ring resonator systems
15	2012	MRR quantum dense coding for optical wireless communication system using decimal convertor
16	2013	Nonlinear Chaotic Signals Generation and Transmission within an Optical Fibre Communication Link
17	2013	IEEE 802.15. 3c WPAN standard using Millimeter optical soliton pulse generated By a Panda ring resonator
18	2013	Optical wireless quantum communication coding system using decimal convertor

1.3 Problem Statement

There are several problems that limit the distance of radio over fibre data transmission (Sauer *et al.*, 2007). The major sources of such problems include dispersion and distortion of the signals (Ip & Kahn, 2008). Dispersion is characterized in optical fibres in terms of maximum transmission speed (Koos *et al.*, 2009). If a non-monochromatic light impulse is transmitted through an optical fibre, its shape changes along the fibre as a consequence of light wave speed dependence on various factors (Thévenaz, 2011). The pulse width gradually increases and the peak power of the impulse is reduced (Slimane, 2007). This fact limits information capacity at high transmission speeds (Essiambre *et al.*, 2010). Dispersion reduces the effective bandwidth and at the same time it escalates the error rate due to an increasing inter symbol interference (Udayakumar *et al.*, 2013). Distortion is a phenomenon that occurs in fibre optics and some other similar waveguides (Atakaramians *et al.*, 2008). Distortion causes the signal to be spread over time because of the various propagation velocities of the optical signals for different modes (Singh & Singh, 2007).

In systems requiring long distance signal transmission (Rosenberg *et al.*, 2007), the mentioned issues cause technical difficulties and problems which have to be dealt with in order to optimize the efficiency and the reliability of such systems. These are listed in the following:

- **Signal loss:** the attenuation phenomenon aka signal loss which can sometimes occur as a result of selective absorption of some particular wavelengths (Ramaswami *et al.*, 2009)
- **Bit error rate:** abbreviated as Bit Error Rate (BER), this is the percentage of bits with errors with respect to the total bits received during a single transmission (Sun *et al.*, 2008). For instance, in a transmission with a BER of 10^{-6}, one bit out of 1,000,000 bits transmitted has been in error. BER is an indication of how many times data must be retransmitted due to error.

1.4 Objective of the study

I. To design a series of micro ring resonators scheme to extend transmission distance of signals over fibre optic.

II To develop a model based on add/drop filter for reducing BER in fibre optic communication systems.

1.5 Scope of the study

- The research thesis focuses on single mode nonlinear fibre optics and generation of soliton signals using micro ring resonator for the aim of radio over fibre systems.
- The Micro Ring Resonator is a nano scale optical waveguide with effective area of the ring varies from 50 to 10 µm2 and the medium has a nonlinear refractive index range of 10-20 to 10-13 m2/W.
- For objective I, this work focuses on transmission of signals in nonlinear fibre optics with the length of 20, 50,100 and 200 kilometres.
- For objective II, this work focuses on the simulation of solitonic signals generation in the range of 57-62 GHz and transmission over 25, 50 and 100 kilometres.
- The research results are based on modelling and simulation of soliton signal generation using Matlab software and the simulation of transmission inside the optical fibre has been done using Optisystem 7 software.

1.6 Significance of the study

The nonlinear behaviour can be used for maximum distance communication based on the chaotic signals, bright soliton generation and conversion and single photon switching in optical communications. With this technique, the data transmission capacity on radio over fibre can be increased with the use of chaotic packet switching. The proposed system comprises a set of micro resonators along with a nano ring. Micro- and nano-ring resonator systems can provide the high-capacity signals, where a variety of optical soliton results such as chaotic waves, dark soliton, multi-soliton and single can be generated. A soliton signal is an ideal candidate for use in long-distance communication. Thus, increasing the soliton channels can be an interesting solution. The large bandwidth of the wavelength from a soliton pulse can be enlarged and stored within a nano-waveguide. Therefore, generation of these signals by using ring resonators is suitable for WPAN networks in case of capacity and reduce the cost due to the using simple antenna instead of current devices.

1.7 Summary

This chapter discusses about brief history of wireless and wired networks and problems and issue on signals transmission over fibre optic. Moreover, aim, objectives, scope and methodology to achieve the results has been mentioned. Section 6 in this chapter clarified the importance of the study.

In next chapter which is chapter two overview of previous works about soliton signals that generated by ring resonator and its applications on communication systems has been discussed.

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