Digital Binary Codes Transmission via TDMA Networks Communication System Using Dark and Bright Optical Soliton

I. S. Amiri, A. Shahidinejad, A. Nikoukar, M. Ranjbar, J. Ali, P. P. Yupapin

Abstract: **In this study, new system of microring resonator for quantum cryptography in network communication is proposed. optical potential well can be generated and propagate via a nonlinear modified add/drop interferometer system incorporated with a beam splitter and a time division multiple access (TDMA) system wherein the quantum binary codes can be generated, propagated and transmitted. A system known as optical multiplexer can be used to increase the channel capacity and security of the signals, where the beam splitters generate high capacity of binary codes within the proposed system. Therefore, ring resonator system is used to form the optical potential wells. The multiplexed potential wells are formed and transmit via an available link, where the logic codes can be sent out with different time, used for high capacity transmission of the secured data. In this work narrow pulses with FHHM of 9.57 nm and 8 nm could be obtained from the drop and through ports of the add/drop interferometer system respectively. The outputs of different center wavelengths are combined and used to generate multiple potential well signals, where the multiple signals with FWHM and FSR of 0.8 nm and 5 nm could be obtained respectively. Digital codes can be generated and transmitted via communication networks systems such as time division multiple access (TDMA) using dark and bright soliton pulses with FHHM and FSR of 0.54 nm and 4.71 nm.**

Keywords: ***Optical potential well, Quantum cryptography, Dark and bright soliton; time division multiple access, Binary codes; Digital codes***

I. INTRODUCTION

Digital multiplexing such as Time Division Multiplexing (TDM) is a type of network system in which two or more bit signals can be transferred simultaneously as sub-channels in one communication channel.

I. S. Amiri (Corresponding Author) is with the Institute of Advanced Photonics Science, Nanotechnology Research Alliance Universiti Teknologi Malaysia (UTM), 81300 Johor Bahru, Malaysia (e-mail: isafiz@yahoo.com).

A. Shahidinejad is with the Faculty of Computer Science & Information Systems (FCSIS), Universiti Teknologi Malaysia (UTM), 81300 Johor Bahru, Malaysia.

A. Nikoukar is with the Faculty of Computer Science & Information Systems (FCSIS), Universiti Teknologi Malaysia (UTM), 81300 Johor Bahru, Malaysia.

M. Ranjbar is with Faculty of Electrical Engineering, Universiti Teknologi Malaysia (UTM), 81310 Johor Bahru, Malaysia.

J. Ali is with the Institute of Advanced Photonics Science, Nanotechnology Research Alliance Universiti Teknologi Malaysia (UTM), 81300 Johor Bahru, Malaysia.

P. P. Yupapin is with the Advanced Research Center for Photonics, Faculty of Science King Mongkut's Institute of Technology Ladkrabang Bangkok 10520, Thailand.

It can be further extended into the time division multiple access (TDMA) system, where several stations connected to the same physical medium, for example sharing the same frequency channel, can communicate.

Therefore, a TDMA system can be realized as a channel access method for shared medium networks, where the users receive information with different time slots. This allows multiple stations to share the same transmission medium while using only a part of its channel capacity. TDMA can be used in digital mobile communications and satellite systems. Thus, in the TDMA system, instead of having one transmitter connected to one receiver, there are multiple transmitters, where high-secured signals of quantum codes along the users can be transmitted.

Secured communication is increasing widely and rapidly every year. The security technique known as quantum cryptography has been widely used and investigated in many applications [1]-[3]. Hence, the internet security becomes an important function which is required to be included in the modern internet service. So far, a quantum technique is recommended to provide such a requirement. Potential of using the optical tweezers and quantum codes, especially, for the hybrid quantum communication in the network system is expressed. Quantum codes can be performed and generated via optical tweezers in the form of potential wells with appropriate soliton input power and MRR parameters. A new technique for QKD (Quantum Key Distribution) was presented by Yupapin et al [4] that can be used to make the communication transmission security and implemented by a small device such as mobile telephone hand set. This technique uses the Kerr nonlinear type of light in the MRR. Mitatha et al [5] have proposed the design of secured packet switching used nonlinear behaviors of light in MRR which can be made for high-capacity and security switching.

To date quantum code is the only form of information that can provide the perfect communication security. Dark-Gaussian soliton controls within a semiconductor add/drop multiplexer has numerous applications [6], [7]. Optical tweezers technique also becomes a powerful tool for manipulation of micrometer-sized particles in three spatial dimensions and has led to widespread applications in biology [8], [9], and in physical sciences [10], [11]. The output is formed when the high optical field is configured as an optical tweezers or potential wells [12]-[18]. Optical tweezers in the forms of valleys (potential wells) are kept in the stable form within the add/drop filter. Several emerging technologies,

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such as integrated all optical signal processes and all-optical quantum information processing, requires strong and rapid interactions between two distinct optical signals [19]. In this paper, we have used a nonlinear MRR to form the high secured correlated quantum codes. Here the novel system of dynamic optical tweezers (potential wells) generation, using dark soliton pulses propagating within an add/drop multiplexer is presented. Due to low power of the potential wells, the output signals from the proposed system can be highly secured during propagation along the communication network. Therefore, signals in the form of digital codes can be detected by different users. Here, different time switching of the signals could be obtained using different fiber length, connecting the digital signal transmitter system to the users.

II. THEORETICAL MODELING

Input optical field of dark soliton and Gaussian pulse are introduced into the input and add ports of the proposed add/drop interferometer system respectively, shown in Fig. 1 [20].

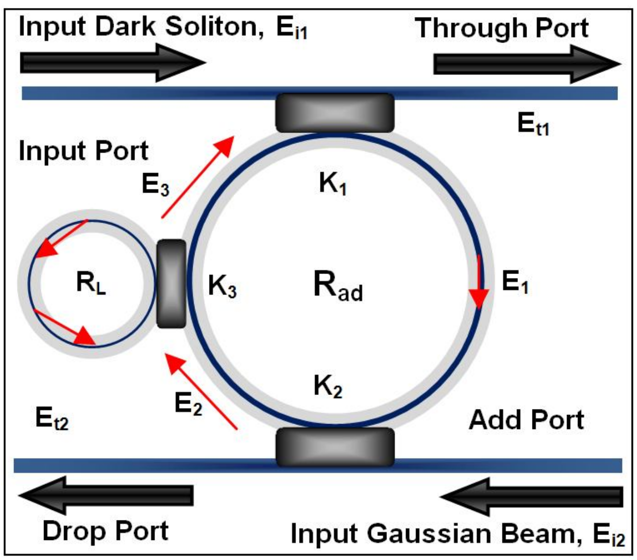

Fig.1: A schematic diagram of an add/drop interferometer system.

Input optical fields of the dark soliton (E_{in}) and the Gaussian pulse (E_{add}) are expressed as Eqs 1 and 2 [21].

$$E_{in} = A \tanh\left[\frac{T}{T_0}\right] \exp\left[\left(\frac{z}{2L_D}\right) - i\omega_0 t\right] \quad (1)$$

$$E_{add}(t) = E_0 \exp\left[\left(\frac{z}{2L_D}\right) - i\omega_0 t\right] \quad (2)$$

A and z are the optical field amplitude and propagation distance, respectively. T is a soliton pulse propagation time in a frame moving at the group velocity, $T = t-\beta_1 \times z$, where β_1 and β_2 are the coefficients of the linear and second order terms of Taylor expansion of the propagation constant. $L_D = T_0^2/|\beta_2|$ is the dispersion length of the soliton pulse. The frequency carrier of the soliton is ω_0. Solution is realized like pulse that keeps its temporal width invariance as it propagates, and thus is known as temporal soliton. Soliton peak intensity is $(|\beta_2/\Gamma T_0^2|)$. Here $\Gamma=n_2\times k_0$, is the length scale over which dispersive or nonlinear effects makes the beam become wider or narrower. A balance should be achieved between the dispersion length (L_D) and the nonlinear length ($L_{NL}=(1/\gamma\varphi_{NL})$, where γ and φ_{NL} are the coupling loss of the field amplitude and nonlinear phase shift, thus $L_D=L_{NL}$. Light propagates within the nonlinear medium wherein the refractive index (n) is given by:

$$n = n_0 + n_2 I = n_0 + \left(\frac{n_2}{A_{eff}}\right)P, \quad (3)$$

where n_0 and n_2 are the linear and nonlinear refractive indexes, respectively. I and P are the optical intensity and optical power, respectively. Effective mode core area of the device is given by A_{eff} [22]. The normalized output of the light field from single ring resonator is the ratio between the output and input fields $E_{out}(t)$ and $E_{in}(t)$ in each roundtrip, which is given by Eq. (4).

$$\left|\frac{E_{out}(t)}{E_{in}(t)}\right|^2 = (1-\gamma)\times \left[1 - \frac{(1-(1-\gamma)x^2)\kappa}{(1-x\sqrt{1-\gamma}\sqrt{1-\kappa})^2 + 4x\sqrt{1-\gamma}\sqrt{1-\kappa}\sin^2(\frac{\phi}{2})}\right] \quad (4)$$

Here κ is the coupling coefficient, and $x = \exp(-\alpha L/2)$ represents a roundtrip loss coefficient where L and α are a waveguide length and linear absorption coefficient, respectively. $k = 2\pi/\lambda$ is the wave propagation number, $\phi(t) = \phi_0 + \phi_{NL}$, where $\phi_0 = kLn_0$ and $\phi_{NL} = kLn_2|E_{in}|^2$ are the linear and nonlinear phase shifts. The iterative method is introduced to obtain the results as shown in Eq. (4). Add/drop interferometer system is proposed with appropriate parameters to generate optical tweezer in the form of potential wells. Two complementary optical circuits of the system can be given by the Eqs. 5 and 6.

$$\left|\frac{E_{t1}}{E_{in}}\right|^2 = \frac{(1-\kappa_1) - 2\sqrt{1-\kappa_1}\cdot\sqrt{1-\kappa_2}e^{-\frac{\alpha}{2}L}\cos(k_n L) + (1-\kappa_2)e^{-\alpha L}}{1+(1-\kappa_1)(1-\kappa_2)e^{-\alpha L} - 2\sqrt{1-\kappa_1}\cdot\sqrt{1-\kappa_2}e^{-\frac{\alpha}{2}L}\cos(k_n L)}, \quad (5)$$

$$\left|\frac{E_{t2}}{E_{in}}\right|^2 = \frac{\kappa_1\kappa_2 e^{-\frac{\alpha}{2}L}}{1+(1-\kappa_1)(1-\kappa_2)e^{-\alpha L} - 2\sqrt{1-\kappa_1}\cdot\sqrt{1-\kappa_2}e^{-\frac{\alpha}{2}L}\cos(k_n L)}, \quad (6)$$

where E_{t1} and E_{t2} represents the optical fields of the through and drop ports respectively. $\beta = kn_{eff}$ is the propagation constant, n_{eff} is the effective refractive index of the waveguide and $L = 2\pi R$ is the circumference of the MRR ring, where R is the radius. κ_1 and κ_2 are coupling coefficients and the ring resonator loss is α. The fractional coupler intensity loss is γ [23].

III. RESULT AND DISCUSSION

Extremely Narrow peak of the output signals can be obtained when dark soliton with input power of 2 W is launched into the MRR system, where the Gaussian beam has power of 0.7 W shown in Fig. 2. The suitable ring parameters are ring radii, where $R_{ad} = 15$ µm and $R_L = 6$ µm. The coupling coefficients of the centered ring are given by $\kappa_1 = 0.12$ and $\kappa_2 = 0.35$, where the ring resonator at the left side has coupling coefficient of $\kappa_3 = 0.5$. Here, the selected parameters of the system fixed to $\lambda_0 = 1.55$ µm, $n_0 = 3.34$ (InGaAsP/InP). The effective core areas range from $A_{eff} = 0.50$ to 0.10 µm^2. The waveguide and coupling loses are $\alpha = 0.5$ dBmm^{-1} and $\gamma = 0.01$, respectively. The nonlinear refractive index has been selected to $n_2 = 2.2\times10^{-17}$ m^2/W. Figure (2a) shows the input dark soliton and Gaussian pulse with center wavelength of $\lambda_0 = 1.55$ µm and powers of 2 W and 0.7 W respectively. Figures (2b), (2c) and (2d) show the amplified interior potential well signals, whereas the sharp pulses with FWHM of 9.57 nm and 8 nm can be seen in Figures (2e) and (2f) for the drop and through port output signals respectively. Soliton signals can be used in optical communication where the capacity of the output signals can be improved by generation of peaks with smaller FWHM.

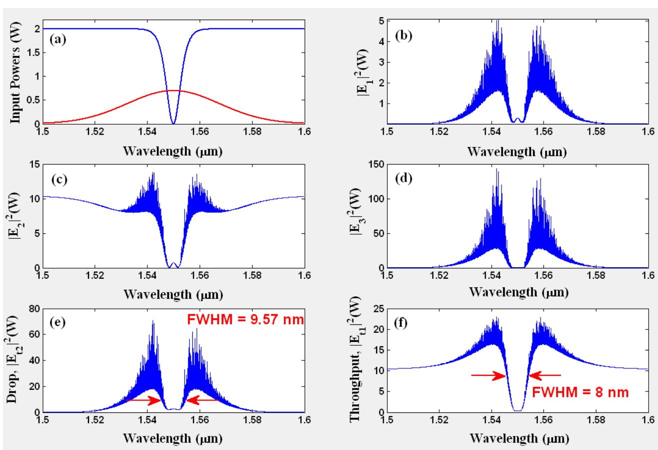

Fig. 2: Results of the potential wells generation (a): input dark soliton and Gaussian pulse,(b), (c) and (d): interior amplified signals, (e) and (f): drop and through port output signals with FWHM of 9.57 nm and 8 nm respectively, where $\kappa_1 = 0.12$ and $\kappa_2 = 0.35$ and $\kappa_3 = 0.5$.

High capacity of transmission obtained when the optical potential wells with different center wavelengths are combined using suitable multiplexer device. Here, series of MRR systems can be integrated in one single system, incorporating with multiplexer device shown in Fig. 3.

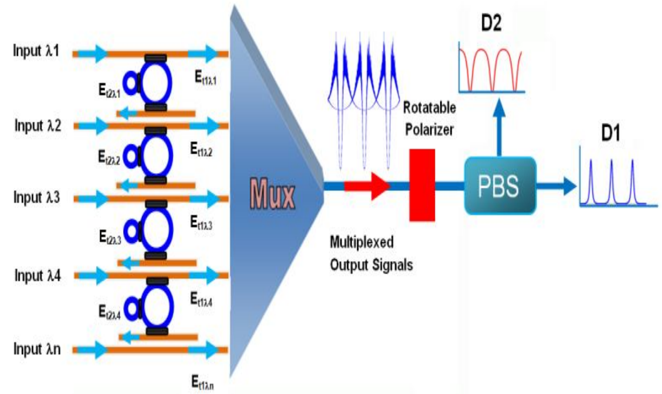

Fig. 3: System of integrated MRR systems, incorporating with a multiplexer device and a beam splitter

Highly potential well signals can be obtained from output of the multiplexer device, shown in Fig. 4. Therefore, signals with center wavelengths of λ_1=1.53µm, λ_2=1.535µm, λ_3=1.54µm, λ_4=1.545µm, λ_5=1.55µm, λ_6=1.555µm, λ_7=1.56µm, λ_8=1.565µm and λ_9=1.57 µm are combined, where pulses with FWHM and FSR of 0.8 nm and 5 nm can be obtained respectively.

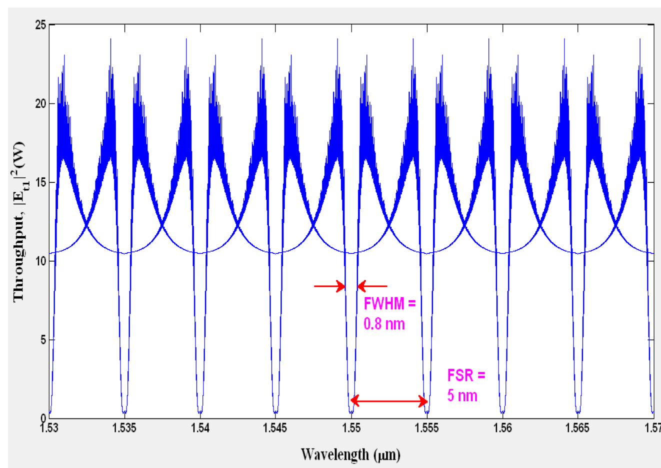

Fig. 4: Multiple potential well generation with FWHM and FSR of 0.8 nm and 5 nm respectively, using multiplexer system

In order to generate quantum binary and logic codes of “0” and “1”, the multiplexed signals from the multiplexer system transmit into a beam splitter (PBS). In operation, the dark and bright soliton can be generated within the proposed system after traveling of the signals through the PBS shown in Figure 5, whereas the polarization phase shift of the two components is 90°.

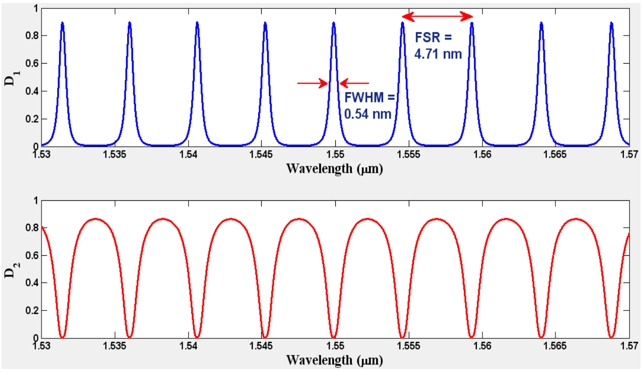

Fig. 5: dark and bright soliton generation with FWHM and FSR of 0.54 nm and 4.71 nm respectively, using multiplexer system

Figure (6) show the normalized binary dark and bright soliton pulses which seen simultaneously from photo detectors 1 and 2. These optical pulses can be converted to digital binary codes of "0" and "1" using suitable analog to digital convertor electronic device.

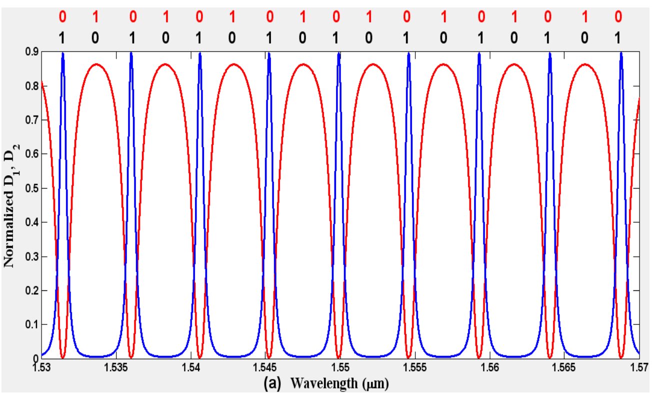

Fig. 6: dark and bright soliton pulses simultaneously seen from photo detectors 1 and 2.

Therefore, random polarization states of two components can be used to form the binary code patterns and the binary code signals. The logic states are set as shown in Figs 7.

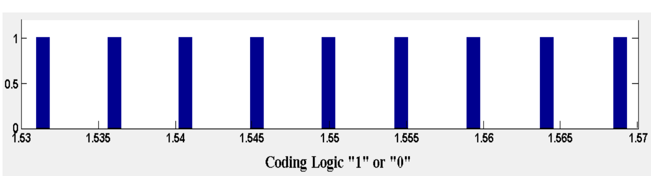

Fig. 7: Generation of logic codes, using PBS

Here, the logic codes detected by D_1 are '10101010101010101' patterns. The logic codes detected by D_2 are '01010101010101010' patterns. Different orders of the logic codes can be used to generate different signal information, propagating in the network communication via TDMA transmission system shown in Fig. 8. This system uses data in the form of secured logic codes to be transferred into the singular users via different length of the fiber optics line to the TDMA transmitter.

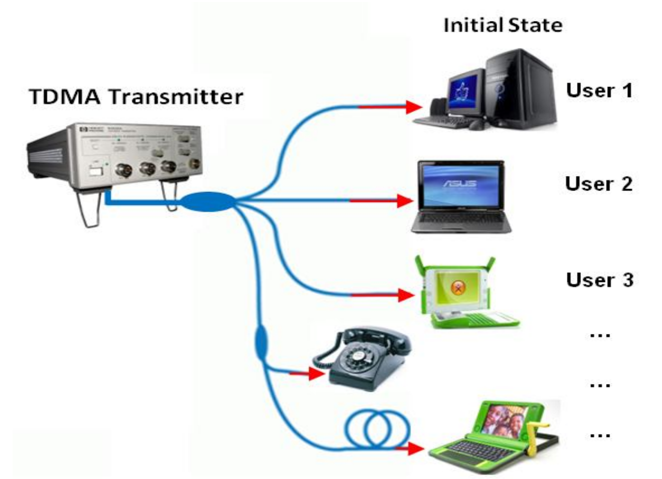

Fig. 8: Schematic of the TDMA system

Therefore, same digital information of codes can be shared between users with different time slots. The transmission unit is a part of quantum processing system that can be used to transfer high capacity packet of quantum codes using extremely short pulses of dark and bright soliton [24]. Moreover, the high capacity of data can be applied by using more wavelength carriers.

IV. CONCLUSION

We have analyzed and described dark-Gaussian soliton collision behaviors within a modified add/drop multiplexer system consisting of one center ring and one smaller ring on the left side. Optical tweezer in the form of potential well could be generated and used to perform binary codes using PBS. We have proposed an interesting concept of internet security based on quantum logic codes where the use of data encoding for high capacity communication via optical network link is plausible. Required binary codes could be generated after the potential well signals were travelling into the PBS. The potential wells are highly secured optical signals because of low intensity of their center wavelengths in which detection of such as signals is extremely difficult. Therefore, the importance of the study is that the generated potential wells signals are highly secured along the MRRs system, where a part of the system consists of transmission part can be used to transfer of the quantum codes. Results obtained have shown that the multiplexed signals of potential wells with FWHM and FSR of 0.8 nm and 5 nm can be performed and used to logic codes generation, where the dark and bright soliton pulses with FHHM and FSR of 0.54 nm and 4.71 nm could be obtained. Furthermore, such a concept is also available for hybrid communications, for instance, wire/wireless, satellite.

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