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MODELLING OF NANO PHOTONICS BY GAP SOLITONS IN AXIALLY UNIFORM FIBRES AND SOPHISTICATED QUANTUM COMMUNICATION TECHNIQUES FOR WIRELESS WAN NETWORKS

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ABSTRACT

The way of using photons as a beam of light for the faster transfer of data is photonics. The main objective of this paper is to effectively model the Nano photonics and to develop a model for quantum communication between Wirelesses WAN. The photonic crystals as a peculiar character by moulding the flow of light in various ways which can lead to a variety of sophisticated and enhanced designs of optical Nano materials and Nano devices in the field of photonics. One example is considered: A cylindrical photonic crystal fiber is designed in such a way that it can exhibit all optical switching without the axial periodicity using nonlinear materials. It is proved that this property arises from the unique structural design of the cylindrical photonic crystal guided mode dispersion relation, and can lead to noteworthy improvements in operating power usage, device size requirements and manufacturing ease making such a system perfect for integrating all optical signal processing. A quantum routing mechanism is proposed to transport a quantum state from one quantum device to another wirelessly even though these two devices do not share EPR pairs mutually. This results in the proposed quantum routing mechanism that can be used to construct the quantum wireless networks. In terms of time complexity, the proposed mechanism transports a quantum bit in time almost the same as the quantum teleportation does regardless of the number of hops between the source and destination. From this point of view, the quantum routing mechanism is close to optimal in data transmission time. In addition, in order to realize the wireless communication in the quantum domain, hierarchical network architecture and its corresponding communication protocol are developed. Based on these network components, a scalable quantum wireless communication can be achieved.

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INTRODUCTION

The volume of digital data conveyed around the globe rises briskly every single year. Whenever large amount of data has to be transferred, or whenever the data needs to be transmitted across greater surface area, optical fibers are the ideal medium for mobility, due to their low losses, and high capacity. A single optical fiber (whose core is less than 10µm in diameter) has been verified to transmit more than 1Tbit/sec, with losses less than 0.2dB/km.

By the same sign, this large amount of data needs to be processed. To perform nearly any kind of process on optical signals today (like pulse regeneration, wavelength conversion, bit-rate conversion, logic operation, etc.) the signals first need to be converted to the electronic field. Unluckily, there are vital physical explanations that hinder the field of electronics from operating well at high frequencies. As a result, the price of electronic components grows rapidly when more sophisticated bit-rates are required, and hence, use all optical signal processing becomes briskly more and more pre

dominant. Since the signal processing needs to be done on rapid-fast pace, the only mechanism at discarding is to explore a material's optical non-linearities. Most researches today is in the area of optical devices which is in high-index-contrast integrated optics. Regrettably, these devices suffer from major losses due to unevenness at the faces of their waveguides, and are highly polarization sensitive. Another approach involves the use of in-fiber all-optical devices, which would prevent these drawbacks. But, silica fiber non-linearities are very low, which combined with their large modal area results into signals having to be disseminated for very long distances before the non-linear effects become evident. Many exciting switching schemes involving excitation of gap solitons can reduce the power necessities, but need an episodic grating along the axial direction, which raises the execution desires.
To achieve quantum teleportation, shared entanglement is needed. Shared entanglement can be accomplished by generating an EPR (named after Einstein, Podolsky, and Rosen) pair and distributing the pair to the source and destination through quantum wires. However, there are lots of challenges in exploiting the quantum teleportation in the area of wireless communication.

One of the main challenges is that the EPR pairs generated at the EPR generator cannot be distributed to wireless quantum device through the air. As a result, wireless quantum devices cannot set up EPR pairs instantaneously. Even if quantum devices can set up EPR pairs by "plugging" in the quantum wires while they are static, it is still unreasonable for a limited storage mobile device to keep many EPR pairs entangled with all possible communication parties for the future use in wireless environment. Therefore, it motivates the need to establish a new quantum mechanism, which allows the teleportation of a quantum state from one site to a remote site even when the two sites do not share EPR pairs mutually. This paper represents the first attempt to address the issue of wireless communication in the quantum domain. A quantum routing mechanism is proposed to construct the quantum wireless communication networks. By executing the quantum circuits at the intermediate nodes in parallelism, the data transmission time by performing the quantum routing mechanism is almost the same as that by applying quantum teleportation, regardless of the number of intermediate nodes in between the source and the destination. This enables a quantum device to teleport a quantum state to another device that does not share EPR pairs mutually, at the time complexity nearly identical to that case in which EPR pairs are shared.In addition, in order to realize the quantum routing mechanism, a hierarchical network architecture is developed. Based on the network architecture, a new wireless communication protocol is also presented.

MODELLING OF NANO PHOTONICS

Modelling of nano-photonics is obtained by polarization – independent waveguides or by gap soliton formation and optical switching. Based on the requirement the suitable modelling can be chosen for the modelling of nano-photonics.

GAP SOLITONS IN AXIALLY UNIFORM FIBERS

Gap solitons and optical switching have been extensively studied in nonlinear dielectric structures with a one-dimensional axial periodicity in their linear refractive properties.

Corresponding experimental realizations include waveguide or fiber Bragg gratingsand integrated multi-layer heterostructures. Such periodic systems exhibit spectral gaps of high reflectivity for wave-propagation along the axial direction. For intense light illumination at a frequency inside one of the gaps and with an optical nonlinearity present, these systems can exhibit solutions whose envelopes take the form of solitary waves. Such solutions, called gap-solitons or Bragg-solitons, introduce a strong power-dependence to the transmissivity, at some powers achieving even full resonant transmission. In some cases a bistable response may be observed, i.e. one of two different transmissivities are possible at the same input power, making the actual optical response a function of the system's history. Such periodic structures are very attractive for all-optical switching, logic-gate operation, memory etc.Because of the necessity of a spectral gap for their existence, gap solitons and gap-soliton-mediated bistability have been exclusively studied in systems with axial periodicity. In this work, we show that gap-soliton excitation is also possible in axially-uniform photonic bandgap (PBG) fibers. These fibers are laterally grated forming a PBG cladding that surrounds the core. Guiding is achieved through a cladding gap-condition, in contrast to usual fibers where guiding is achieved through total internal reflection. We show that in the presence of an optical Kerr-type nonlinearity, such axially-uniform PBG fibers exhibit gap-soliton generation and gap-soliton-mediated bistability. The observed nonlinear response is a direct consequence of the particular guided-mode dispersion relation, which involves a frequency cut-off at k=0, and is unique among axially uniform systems to high index-contrast PBG fibers, and metallic waveguides.

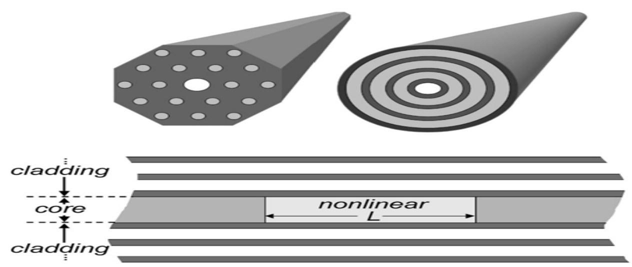

Fig. 2.1. Top: Schematics of two photonic band gap fibers, the Holey fiber and the Omniguidefiber respectively. Bottom: The 2D simulation system which is an embodiment of the Omniguidefiber

Cladding consists of alternating dielectric layers of high-index (2.8) with thickness 0.3a and low-index (1.5) with thickness 0.7a, where a is the period of the cladding layers and serves as the unit oflength. The core has a diameter $d_{linear}=d_{nonlinear}=1.2a$ and consists of linear material (darker gray) with index n=1.9 and nonlinear material (lighter gray) with index $n_{\varpi}= n_0+n_2|E|^2$, where $n_0=1.6$. The guiding direction is parallel to the layers.We study a two-dimensional embodiment of PBG fibers[20], described fully in Fig 2.1. This system captures the most essential features of the 3D fiber, in particular, guided-mode dispersion relations with a frequency cut-off at k=0, and the absence of a full spectral gap. For example in Fig 2.2a we superimpose the dispersion relations for the linear material and for the nonlinear material when $n_{\varpi}=n_0=1.6$, as calculated by the FDTD method. In each case there is a frequency cut-off at k=0 which we denote as τ_c for the linear material and $\tau_{\varpi c}$ for the nonlinear material. The difference in refractive index results in an almost parallel shift in dispersion relations. Any other choice of refractive indexes and structural parameters should suffice as long as one has single mode operation and $\tau\varpi c > \tau c$. For example, setting $n = n0*1$ and shrinking the nonlinear core dnonlinear<dlinear would have a similar effect, since guided modes with a reduced modal area appear at a higher frequency, and thus with an increased cut-off frequency. This is particularly important in terms of implementation and applications, since there exist many easy ways for externally controlling the dispersion relation, such as mechanical strain, temperature, radiation, etc.

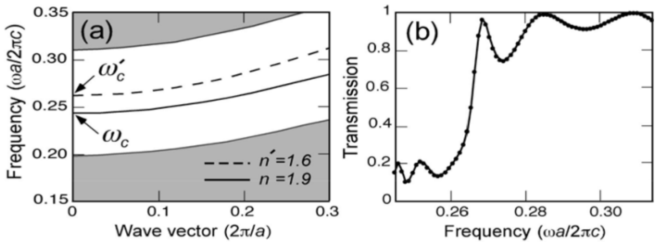

Fig 2.2. (a) Dispersion relations calculated by the FDTD method for two values of the core index. . (b) Transmission coefficient vs frequency for a linear-material system with an nϖ=n0=1.6 defect core of size L=5a

The cut-off frequencies are $\tau c = 0.244$ and $\tau\varpi c = 0.26215$. Gray areas represent cladding and radiation modes, where light is either guided through the cladding or escapes out of the fiber.

These modes cover the entire frequency region at higher wave vectors.At low input power, guided waves in the linear-material core (i.e. $\tau > \tau c$) should be strongly reflected upon incidence on the nonlinear region if $\tau < \tau c\varpi$. Such a linear transmission coefficient is shown in Fig 2.2b. At high input power, however, we should observe a wide range of nonlinear phenomena, similar to those found in the study of nonlinear periodic gratings. For example, a power-dependent frequency shift of the nonlinear-material's dispersion relation should result into a power-dependent transmission, such as in optical limiting systems. For the proper sign of n2 (n2>0 in our case), we should also observe the excitation of resonant structures such as gap solitons, resulting in resonant transmission and bistability. It is the latter effects in the limit of small nonlinearities (which is the experimentally correct limit anyway) that will be our focus here. In Fig 2.3we plot the intensity along the nonlinear core as a function of time, around the switch-up point for the L=5a system (CW response). It can be seen how the gap soliton is excited in the structure. At first it undergoes a damped oscillation until it reaches equilibrium. These oscillations are well correlated with the fluctuations of the output in Fig 2.3. This transient time is a measure of the response (switching) time of our device, which is of the order of 200 periods (for η=1.55mm this time is about 1ps).

A similar plot (not shown), but inverted and with less fluctuations is obtained at the switch-down point. In the L=8a case, on the other hand, these oscillations are not damped, and so the soliton does not reach equilibrium, but rather it gets transmitted out of the nonlinear core, only to be followed by a new soliton, resulting into a periodic train of pulses in the output. The peak intensity of each pulse is about 10 times larger than that of an equivalent transmitted CW. The duration of each pulse is about 20 periods and the pulses appear at a frequency of about 100 periods (for η=1.55 ∝m this is a pulse width of about 100 fs at a period of about 500 fs). In Fig 2.4 we plot the intensity along the nonlinear core for the L=5a system at two different points: at the peak of the upper transmission branch where a gap soliton has been excited (at time5900T of Fig 2.3), and at the lower branch where the wave decays exponentially (at time5400T of Fig 2.3).

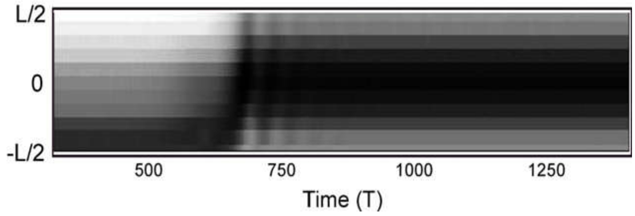

Fig2.3. Intensity along the nonlinear core as a function of time, around the switch-up point for the L=5a system (CW response)

Darker regions mark higher intensity. The vertical axis is the axial (propagation) direction, with the input is at –L/2 and the output at L/2. Before the switch-up, the intensity decays along the axial direction, while after switch-up, the intensity is maximum in the center of the nonlinear core, corresponding to a gap soliton.

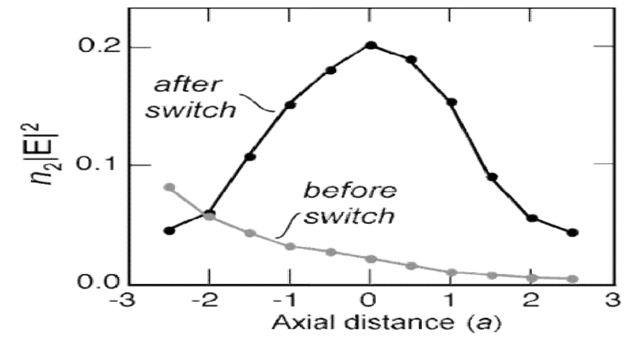

Fig 2.4. Normalized intensity (or local index change βn=n2|E|2) along the nonlinear core for the L=5a system at, the peak (100% resonant transmission) of the upper transmission branch (black), and, at the lower transmission branch (gray).

The excitation of a gap soliton is seen at the resonant transmission case. Our axially uniform nonlinear system responds very similarly to a nonlinear Bragg grating system. However, it is different in terms of performance and implementation. Having no need for a periodic modulation it is easier to make. Materials used in these fibers are chalcogenide glasses which are highly nonlinear, and so all that is needed is a frequency cut-off.

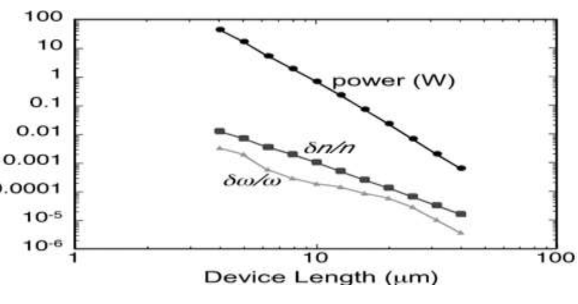

Fig. 2.5.Power and bandwidth requirements for the proposed device as a function of its nonlinear core size

This can be achieved by replacing part of the core with a lower index nonlinear material (as we did here), or alternatively, it can be achieved by external means, such as mechanical strain, temperature, radiation, etc. For example, shrinking part of the core by externally creating a constriction will have the same effect in creating a frequency cut-off. Given that the device's mode of operation (CW or pulsed) depends on the device structural parameters, we can use these external means to control its operation, without having to change the input power or frequency. For chosen parameters η=1.55 μm and n2=1.5×10-13 cm2/W. Power is measured at the switch-up point at which the width of the bistable loop is 10% of its mid-input power. Bandwidth βτ/τ is the frequency change necessary to change the switch-up power by 10%.Finally, we used a simplified 1D nonlinear model based on a fit of the dispersion relations of Fig 2.3a, to estimate how various experimental parameters would depend on the system's size L. We do not present details of this model here. We have found the 1D model's predictions to agree well with the simulation data and it is thus a valid and useful tool for practical estimates. We calculated the operating power P, the maximum nonlinear index change induced βn/n and the operational bandwidth βτ/τ as a function of L, while we tuned the frequency so that the width of the bistable loop is 10% of its center intensity. These results are shown in Fig 2.5. We find that all three quantities drop exponentially with increasing size L. As a quantitative example, a system with an nonlinear core length of L=10∝m operating at a vacuum wavelength of η=1.55∝m (i.e. a=0.406∝m) and with a nonlinear coefficient of n2 = 1.5 υ10<13 cm 2 / W (typical of many chalcogenide glasses), requires an operating power of about P=800mW, a maximum nonlinear-index-change of about βn/n=0.001, and offers a bandwidth of about βτ/τ=0.0002540GHz.

QUANTUM ROUTING MECHANISM

Two important schemes in the proposed quantum routing mechanism are quantum relay and EPR-pair bridging. The prin-ciple of quantum relay is to perform the quantum teleportation hop by hop from the source to destination when there is (are) intermediate node(s) in between. The significance of EPR-pair bridging is to speed up the whole quantum relay process by performing the quantum teleportation at each intermediate node in parallelism.

Quantum Relay Scheme

Quantum teleportation is known to be the most efficient mechanism to accomplish qubit transmission in wired line.

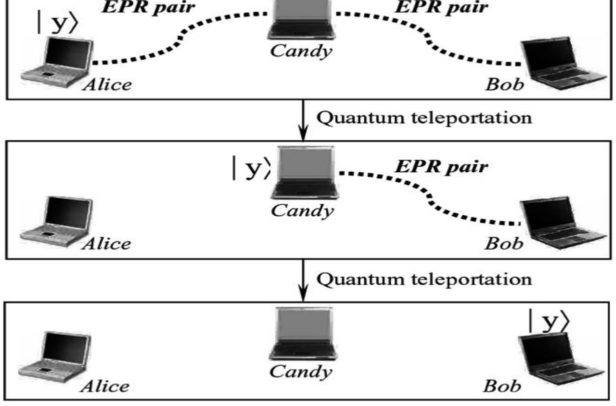

Fig 3.1 Skeleton diagram for Quantum relay scheme.

To perform quantum teleportation, it is necessary for source and destination to share entangled qubits like EPR pairs in advance. However, in a networking environment, it is impossible for one device to share EPR pairs with all possible communication parties simultaneously. Even if there exist EPR generators and quantum wires for wired quantum nodes to establish entangled EPR pairs, it is still infeasible to transmit EPR pairs to mobile devices wirelessly. Quantum relay solves the above problem by performing quantum teleportation hop by hop across the network. In the above figure, let us consider the qubit information to be transferred from source (Alice) to destination (Bob). But in quantum teleportation the qubit transportation will take place only if any intermediate node (Eg. Candy) is present. If not the transportation is not possible how in Quantum relay scheme the intermediate node (Eg.Candy) will know the EPR pairs of both Alice and Bob. The information from Alice reaches Candy and finally through another EPR pair information is received by Bob.

EPR-Pair Bridging

In the quantum relay scheme, each intermediate node shares EPR pairs with its upstream node and downstream node. We observe that each intermediate node can be served as the role of the EPR generator and the node is able to establish the en-tanglement-assisted quantum channel between its upstream and downstream nodes. The observation motivates the development of EPR-pair bridging. The accuracy of the EPR-pair bridging can be verified as follows.

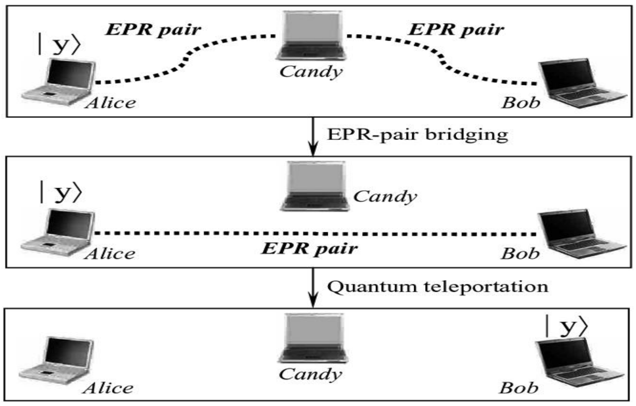

Fig 3.2 Skeleton diagram for EPR-Pair bridging

In the above figure, at first Candy gets the EPR pair of both Alice and Bob now after the EPR-pair bridging a common EPR pair is established between Alice and Bob now the information is transmitted directly without the needs for Intermediate node after the process of bridge pairing. Fig 3.3 shows the finally quantum routing mechanism either adopting quantum relay scheme or EPR-pair bridging scheme.

Quantum wireless Communication network

In this section, we focus on the wireless WAN and propose a two-tier network architecture for wireless communication in quantum domain. In addition, based on the proposed network structure, a wireless communication protocol is proposed.

Hierarchical Network Architecture

The fundamental network components in the network architecture can be roughly sketched in Fig. 4.1.

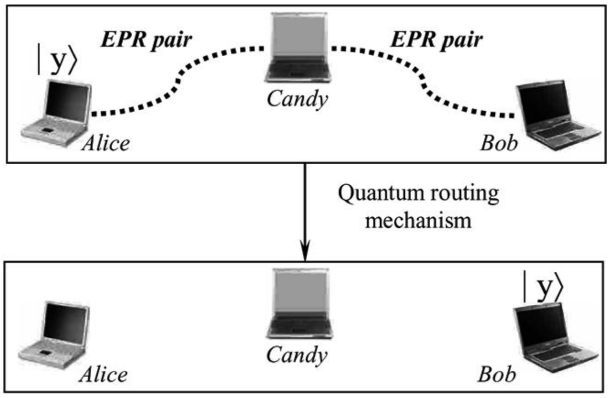

Fig 3.3 Skeleton diagram of Quantum routing mechanism

It can be seen from Fig. 11 that one of the main components in the network is the quantum bridge keeper (QBK). These QBKs constitute the radio interface between the radio access and fixed network systems. Each QBK is equipped with one or more radio transceivers (RTs), which are used to transmit and receive classical data in the form of electromagnetic waves. Moreover, based on the maximum transmission radius of these radio transceivers, each QBK has its own effective serving coverage, which is denoted by the QBK's coverage.

In addition to LPWs, there exists a global database, which is called the Global Position Warehouse (GPW), in the core network. The main purpose of the GPW is to manage the location information of all mobile quantum devices. It records the current location of all quantum mobile devices. By inquiring the GPW, one can find out which QBK's coverage a specific wireless quantum device is in. Thus, the data stored in the GPW needs to be updated frequently. In other words, as long as a quantum mobile device moves from one QBK's coverage into another QBKs, the data in the GPW shall be updated synchronously so that it keeps the current location of all wireless quantum devices. The EPR generator is included in the network infrastructure as well. The EPR generator is responsible for generating EPR pairs. Once two QBKs need to set up a quantum channel for the devices under their coverage, the EPR generator would dis-tribute the generated EPR pair by sending one qubit to one QBK and the other qubit to the other QBK by quantum wires. It can be seen from Fig. 11 that quantum wires are shown between each QBK and the EPR generator. Each mobile quantum device is assigned to a home QBK with which the mobile device shares a lot of EPR pairs initially. Furthermore, in order to transmit/receive the classical data to/from the QBKs through the air, each quantum device is also equipped with an antenna so that it can transmit and receive classic data in the form of electromagnetic waves.

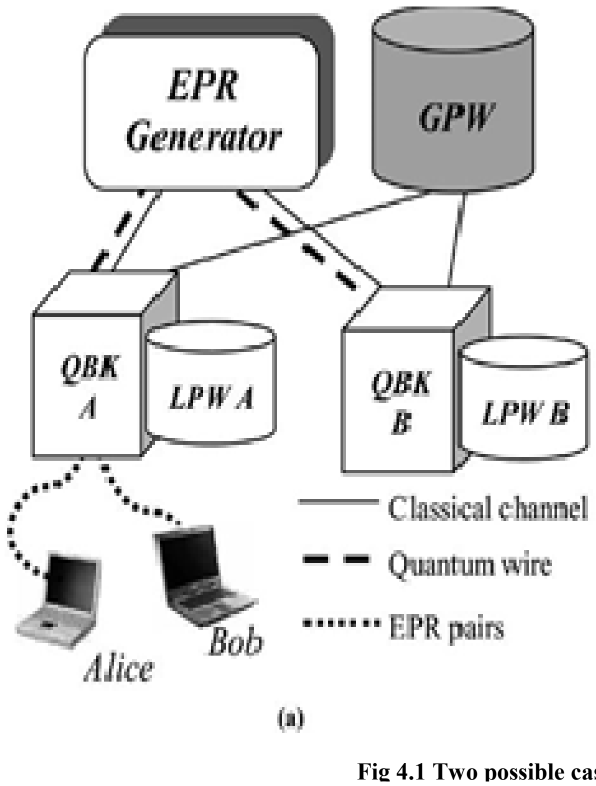

Fig 4.1 Two possible cases for the location of Bob

The main purpose of the QBK is to manage EPR pairs shared with itself and mobile quantum devices that are inside its coverage. When a mobile quantum device moves into another QBK's coverage, the EPR pairs shared with the previous QBK need to devolve upon the new QBK. When a wireless quantum device inside its coverage transmits or receives a quantum state, the QBK plays the role of an intermediate node to relay the qubit. In addition, each QBK is equipped with a regional database, Local Position Warehouse (LPW), to record the information of each wireless quantum device inside the QBK's coverage. LPW can also be used to determine whether a certain quantum sub-scriber is inside the coverage of this QBK or not.

When a mobile device roams to the coverage area of another QBK, a handoff scheme is required to update the location of the quantum device and to set up the entanglement-assisted quantum channel between the device and the new QBK.

Quantum Wireless Communication Protocol

Consider the scenario in which a wireless quantum device, Alice, would like to deliver a qubit to another wireless quantum device, Bob. In the beginning, Alice who is inside the coverage of QBK A sends a request to notify QBK A that Alice wants to teleport a quantum state to Bob.

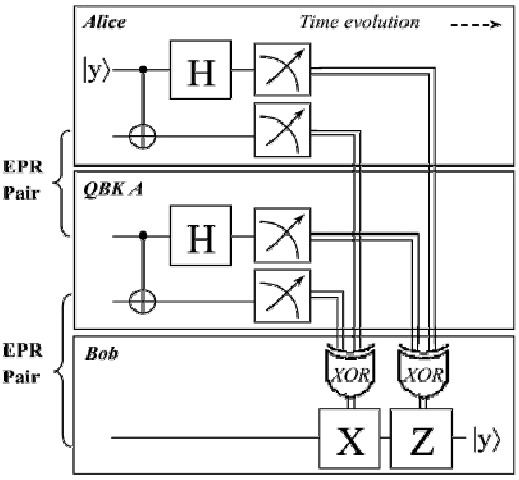

Fig 4.2a.Quantum circuits for the case that Alice and Bob are within the same QBK's coverage

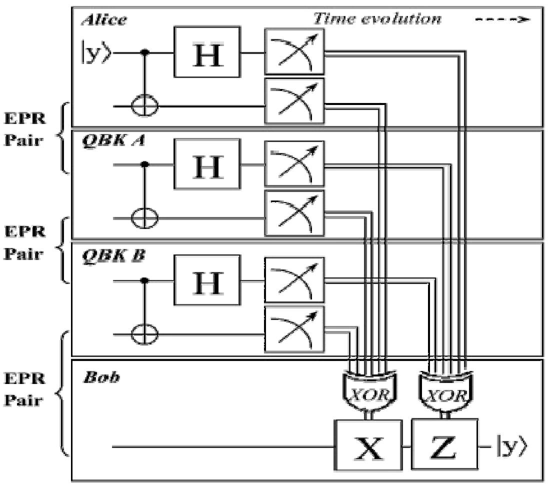

Fig 4.2b.Quantum circuits for the case that Alice and Bob are under the coverage of different QBKs

Then, QBK A would query its own LPW to check whether Bob is inside its coverage. Two possible cases may occur afterwards.

Case 1: Bob is inside the coverage of QBK A, as shown in Fig.4.1(a). Namely, Bob also shares EPR pairs with QBK A. In this case, QBK A plays the role of the intermediate node between Alice and Bob. Therefore, after applying the quantum routing mechanism with routing path Alice->QBK A->Bob, the qubit transmission would be achieved. The quantum circuit for this case is shown in Fig. 4.2.

Case 2: Bob is not inside the coverage of QBK A, as shown in Fig 4.1(b).

In this case, QBK A would inquire the GPW to determine which QBK Bob resides in. The GPW would respond to QBK A that Bob is inside the coverage of QBK B. Then, QBK A asks the EPR generator to set up an EPR pair between QBK A and QBK B. Afterwards, the EPR generator would distributean EPR pair by sending one qubit to QBK A and transporting the other qubit to QBK B. After QBK A and QBK B receive the qubits from the EPR generator, they serve as the intermediate nodes between Alice and Bob together. Consequently, after performing the quantum routing mechanism with routing path Alice-> QBK A->QBK B-> Bob, the qubit transmission would also be carried out. The quantum circuits for this case are shown in Fig 4.3. On the other hand, it reveals that some of the existing RRM strategies (e.g., handover strategy) for wireless WAN need to be investigated in order to enhance the new wireless communication protocol. As a result, in the next section, we discuss these emerging problems and also present possible solutions to these problems.

Conclusion

Thus, the various photonics techniques used for communication, selecting model of nano photonics and quantum communication techniques are explained. In conclusion, we have shown only one case where the use of photonic crystals can lead to novel and improved designs of optical nano components and nano devices in photonics. We have studied an axially uniform nonlinear system that exhibits gap-soliton formation and optical switching. This ability to obtain soliton formation and switching without imposing axial periodicity may lead to new design and fabrication opportunities for eventual experimental realization of all-optical nano devices. Also now the future research will be more focused on the safety, security and efficiency. The security must be of top notch level to prevent hacking or any unauthenticated use.This paper proposes a quantum routing mechanism, which enables a quantum mobile device to teleport a quantum state to a remote site even if they do not share EPR pairs mutually. In terms of the time complexity, the time that quantum routing mechanism takes to teleport a quantum state is independent of the number of routing hops. From this aspect, the proposed quantum routing mechanism is close to optimum in data transmission time. In addition, in order to establish a quantum communication infrastructure, this paper also presents a network architecture for wireless WAN. This architecture is scalable and its corresponding communication protocol is developed as well.

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