Analyzing Communication in Quantum Based Mobile Ad Hoc Networks

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Abstract. According to the current trends, there could be several situations where devices can communicate over an ad hoc network architecture without human interaction, making the number of end user parties much higher than in an only human communication scenario. In our work, we focused on a quantum based ad hoc network, in which all devices are quantum based and the communication is via free space medium. We investigated how different quantum protocols can be applied in such a network.

Keywords: quantum communication, quantum ad hoc network

1 Introduction

Typically, the wireless networks are built around an infrastructure, where all communications are routed through base stations that act as gateways between the wireless and wired network. However, there may be situations in which it is not economically viable to build such an infrastructure. In these cases, a collection of wireless mobile nodes could self-organize into a temporary ad hoc network [1]. Our everyday environment is increasingly populated by multitudes of decentralized and networked computing systems [2] (e.g, ad hoc networks of mobile computer-based devices, sensor networks). One of the primary fields of research and development includes the services offered by the devices and the faster and more efficient communication. In other hand, the working quantum computer [3] is still a promising tool of the not so far future, but there are many solutions which were demonstrated successfully by different experiments [4]. In our research, we analyzed how a quantum based communication can be combined with classical ad hoc networks. Our goal was to prove that an ad hoc network that uses quantum communication is more effective in data rate than a classical one. Our quantum network is based on a classically working system (CASCADAS) [5]. The classical system is based on the Autonomic Communication Element (ACE) [6], which gathers information about its environment, automatically adapts to the situation without outside intervention and acts accordingly. We developed the classical system into a quantum one. The quantum equivalent version of ACE is the QACE (Quantum ACE) [7]. It enhances the properties of the communication elements of the classical system, enabling faster and more complex computations with the help of the quantum Grover algorithm. Based on QACE, we have created a quantum based ad hoc communication network. The QACE devices (also referred as nodes or peers) are able to send classical and quantum messages since they use both the classical and quantum methods for messaging and computations. We have adapted two quantum protocols into our network, the superdense coding and the teleportation [4].

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2 Overview of our network

In a classical environment, the participants of an ad hoc network (peers or nodes) can be connected by an Access Point (AP) or through each other on equal level. In our network, the peers have the ability to self-organize, which means that the nodes can decide if they are using an AP or a non-AP version of the network. In the classic version of the network, every peer is fully aware of the environment and can make decisions based on their knowledge base, which is dynamically formed by their own and other nodes' perceptions. With a quantum adaptation of the CASCADAS system, both the QACEs' operations and the data transmission can become more complex and faster by using quantum algorithms. With the possibility of parallel calculations, the Grover algorithm can find the best and most cost-effective solution from an unsorted knowledge base. This gives the option to use a fast and complex artificial intelligence (AI) system for the QACEs' inner logic [7]. Once the solution is found by quantum means, the QACEs use the results to operate in classical way.

Our network is illustrated in Fig. 1. It contains mobile nodes (peers) and fix positioned ones. The constant appearance and disappearance of the nodes simulate a real network behavior, where the number of nodes within an area changes dynamically. The areas are not distinguished by numbers but the connections each node has. Every node that can be found in the hearing distance of one's periodical HELLO signaling message is in the area of that node. Upon receiving the HELLO message, the nodes start to exchange Bell-pairs. The network has two hierarchical levels, there can be peers and superpeers. The peers also get a priority for the case of superpeer interference. Initially, every node is a peer, and there are events that can trigger a peer to challenge its area to become a superpeer. There can only be one superpeer per area, which means that the nodes that have a superpeer in their connection list can not become one. Working with mobile nodes also entails that a peer can move to a position where it can connect to other peers that are superpeers in their areas. In this case, the higher priority

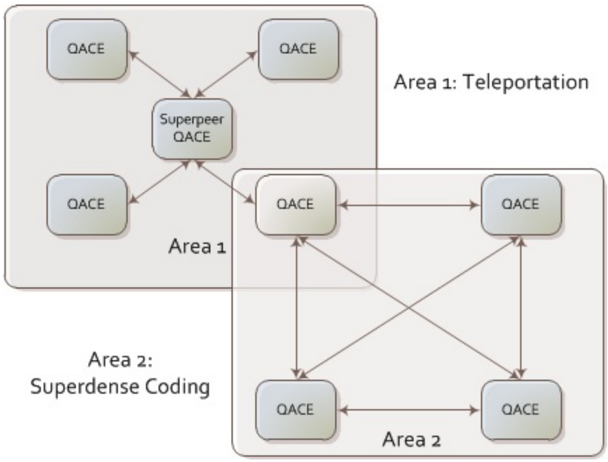

Figure 1: Topology of a mixed network

value decides which superpeer's command to listen to.

The peers can communicate by either classical or quantum means. The classical communication is used for signaling, and it is also good as a back-up solution. There are two types of quantum protocols exploited to create the network, the quantum teleportation and superdense coding. Both require Bell-pairs to operate, therefore it is essential for the nodes to share Bell-pairs before they start to send data by quantum means. Distributing qubits via free space channel means that the nodes have to have clear visibility of each other, as qubits are represented by photons that are sent using their built in lasers. This means that no obstacle can be found in the channel for quantum data transmission, otherwise the nodes can use classical radio interface for control communication.

The peers can either perform the last step of their knowledge base search [7], measuring the quantum result, thus getting a classical answerand use the superdense coding as it requires classical input, or leave the result in quantum state and transmit the quantum bit to the other peer using quantum teleportation. To be able to act on its own, the QACE needs the answers in classical form, so if it does not measure the quantum result it will not get a picture of its environment and will not be able to perform actions. That is why this form of communication is only recommended when there is a superpeer present and it analyzes the incoming reports, then sends back commands to the peers.

We used the superdense coding in its original form, but we enhanced the basic quantum teleportation algorithm so it can work bidirectional with different types of Bell-pairs. In our solution, different Bell pairs can be used at the beginning of the algorithm, so we need to use different order of the Pauli X and Pauli Z gates to restore the original qubit which was sent by the sender. To switch and control the gates without modifying the quantum circuit, we used XOR gates to modify the control input of the quantum gates.

We have developed a simulator program that can evaluate the setup in both classical and quantum basis. The quantum version of the communication has three different scenarios: using only superdense coding, using only quantum teleportation, and the mix of these two protocols. At normal behavior, the network should operate with the mixed protocol version but we simulated the network in all three scenarios. Initially, the network is started with 10 nodes, divided into two areas. During the simulation, nodes join and leave the network, and these nodes want to communicate with each other. To simulate a real environment, random timers provide realistic delays and requests as nodes arrive and leave the network. Our results show that the superdense coding is better than classical point-to-point solution, but it greatly depends on the quantum channel's fault-tolerance. In case of teleportation, pure teleportation network performs better, but such a network is only feasible if the peers are capable of operating on pure quantum basis.

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References

[1] C. Borcea, D. Iyer, P. Kang, A. Saxena, and L. Iftode. Cooperative computing for distributed embedded systems. In *Proc. of 22th Int. Conf. Distributed Comput. Syst.*, pages 227–237, 2002.

[2] M. Mamei, A. Roli, and A. Zambonelli. Emergence and Control of Macro-Spatial Structures in Perturbed Cellular Automata, and Implications for Pervasive Computing Systems. *IEEE Transactions on Systems, Man, and Cybernetics*, 35(3):337–348, 2005.

[3] D. Deutsch. Quantum theory, the Church-Turing principle and the universal quantum computer. In *Proc. of the Royal Society of London; Series A, Mathematical and Physical Sciences.*, pages 97–117, 1985.

[4] S. Imre and F. Balazs. *Quantum Computing and Communications: An Engineering Approach.* Wiley, 2005.

[5] CASCADAS Project Webpage: http://acetoolkit.sourceforge.net/cascadas/ Last visited July 28, 2013

[6] E. Hofig, B. Wust, B. K. Benko, A. Mannella, M. Mamei, E. Di Nitto. On Concepts for Autonomic Communication Elements. In *Proc. of IEEE International Workshop on Modelling Autonomic Communications Environments.*, Dublin, Ireland, 2006.

[7] L. Gyongyosi, L. Bacsardi, S. Imre. Novel Approach for Quantum Mechanical Based Autonomic Communication. In *Proc. of FUTURE COMPUTING 2009.*, pages 586–590, 2009.