Coordination of Quantum Internet Agents

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ABSTRACT

Intelligent agents in the quantum internet are supposed to operate on networked hybrid quantum computers to individually or jointly accomplish their goals by means of both classical and quantum computation, and communication. We present initial quantum based solutions to the classical coordination problem of matchmaking which can be performed under certain conditions more efficient and secure than in the classical case.

Categories and subject descriptors: I.2.11. Distributed Artificial Intelligence; **Keywords:** Quantum Internet, Quantum Matchmaking

1. INTRODUCTION

Quantum computation provides a paradigm for information processing that differs fundamentally from ordinary digital computation: Information is mechanical, that is the way in which quantum systems such as spins, photons, and atoms store and process information is inherently governed by the laws of quantum physics. Quantum physics uses quantum mechanics as a mathematical language to explain nature at the atomic scale, in particular, superposition of quantum states that enables for quantum parallelism, interference effects during the course of unitary state evolution, and non-local effects of spatially separated but quantum entangled data that are impossible to realize by means of classical physics. Quantum computing devices have been physically implemented since the late 1990's by use of, for example, nuclear magnetic resonance, and solid state technologies. Current efforts in nanoscale molecular engineering, and achievements made in realizing few qubit quantum processors and quantum communication channels provide strong evidence in favor of the development of more sophisticated and networked quantum computing devices that will make up the so called quantum internet beyond 2020. How shall intelligent software agents perform service matchmaking in the quantum internet, that is how to connect the ultimate service requester with the ultimate service provider?

2. QUANTUM INTERNET AGENTS

Quantum computation is the extension of classical computation to the processing of quantum information based on physical two-state quantum systems such as photons. The unit of quantum information is the quantum bit (qubit) with coherent superposed basis states; qubit registers can be described as a tensor product of its component qubit states in complex Hilbert space. In particular, measuring one of entangled qubits can instantaneously affect the probability amplitudes of the other qubit no matter how far they are spatially separated. For a comprehensive introduction to quantum computing and communication we refer the interested reader to, for example, [3].

A quantum computational agent (QC agent) [2] is an intelligent software agent that is able to perform both classical and quantum computing to accomplish its goals individually, or in joint interaction with other QC agents. The future quantum internet is expected to consist of networked classical and quantum computers, and populated with QC agents, so called quantum internet agents, that operate on quantum computers and communicate with each other according to the quantum communication model of either physical direct quantum transmission, or quantum teleportation, or quantum dense coding, each of which has been experimentally verified. Quantum internet agents can be classified based on the used quantum communication model.

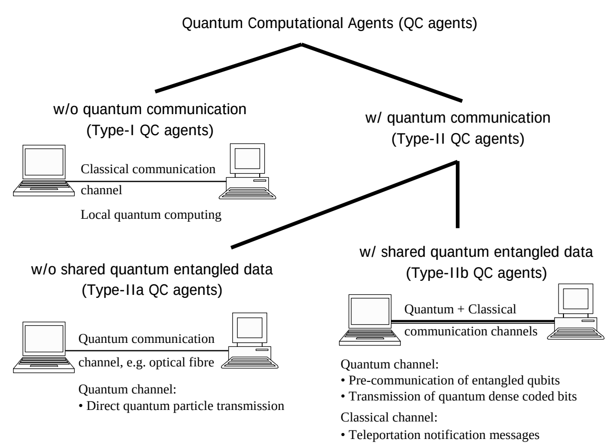

Figure 1: Communication based classification of quantum internet agents.

It has been shown in [2] that QC agents are feasible to implement on a hybrid quantum computer in principle.

3. QUANTUM MATCHMAKING

We distinguish between scenarios of type-I and type-II quantum

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matchmaking depending on the type of quantum internet agents involved.

3.1 Type-I quantum matchmaking

Quantum internet agents communicate to the type-I quantum matchmaker over classical channels which, in turn, performs an oracle-based quantum search of its local classical database of size N for those (M) advertisements ad_x that best match a given request r. Each classical matching function f can be converted into an equivalent quantum operator U_f that is implementable in an appropriate quantum logical circuit with the same order of efficiency. It can be shown that type-I quantum matchmakers can polynomially speed up the classical search for matching services to be performed in $O(\sqrt{N})$ ($O(\sqrt{N/M})$) time by using Grover's quantum search algorithm [1]. Classical communication between type-I QC agents have to be additionally secured which is not necessary in case of inherently secure type-II quantum matchmaking.

3.2 Type-II quantum matchmaking

We distinguish between two scenarios of type-II quantum matchmaking depending on whether the type-II QC agents involved are sharing sufficient supplies of entangled qubits for quantum communication, or not.

3.2.1 Matchmaking with shared entanglement

Suppose that type-IIb quantum internet agent A transmits N quantum dense coded n-bit service advertisements and requests each of size $n/2$ qubits to a type-IIb QC matchmaker M over a quantum channel. Alternatively, A could teleport its messages to M at the cost of $2n$ bits via a classical channel. The matchmaker then quantum searches its database and returns those advertisements that match according to the applied individual matching oracle. The type-IIb quantum matchmaking process restricted to the interaction between service requester and matchmaker agent using quantum dense coding for communication is provided in figure 2.

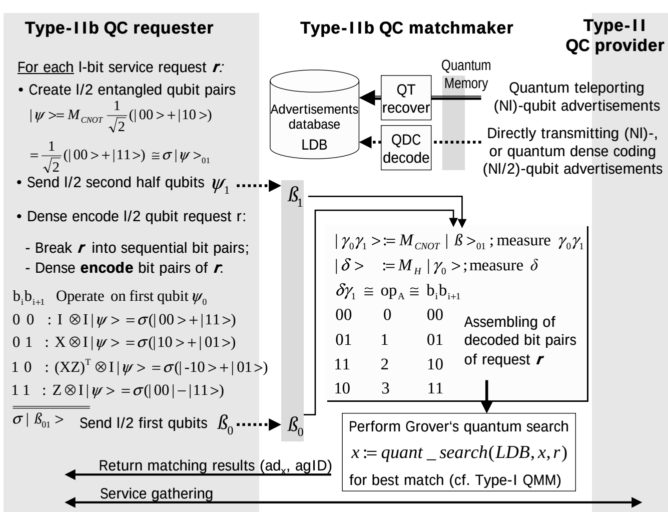

Figure 2: Type-IIb quantum matchmaking with dense coding based communication

Any type-II QC agent is able to instantaneously corrupt individual or joint quantum computation with other type-II QC agents, as it can be influenced by the same agents the same way. There is no other way of preventing such mutual remote influence than to dispense with sharing any supply of entangled qubits. This is the case for type-II quantum matchmaking without shared entanglement.

3.2.2 Matchmaking without shared entanglement

Suppose a type-IIa quantum internet agent directly transmits its l-qubit service advertisements ad, or requests r to the type-II quantum matchmaker agent via quantum wires. Upon receipt of r the type-IIa quantum matchmaker checks whether it exactly matches with any of its locally stored and indexed advertisements ad_x with the extra promise that the Hamming distance $h(r, ad_x)$ between both qubit strings, that is the number of qubits where ad_x and r are different, is either 0 or $l/2$. We restrict the quantum service matching operation to the qubit comparison level ($|ad_x >=|r>$). The corresponding type-IIa quantum matchmaking protocol is provided in figure 3.

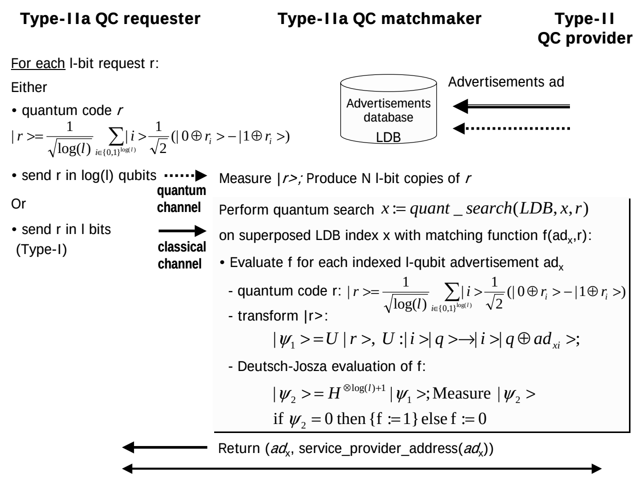

Figure 3: Quantum matchmaking by integrated application of Grover's quantum search, and Deutsch-Josza's quantum evaluation

Evaluation of matching function f during quantum search is performed in $O(1)$ calls using the integrated Deutsch-Josza's function evaluation algorithm which is an exponential speed up over the classical case of $O(2^l/2)$ evaluations. Hence, the overall computational complexity is $O(\sqrt{N})$ per service request and N indexed advertisements communicated in $O(N \cdot log(l))$.

4. CONCLUSIONS

We presented means of coordinating quantum internet agents in terms of quantum matchmaking which can be performed under certain conditions more efficient than in the classical case. In addition, quantum communication between any pair of type-II quantum internet agents involved in the process of quantum matchmaking is per se physically secure.

5. REFERENCES

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