A Multi-Node Quantum Network with Defects in Diamond

Ph.D. proposal

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November 23, 2018

introduction

A perfect introduction here. Also Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

Write a real introduction

contents

1 research goals

The goal of my Ph.D. is:

Demonstration of quantum applications on a multi-node network.

Breakdown the steps

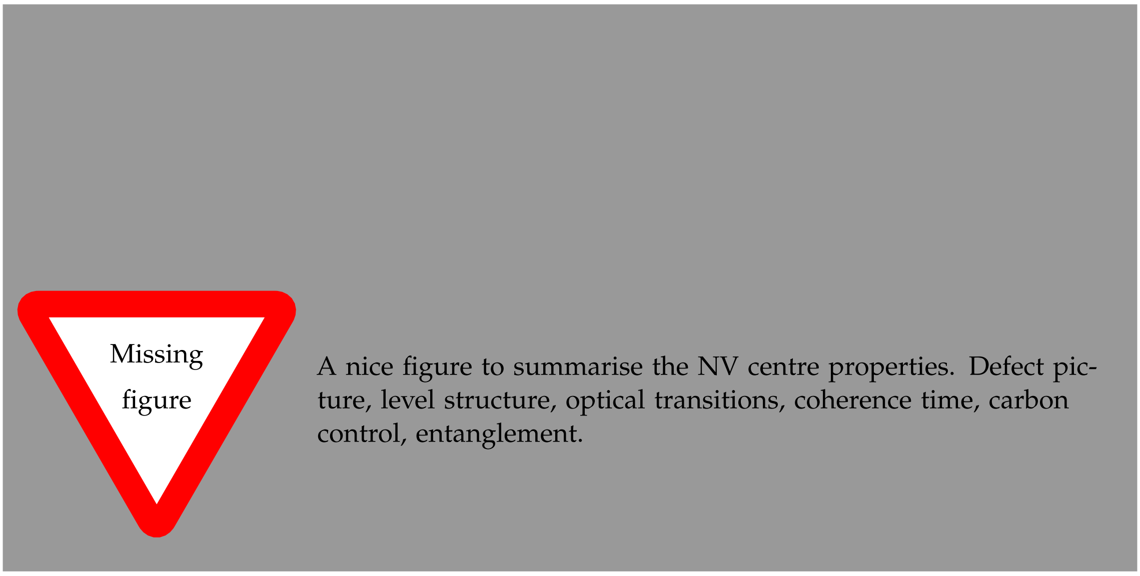

Figure 1: The NV centre as a quantum network node. a) The NV is an atomic defect in diamond with trapped ion-like properties. b) Spin selective optical transitions allow for high-fidelity initialization and single-shot read-out. c) Neighbouring C^{13} atoms can be used as quantum memories. d) Entanglement can be generated among remote NVs.

2 THE NV CENTRE AS A QUANTUM NETWORK NODE

Quantum networks are expected to deliver definitive security for communication, blind quantum computation, improved clock synchronization and more exotic applications such as connecting far apart telescopes [1].

A node of such a network needs to: 1) generate entangled states with other nodes, 2) manipulate quantum states and 3) store quantum states. The Nitrogen-Vacancy (NV) centre in diamond is a promising candidate to act as node of such a network, as it fulfils all the mentioned requirements. Figure 1 summarises the fundamental properties of the NV centre.

Recent work from our group demonstrated the on-demand generation of remote entanglement between two NV centres with rates up to 39 Hz [2]. Such high rates, three orders of magnitude higher than previous results on the same platform, are a consequence of moving from a two-photon detection protocol, such as the one used in Ref. [3], to a single-photon protocol.

Figure 2 summarises the Single Click Entanglement (SCE) protocol. If only a single photon was detected at the end of the protocol, the state of the two NVs would be $|\psi\rangle = |\uparrow\downarrow\rangle + e^{i\theta} |\downarrow\uparrow\rangle$, a maximally entangled state, where θ is the optical phase difference between the two photons. Since our detectors cannot discriminate between one or more incoming photons, the state of two NVs is actually, in the limit of small detection efficiency, $\rho = (1-\alpha) |\psi\rangle \langle\psi| + \alpha |\uparrow\uparrow\rangle \langle\uparrow\uparrow|$.

3 GENUINE REMOTE MULTIPARTITE ENTANGLEMENT

A two-particle state can either be entangled or separable. When three or more particles are involved in the state, there are more possibilities. The state can be fully separable, where each of the systems can be described independently of the others, partially separable, where some systems are entangled with each other but not all of them are, and genuinely entangled, where none of the systems are separable from each other. It is possible further to categorise genuinely entangled states: if it is possible to transform one state into another via stochastic local operations and classical communication (SLOOC), then we say that the two states are SLOOC-equivalent.

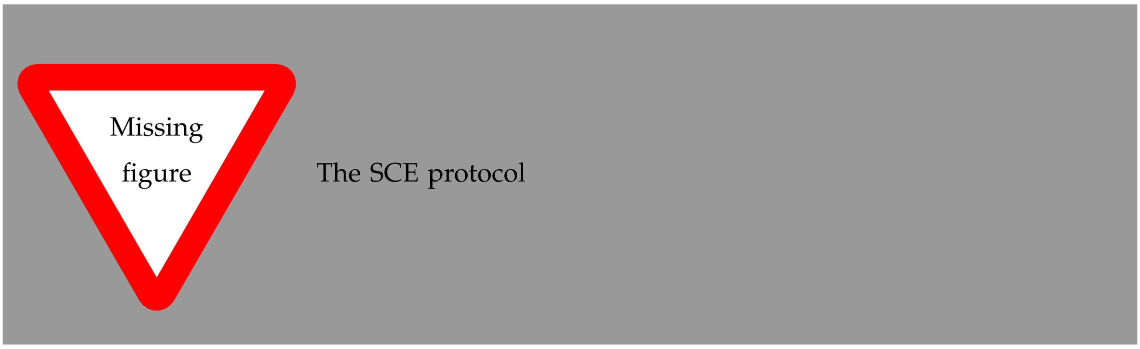

Figure 2: The Single Click Entanglement (SCE) protocol. a) Two remote NVs are put in a superposition state $|\alpha\rangle = \sqrt{\alpha}\,|\uparrow\rangle + \sqrt{1-\alpha^2}\,|\downarrow\rangle$ via a MW pulse. b) A laser pulse resonant with the $|\uparrow\rangle$ state, entangles the state of photon with the state of each NV. c) The two photonic modes interfere on a BS. d) The detection of a single photon heralds the entanglement between the NVs.

There are two such categories of triparite genuinely entangled states: the ones that are SLOOC-equivalent to the Greenberger-Horne-Zeilinger (GHZ) state, $|\mathrm{GHZ}\rangle = (|000\rangle + |111\rangle)/\sqrt{2}$, and the ones that can be transformed into the W state, $|\mathrm{W}\rangle = (|001\rangle + |010\rangle + |100\rangle)/\sqrt{3}$. While the W state has the interesting feature of maintaining entanglement even if some of the parties are lost, the GHZ is usually considered more powerful and most quantum network protocols use a GHZ state as a resource . cite here!

Generation of remote GHZ states have been demonstrated on the photonic platform [4], and local GHZ states have been generated with NV centres . Moving beyond two-node experiments Did we? requires the generation of remote genuine multipartite entanglement. Figure 3 shows the proposed experimenal sequence to generate a GHZ state among three remote NV centres.

The experiment requires three experimental setups. Two of them, named LT3 and LT4 (Low-Temperature) are the same setups used in Refs. [5, 2]. I built a new setup, named LT5, which has the same functionalities of the other setups and some upgrades to make it easier to use and more performant. The new setup is in a new laboratory, approximately 20 m from the other two setups, which are 1 m apart.

Comparison of previous and near-future SCE performance

High magnetic field

Entanglement witness, expected violation map

4 LINK LAYER: A PROOF OF CONCEPT

5 ENTANGLEMENT TELEPORTATION

6 CLIENT-SERVER SECURE DELEGATION

7 CHALLENGES AND RISKS

8 GRADUATE SCHOOL PROGRESS

8.1 *Courses*

I attended (or I am currently attending) the following courses:

- Collaboration across disciplines (2 GSC) Ask Sandrine!

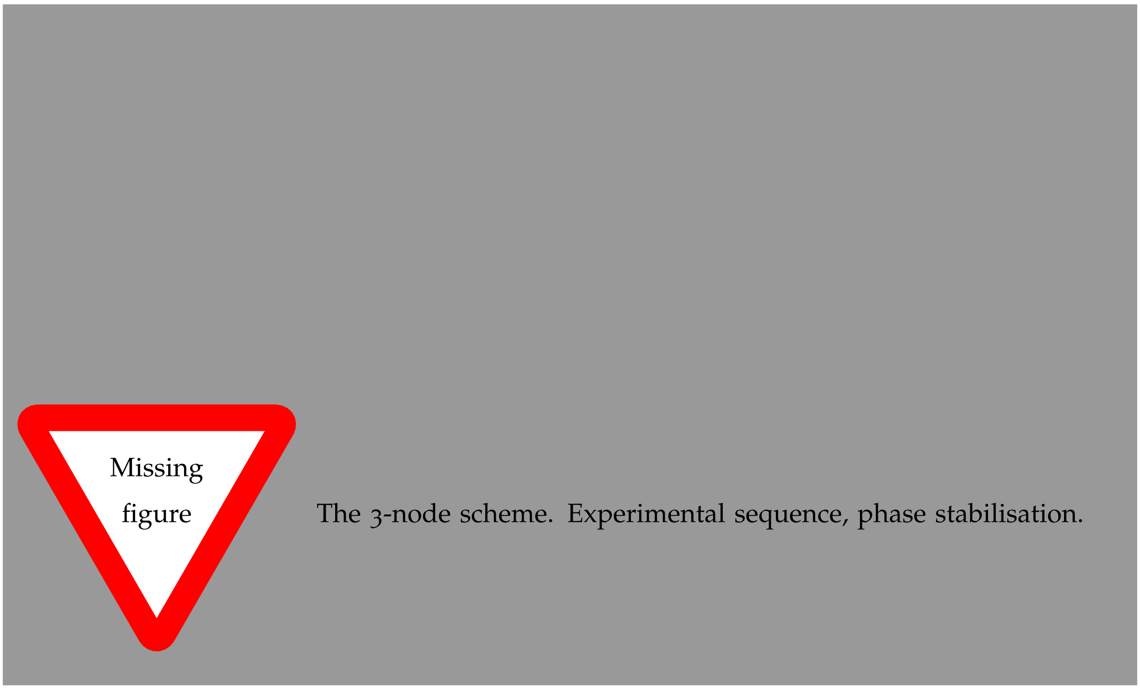

Figure 3: Generation of a remote GHZ state with three NV centres.

- PhD Start-up (2 GSC)
- Conversation skills (2 GSC)
- Casimir Course - Programming (5 GSC)
- Casimir Course - Electronics for Physicists (5 GSC)
- QuTech Academy - Quantum Communication and Cryptography (5 GSC)

8.2 *Supervision*

I have been supervising Hans K. C. Beukers, a MSc student, since February 2018. Hans has been working on setup improvements and techniques that, if successful, will increase the lifetime of our memory qubits.

8.3 *Outreach*

As an Early Stage Researcher (ESR) in the Marie Skodowska-Curie Actions (MSCA) Innovative Training Network (ITN) Spin-NANO, I have to carry out outreach activities regarding my research field to the wider audience. I have currently carried out two outreach activities:

- January 2018, Sheffield, UK. Introduction to quantum- and nano-technologies to local high-school students, as part of an ITN meeting.
  1 GSC?
- September 2018, Brussels, BE. Two days stand about quantum technologies at the European Researchers Night, EU Parlamentarium, mainly to children between 5 and 10.
  2 GSC?

9 PH.D. TIME-LINE

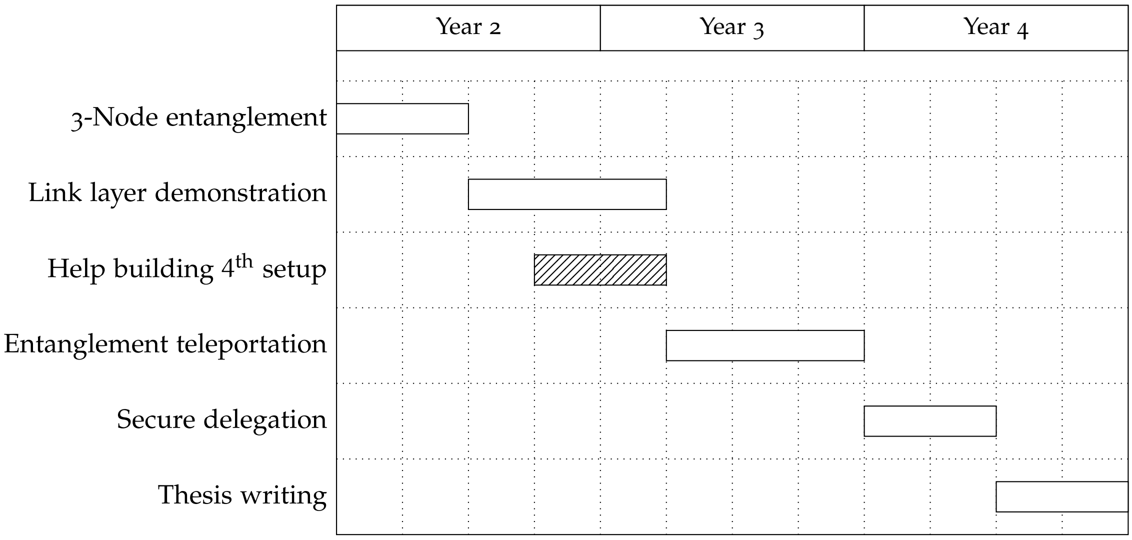

Figure 4: Proposed Ph.D. time-line.

Write caption. Explain 4th setup.

ACKNOWLEDGEMENTS

I would like to thank everybody.

actually thank people

REFERENCES

[1] Stephanie Wehner, David Elkouss, and Ronald Hanson. "Quantum internet: A vision for the road ahead". In: *Science* 362.6412 (Oct. 2018), eaam9288. DOI: 10.1126/science.aam9288.

[2] Peter C. Humphreys et al. "Deterministic delivery of remote entanglement on a quantum network". In: *Nature* 558.7709 (June 2018), pp. 268–273. DOI: 10.1038/s41586-018-0200-5.

[3] B. Hensen et al. "Loophole-free Bell inequality violation using electron spins separated by 1.3 kilometres". In: *Nature* 526.7575 (Oct. 2015), pp. 682–686. DOI: 10.1038/nature15759.

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[5] N. Kalb et al. "Entanglement distillation between solid-state quantum network nodes". In: *Science* 356.6341 (June 2017), pp. 928–932. DOI: 10.1126/science.aan0070.