A Multi-Node Quantum Network with Defects in Diamond

Ph.D. proposal

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November 23, 2018

introduction

A perfect introduction here. 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. 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

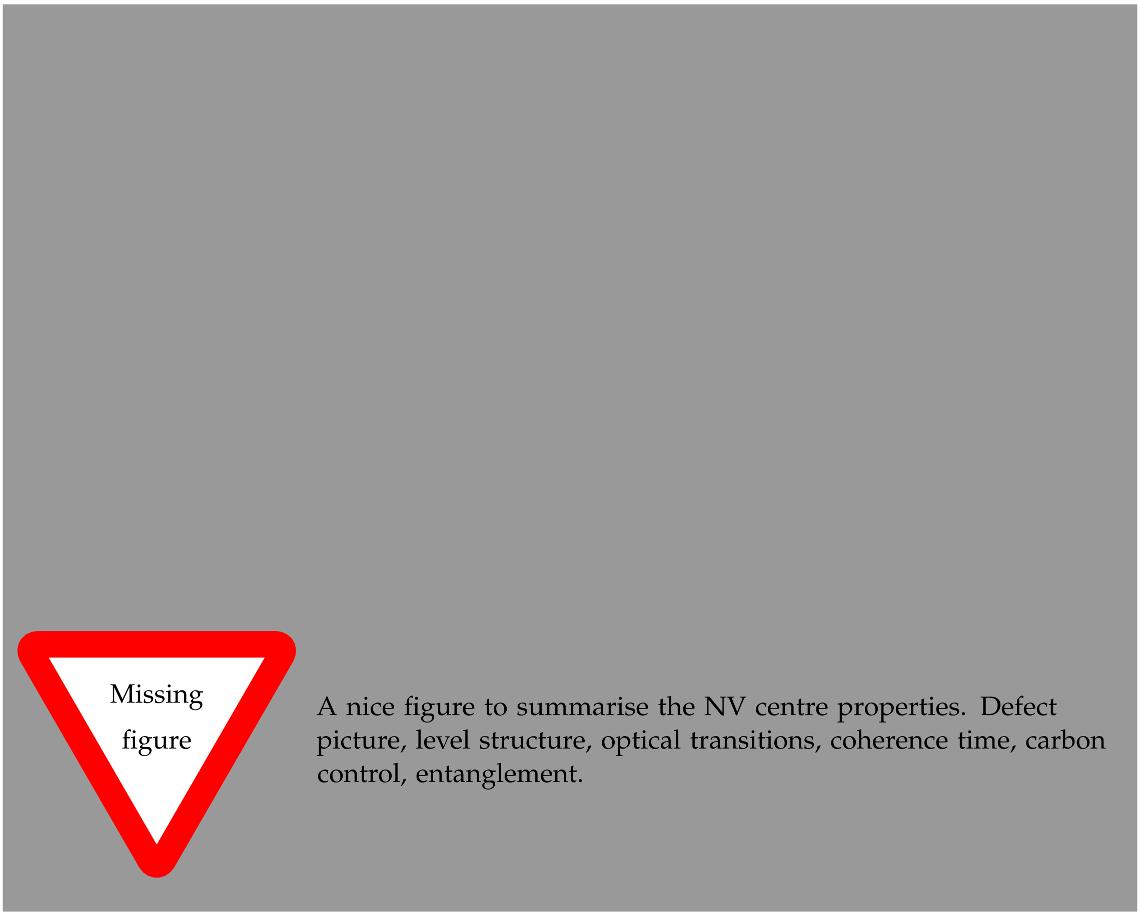

Figure 1: The NV centre as a quantum network node. a) The NV is an atomic defect in diamond with trapped ion-like properties. b) Spin selective optical transitions allow for high-fidelity initialization and single-shot read-out. c) Neighbouring C^{13} atoms can be used as quantum memories. d) Entanglement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

1 RESEARCH GOALS

The goal of my Ph.D. is:

<u>DEMONSTRATION OF QUANTUM APPLICATIONS ON A MULTI-NODE NETWORK.</u>

Breakdown the steps

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.

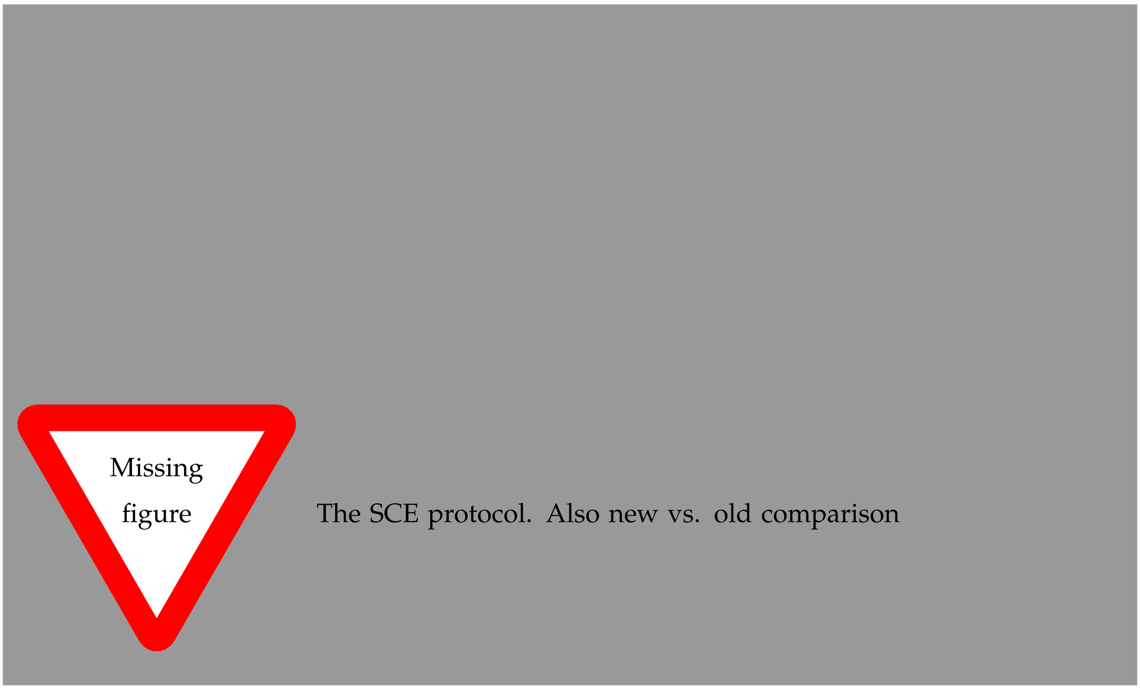

Figure 2: The Single Click Entanglement (SCE) protocol. a) Two remote NVs are put in a superposition state $|\alpha\rangle = \sqrt{\alpha}\,|\uparrow\rangle + \sqrt{1-\alpha^2}\,|\downarrow\rangle$ via a microwave (MW) pulse. b) A laser pulse resonant with the $|\uparrow\rangle$ state, entangles the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

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 probability of detection, $\rho = (1-\alpha)\,|\psi\rangle\,\langle\psi| + \alpha\,|\uparrow\uparrow\rangle\,\langle\uparrow\uparrow|$.

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.

There are two such categories of triparite genuinely entangled states: the ones that are SLOOC-equivalent to the Greenberger-Horne-Zeilinger (GHZ) state, $|GHZ\rangle = (|000\rangle + |111\rangle)/\sqrt{2}$, and the ones that can be transformed into the W state, $|W\rangle = (|001\rangle + |010\rangle + |100\rangle)/\sqrt{3}$. 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 experimental sequence to generate a GHZ state among three remote NV centres.

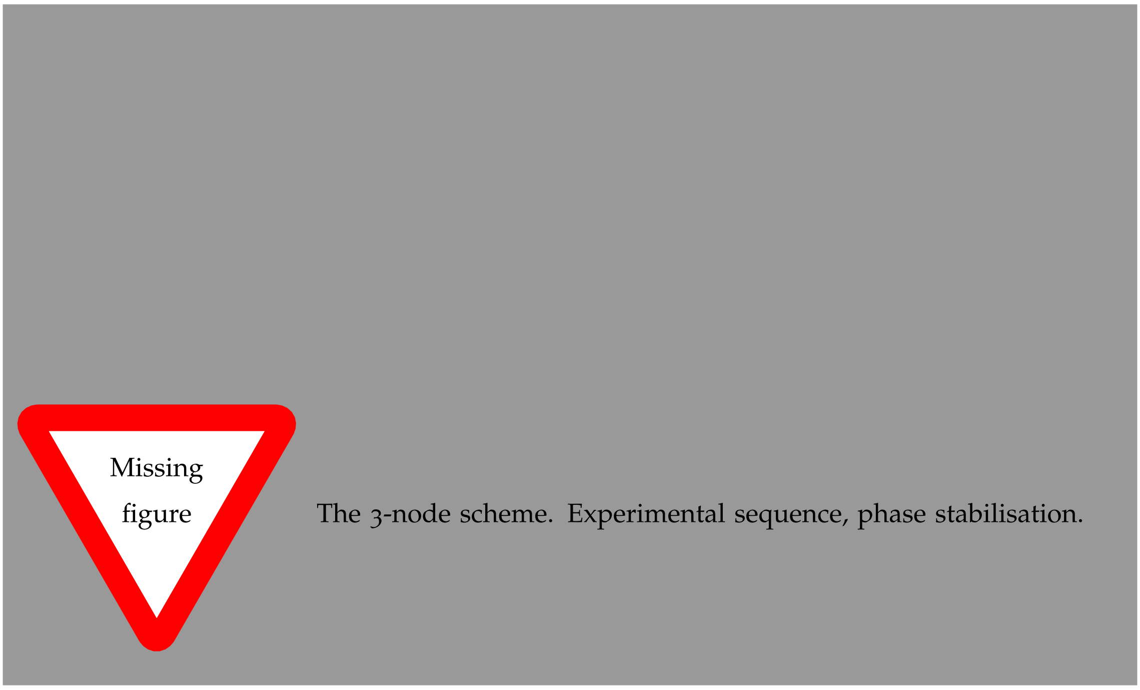

Figure 3: Generation of a remote GHZ state with three NV centres.

	p_{det}	σ_θ	p_{2exc}	$\mathcal{V}$
Ref. [2]	3×10^{-4}	$14°$	0.04	0.80
Near-future	1×10^{-3}	$20°$	0.01	0.95

Table 1: Comparison of experimental parameters for SCE

Add more relevant parameters

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.

Finish comparison

In Figure 2d there is a comparison between the results in Ref. [2] and estimated entanglement fidelities and rates with near-future experimental parameters (reported in Table 1).

After the first round of SCE is executed, the state of the central node needs to be saved on a memory qubit. This will be done via a SWAP operation similar to the one used in Ref. [5]. A second round of SCE will then take place, which will have a timeout, because of the decoherence of the first entangled state. If a second SCE is successful within the timeout window, a local controlled gate on the central node will entangle the electron and carbon, therefore generating a 4-qubit entangled state. By measuring the electron of the central node, and feeding back the result to the other nodes it is possible to generate a GHZ state among the three nodes.

High magnetic field

An efficient way to show that a state is entangled is measuring entanglement witnesses [6]. An entanglement witness is quantity that is negative when evaluated on a target state, and positive otherwise. For example the quantity $\mathcal{W}_{GHZ} = \mathbb{1}/2 - |GHZ\rangle\langle GHZ|$ is negative on genuine multipartite states (up to a certain noise) and positive for all separable and biseparable states. Measuring a negative value for $\mathcal{W}_{GHZ}$ is therefore a witness of a genuine multipartite entangled

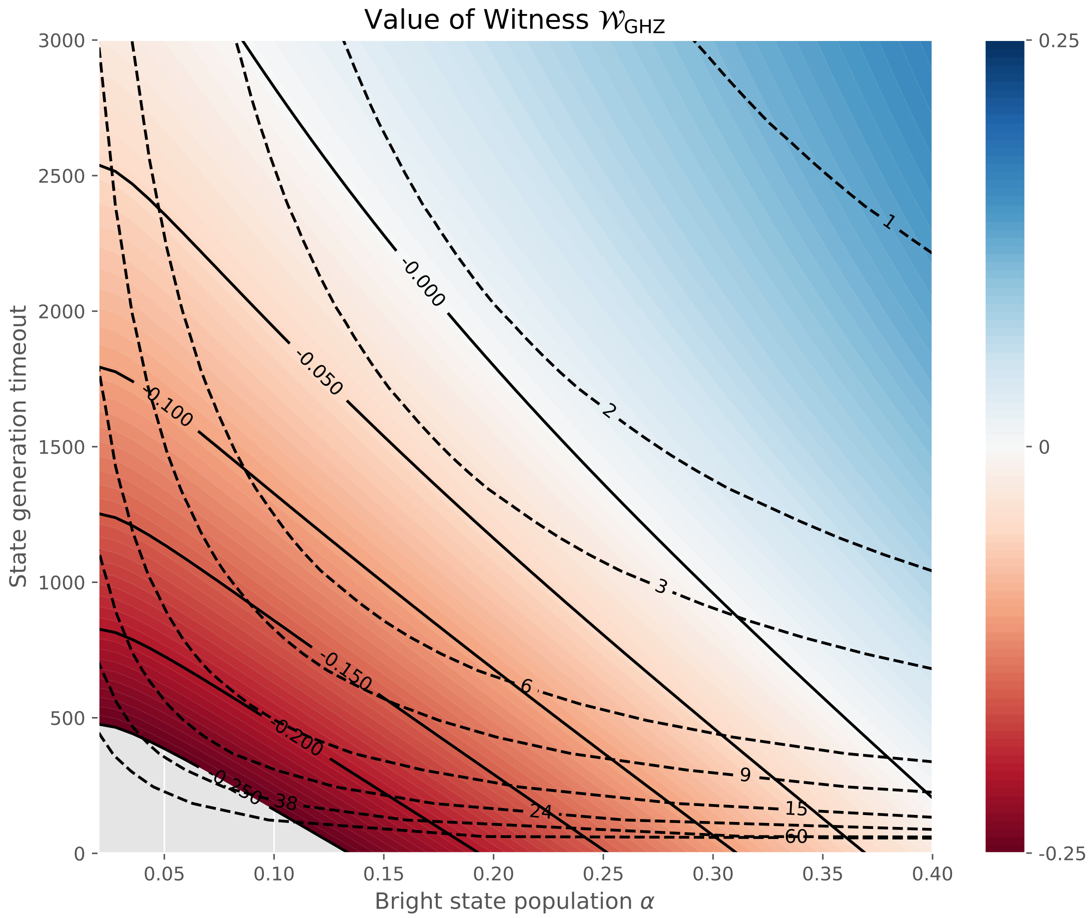

Figure 4: Simulation of $\mathcal{W}_{GHZ}$ with near-future experimental parameters. The solid lines on the plot represent curves where the witness value is constant. The dashed lines represent the time (in minutes) that it will take to generate such a state.

state. There are two parameters that we can tweak during the experiments: 1) the timeout for the generation of the second entangled state and 2) the bright state population α for the second round of SCE. In Figure 4 the expected value of $\mathcal{W}_{GHZ}$ while varying those two parameters. A negative value of the witness (i.e. a fidelity of the generated state $\mathcal{F} > 1/2$) can be obtained with states generated in approximately three minutes.

A Monte-Carlo simulation shows that, with current measurement uncertainties, we would need ?? hours of data taking to show that the witness is negative with a statistical significance of 5σ. Make simulation

4 LINK LAYER: A PROOF OF CONCEPT

Quick ref to network stack

What do we need to do it

5 ENTANGLEMENT TELEPORTATION

How does the protocol works

What do we need

Where is it used

6 CLIENT-SERVER SECURE DELEGATION

How does the protocol works

What do we need

Where is it used

7 CHALLENGES AND RISKS

8 GRADUATE SCHOOL PROGRESS

Courses

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

Ask Sandrine!

- Collaboration across disciplines (2 GSC)
- 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)

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.

Outreach

As an Early Stage Researcher (ESR) in the Marie Skłodowska-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:

1 GSC?

- January 2018, Sheffield, UK. Introduction to quantum- and nano-technologies to local high-school students, as part of an ITN meeting.

2 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.

9 PH.D. TIME-LINE

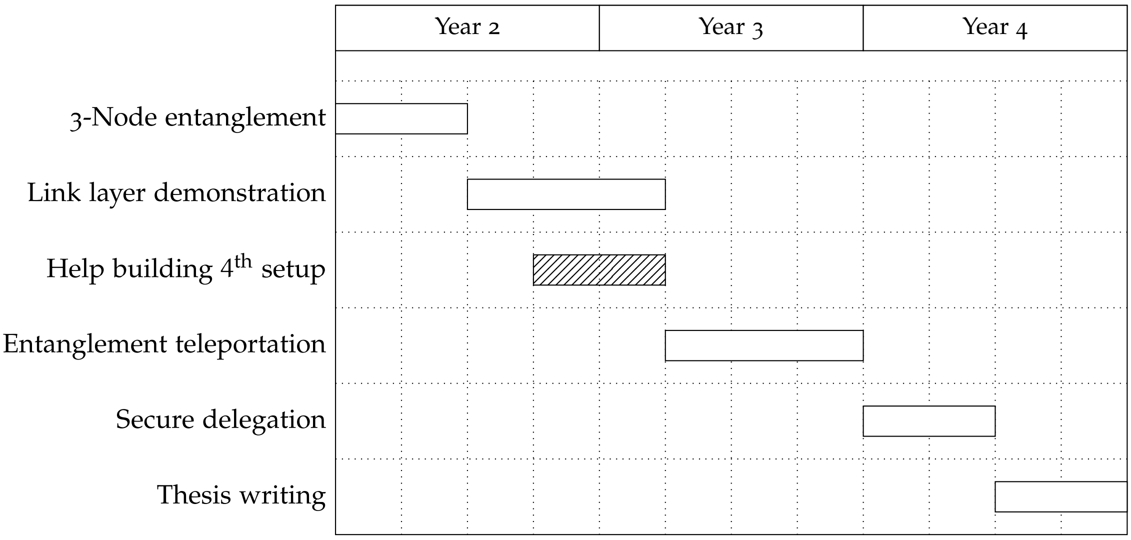

Figure 5: Proposed Ph.D. time-line.

Write caption. Explain 4th setup.

ACKNOWLEDGEMENTS

I would like to thank everybody.

actually thank people

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