Laying the Foundation for a Quantum Network Benchmark Suite

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1 Research Question

Can this quantum network application (CHSH[2] game) be used as an informative benchmark for the total quantum network system?

Subquestions:

1) How sensitive is the application in recognizing errors in the quantum network's properties?
2) Can we use the application to make quantitative predictions about certain properties?
3) Should this application be included in the benchmark suite?

2 Introduction

- Currently, many quantum network architectures are being developed **without** a way to determine which one is better.
- **Our benchmark suite** will evaluate the performance of the host network by executing existing Quantum Network Applications.
- **As a result,** the calculated quantity assessments can be used to compare different quantum network systems.
- However, we don't know which applications can be used as informative benchmarks.
- Hence, this study evaluates the inclusion of the CHSH game application as shown in Figure 1. Specifically, a single game starts with the Referee providing a single bit to each player. Then both players respond with another bit. The game is won if the equation shown in Figure 1 is satisfied.

3 Methods

- Using SquidASM[1] we perform experiments on simulated quantum networks with a single property as the x-var.
- For each experiment we evaluate how the following performance metrics vary using plots:
  - number successes per second (Figure 2)
  - success probability of a single game (Figure 3)
- Using the one-way ANOVA test we determine if this variation is significant (i.e the p-value < 0.05)
- Also, using the Root Mean Square Error metric we compare the success probabilities based on different inputs.

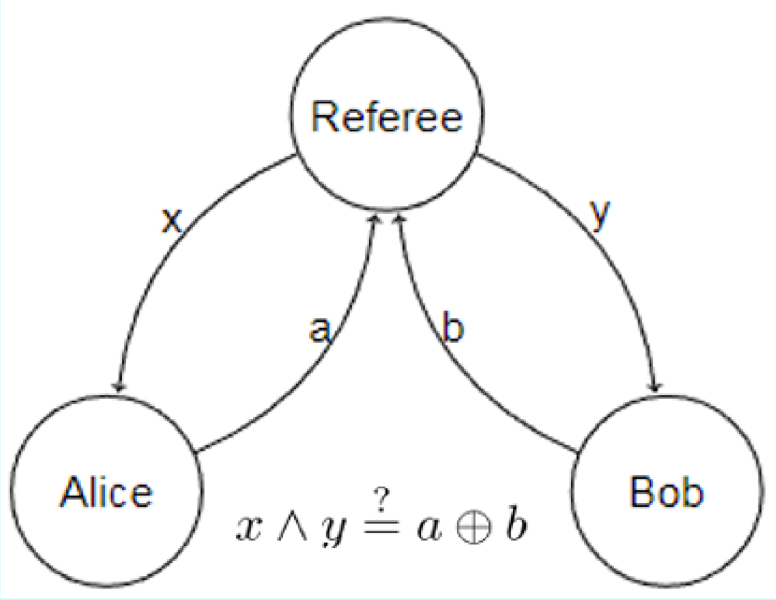

Figure1: The CHSH game is won when the equation is satisfied where x,y,a,b are bits

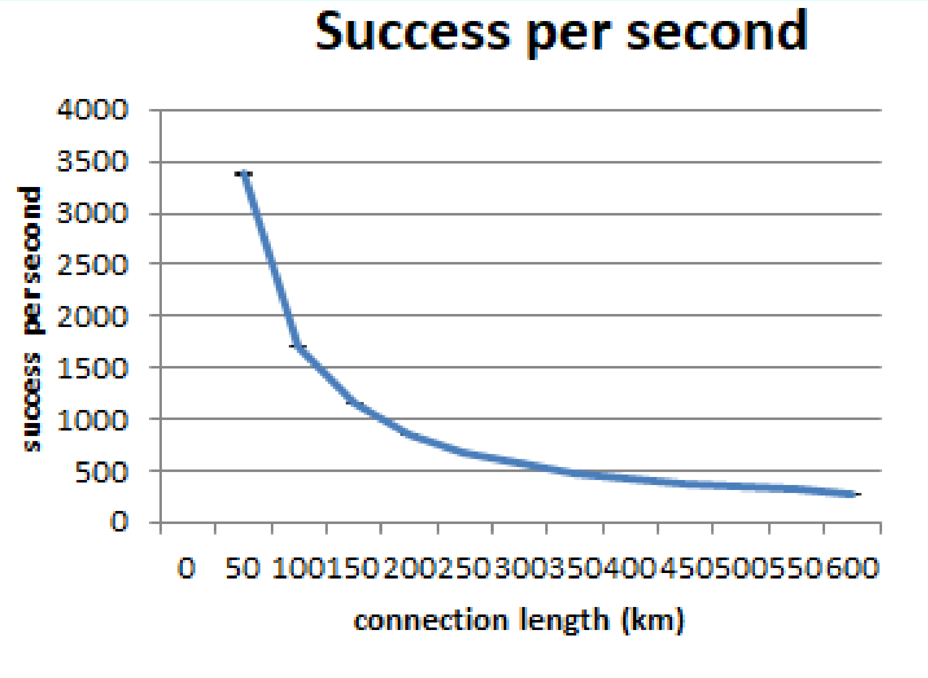

Figure2: Number of successes per second vs connection length of heralded link

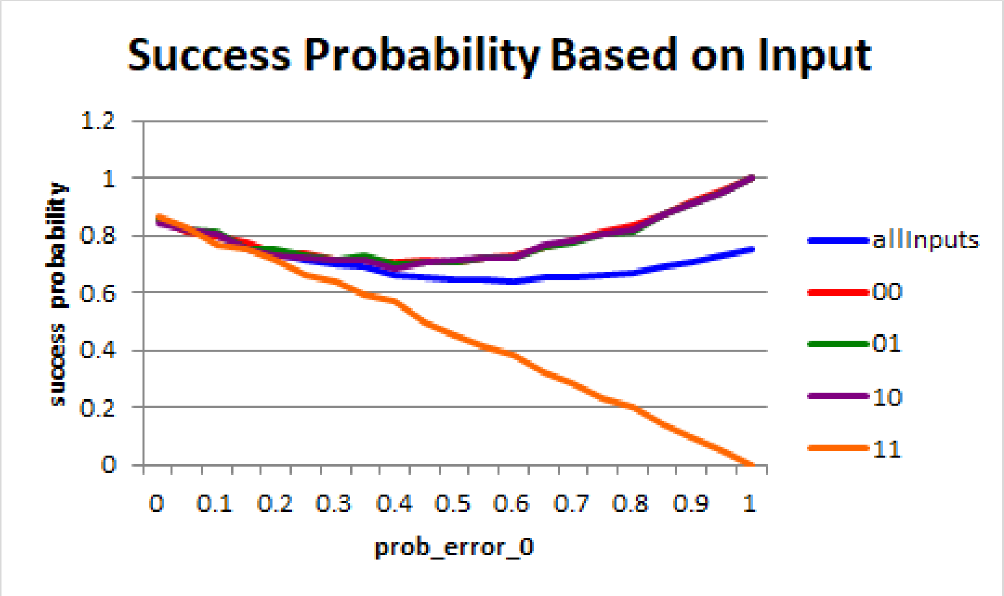

Figure3: Plot of success probability vs prob_error_0 property. The first bit in the legend is x and the second is y.

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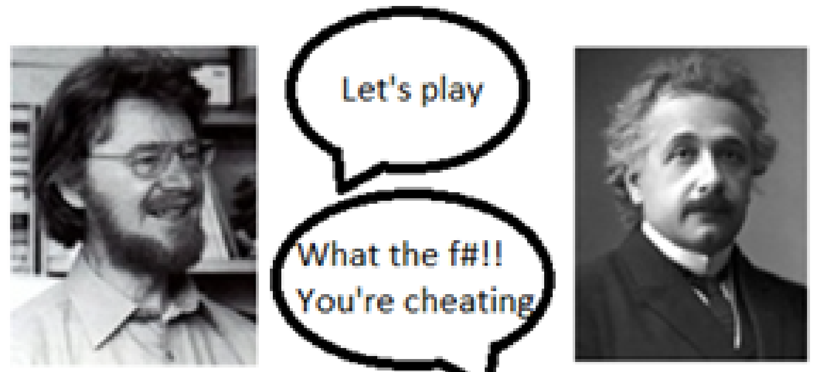

John Bell [3] Albert Einstein[4]

4 Definitions

- e0 = prob_error_0 = error probability of measuring bit zero as one
- e1 = prob_error_1 = error probability of measuring bit one as zero

5 Results

1. The results of the one-way ANOVA test on each experiment are visualized in Figure 4.
2. We constructed a proof for the equality in Figure 5 relating e0,e1 to the success probability .
3. Using the RMSE metric we determined that the deviation between the inputs x=y=1 and x=0 ,y=1 is only affected by the e0,e1 properties and no other tested property.

W.M.S.D link	Heralded link	Generic QDevice	Nv Qdevice
fidelity	length	init_time	electron_init_depolar_prob
t_cycle	p_loss_length	single_qubit_gate_time	electron_single_qubit_depolar_prob
prob_succ	p_loss_init	two_qubit_gate_time	prob_error_0
	dark_count_prob	measure_time	prob_error_1
	detector_eff	single_qubit_gate_depolar_prob	carbon_init_depolar_prob
	visibility	two_qubit_gate_depolar_prob	carbon_z_rot_depolar_prob
			ec_gate_depolar_prob
			measure

Figure4: This table highlights the properties that affect each performance metric based on the results of the one-way ANOVA test (i.e p-value < 0.05). Red properties affect the success probability metric, blue ones affect the number of successes per second metric, and green properties affect both.

$$P(success|x=1 \wedge y=0) - P(success|x=1 \wedge y=1) = (e0-e1)^2$$

Figure5: This equation assumes an ideal quantum network with arbitrary values for e0,e1. It states that the difference between these success probabilities is equal to the square difference of e0 and e1.

6 Conclusions

1. The CHSH game is sensitive to all properties related to the quality of the link, the execution time of the application, single qubit gates and memory operations .
2. We can use this application to make quantitative predictions on the e0 and e1 properties.
3. The CHSH game should be included in the suite if the qualities that it offers are desirable.

7 Future Work

- Additional data processing should be applied to the dataset generated to uncover more useful patterns.
- Not all properties were tested such as the coherence times properties.
- Determine if the equality in Figure5 holds for non-ideal quantum networks.

References

[1] van der Vecht, B., Wehner, S., & Dahlberg, A. (2021). Squidasm github repo. https://github.com/QuTech-Delft/squidasm.
[2]Clauser, J. F., & Horne, M. A. (1974). Proposed experiment to test local hidden-variable theories. Physical Review Letters, 23(15), 880–884.
[3] https://mathshistory.st-andrews.ac.uk/Biographies/Bell_John/
[4] https://www.nobelprize.org/prizes/physics/1921/einstein/biographical/