Simulated Design of Quantum Networks

DESIGN DOCUMENT

sddec23-17

Client/advisor
Dr. Durga Paudyal

Team members/Roles
Benjamin Amick/Network security engineer
Derrick Wright/System integration engineer
Ohik Kwon/System component designer
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Team Github
https://github.com/Kcops11/SeniorDesignQuantum17

Executive Summary

Development Standards & Practices Used

- Waterfall and Agile Methodology (Development Practice)
    - We are using this because, while being in the domain of software, it requires a lot of research and discussion which fits the Waterfall methodology. We then switched to Agile because it allows us to quickly change constraints and add new features as we develop and gain more understanding of our project and its goals.
- IEEE 802.3 Ethernet: This standard defines the physical and data linky layers of wired Ethernet networks. These networks are going to be critical to set up as they will be used in conjunction with our quantum network we are creating and provide a good baseline network that we can build off of.
- IEEE P7130: Standard for Quantum Computing Definitions. These standards provide standards on how quantum computing framework functions are described and what terminology is used. This is important because if we are to communicate with our advisor, we will need to use the proper terms so that he can understand and implement our design.

Summary of Requirements

- The quantum router should be able to communicate with the quantum nodes in both the classical and quantum channels.
- The router should be able to take a quantum algorithm which has been split into jobs and distribute those jobs between the quantum computers (nodes).
- The router should be able to do statistical analysis on the quantum nodes answers and produce a human-readable output.

Applicable Courses from Iowa State University Curriculum

- Com S 309 - Software Development Practices
- CprE 381 - Computer Organization and Assembly Level Programming
- CprE 430 - Networking Protocols and Security
- EE 332 - Semiconductors Materials and Devices
- EE 439 - Nanoelectronics
- EE 538 - Optoelectronic Devices and Applications

New Skills/Knowledge acquired that was not taught in courses

- Quantum mechanics, quantum computing, and quantum information systems
- Communication with clients on project constraints
- Cluster computing design and implementation

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List of figures/tables/symbols/definitions (This should be the similar to the project plan)

1 Team

Simulated design of Quantum Networks

1.1 Team Members

Benjamin Amick - Cyber Security Engineering major
Ohik Kwon - Electrical Engineering major, Physics minor
Steven Tompary - Cyber Security Engineering major
Derrick Wright - Software Engineering major

1.2 Required Skill Sets for Your Project

Understanding of Quantum mechanics and matrix operations are required. Knowledge of information systems (security, networks etc.) are encouraged to be prepared. Coding skills are also required to build our simulated quantum networks. Self-motivating attitude, communication skills, writing and reading skills are required for this project.

1.3 Skill Sets covered by the Team

Understanding of quantum computation and qubits - Ohik and Derrik
Knowledge of information systems and network architecture - Ben, Steven
Coding and software development skills - Derrik
Self motivation and communication skills - Everyone

1.4 Project Management Style Adopted by the team

We believe that a hybrid management which consists of Agile and waterfall is the best framework for our group to use. Since our project is research intensive, we're planning to keep updating the performance of our quantum network for the cluster computing based on the very basic and rudimentary network. To meet our clients' needs as possible. For example, we're planning to make 1 quantum bit centralized router that determines every behavior of the network. After that, we will evolve our network by adding functions such as quantum key distribution, error correction, and decentralized router.

1.5 Initial Project Management Roles

Benjamin Amick - Network security engineer
Ohik Kwon- System component designer
Steven Tompary- Network engineer
Derrick Wright - System integration engineer

2 Introduction

2.1 Problem Statement

What problem is your project trying to solve? Use non-technical jargon as much as possible.

Dr. Durga, who is our advisor and client, is very interested in research about quantum computation and information technology. He is currently working with Dr. Smith who also researches quantum computation and information with him. They want to have their own quantum platform such as quantum gates and quantum networks for their research, quantum cluster computing. Having actual quantum networks for cluster computing is demanding since they need working quantum computers. To initiate their work on simulated quantum cluster computing, having a quantum teleportation channel which runs close to reality is very essential. However, in Qiskit, which is the well-known quantum simulation tool, we can not run quantum circuits by parts to embrace realistic simulation. Thus, in this project, we built a quantum teleportation channel that could be run by parts, which is close to the realistic situation for their future work on cluster quantum computing.

2.2 Requirements & Constraints

List all requirements for your project . This includes functional requirements (specification), resource requirements, qualitative aesthetics requirements, economic/market requirements, environmental requirements, UI requirements, and any others relevant to your project. When a requirement is also a quantitative constraint, either separate it into a list of constraints, or annotate at the end of requirement as "**(constraint)**". Other requirements can be a single list or can be broken out into multiple lists based on the category.

Our network has to be considered as a physical aspect of the quantum. When we run our simulation, although we don't use actual quantum bits unless we're purchasing computation resources from IBM, we should consider the nature of quantum such as quantum entanglement restriction (distance etc.) since our client want to have a simulated quantum network for cluster computing which reflects limitations as much as possible. Also, our simulation has to reflect the realistic situation when they run it. Thus, building a simple quantum teleportation circuit in Qiskit and running it entirely at the same time is not what we are looking for. It has to be implemented by parts and use our designed classical network.(Functional requirements)

Our network has to be cost efficient. It can't not use many Qubits since that means it will cost a lot when our clients request to run our network on IBM quantum computers. Our clients goal is to save their research funding as much as possible related quantum networks to fabricate actual quantum nodes. (Economic Constraint)

Our network has to have an expandable network protocol since Dr. Durga and Dr. Smith might want to add functions to our prebuilt network protocol. Also our work is needed to be compatible for future students who want to evolve our work. Thus, we should stick on to the widely used Application Programming Interface which won't be supported in the future. (Expandable Requirement)

Our network has to be easy to implement when our researchers have all requirements to run our network such as quantum computers for running simulations to make them available to keep focus on Quantum information research. (User interface Requirement / User skill Constraint)

2.3 Engineering Standards

What Engineering standards are likely to apply to your project? Some standards might be built into your requirements (Use 802.11 ac wifi standard) and many others might fall out of design. For each standard listed, also provide a brief justification.

IEEE 802.3 Ethernet: This standard defines the physical and data linky layers of wired Ethernet networks. These networks are going to be critical to set up as they will be used in conjunction with our quantum network we are creating and provide a good baseline network that we can build off of.

IETF RFC 2544: Methodology for measuring the performance of network devices. This standard from the Internet Engineering Task Force describes standards on how network devices are monitored and how their performance is tracked. Once our network is running, we will need to test the speed and reliability using these standards to ensure that it is a viable option compared to standard internet.

IEEE P7130: Standard for Quantum Computing Definitions. These standards provide standards on how quantum computing framework functions are described and what terminology is used. This is important because if we are to communicate with our advisor, we will need to use the proper terms so that he can understand and implement our design.

IEEE P802.1Q-2021: Bridges and Bridged Networks, Amendment 28: Quantum Key Distribution Protocol. This amendment to IEEE 802..1Q defines the Quantum Key Distribution (QKD) protocol which is used to secure network traffic over a quantum network. This is important because if we want the traffic on our network to be secure therefore we will need to implement QKD.

2.4 Intended Users and Uses

Who benefits from the results of your project? Who cares that it exists? How will they use it? Enumerating as many "use cases" as possible also helps you make sure that your requirements are complete (each use case may give rise to its own set of requirements).

Who may benefit from our project?

- Researchers and academics in the field of quantum computing and quantum networking who are looking for new designs of quantum networks for quantum cluster computing.
- Companies and organizations which are looking to initiate their projects related to quantum cluster computing. Our network would be helpful to initiate their project, or they even use our network for cluster computing.
- The General Public who are interested in the great potential of quantum cluster computing which might save tremendous computational resources if it is conducted via a single quantum computer.

How would they use it?

- Researchers could use our network for initiating to make their own quantum network for cluster computing.
  - Researchers could use our network for cluster computing to run their cluster algorithm to test feasibility of their work.
  - Researchers could use our network for cluster computing to add their quantum key distribution function to test feasibility of their work.
- The General Public interested in quantum computing and cluster computing could download our network and use it for their own study or evolve our network such as any open-source project.

3 Project Plan

3.1 Project Management/Tracking Procedures

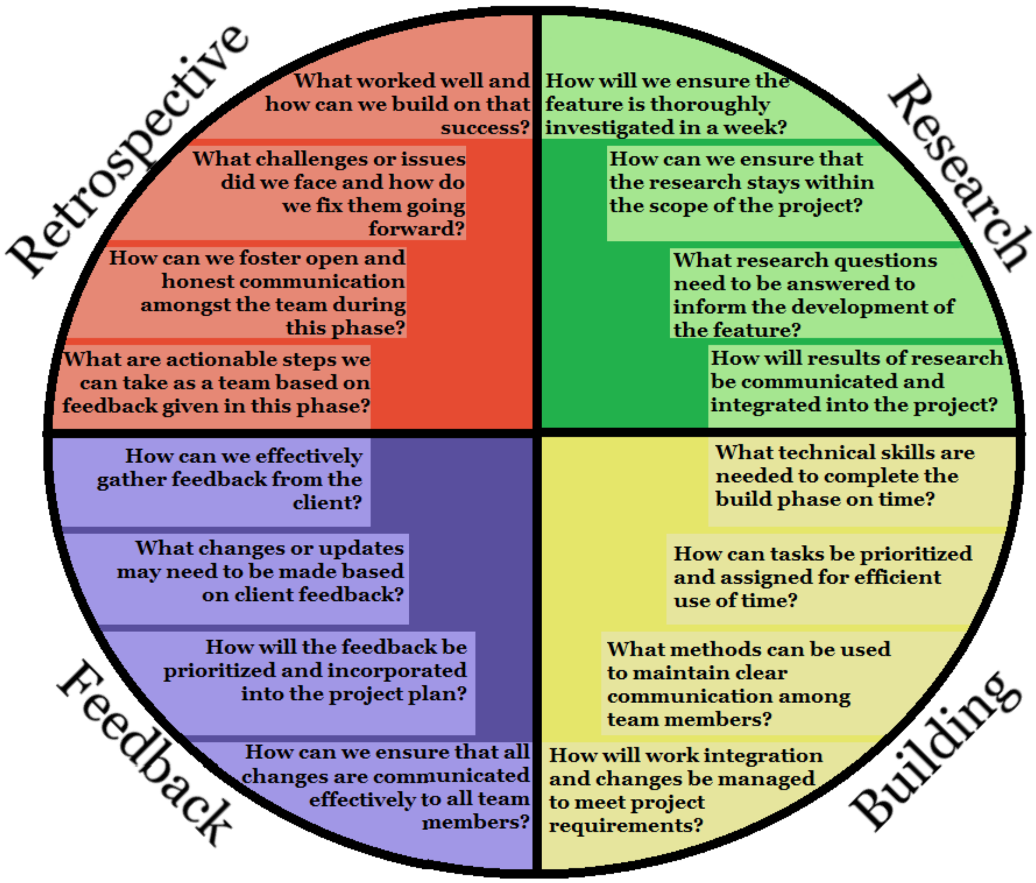
Which of agile, waterfall or waterfall+agile project management style are you adopting? Justify it with respect to the project goals.

For this project, we will be using agile + waterfall management. This approach is being taken since our project is research intensive and our project will ultimately serve as a proof of concept for a later physical implementation.

There are some existing quantum networks that we must research and draw from to suit our clients needs, which is distributing information for quantum cluster computing.

Waterfall approach in the beginning will allow us to do the needed research and coordinate together to ensure a cohesive design. Afterwards we will switch to agile and quickly iterate through as we design the network and companion components.

It's important to keep in mind that our project is considered too big by our advisor to be done as a single undergraduate senior design project. Our work will very likely be built upon by another group.



[figure 1 : project management cycle]

Each section will take about 1 week to complete in earnest.

What will your group use to track progress throughout the course of this and the next semester. This could include Git, Github, Trello, Slack or any other tools helpful in project management.

We're using various tools for tracking our work progress. Below is a list of tools we're using for this project and senior design class.

Discord- general communication tool to set our meeting times and share our recent work in a non-formal way. It also be used as our cloud directory for sharing reading materials and journals

Google drive- all paper works such as ppt slides for a weekly meeting with our advisor are stored in google drive. Collective work for the class is also done in google drive.

Github- we're using github for storing and sharing our code. It is easy to keep track of our working progress and backup history.

3.2 Task Decomposition

In order to solve the problem at hand, it helps to decompose it into multiple tasks and subtasks and to understand interdependence among tasks. This step might be useful even if you adopt agile methodology. If you are agile, you can also provide a linear progression of completed requirements aligned with your sprints for the entire project.

Our project consists of two parts, building a quantum router which takes jobs and makes each node conduct corresponding jobs and building a quantum communication network between quantum router and quantum nodes. Regardless of the name of the quantum router, it's actually highly dependent on classical network and computing architecture. Unlike quantum routers, quantum communication networks between quantum nodes are highly dependent on quantum circuits and quantum computing. Thus we divided our project into these two.

It is important to note that although our project goal of building a quantum network for quantum cluster computing is clear to us, since it is so research intensive and is meant to serve as a prototype for a potential physical implementation, our design and its requirements are subject to change as we continue to clarify with our client on what they want this design to be and accomplish. This is also well noted at section 2.1

Making quantum network components

- Building quantum router :
  - Take quantum information and start pre-constructed circuits.
  - Depending on the degree of centralization, track job status for each node and summarize output.
  - Ensure the router is capable of reading routing information and flag signals.
  - Test before the integration process using dommy job whether it is working correctly or not
- Building quantum communication network and quantum switches :
  - Design the quantum circuit to use the EPR pair in our quantum network.
  - Research and implement communication protocol to make our quantum network more efficient. The degree of efficiency will be kept modified through maintenance progress.
  - Research and development quantum switches for swapping quantum information between quantum networks.
  - Test before the integration process using simple network protocol whether it is working correctly or not.

System integration and testing

- Integrate our network system and run our network on the quantum computer via simulation(one quantum computer, simulating our network). Testing is also done using a quantum computer environment.

Maintenance

- Keep tracking our work progress and get feedback from our advisor. Ensure the project is on the right track and modify our design requirements accordingly by analyzing advisors' needs and realizable goals.

3.3 Project Proposed Milestones, Metrics, and Evaluation Criteria

What are some key milestones in your proposed project? It may be helpful to develop these milestones for each task and subtask from 2.2. How do you measure progress on a given task? These metrics, preferably quantifiable, should be developed for each task. The milestones should be stated in terms of these metrics: Machine learning algorithm XYZ will classify with 80% accuracy; the pattern recognition logic on FPGA will recognize a pattern every 1 ms (at 1K patterns/sec throughput). ML accuracy target might go up to 90% from 80%.

In an agile development process, these milestones can be refined with successive iterations/sprints (perhaps a subset of your requirements applicable to those sprints).

Milestones for making our quantum network are the same as below.

- Create quantum router for having two nodes
  - Identify jobs from user
  - Sent job instruction to each nodes
  - Track job status for each node
  - Send instructions to quantum switches which are part of the quantum communication network.
- Create rudimentary quantum communication network and quantum switches
  - Design quantum network protocol packet for implementation of feature which our advisor needed
  - Design quantum network switches for two nodes which can swap quantum information using the EPR pair.
- Integrate two parts
  - Integrate rudimentary quantum router with quantum communication network / switches.
- Improve quantum network performance
  - Improve our network to make it can hold more than two nodes. Specific number of nodes will be settled during the maintenance.
  - Improve our quantum communication network that can hold more than two EPR pairs for quam information exchange. This determines the availability of implementation of security features.
  - Improve our quantum communication network protocol algorithm. Specific requirements will be settled during the maintenance. It also depends on the client's needs.

3.4 Project Timeline/Schedule

• A realistic, well-planned schedule is an essential component of every well-planned project

• Most scheduling errors occur as the result of either not properly identifying all of the necessary activities (tasks and/or subtasks) or not properly estimating the amount of effort required to correctly complete the activity

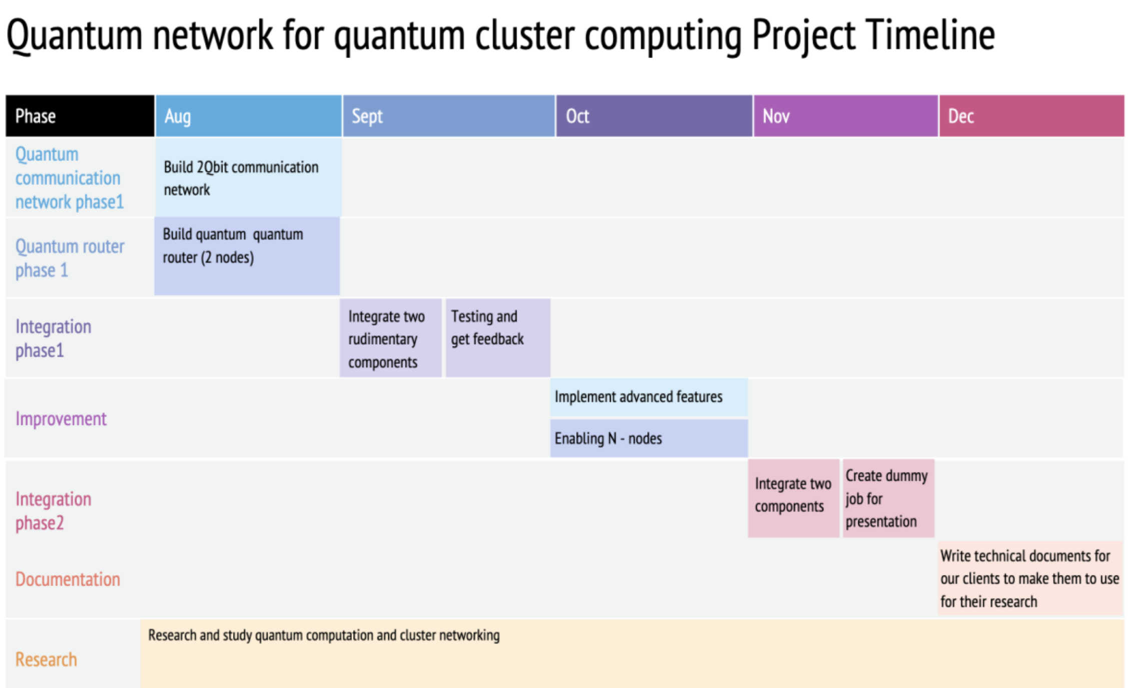
• A detailed schedule is needed as a part of the plan:

– Start with a Gantt chart showing the tasks (that you developed in 2.2) and associated subtasks versus the proposed project calendar. The Gantt chart shall be referenced and summarized in the text.

– Annotate the Gantt chart with when each project deliverable will be delivered

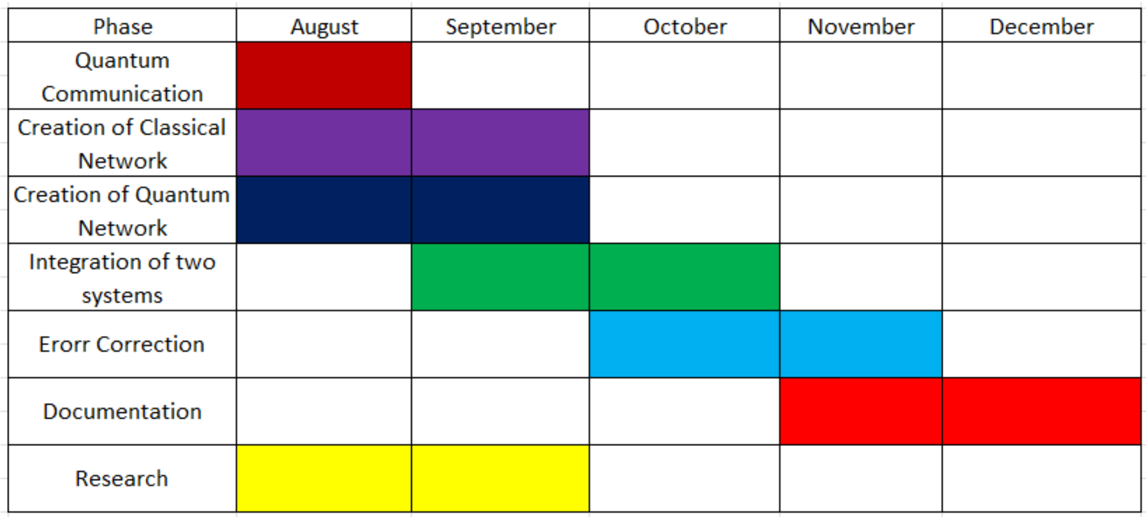
• Project schedule/Gantt chart can be adapted to Agile or Waterfall development models. For agile, a sprint schedule with specific technical milestones/requirements/targets will work.

Proposed Development Gantt Chart



[figure 2 : proposed project timeline]

Actual Development Gantt Chart



[figure 2.1 : Actual project timeline]

During our development, we made a few key realizations between what was feasible using our technology and current limitations. We determined that the base of our system will function off of the creation of our classical and quantum network. Therefore, we determined that this was one of the first things we should focus on. On top of this, integration of the two systems was something we did not originally plan on taking as long as it did but due to the format of the information we were dealing with we were required to spend a lot of time integrating the two systems. Also, we found that we did not want to waste much of our time doing research as we were afraid of falling into a loop of research and development without any creation of our final product.

3.5 Risks And Risk Management/Mitigation

Consider for each task what risks exist (certain performance targets may not be met; certain tools may not work as expected) and assign an educated guess of probability for that risk. For any risk factor with a probability exceeding 0.5, develop a risk mitigation plan. Can you eliminate that task and add another task or set of tasks that might cost more? Can you buy something off-the-shelf from the market to achieve that functionality? Can you try an alternative tool, technology, algorithm, or board? Agile projects can associate risks and risk mitigation with each sprint.

Planning and Design - Nonworking Design.

Probability - 0.3

Implementation 1 to 1 - Issues with simulation not working as intended.

Probability - 0.2

Creating rudimentary quantum router - Issues concerning communication with quantum nodes.

Probability - 0.7

Mitigation - quantum router, although it's mainly dealing with classical information and very similar with classical computing architecture, is the most complex unit especially we have to add communication with quantum communication network / quantum switches. We have researched classical routing protocols and our design will be mimicking an already existing design. On top of this, we plan on meeting with professors who are well versed in networking and routing protocols and get feedback on if our design is feasible.

Troubleshooting - Design issues could cause full rebuild / redesign of the project.

Probability - 0.6

Mitigation - We will keep in close contact with our advisors and tell them our designs before we spend time implementing them so that they can give feedback on if they will work or not and why.

Presentation Preparation - Not communicating our project enough where the audience cannot understand it.

Probability - 0.4

For a lot of our project, buying something off the shelf is not an option because nothing exists that can do this reliability. There are some algorithms that we can use in our design which have been tested but these are unrelated to the end goal of our project to route quantum information.

3.6 Personnel Effort Requirements

Include a detailed estimate in the form of a table accompanied by a textual reference and explanation. This estimate shall be done on a task-by-task basis and should be the projected effort in the total number of person-hours required to perform the task.

[table 1 : personnel effort requirement]

Task	Person	Hours
Planning and design	All	30
Implementing 1 to 1 connection	Ohik & Derrik	70
Creating classical network packet	Steven & Ben	70
Implementing classical network in quantum	Ohik & Steven	70
Integration	Derrik	15
Troubleshooting	All	40

Documentation	All	25
Presentation prep	All	20

3.7 Other Resource Requirements

Identify the other resources aside from financial (such as parts and materials) required to complete the project.

Our project will require other resources such as quantum computer simulators as well as possibly some server space. These resources are either all provided or free off the internet therefore should cause no issues in the completion of our project.

IBM Q system One - We're using IBM Q system for simulating our quantum network. We can use up to 7 qbits without any extra charge.

4 Design

4.1 Design Context

4.1.1 Broader Context

Describe the broader context in which your design problem is situated. What communities are you designing for? What communities are affected by your design? What societal needs does your project address?

List relevant considerations related to your project in each of the following areas:

[table 2 : design context]

Area	**Description**	**Examples**
Public health, safety, and welfare	Quantum computers have the possibility to affect every aspect of modern life. Conversely, quantum networks will enable these computers to coordinate and share information.	Increasing human understanding of virtually every field of science and thereby improving the quality of human life.
Global, cultural, and social	The project we are working on has the long term potential to affect virtually every human being on the planet. For our purposes, we intend to integrate a humanistic approach to our work. This	As a potentially powerful tool, it will be possible to enable great harm to society and also great benefit as well.

	means that as we design and realize our work, we are always considering the impact to humanity and its best interests.	
Environmental	Immediately this project has no environmental impact. However it does have the potential to drastically impact the environment.	Will likely aid in the developing of renewable materials and battery solutions etc etc , will likely have a dramatically positive impact but may also have a profoundly negative one as well
Economic	Immediately this project poses little impact on the local or global economy. This project is serving as a prototype for a later physical implementation. Long term this project may have some significant impact on economic activity.	Product will be a simulation of a network. This will be free. Our client does not need to pay us for this either.

4.1.2 User Needs

List each of your user groups. For each user group, list a needs statement in the form of:

User group needs (a way to) to do something (i.e., a task to accomplish, a practice to implement, a way to be) because of some insight or detail about the user group.

Dr. Durga needs us to design a system that can take a list of quantum computing tasks, and split them into nodes and determine which nodes need what information. To initiate and qualify his needs, we decided to build the basic building blocks of fundamental quantum communication, which is the quantum teleportation system. It has to embrace the realistic way of running. For example, if we built a quantum teleportation system, we can not implement our designed classical network as the part of quantum teleportation since Qiskit is made for different purposes. What our client wants is to have a quantum teleportation system which runs by parts while using our own classical network which captures the realistic situation well for their future quantum cluster computing project.

4.1.3 Prior Work/Solutions

Include relevant background/literature review for the project

– If similar products exist in the market, describe what has already been done

– If you are following previous work, cite that and discuss the **advantages/shortcomings**

– Note that while you are not expected to “compete” with other existing products / research groups, you should be able to differentiate your project from what is available. Thus, provide a list of pros and cons of your target solution compared to all other related products/systems.

Detail any similar products or research done on this topic previously. Please cite your sources and include them in your references. All figures must be captioned and referenced in your text.

Quantum routers exist and have been used in a closed setting, but they have never been used as a quantum cluster to split quantum tasks into smaller tasks. Classical clusters are used extensively in computing but they have never implemented any quantum elements. Our project is going to combine both of these to create the first ever quantum computing cluster. *ex)IBM Quantum router : https://arxiv.org/abs/1803.06530*

4.1.4 Technical Complexity

Provide evidence that your project is of sufficient technical complexity. Use the following metric or argue for one of your own. Justify your statements (e.g., list the components/subsystems and describe the applicable scientific, mathematical, or engineering principles)

1. The design consists of multiple components/subsystems that each utilize distinct scientific, mathematical, or engineering principles –AND–
2. The problem scope contains multiple challenging requirements that match or exceed current solutions or industry standards.

Our project fulfills these needs. We are going to have two iterative designs: a cluster computer that starts with each node and has tasks that have no dependencies on each node. That should be easier because the router just has to juggle errors from each node. These "errors" should have no correlation between each node. The next step is to have the tasks are what we call "later dependencies." For example, if our cluster has 2 nodes, A and B, and task 30 of B requires an answer from task 3 of node A. If everything moves smoothly there should be no issues. However, if A gets stalled there should be a functionality that alerts the primary computer that node B might need to stall. That is where an interrupt handler will come in. We will create an interrupt handler that will handle all the errors that we find. For example but not limited to, if entanglement has an issue the classical portion will fire an interrupt to let the primary router know what to initiate to fix the issue.

4.2 Design Exploration

4.2.1 Design Decisions

List key design decisions (at least three) that you have made or will need to make in relation to your proposed solution. These can include, but are not limited to, materials, subsystems, physical components, sensors/chips/devices, physical layout, features, etc.

1. Deciding how much information should the quantum nodes have, should they know that there are other nodes, this would generate problems with node configuration but would help with routing. We have decided to make our quantum nodes as simple as possible to help the system be as scalable as possible and easy to implement more nodes.
2. Task Distribution and Scheduling we have decided to first implement a system with no dependencies and implement this into our switch later in development.
3. How quantum information will be exchanged. We decided to use one of the basics of quantum computing, Bell states or EPR pairs, which are used to exchange quantum information over a short distance with reliability. On top of this, our router will use quantum swapping to exchange information between nodes.

4.2.2 Ideation

For one design decision, describe how you ideated or identified potential options (e.g., lotus blossom technique). List at least five options that you considered.

For deciding on the quantum nodes, we considers a

- Quantum nodes have an entire operating system and route themselves.
- Quantum nodes know only their closest neighbors
- Quantum nodes route through the router but create the destination themselves
- Quantum nodes have no knowledge other than what their task is
- Quantum nodes know how to send it back to the router when they are done

4.2.3 Decision-Making and Trade-Off

Demonstrate the process you used to identify the pros and cons or trade-offs between each of your ideated options. You may wish to include a weighted decision matrix or other relevant tool. Describe the option you chose and why you chose it.

		63	90	112
Options		No depende	Later depen	Immediate c
Decision making factors	**Weighting**	**Your Score**	**Your Score**	**Your Score**
Complexity	1	1	5	10
Scalability	5	4	8	10
Speed	3	10	7	4
Usefulness	4	3	6	10

[figure 3 : design decision on degree of dependencies of nodes]

It is preferable to pick an immediate dependency. We want to choose this because it is easy to scale and it has uses that far outway the other two options. It also gives the user the most options for jobs that they can give to the cluster.

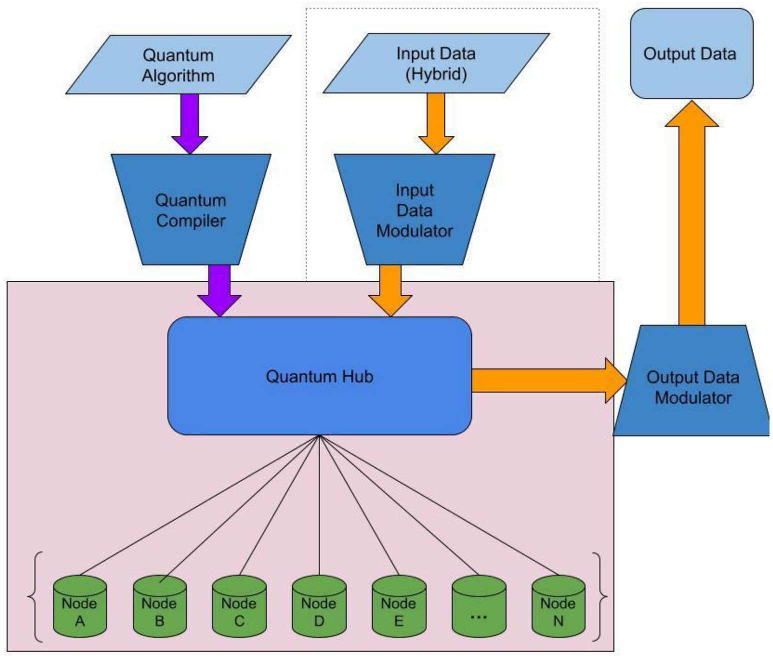
4.3 Proposed Design

We determined the basic function and architecture of our quantum cluster computing network architecture through discussions with our client and advisor.

4.3.1 Design Visual and Description

Include a visual depiction of your current design. Different visual types may be relevant to different types of projects. You may include: a block diagram of individual components or subsystems and their interconnections, a circuit diagram, a sketch of physical components and their operation, etc.

Describe your current design, referencing the visual. This design description should be in sufficient detail that another team of engineers can look through it and implement it.



[figure 4 : high level architecture of our quantum cluster network]

This diagram shows our quantum network for cluster computing very conceptually. For cluster computing, we should first take care of distributing one big job to several tasks which also requires very profound algorithms. Since it is not what our advisors and customers expected of us, we assume that one job is already distributed efficiently. What we are trying to achieve is to make a quantum router which is almost the same as a scheduler in a classical cluster computing or in an operating system. What differentiates between classical cluster computing router and our quantum cluster computing router is that our quantum router includes quantum gates which enable us to share data the same as the speed of light. To do this, We're planning to take care about error correction of quantum nodes, dependency of distributed tasks etc. But we're planning to make a very rudimentary quantum network router and move to take care of real problems such as error correction and task distribution.

4.3.2 Functionality

Describe how your design is intended to operate in its user and/or real-world context. This description can be supplemented by a visual, such as a timeline, storyboard, or sketch.

How well does the current design satisfy functional and non-functional requirements?

As we highlighted several times, this topic is state of the art of technology and still needs intensive research concerning building practical quantum networks. For example, we need to take care more seriously about the difference between quantum and classical when we distribute a single job to multiple tasks for the quantum router scheduling process. But since that is not our goals and needs for our advisors and customers, we're not caring about practical difficulties when we're simulating at the first time. We're planning to take care of practical difficulties after we successfully get a rudimentary version of quantum networks. However, our simulated version of the network will be used for the basic structure of Dr Durga's future research. And our simulated version of the network also works well if we have the same environment as our simulation's assumption. For example, our work can be used to compute complex quantum operations which would take too long to compile on one quantum machine when the ideal state is assumed. It will need to do this quickly and reliably as well as not lose any information along the way. This design works because it will be scalable, as once the switch is working, we can implement as many nodes as we want which will all increase how fast our system can compute complex algorithms.

4.3.3 Areas of Concern and Development

Based on your current design, what are your primary concerns for delivering a product/system that addresses requirements and meets user and client needs?

What are your immediate plans for developing the solution to address those concerns? What questions do you have for clients, TAs, and faculty advisers?

Our main concerns are about scheduling and dependencies on our tasks which are essential parts of what our advisors and customers need. Our immediate plan for our project is, thus, to make a rudimentary quantum network for quantum cluster computing to meet basic requirements for our advisors and users. We assumed ideal states for some points to meet our primary goal for this, such as, we're assuming that quantum information that we used for our simulations are entangled and very stable. After we handle the primary problem, we're planning to consider other practical considerations such as error correction, entanglement time.

4.4 Technology Considerations

Highlight the strengths, weaknesses, and trade-offs made in technology available.

Discuss possible solutions and design alternatives

The main issue with technology today is that problems must be solved on one quantum computer. Because when we measure the quark it changes there is going to be a chance that a computer doing a problem will produce a wrong result. This is where having a router controlling a number of nodes, you can compare the results from each node and do that statistical analysis as the user wants.

4.5 Design Analysis

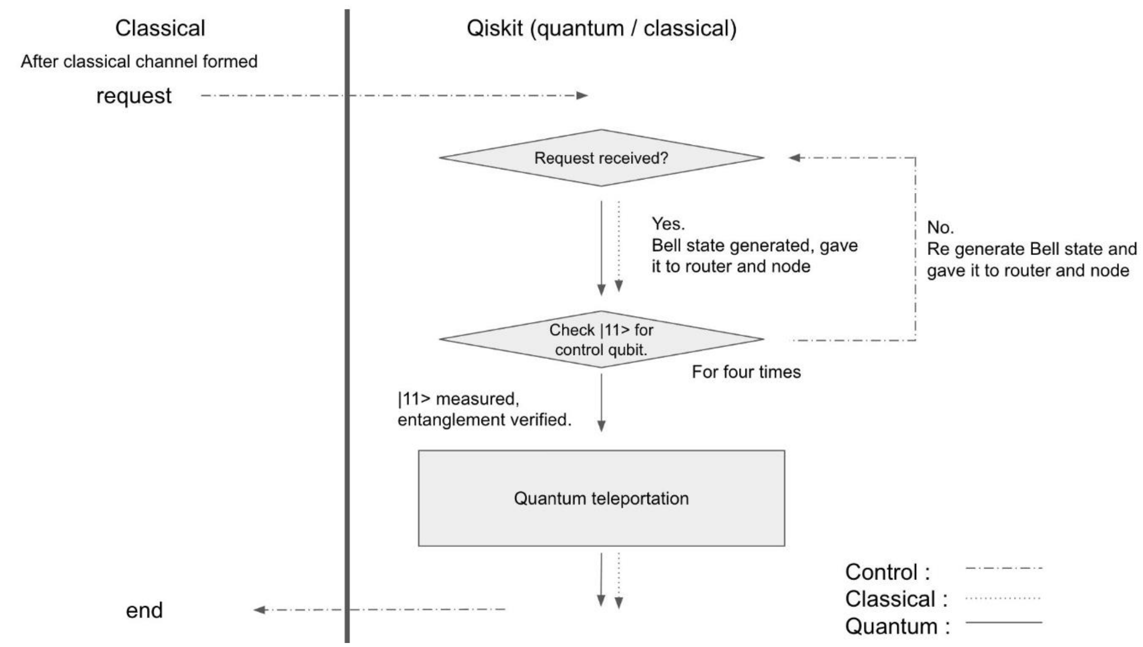
4.5.1 Revised Project Design

Originally, our design depended on a few things which ended up not working out how we had planned. For one, qiskit not being able to run multiple circuits at the same time forced us to change how we looked at our problem as we could not accurately simulate it. On top of this, originally, we assumed that there was a method of dynamically changing quantum circuits such as VHDL in classical systems and we could take our knowledge of these systems and apply it. Because neither of these was the case, we were forced to implement our system as a collection of quantum information systems and really focused on putting the main building blocks of our system in place so that future research could be done with it.

– What are your observations, thoughts, and ideas to modify or iterate over the design?

Our design does work theoretically. The reason for it is we have a way of communicating tasks and solutions between lots of machines and collecting those solutions to create an answer. We also are only going to simulate it so that it also completes our customers' demands. We think that we can add more customization to the design to allow for control over the amount of nodes working, if every node is doing the same job, or even how the statistical analysis at the end will change. The goal is to create a system that allows for customization to the user's liking.

Revised project system architecture is the same as the diagram below.

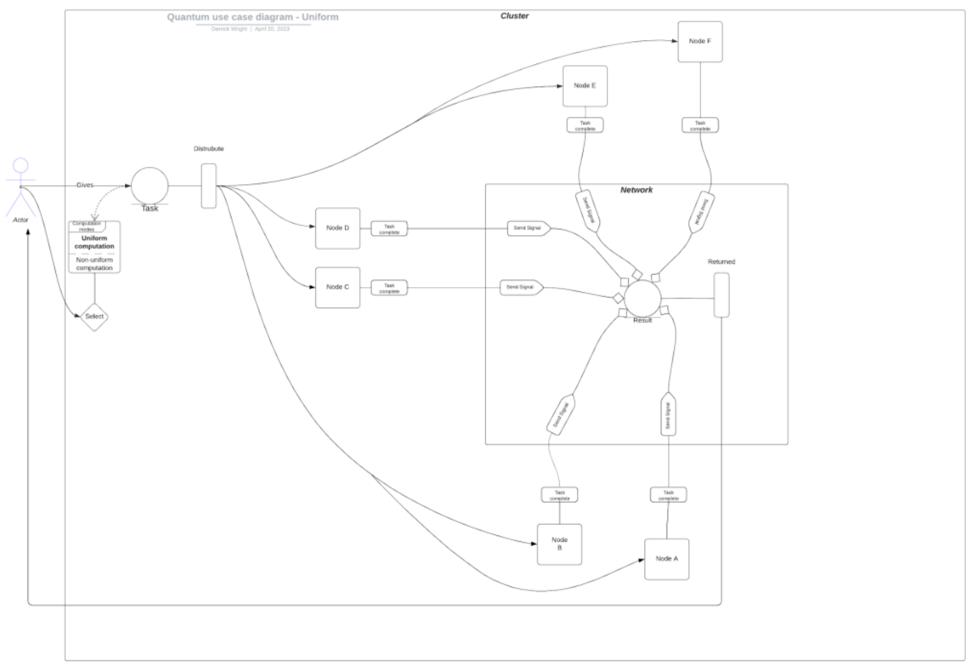


[figure 5 : Quantum teleportation system diagram]

4.6 Design Plan

Describe a design plan with respect to use-cases within the context of requirements, modules in your design (dependency/concurrency of modules through a module diagram, interfaces, architectural overview), module constraints tied to requirements.

Since our project is for researchers who want to initiate their study on quantum cluster computing, and our final project result will be a platform(network) not a product, we don't want to consider any UI to enhance user experience. User-cases diagram could be the same as the figure below. Although any hierarchy or dependency between each module isn't required for our project as we can see below figure, all modules have to be worked stable to meet user's needs. We want to create a router and architecture for nodes that allow for complex quantum problems to be completed quickly and with lots of iterations. The router will be able to take the chosen program and distribute it to an amount of quantum nodes that are chosen by the user. From there, the nodes will complete the problem with the given algorithm and return the data in an organized manner. The organization of the solution is important because the router will take that information and create statistics that the user can interpret as they want.



[figure 6 : user case diagram]

In our revised design, we built a single wire which connects between nodes to the router. Even though they look like just a wire, actually they have to carry quantum information associated with classical networks. Users will use our quantum teleportation wire which embraces the realistic operation protocols with our classical network, so users can take care of the realistic situation of running a quantum teleportation circuit.

5 Testing

Testing is an **extremely** important component of most projects, whether it involves a circuit, a process, power system, or software.

The testing plan should connect the requirements and the design to the adopting test strategy and instruments. In this overarching introduction, given an overview of the testing strategy. Emphasize any unique challenges to testing for your system/design.

5.1 Unit Testing

What units are being tested? How? Tools?

For our project, we have two big parts that need to be tested. The two parts are 1) classical networks which will be used for communication between router and nodes, and 2) quantum communication lines which will be essential to make our network maintain integrity of quantum information as it is being transported. For each part, there are small units to be worked on to make our network work in an appropriate and reliable manner.

In this part, we're talking about small units for network functions. Units for interface tracking, and reliability tracking, such as logger will be discussed in later chapters.

Classical networks

Our classical networks will be coded in python, and it will be needed to make nodes communicate with each other inside of our simulated network. To make this possible, our network will consist of below units and will be tested same as below description.

1) Router

   Router is the main component of our classical networks and the "big brain" of our classical network. Likewise with the analogy of "big brain", it handles important jobs concerning our network. It will identify jobs and distribute jobs to entire nodes, and communicate with each other to determine which nodes finish their job, and summarize outputs to create one final answer. It is more like a container which has components below and works as a single entity inside of our network. This component will be tested consistently while we build each small subunit same as below description a)~c) and it will be integrated when we can ensure each subunit works perfectly.

   a) Communication unit with each classical nodes

      This unit is communicating with each classical node in our quantum network. Again, in the future each node also will be quantum, but now, we're using classical nodes. This unit will be used to communicate with router and classical nodes to make sure the router knows which nodes finish their job or not. It will be a module in python, so it will be tested whether it sends a flag signal well or not. We can test it in a python interpreter.

   b) Output unit

      This unit summarizes answers from each classical node and makes one final answer to users who input corresponding works. It might not be required for our current project since at this stage we're using classical nodes, but we're planning to make this module since it will be essential for quantum nodes. Likewise other router components, It will be a module in python and we can test it in a python interpreter.

Quantum communication part

Our quantum communication line will be also made by python, especially using Qiskit. This communication line will consist of below units and will be tested same as below description.

1) Bell State Generator

Bell State is the essential component for quantum teleportation since we need entangled quantum states to teleport quantum information from one to the other. We implemented Bell state generators in Qiskit and also made debug mode, so we can check by following calculations step-by-step to verify that we have entangled quantum states.

2) Quantum teleportation circuit

Quantum teleportation circuits enable people to send quantum information to others. It was proposed by Charles H. Bennet. It was proved that this circuit actually sends quantum information as long as we have entangled quantum states. We implemented this quantum teleportation circuit which can be run by parts for debugging purposes that enable us to check whether it actually sends quantum data by following step-by-step implementation with handwritten calculation for verifying.

3) Quantum verification protocol

It is important to check that our quantum wire actually can hold qubits as entangled while our simulation. Right now, since we only take care of the ideal situation, we don't have to embrace it. However, for the compatibility for the future work, we implemented quantum entanglement verification quantum circuit which is also run by parts using two controlled SWAP gates. We can run using Qiskit and we also implemented debug mode to verify that this circuit actually works well for verification.

5.2 Interface Testing

What are the interfaces in your design? Discuss how the composition of two or more units (interfaces) are being tested. Tools?

Our design had virtually no interfaces beyond interfacing directly with the files containing the relevant python code. As such, no interface testing needed to be performed.

5.3 Integration Testing

What are the critical integration paths in your design? Justification for criticality may come from your requirements. How will they be tested? Tools?

All integration testing was handled manually during integration itself. Given the small scope and precise nature of the project, a large robust and automated integration testing suite was not needed. Manual testing was handled by simply running the project and making sure that the output was within acceptable ranges. If it was not, changes were made to the code.

Given the small scope, and the private nature of the project, this was deemed an acceptable approach due to the low likelihood of meaningful changes made by unauthorized persons.

5.4 System Testing

Describe system level testing strategy. What set of unit tests, interface tests, and integration tests suffice for system level testing? This should be closely tied to the requirements. Tools?

System testing was done manually during integration. Due to the small scope of the project, a large systems testing suite was unnecessary.

5.5 Regression Testing

How are you ensuring that any new additions do not break the old functionality? What implemented critical features do you need to ensure they do not break? Is it driven by requirements? Tools?

Regression testing was unnecessary. We have a very small code base and only had one or two persons making any meaningful changes to the code.

5.6 Acceptance Testing

How will you demonstrate that the design requirements, both functional and non-functional are being met? How would you involve your client in the acceptance testing?

Acceptance testing was done in coordination with our client. With and understanding of what was capable with the technologies we had access to and what was acceptable to our client, acceptance testing was done manually while keeping the agreed upon criteria in mind.

5.7 Security Testing

Security testing was done via a quantum verification algorithm implemented by our team. Other than that, no security testing was needed as the network was simulated on one computer as well as the nodes that would connect to this network.

5.8 Results

What are the results of your testing? How do they ensure compliance with the requirements? Include figures and tables to explain your testing process better. A summary narrative concluding that your design is as intended is useful.

Our results from testing were ensuring that the simulation we wrote did what we intended it to do. This was of utmost importance during the integration phase as many loose wires needed to be connected and accounted for.

Our result from testing was a successful simulation.

6 Implementation

Describe any (preliminary) implementation plan for the next semester for your proposed design in 3.3. If your project has inseparable activities between design and implementation, you can list them either in the Design section or this section.

Quantum teleportation

In this section, we describe how we made modules required for quantum teleportation such as Bell generator, teleportation, and entanglement verification circuits.

Functions we made for the entire quantum teleportation are the same as below.

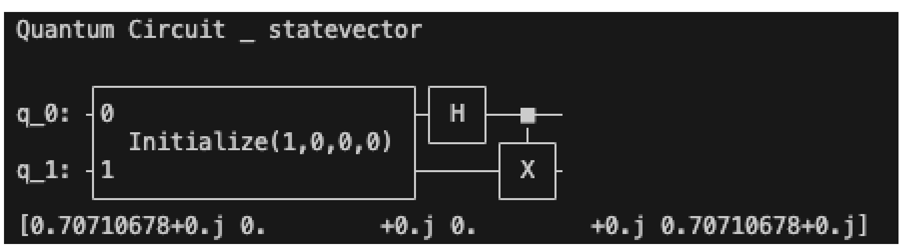
```
> def Entanglement_verification(simulator, Bell_state, debug = False):…

> def gen_Bell(simulator, debug = False):…

> def random_state(nqubits):…

> def information_initialize_to_statevector(init_gate, simulator,debug = False):…

> def compound_information_zero_states(init_statevector, debug = False):…

> def Alice_quantum_operation(compound_statevector, simulator, debug = False):…


> def Alice_measure(Bell_info_statevector, simulator, debug = False):…

> def Bob_quantum_opertaion(alice_measurement_result, Alice_statevector, simulator, debug = False):…

> def Bob_measure(Bob_statevector, inverse_init_gate ,simulator, debug = False):…
```

[Figure 7 : Quantum modules]

From this document, we will mention some important quantum modules for operating our quantum teleportation simulation.

random_state(nqubits) - it generates a number of random qubits which stems from '0' quantum bits. The idea of your testing is building random qubits from the '0' state, and applying reverse operation when they are teleported. Due to the nature of the quantum, we expected to see '0' for received data for all cases.

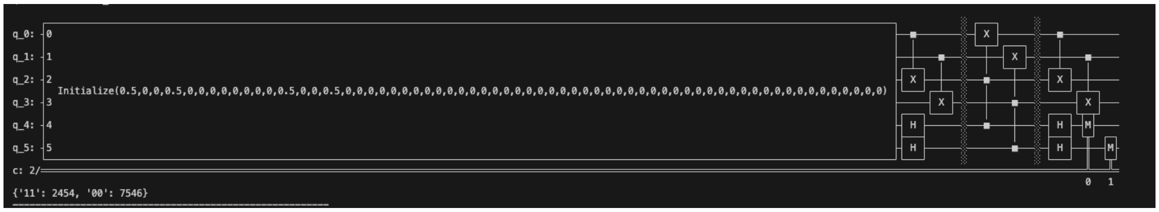
gen_Bell(simulator, debug=False) - it generates Bell states from the '00' qubits. We can also check by turning on the debug mode. The result is the same as below.



[Figure 8 : gen_Bell result]

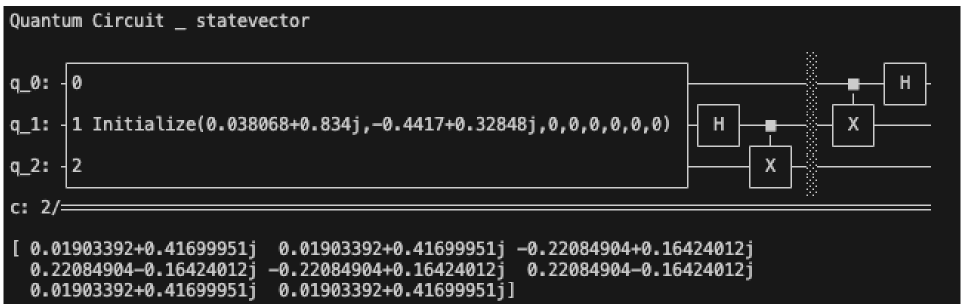
The result from this simulation shows that we generate Bell state successfully.

Entaglement_verification(simulator, Bell_state, debug = False) - it is used to control the SWAP gate and verify whether our quantum wire is entangled or not. From the theories, we should get '11' for close to the 25% chance when both states are entangled. Below screenshot shows that our system can hold entangled qubits. From the 10000 tries, we got 2454 '11' which is close to 25%.

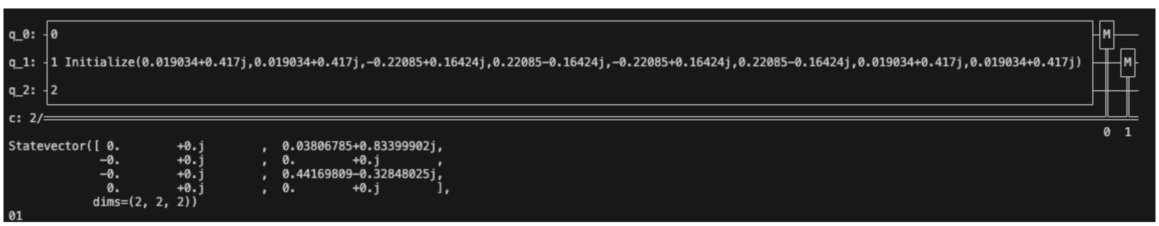


[Figure 9 : quantum verification circuit.]

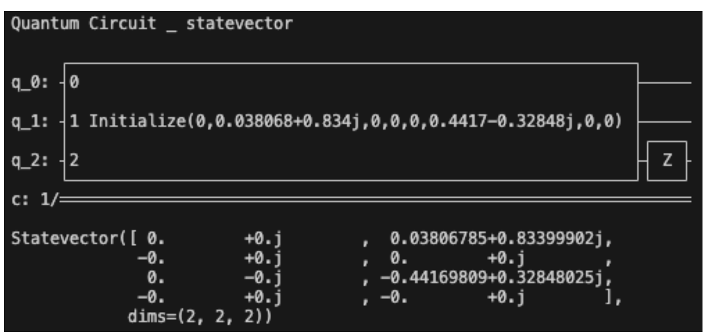
Quantum teleportation circuits - Due to meeting our advisors' needs, we implemented our quantum teleportation circuit by parts. The entire circuit can be checked by enabling debug mode turned on. The below image shows the part of our quantum teleportation circuits, and the initial quantum information and final quantum information which is teleported.



[Figure 10 : initial quantum data with bell state circuit with its outcome]

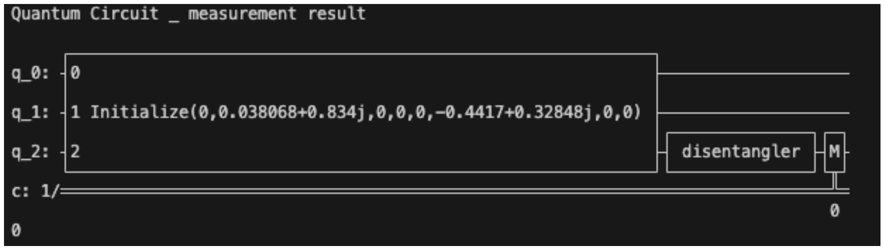


[Figure 11 : Measuring process and its result]



[Figure 12 : Quantum gate operation dependent by measured outcome]

From the last image, we can see that the initial data teleported successfully to the receiver's side.



[Figure 13 : Apply inverse operation]

As we described already, from the inverse operation we should always get '0' for the outcome since our initial data came from the '0' state. From this part, we successfully built a quantum circuit which runs separately to embrace realistic situations and verified that this circuit is actually working through the debug mode.

Classical Network

The development of a classical network architecture for interfacing with quantum cluster computers required innovative approaches. The conventional network models were inadequate for the unique demands of quantum computing, which involves handling complex, highly interconnected quantum states. Therefore, a fresh, ground-up design was essential.

In this new model, the network had to support dynamic connectivity, enabling any number of nodes to connect or disconnect at will. This requirement is crucial for quantum cluster computers, where nodes might represent different quantum processors or quantum-enabled devices, each requiring the ability to join or leave the network seamlessly. To facilitate this, the design included the creation of a new thread for every connecting node. This approach allowed each node to operate independently, managing its computations asynchronously. This is particularly important in a quantum computing context, where synchronization of quantum states across nodes is a complex task.

The testing process for this network model was methodical and thorough. Initially, an instance of the router, the central hub of the network, was set up. This router was equipped with all necessary data and configurations to manage network traffic effectively. Its primary function was to listen for incoming connections from various nodes, a critical capability for a dynamic quantum network.

For each test case, a node instance was also created. These nodes were designed to mimic quantum computing devices or processors. Each node was programmed with specific instructions to connect to the router using a designated IP address and port. This process simulated the real-world scenario of quantum nodes connecting to a central network.

The tests were designed to assess various aspects of the network. These included the stability and reliability of connections, the efficiency of data transfer between the router and the nodes, and the network's ability to handle simultaneous connections and disconnections. The performance of individual threads, each managing a node, was also scrutinized to ensure that they could independently handle computations without causing bottlenecks or synchronization issues.

Overall, the development of this classical network for quantum cluster computers represented a significant step forward in quantum computing. By ensuring efficient and flexible connectivity among quantum nodes, it paved the way for more advanced and scalable quantum computing architectures.

Integration

There was less of anything made during the integration process, and more of things made to work. Integration was the process of taking the separate parts of the Quantum and Classical Network and wiring them together.

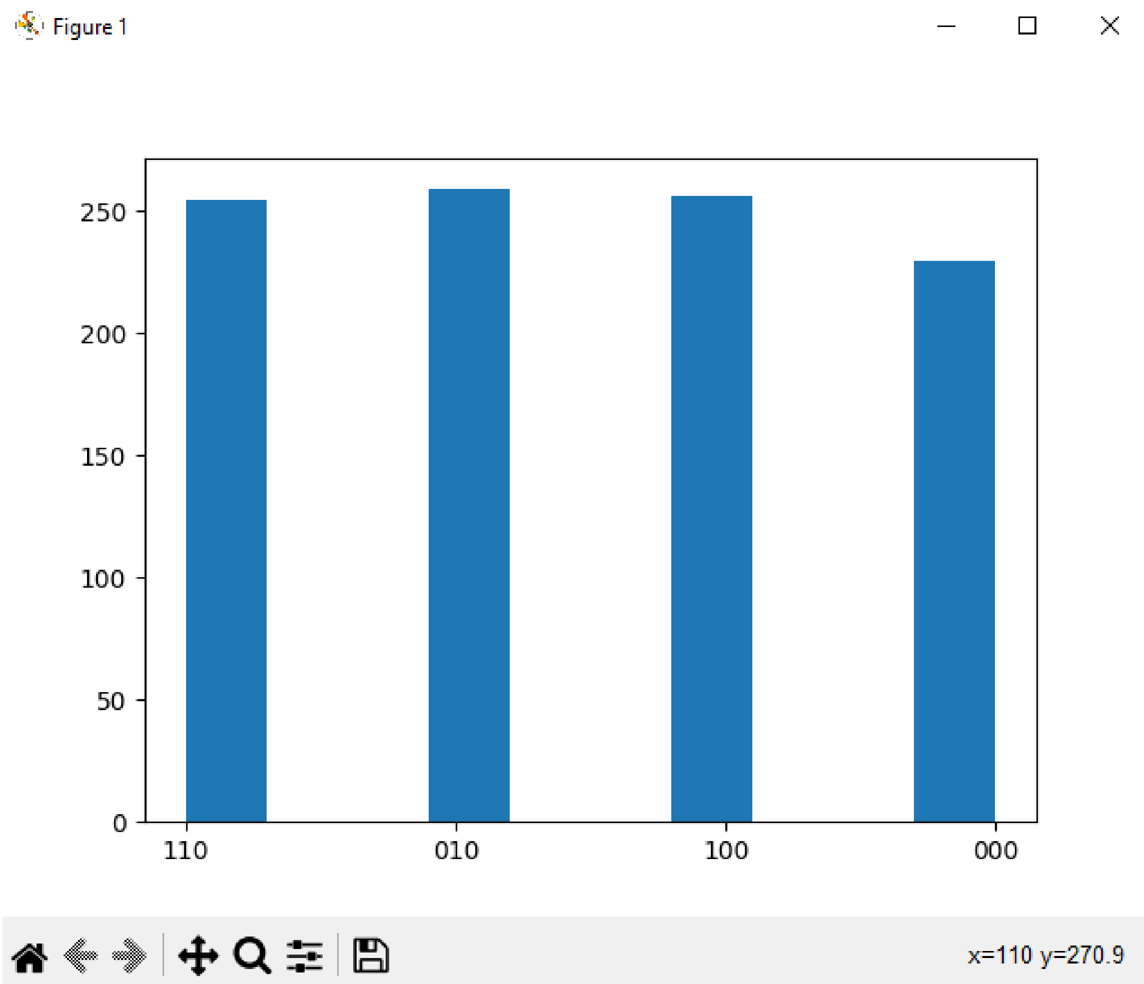
During the initial stages of integration, there was only the router to work with. So our team decided to initiate the nodes and assign them with their own ip addresses. We ran into a number of problems during this stage and had to make changes to both the node class and the router class to enable a smoother connection.

During the middle stages of integration, the quantum function was ready to be used, but was only used in a rudimentary fashion. Bundled all together and called as one function. Further changes were made to the router, node, and also the quantum function itself to allow it to work in a programmatic fashion as needed by the simulation. Messages containing data were being created in the quantum function, being carried by the node class and objects, and being delivered to the router.

During the final stages of the integration, the quantum function was broken into multiple separate functions that interacted with each other and passed data as necessary. This was to ensure that we were more able to accurately simulate a quantum network and or a quantum function. Additionally messages were being delivered to the router at separate times rather than as one packet as it was before. Said quantum information was being stored in the router as a message array. This message array was then utilized by a histogram plotting function created by one of our network engineers.

current message array: ['11', '0', '01', '0', '11', '0', '01', '0', '10', '0', '11', '0', '11', '0', '10', '0', '11', '0', '10', '0', '01', '0', '10', '0', '10', '0', '00', '0', '01', '0', '11', '0', '10', '0', '11', '0', '11', '0', '11', '0', '11', '0', '11', '0', '11', '0', '11', '0', '01', '0', '01', '0', '10', '0', '00', '0', '10', '0', '11', '0', '00', '0', '01', '0', '00', '0', '11', '0', '01', '0', '01', '0', '01', '0', '11', '0', '01', '0', '01', '0', '10', '0', '01', '0', '01', '0', '01', '0', '10', '0', '10', '0', '01', '0', '01', '0', '01', '0', '10', '0', '11', '0', '10', '0', '01', '0', '00', '0', '00', '0', '01', '0', '11', '0', '01', '0', '01', '0', '00', '0', '00', '0', '10', '0', '11', '0', '10', '0', '01', '0', '00', '0', '10', '0', '00', '0', '00', '0', '01', '0', '10', '0', '01', '0', '11', '0', '11', '0', '01', '0', '10', '0', '10', '0', '01', '0', '11', '0', '00', '0', '01', '0', '00', '0', '01', '0', '00', '0', '00', '0', '00', '0', '10', '0', '11', '0', '10', '0', '10', '0', '01', '0', '11', '0', '00', '0', '11', '0', '01', '0', '10', '0', '11', '0', '11', '0', '11', '0', '00', '0', '00', '0', '11', '0', '00', '0', '11', '0', '01', '0', '01', '0', '10', '0', '00', '0', '00', '0', '10', '0', '10', '0', '00', '0', '01', '0', '10', '0', '00', '0',]

A sampling of the array of data in the Router's message array



[Figure 14 : Histogram produced at the end of a run]

7 Professionalism

This discussion is with respect to the paper titled "Contextualizing Professionalism in Capstone Projects Using the IDEALS Professional Responsibility Assessment", *International Journal of Engineering Education* Vol. 28, No. 2, pp. 416–424, 2012

7.1 Areas of Responsibility

Pick one of IEEE, ACM, or SE code of ethics. Add a column to Table 1 from the paper corresponding to the society-specific code of ethics selected above. State how it addresses each of the areas of seven professional responsibilities in the table. Briefly describe each entry added to the table in your own words. How does the IEEE, ACM, or SE code of ethics differ from the NSPE version for each area?

[table 3 : Areas of responsibility]

Area of responsibility	*Definition*	*NSPE Canon*	*ACM code of Ethics*
Work Competence	Perform work of high quality, integrity, timeliness, and professional competence	Perform services only in areas of their competence; Avoid deceptive acts	The ACM code 2.2 says that we are obligated Acquire and maintain professional competence
Financial Responsibility	Deliver products and services of realizable value and at reasonable cost	Act for each employer or client as faithful agents or trustees.	ACM code 3.3 and 3.4 says that engineers should provide articulates during system evaluation or improvement to customers who might be affected by the engineer's work for preventing their profitable acts.
Communication Honesty	Report work truthfully, without deception, and understandable to stakeholders	Issue public statements only in an objective and truthful manner; Avoid deceptive acts.	ACM code 2.5 says to give comprehensive and thorough evaluations of systems and their impacts. This falls on communicating with fully to the point where they are able to understand what you are telling them
Health, Safety, Well Being	Minimize risks to safety, health, and well-being of stakeholders.	Hold paramount the safety, health, and welfare of the public.	ACM code 1.1 is to contribute to society and human well-being. You must always be sure your work is being used to keep people safe and healthy

Property Ownership	Respect property, ideas, and information of clients and others.	Act for each employer or client as faithful agents or trustees.	ACM code 2.8 respecting access to computing systems and only using them when authorized. These systems are the property of our organization which we are working for
Sustainability	Protect environment and natural resources locally and globally	Hold paramount the safety, health, and welfare of the public.	ACM code 1.2 is to avoid harm to others. Because not protecting the environment is causing harm to people it is important to reduce your impact on the climate and natural resources.
Social Responsibility	Produce products and services that benefit society and communities	Conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession.	The ACM code 1.7 says to respect the privacy of others. Because privacy is something that everyone holds dear we have a social responsibility to protect the people we are working for

7.2 Project Specific Professional Responsibility Areas

For each of the professional responsibility area in Table 1, discuss whether it applies in your project's professional context. Why yes or why not? How well is your team performing (High, Medium, Low, N/A) in each of the seven areas of professional responsibility, again in the context of your project. Justify.

[table 4: project specific professional responsibility areas]

Area of responsibility	*Does it apply in our project's professional context?*	*How well is your team performing in each of the seven areas of professional responsibility?*
Work Competence	Because the type of work we are doing is very high level networking and computing it is important that we are all aware of the types of things we are doing so that we do not end up making a mistake	High - We have all spent weeks researching and reading papers as well as meeting with people studying this topic to ensure we are competent.
Financial Responsibility	Our project does not have any real financial burden as most of it is computer code and free libraries	N/A - Most quantum networking technologies are open to the public, same as ours. Thus even though our network crashed, there is no financial responsibility we have to charge in. However, the reliability of a product depends on the success of an open source project, we should take care of.
Communication	Our project requires us to communicate with	High - we have strict guidelines in place as to

Honesty	people on high level topics. It is important that we are honest with them on any issues we are facing so that they are able to aid us. If we were not honest in how we communicated we would not understand the project and it would not be completed	how we communicate and what is expected of us. On top of this we give weekly updates to our advisor on what we have done the previous week
Health, Safety, Well Being	Our project does not involve any healthy or safety issues as it is all simulated code on our own computers. Because of this the risk of anyone's safety or wellbeing being damaged is very low(this is based on assumption that nobody will use our network for security application)	NA, or High - Based on the assumption that no one will use our simulated network for security applications such as alert network or emergency communication network, no one will get harm or in danger due to our product.
Property Ownership	Intellectual property rights are the primary concern here. There may be some hardware down the line but that will probably belong to Iowa State.	Medium - As of now we are only simulating our project on our own devices but when we move to other computers to simulate this we will need to understand the rules of the devices we are using and respect them.
Sustainability	Computing takes up the vast majority of resources produced on our planet. There is a major concern about the amount of power it would take to power a commercial level quantum computer. Currently this area is of little concern to us and we have not reached the realm of using actual quantum computers and are relying on classical computers simulating quantum properties.	Low - It's hard to find ways to use computers sustainably in the modern age. We could try to use sustainable power supplies or find ways to mitigate our power consumption but this is of little concern to us at this point in time.
Social Responsibility	There is some concern about the potential to do damage with the power behind a quantum computer. This is of little concern to us at the moment as we can only contribute very little to this potential problem. It will be something we will discuss as a group in the future.	Medium - the type of work we are doing is groundbreaking and could change a lot of current systems in place. It is important that we do our best to ensure we understand the work as well as document everything so that people can build off what we are doing.

7.3 Most Applicable Professional Responsibility Area

Work competence is important especially for projects such as quantum networking which requires a high level of understanding of physical, mathematical background and technical skills. In order to successfully build quantum networking, all team members have to have a high level of understanding of both physics and math, especially quantum physics and linear algebra, but also they have to know about computer networking, communication, and security. These combined skills are all required to build a quantum network.

Our team has been working on building a solid background for understanding current quantum networking and modifying it to make it better. For this, we have researched and studied individually for each specific area and shared our work at weekly meetings to learn at the same time. This work will be done for our future project schedule to enhance our work competence. We believe that by doing this, we could gain collective knowledge from quantum physics to computer networks which are all required for this project, and make reliable quantum networking.

8 Closing Material

8.1 Discussion

Discuss the main results of your project – for a product, discuss if the requirements are met, for experiments oriented project – what are the results of the experiment, if you were validating a hypothesis – did it work?

From our work, we successfully built the quantum teleportation circuit which is the essential building block for our advisor's future quantum cluster computing research. Our final product can use our own classical network which was impossible when we used Qiskit. It embraces the realistic quantum teleportation protocols. By using our work, we hope that other student senior design teams can start to build quantum cluster computing projects.

8.2 Conclusion

Summarize the work you have done so far. Briefly reiterate your goals. Then, reiterate the best plan of action (or solution) to achieving your goals. What constrained you from achieving these goals (if something did)? What could be done differently in a future design/implementation iteration to achieve these goals?

We built a quantum teleportation channel successfully. We pivoted our project from the beginning of this semester since we faced Qiskit's inability to meet our advisors' technical requirement, which is running a quantum teleportation circuit by parts while using our classical network. However, we succeeded in implementing their requirements in our final product and we expect that future students can start their work based on our quantum teleportation system.

8.3 References

List technical references and related work / market survey references. Do professional citation style (ex. IEEE).

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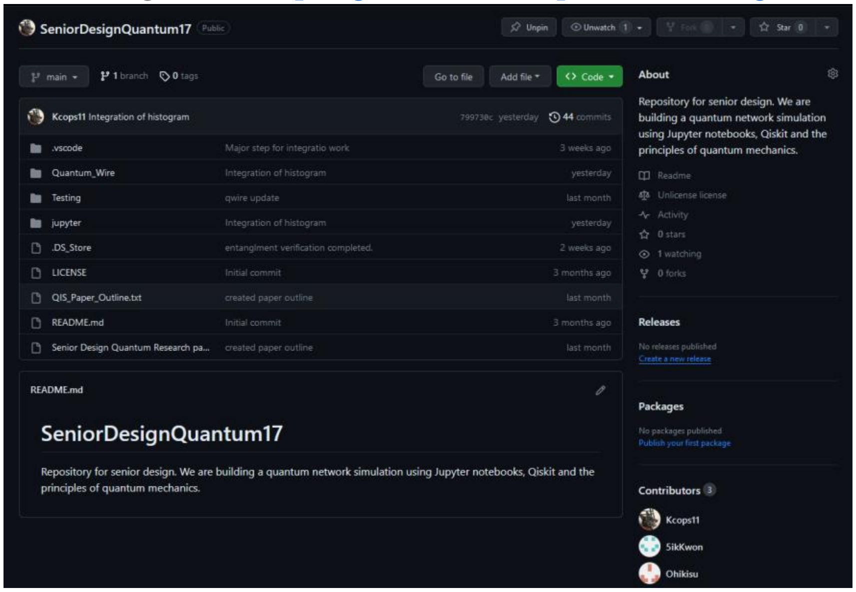
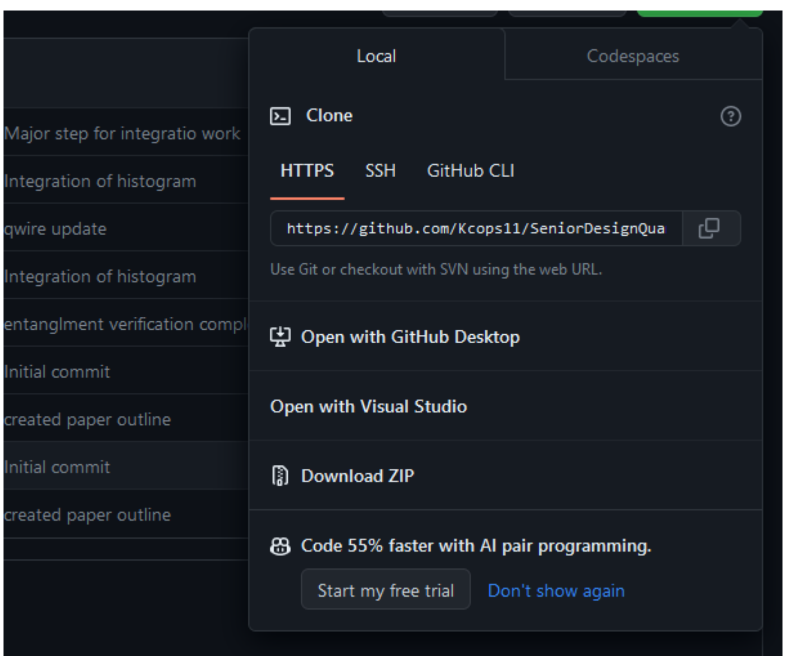
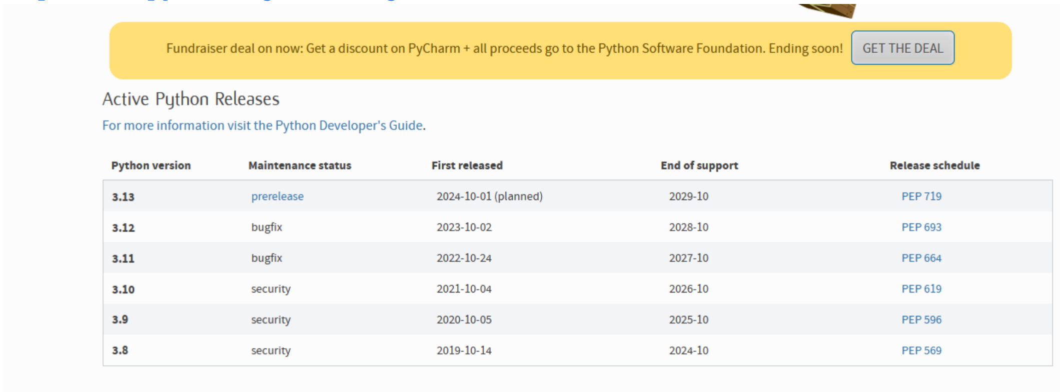
8.4 Appendices

8.4.1 Operation Manual

1. Clone the github
   1.1. https://github.com/Kcops11/SeniorDesignQuantum17
   1.2. clone with git clone https://github.com/Kcops11/SeniorDesignQuantum17
   1.3. 

   Github looks like above, if you see anything else, you are not in the right place

   1.4. 

2. **Install python within your cloned directory. Ideally you should be within SeniorDesignQuantum17\jupyter**
    2.1. https://wiki.python.org/moin/BeginnersGuide/Download
    2.2. 

Fundraiser deal on now: Get a discount on PyCharm + all proceeds go to the Python Software Foundation. Ending soon! GET THE DEAL

Active Python Releases

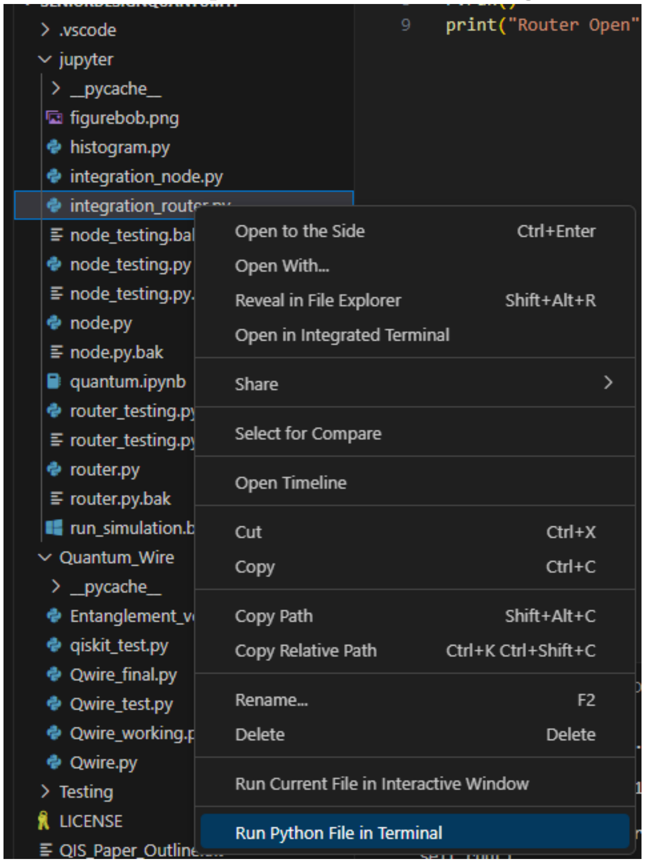
For more information visit the Python Developer's Guide.

Python version	Maintenance status	First released	End of support	Release schedule
3.13	prerelease	2024-10-01 (planned)	2029-10	PEP 719
3.12	bugfix	2023-10-02	2028-10	PEP 693
3.11	bugfix	2022-10-24	2027-10	PEP 664
3.10	security	2021-10-04	2026-10	PEP 619
3.9	security	2020-10-05	2025-10	PEP 596
3.8	security	2019-10-14	2024-10	PEP 569

Any of the current versions will work

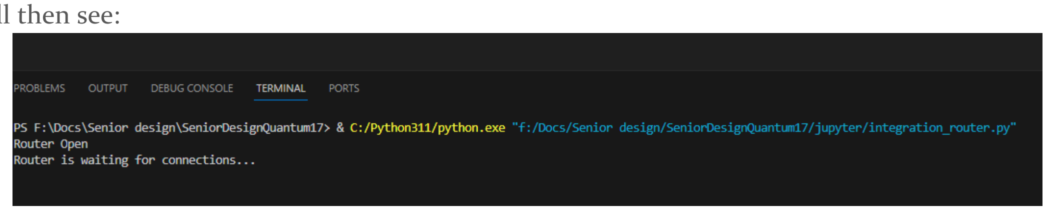
    2.3. You can check your Python version by running `python --version` or `python3 --version` in your terminal or command prompt
3. **Install pip**
    3.1. https://pip.pypa.io/en/stable/installation
    3.2. Ensure pip is up to date with
        3.2.1. python -m pip install --upgrade pip
4. **Install Qiskit**
    4.1. https://docs.quantum.ibm.com/start/install
    4.2. You can follow the guide above or simply run
        4.2.1. pip install qiskit
    4.3. Verify installation with
        4.3.1. import qiskit
        4.3.2. print(qiskit.__qiskit_version__)
5. Install matplotlib with
    5.1. https://matplotlib.org/stable/users/installing/index.html
    5.2. Or simply pip install matplotlib

6. Assuming you have installed everything correctly, you should be ready to run the simulation. Youre next step is to click on the following file:

6.1. 

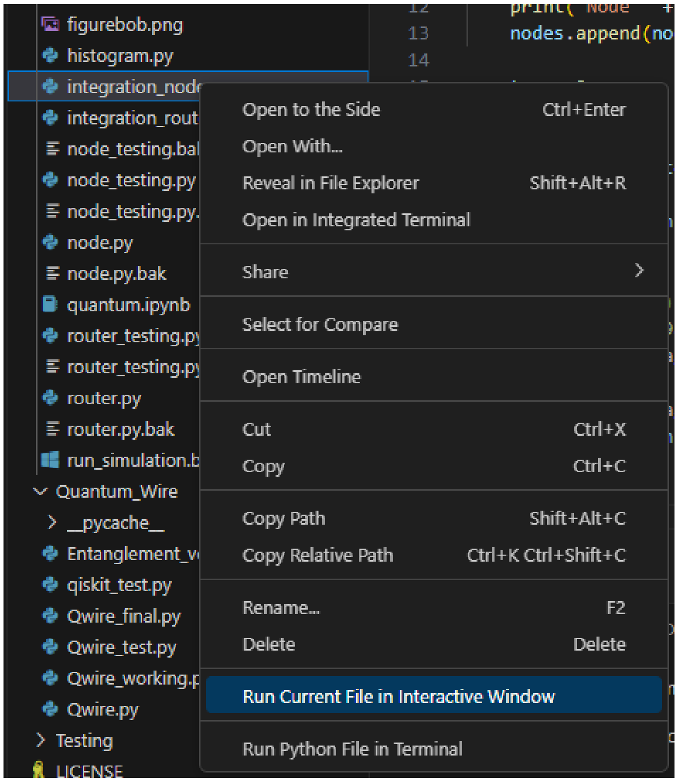
As you can see, you click on integration_router.py, and select run python file in terminal. IMPORTANT: THIS FILE NEEDS TO BE RAN FIRST

6.2. You will then see:

6.2.1. 

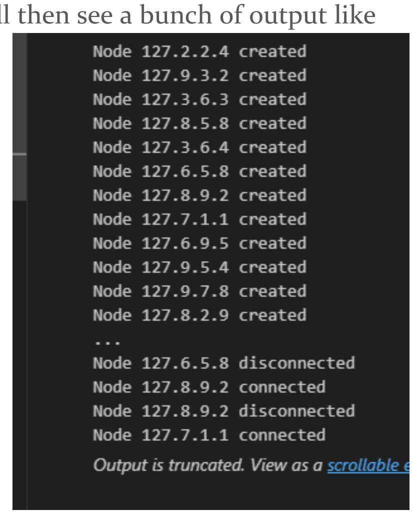
Router is waiting for connections

7. Next click on:

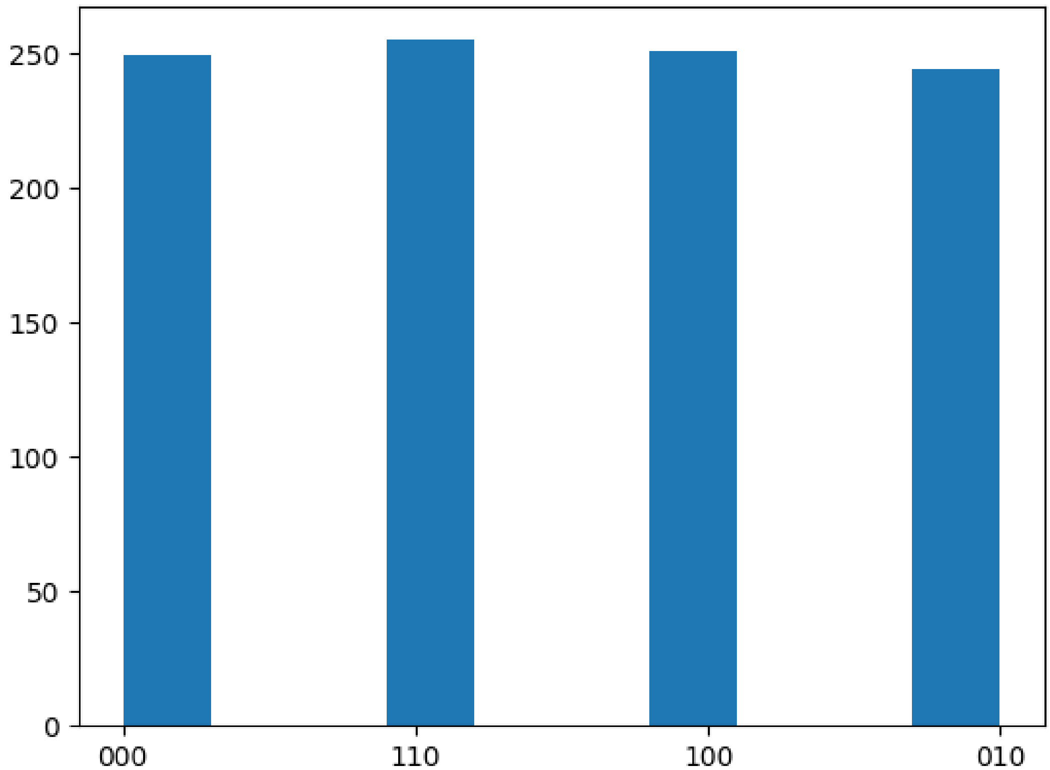
7.1. 

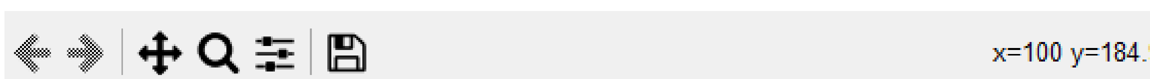
Click on integration_node.py and select run current file in interactive window. IMPORTANT: THIS FILE MUST BE RUN SECOND

7.2. You will then see a bunch of output like

7.2.1. 

8. After the program finishes running you will see the histogram:



8.1. 

8.4.2 Code

To view the most up to date code please visit our git repository:
https://github.com/Kcops11/SeniorDesignQuantum17

8.4.3 Team Contract

Team Members:

1) Benjamin Amick
2) Ohik Kwon
3) Steven Tompary
4) Derrick Wright

Team Procedures

1. Day, time, and location (face-to-face or virtual) for regular team meetings:

Every Thursday at 4 p.m. to 5 p.m. at the Student Innovation center with an advisor.
Every Monday 6 p.m. to 7 p.m. - team member only meeting
Every Friday 7 p.m. to 8 p.m. - team member only meeting

2. Preferred method of communication updates, reminders, issues, and scheduling (e.g., e-mail, phone, app, face-to-face):

Thursday meeting held in-person. Other two team meetings are on a team discord meeting.
Phone call communication is for emergencies only.
Other non-emergency communications are on Email.

3. Decision-making policy (e.g., consensus, majority vote):

Consensus is our base rule. If there were controversies, than majority vote will be used

4. Procedures for record keeping (i.e., who will keep meeting minutes, how will minutes be shared/archived):

Ben takes charge of recording meeting minutes and uploading our google drive.
Other team members also take notes if they think it is needed.

Participation Expectations

1. Expected individual attendance, punctuality, and participation at all team meetings:

We will expect all team members to attend all meetings or at least make the whole team aware if they will be missing or late.

2. Expected level of responsibility for fulfilling team assignments, timelines, and deadlines:

All team members are expected to prepare a 3 minute presentation which will be shared each Thursday to Dr. Pudyal. These presentations are expected to be short summaries of what we have each learned over the previous week. Team assignments are expected to be completed early so that everyone has a chance to review them before they are submitted.

3. Expected level of communication with other team members:

Team members will communicate with everyone using the discord or email to explain any absences or issues with completing their work.

4. Expected level of commitment to team decisions and tasks:

Every team member is expected to provide input on each team decision and tasks. If a certain member is feeling as though the team should go a different direction or there is some issue with tasks they are to bring it up with the group so it can be discussed at a meeting.

Leadership

1. Leadership roles for each team member (e.g., team organization, client interaction,

individual component design, testing, etc.):

Benjamin Amick - Communication with Client, recording meeting minutes. Design of usable Quantum Key Distribution for our simulated quantum network.
Ohik Kwon- Writing weekly reports. Making quantum gates for our quantum network simulations.
Derrik Wright - Compiling weekly reports and minutes into the team website, researching Qiskit framework and understanding base level quantum computational gates.
Steven Tompary - Compiling weekly reports and minutes into the team website, Creating a quantum network simulation using Qiskit.

2. Strategies for supporting and guiding the work of all team members:

Since our senior design consists of two sections which are building networks and building systems, if someone in one field struggled then communicate within each section and help each other to handle problems. When one section has tough issues which can not be solved easily, then share their situation in meetings and solve them together.

3. Strategies for recognizing the contributions of all team members:

Share our current work such as what is currently working(building) on and what have been tried for last week and results during a weekly meeting with advisor and team meetings.
Use a time tracker excel sheet for updating how many times we put on our senior project and updating works we have completed.

Collaboration and Inclusion

1. Describe the skills, expertise, and unique perspectives each team member brings to the

team.

Ben: Network engineering experience, understanding of currently used key distribution techniques
Ohik: Knowledge of Quantum Computation and
Steven: Network engineering experience, has done work with creating and simulating up new networks as well as key distribution algorithms
Derrik: Software development skills, has knowledge of quantum information systems

2. Strategies for encouraging and support contributions and ideas from all team members:

Self motivation is important for this project since simulating quantum networks requires not just quantum mechanics and science but also information communication systems. If someone were losing their interest in this project due to too much reading materials and study, then other team members can assist, help, and teach each other to keep us at the same level of understanding.

3. Procedures for identifying and resolving collaboration or inclusion issues (e.g., how will a team member inform the team that the team environment is obstructing their opportunity or ability to contribute?)

If someone in our team has an issue they are to bring it up at the next team meeting and the group will work together to find a solution to the problem. The group will make an effort so that each team member feels valued and is able to contribute to the project.

Goal-Setting, Planning, and Execution

1. Team goals for this semester:

Our goal for this semester is researching and understanding quantum computing to the point where we are able to design our own simulation of a quantum network.

2. Strategies for planning and assigning individual and team work:

Our plans include reaching out to professionals who are well versed in Quantum networking as well as read textbooks and papers which they recommend.

3. Strategies for keeping on task:

To keep the group on track, we are going to have weekly presentations to our advisor on what we accomplished the past week and include a summary of what we learned.

Consequences for Not Adhering to Team Contract

1. How will you handle infractions of any of the obligations of this team contract?

Any team member not adhering to this contract will be asked to provide context as to why they were not performing their duties. On top of this, they will be expected to pick up extra work the next week so that the team does not fall behind.

2. What will your team do if the infractions continue?

If issues continue, then we will take matters to the professor and seek further guidance.

****

a) I participated in formulating the standards, roles, and procedures as stated in this contract.

b) I understand that I am obligated to abide by these terms and conditions.

c) I understand that if I do not abide by these terms and conditions, I will suffer the consequences as stated in this contract.

1) Benjamin Amick	DATE 2/19/2023
2) Ohik Kwon	DATE 2/19/2023
3) Steven Tompary	DATE 2/19/2023
4) Derrick Wright	DATE 2/19/2023