This file contains guidelines to run the SQripT toolbox.

**Pre-requisite installations needed**


4. Matplotlib for Python 2.7  [https://pypi.python.org/pypi/matplotlib](https://pypi.python.org/pypi/matplotlib)

**Running the Code**

For the performance simulations of given benchmark circuit, please open, edit and run the corresponding *config.py file as listed below. The configuration variables are explained in the comments and can be understood more thoroughly by referring to my thesis (available in the same folder)

Adder_input_config.py: QCLA, QRCA circuit

QFT_input_config.py: AQFT circuit

The output is displayed on the python Idle window (if the program was run using Python Idle) or command prompt (if the program was run in command window/terminal as >> python Adder_input_config.py or >> python QFT_input_config.py) below the string 'Begin Printing Statistics'. The output is also stored in the more user friendly output file: Output_Statistics.txt

For questions, send an e-mail to ahsan_naeem70@yahoo.com
Explanation of Input Configuration Variables

Circuit input parameters

1. **Adder_name** [type: string]
   Name of the adder circuit to be analyzed for resource performance trade-offs.
   Valid options: ‘QCLA’, ‘QRCA’

2. **Adder_size** [type: positive integer]
   Size of the adder circuit to be analyzed for resource performance trade-offs.
   Valid options: 8, 16, 32, 64, 128, 256, 512, 1024, 2048

3. **QFT_size** [type: positive integer]
   Size of the Quantum Fourier Transform QFT circuit to be analyzed for resource performance trade-offs.
   Valid options: ≥ 2. Typical input values tend to be powers of 2.

4. **Approx** [type: positive integer]
   Specifies d in Approximate Quantum Fourier Transform which truncates arbitrary z-rotation: Rz (π/2^k) to Rz (π/2^d) where d ≤ k. This input is specific to the Quantum Fourier Transform circuit.
   See section 7.2.2 of the thesis for details.
   Valid options: ≥ 1.

5. **Approx_inaccuracy** [type: float]
   Specifies how accurately a z-rotation gate Rz (π/2^k) is approximated using a sequence of single-qubit Clifford and π/8 (or T) gates. This input is specific to the Quantum Fourier Transform circuit.
   See section 7.2.2 of the thesis for details.
   Valid options: > 0 and < 1.

6. **Clifford_T_ratio** [type: float]
   Average number of sing-qubit Clifford gates before the occurrence of the π/8 gate (or its inverse gate) in the z-rotation gate approximation sequence\(^1\).
   Valid options: > 1.

7. **EC_after_T_gates** [type: positive integer]
   Specifies after how many π/8 gates should error correction is inserted in the approximation sequence.
   Valid options: > 1 and < total π/8 gates in the sequence.

8. **concat_layer** [type: positive integer]

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\(^1\)https://www.google.com/fusiontables/DataSource?docid=1t4wMvvYKiRs1VUbsrHg70nXIbV8DjEtA5oJlbk#card:id=2
Number of concatenation layers of Steane [[7, 1, 3]] encoding.
Valid options: 1 or 2

**Architecture parameters inputs**

9. **Data_Tiles** [type: positive integer]
   Minimum number of Data Tiles per Segment. See section 7.3.2 of the thesis.
   Valid options: ≤ maximum number of logical data qubits in the application circuit.

10. **Ancilla_Tiles** [type: positive integer]
    Minimum number of Ancilla Tiles per Segment. See section 7.3.2 of the thesis.
    Valid options: ≥ 4 for ‘QCLA’, ‘QRCA’ and ≥ 1 for ‘AQFT’.

11. **Comm_Tiles** [type: positive integer]
    Minimum number of Communication Tiles per Segment. See section 7.3.2 of the thesis.
    Valid options: ≥ 1

12. **Num_Fac** [type: positive integer]
    Minimum number of Computational Segments (section 7.3.2 of the thesis) in the system. See section 7.3.2 of the thesis.
    Valid options: ≥ 1

13. **Segment_Budget** [type: positive integer]
    Upper bound on total number of qubits to be clustered in the Segment. See section 7.5.3 of the thesis.
    Valid options: Should be commensurate\(^2\) with Data_Tiles, Ancilla_Tiles, Comm_Tiles in the Segment and Total_Budget specified. Use float(‘inf’) to let simulator set the default value.

14. **Total_Budget** [type: positive integer]
    Upper bound on total number of qubits to be clustered in the quantum computer. See section 7.5.3 of the thesis.
    Valid options: Should be commensurate with Segment_Budget and Num_Fac specified. Use float(‘inf’) to let simulator set the default value.

15. **LO_L1** [type: list of two positive integers]
    A list of form [x,y] describing the 2D- grid of the L1 Tile containing physical (LO) qubit storage cells. The product xy should be larger than the total physical qubits to be clustered in the Tile. See section 7.3.2 of the thesis for details.

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\(^2\) In the code example, an L1 Data Tile contains 7+15 = 22 qubits, Ancilla Tile contains 15 qubits while Communication Tile contains 7+7+15=29 qubits
Valid options: \([x>0, y>0]\). For Steane L1 Tile, \(x, y\) may be assigned integer 5-8 depending upon the number of resident Ancilla qubits to be used in error correction as well as temporarily storing non-local logical qubit for the logical CNOT.

16. **L1_L2** [type: list of two positive integers]
   A list of form \([x, y]\) describing the 2D- grid of the L2 Tile containing L1 Tiles. The product \(xy\) should be larger than the total L1 Tiles to be clustered in the L2 Tile. This input is used only if concat_layer = 2. See section 7.3.2 of the thesis for details.
   Valid options: \([x>0, y>0]\). For Steane L2 Tile, \(x, y\) may be assigned integer 5-8 depending upon the number of resident Ancilla Tiles to be used in error correction as well as temporarily storing non-local logical qubit for the logical CNOT.

17. **Lower_Level_Data_Ancilla** [type: list of two positive integers]
   A list of form \([x, y]\) describing the composition of Li Tile in terms of Data and Ancilla in order to construct Li+1 Tile. Here \(x\) specifies number of Data qubits (or Tiles) while \(y\) specifies number of Ancilla qubits (or Tiles). See section 7.3.2 of the thesis for details.
   Valid options: \([x>0, y>0]\). For Steane code Tile, \(x\) is 7 while \(y\) can be anywhere 5 to 30 when using Shor type error correction.

18. **Top_level_Anc_Size** [type: positive integer]
   Number of Li Tiles/qubits to be clustered in an Li+1 Ancilla Tile to be employed as Li+1 error correction for logical Data and Communication e-bit or for magic state preparation in association with other Li+1 Ancilla Tiles. See section 7.3.2 of the thesis for details.
   Valid options: > 12. In the example code, this input is set to 15 so that Li+1 Ancilla Tile can hold logical qubit which acts as operand for magic-state and can act as correction resource for Data, Communication.

### Device parameters inputs

19. **Tgen_glob** [type: positive integer or floating point]
   Time taken (in us) to generate photon assisted EPR pair generation to connect different Segment using an optical switch. See section 7.3.1 of the thesis.
   Valid options: > 0. State of art experiment in heralded entanglement suggests that this value should be 2 to 3 orders of magnitude higher than physical gate time.

20. **OS_Ports** [type: positive integer]
   Number of optical switch ports to connect segments using heralded entanglement. See section 7.3.1 of the thesis.
   Valid options: > 0. A 1000 port optical switch have been demonstrated experimentally.

21. **OS_hierarchy_latency_factor** [type: positive integer or floating point]
   Constant multiplying factor describing increased latency in generating an EPR pair through more than one optical switches in the quantum computer communication network. See section 7.3.1 of the thesis.
   Valid options: > 0. State of art experiments suggest 2 or 3 can be the adequate input values.
22. **T_shutt** [type: positive integer or float]
   Time taken (in us) by an ion to physically move between two adjacent ion trap cells in the Tile.
   See chapter 6, 7 (simulator, 2015).
   Valid options: > 0. State of art experiments suggest 1 - 10 can be the adequate input values.

23. **mem_coherence_time** [type: positive integer or float]
   Time (in seconds) for which an ion can retain its correct quantum mechanical state when it undergoes no-operation (I gate). The fidelity $f$ of an ion qubit is assumed to degrade as $f = e^{-at}$ where $t$ is the time (in seconds) for which qubit sits idle while $a = 1/mem_coherence_time$. See section 7.3.1 of thesis.
   Valid options: > 0. State of art experiments suggest 10 - 100 can be the adequate input values.

24. **Physical_err** [type: float]
   The failure probability of physical quantum gate or measurement. All physical operations are assumed to have this fixed failure probability value.
   Valid options: > 0 and < 1. State of experiments can achieve $10^{-6}$ to $10^{-3}$ for different physical quantum operations demonstrated in the trapped ion hardware. However, the simulations in (simulator, 2015) assume optimistic value: $10^{-7}$.

25. **EPR_phys_err** [type: float]
   The failure probability of EPR pair generated through heralded entanglement using optical switch.
   Valid options: > 0 and < 1. The simulations in Ref (simulator, 2015) assume optimistic value: $10^{-4}$.

26. **BPFP** [type: positive integer]
   A positive integer counting the number of ways an error correction step introduces a single error in the logical qubit. See section 4.7 and 4.13 of the thesis for details.
   Valid options: > 0.

27. **BPFP_x** [type: positive integer]
   A positive integer counting the number of ways a logical operation $x$ step introduces a single error in the logical qubit. See section 4.7 and 4.13 of the thesis for details.
   Valid options: > 0.

28. **Threshold_BPFP** [type: positive integer]
   A positive integer setting a threshold value which specifies when to apply error correction on the logical qubit. An error correction in inserted when *Threshold_BPFP* exceeds BPFP of the logical qubit. After error correction *Threshold_BPFP* is set to BPFP. See 4.13 of thesis for details.
   Valid options: > 0.

29. **L1_EC_Time** [type: float]
   The execution time (in us) of L1 error correction. Used when *concat_layer* = 2. This input can be pre-computed using TDPA or provided directly.
   Valid option: > 0.
30. $T_x$ [type: float]
   The execution time in (us) of top layer (L1 or L2 as specified by concat_layer) encoded operation $x$. This input can be pre-computed using TDPA or provided directly.
   Valid option: $>$ 0.

31. $err_p$ [type: float]
   The failure probability of top layer (L1 or L2 as specified by concat_layer) encoded operation $x$.
   This input can be pre-computed using TDPA or provided directly.
   Valid option: $>$ 0 and $<$ 1.

Visualization parameter input

32. Vis_En [type: boolean]
   A Boolean variable which enables or disables visualization plots in the output. Details on visualization can be found in section 4.15 while example demonstration in section 7.5.2 of the thesis.
   Valid options: True enables visualization and False disables visualization. Note that total run time may increase up to seven times if Vis_En = True.

Explanation of Output Variables

1. **Total execution time**: The total execution time (latency) of the input quantum circuit
2. **Ancilla preparation latency**: The execution time component of the critical path (section 4.14 of the thesis) spent in preparing magic-state for non-Clifford gates (see section 7.4 of the thesis).
3. **Shuttling latency**: The execution time component of the critical path spent in ballistic shuttling of ion qubits for intra-Segment gates (see section 7.4 of the thesis).
4. **Teleportation and purification latency**: The execution time component of the critical path spent in generating and purifying EPR pairs for inter-Segment CNOT gates (see section 7.4 of the thesis).
5. **Latency due to the unavailability of T Ancilla**: The execution time component of the critical path spent in waiting for the Ancilla Tile to be available for prepare $T|+>$ magic-state preparation (used in AQFT circuit)
6. **Latency due to the unavailability of EC Ancilla**: The execution time component of the critical path spent in waiting for the Ancilla Tile to be available for performing error-correction on Data Tiles (see section 7.4 of the thesis).
7. **Cross-Segment Transfer latency**: The execution time component of the critical path spent in reliably teleporting operand logical qubit to the Computation Segment (see section 7.4 of the thesis). This output is specific to the adder circuits.
8. **High level error correction latency**: The execution time component of the critical path spent in reliably performing error correction (see section 7.4 of the thesis).
9. **Gate latency**: The execution time component of the critical path spent in application-level quantum gates (see section 7.4 of the thesis).
10. **Total Failure Probability**: The probability that quantum circuit execution fails to give correct output (see section 7.4 of the thesis).

11. **Teleportation noise**: The component of total failure probability incurred due to the infidelity of EPR pairs for cross-Segment communication (see section 7.4 of the thesis).

12. **Shuttling noise**: The component of total failure probability incurred due to the infidelity of ballistic channel for qubit-qubit communication localized to the Segment (see section 7.4 of the thesis).

13. **Memory noise**: The component of total failure probability incurred when logical qubit sits idle (see section 7.4 of the thesis).

14. **Noise due to T gates**: The component of total failure probability incurred due to the infidelity of fault-tolerant z-rotation gate \(R_z(\pi/2^k)\).

15. **Approximation inaccuracy**: The component of total failure probability due to the inaccuracy of approximating \(R_z(\pi/2^k)\) using \(\pi/8\) gate and single-qubit Clifford gates.

16. **Gate noise**: In case of AQFT, it reflects the component of total failure probability due to the infidelity of application-level Clifford gates. In case of adders, \(Gate\_noise\) captures total infidelity due to all application-level gates (see section 7.4 of the thesis).