Communication Trade Offs in Intermediate Qudit Circuits

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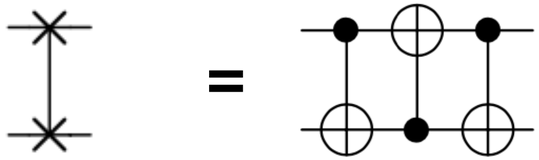
Outline

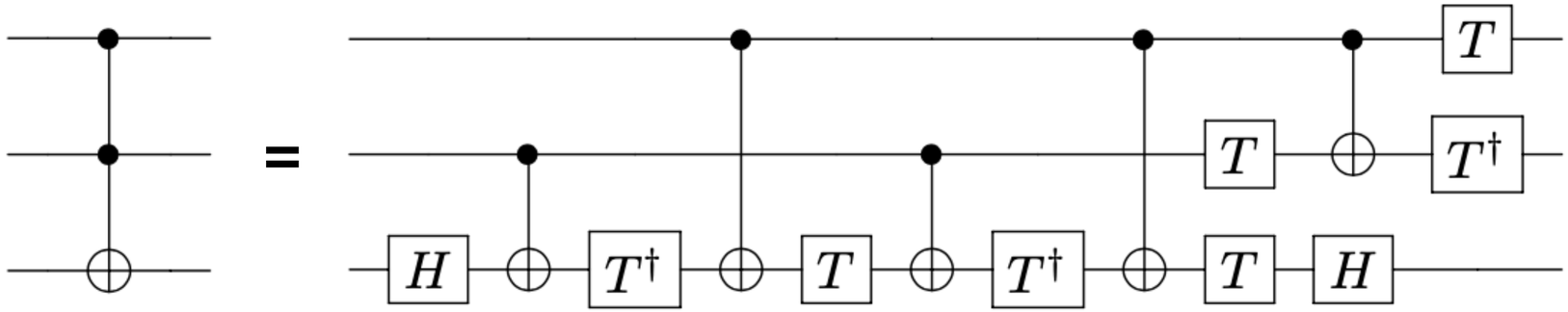
1. Current Intermediate Qutrit Circuits
2. Higher Radix Qudit Circuits
3. Compilation
4. Evaluation

Quantum Circuits and Hardware

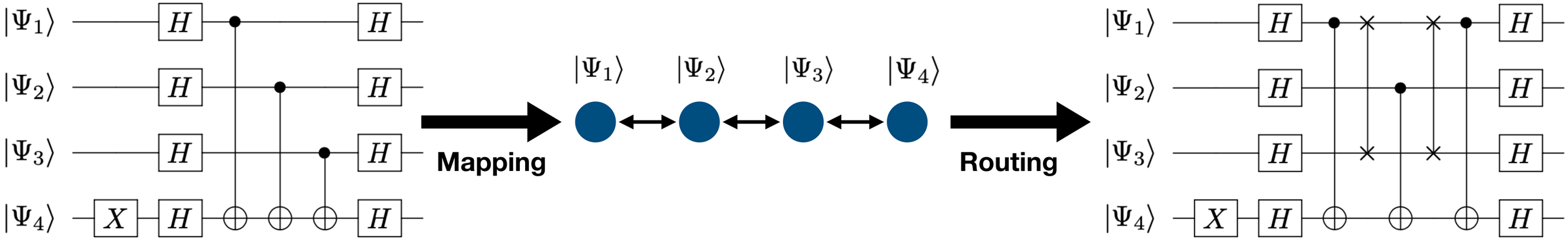
Qubit Swap



Toffoli Gate



Quantum Circuits and Hardware

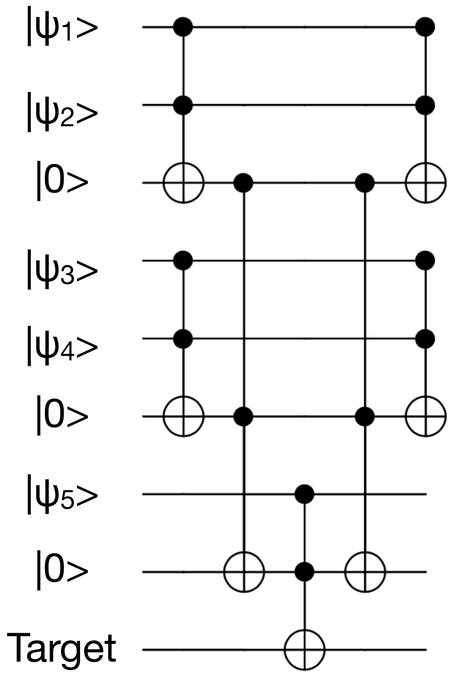


Qubit to Qutrit Circuits

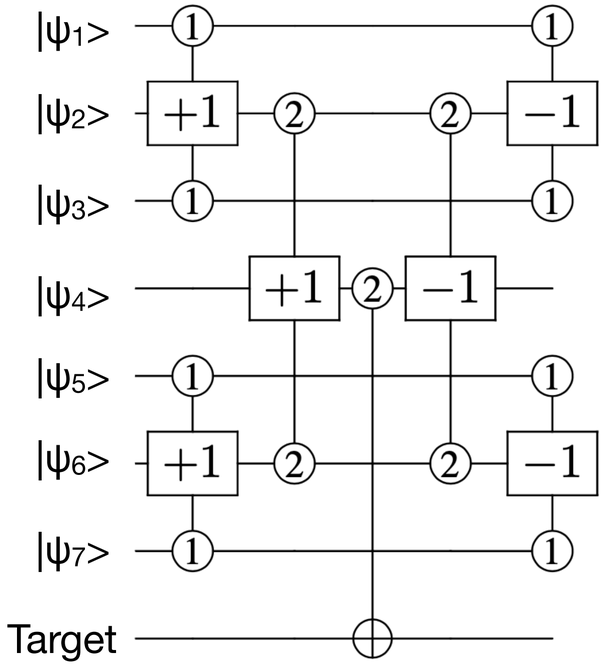
Qudit Levels	Interaction Time (ns)	Swap Time (ns)
1	30	-
2	50	-
3	50	-
4	50	-
0, 1*	150	600
0, 2	500	1200
0, 3	500	1500
0, 4	600	1800
1, 1	500	900
1, 2	500	1200
1, 3	500	1500
1, 4*	600	1800
2, 2*	675	2950
2, 3	850	5000
2, 4*	1025	7050
3, 3	850	5000
3, 4*	1025	7050
4, 4*	1200	7500

TABLE I: Times used for various gates across different levels of qudits. An asterisk indicates an interpolated value.

Qubit to Qutrit Circuits



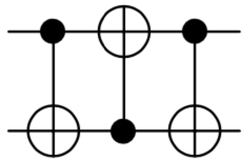
5 Control Qubit Generalized Toffoli Uses 9 Qubits



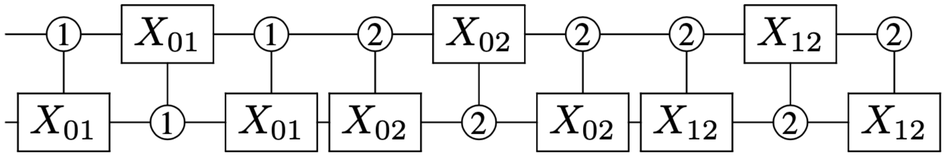
7 Control Qutrit Generalized Toffoli Uses 8 Qutrits

Higher Radix Communication

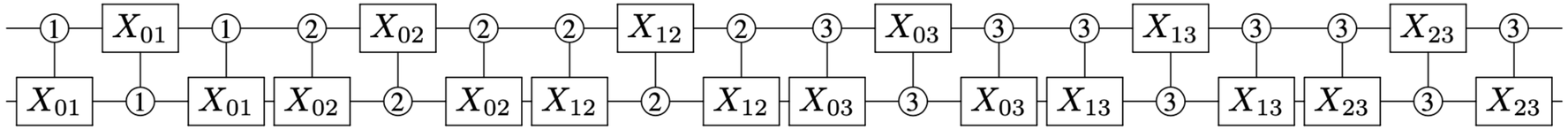
Qubit Swap



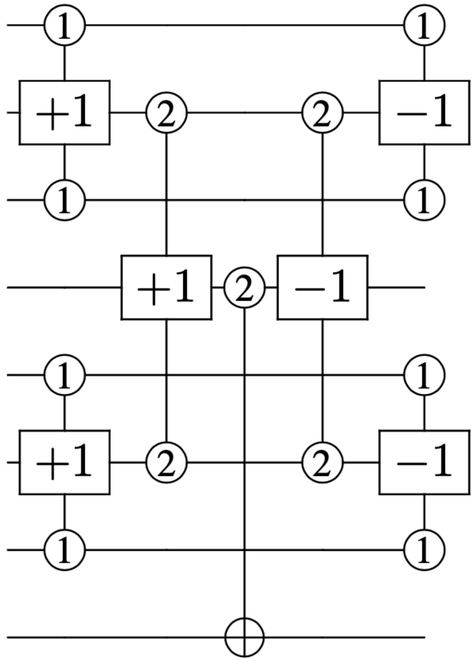
Qutrit Swap

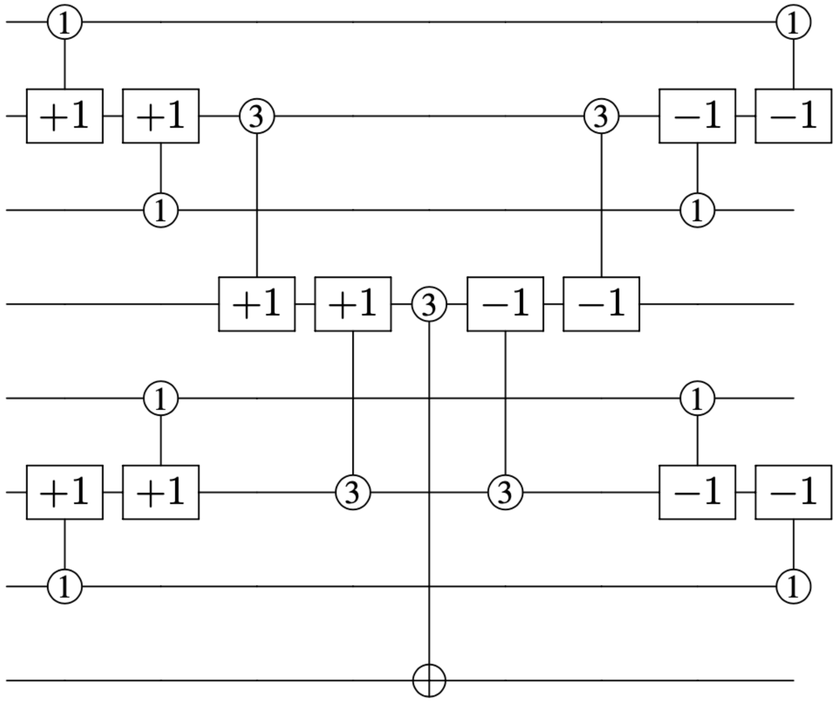


Ququart Swap



Arbitrary Qudit Circuits

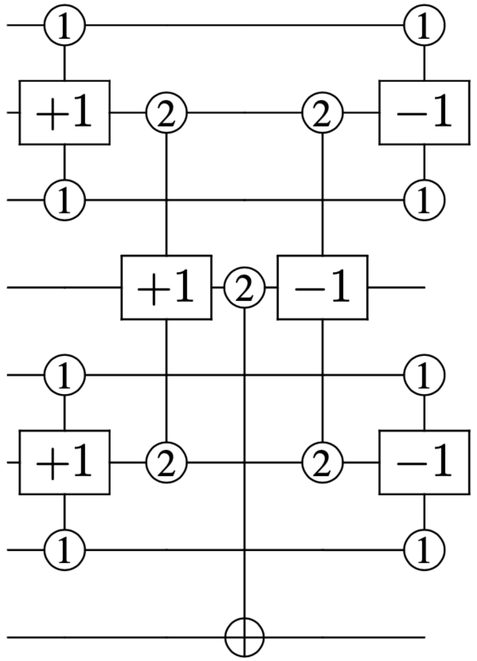




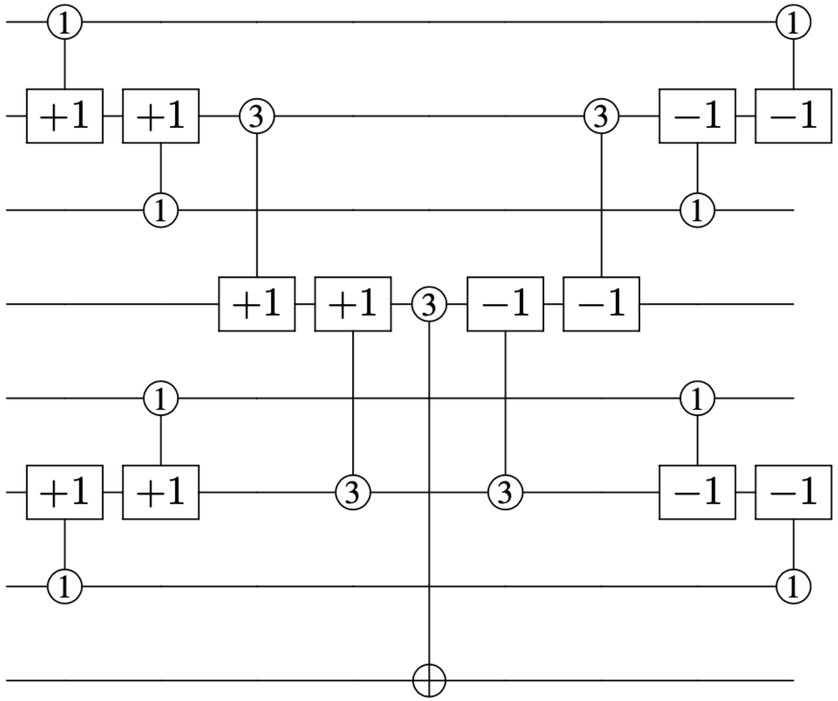
7 Control Qutrit

7 Controls Ququart

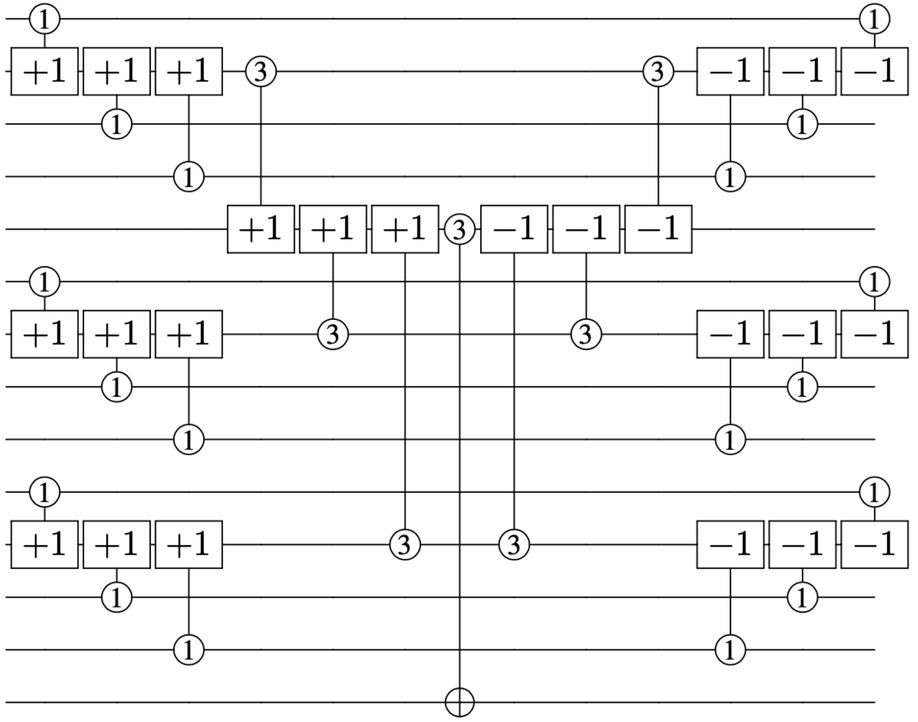
Arbitrary Qudit Circuits



7 Control Qutrit



7 Controls Ququart



13 Control Ququint

Compilation with Higher Radix Qudits

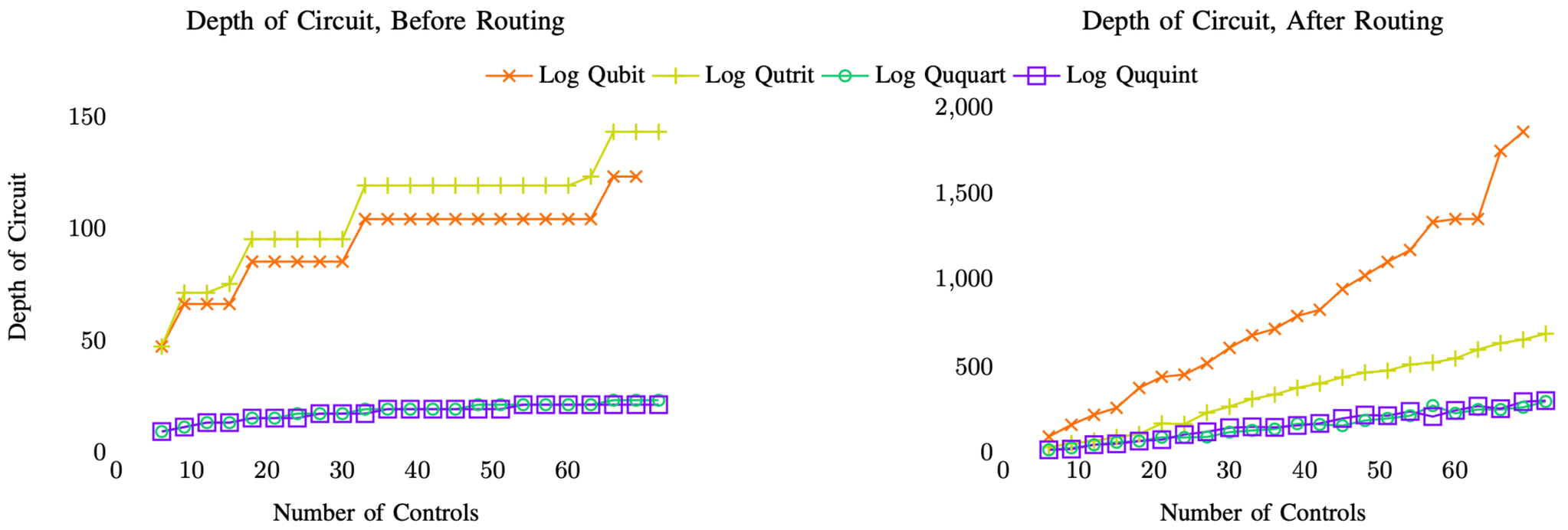
Routing Scores

$$s(Q, w, d) = \sum_{u,v \in Q \times Q} w(u, v) \times d(\varphi(u), \varphi(v))$$

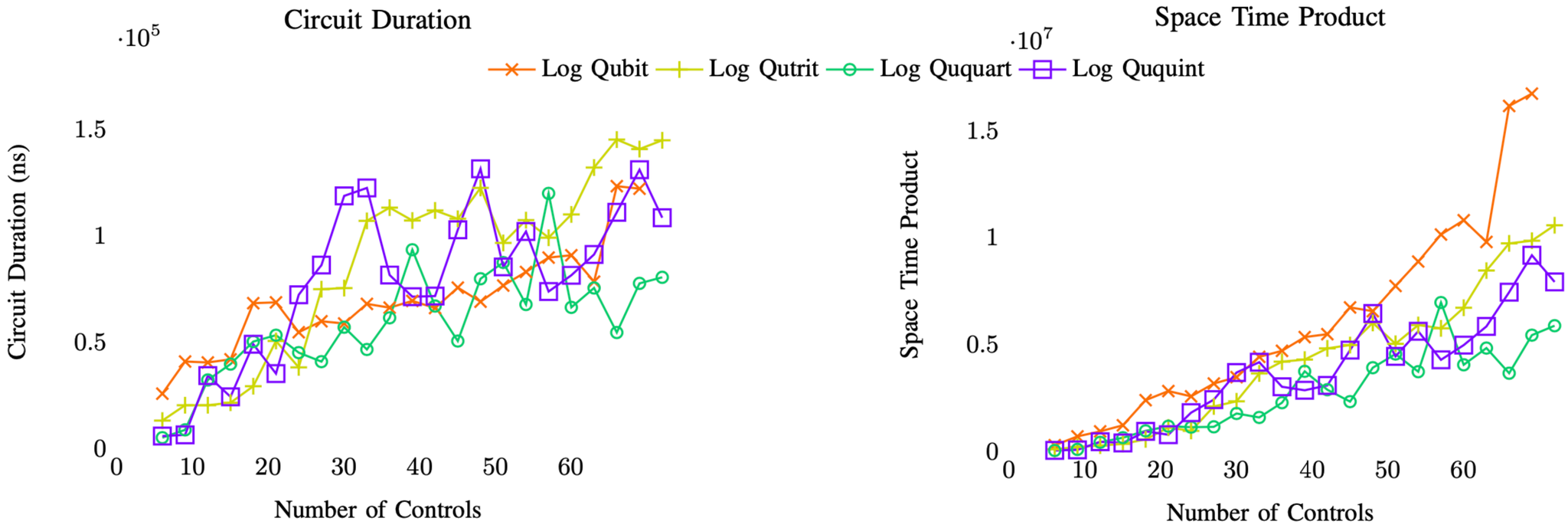
Q: Circuit Qubits
w(u, v): Number of remaining operations between qubits u and v
d: Time to swap from location 1 to 2.
φ: Qubit to current architectural location

Evaluation

Evaluation


Depth of Circuit, Before Routing
Log Qubit
Log Qutrit
Log Ququart
Log Ququint
Depth of Circuit
150
100
50
0
0
10
20
30
40
50
60
Number of Controls
Depth of Circuit, After Routing
2,000
1,500
1,000
500
0
0
10
20
30
40
50
60
Number of Controls

Evaluation


Circuit Duration
$\cdot 10^5$
Log Qubit
Log Qutrit
Log Ququart
Log Ququint
Circuit Duration (ns)
1.5
1
0.5
0
0
10
20
30
40
50
60
Number of Controls
Space Time Product
$\cdot 10^7$
Space Time Product
1.5
1
0.5
0
0
10
20
30
40
50
60
Number of Controls

Conclusion

- Increased Higher radix communication operations scale quadratically
- Intermediate qudit circuits can be constructed that reduce gate count and circuit depth
- Reductions in gate count from intermediate qudit circuits do not necessarily outweigh increased time, and provide additional computational space for larger quantum circuits.