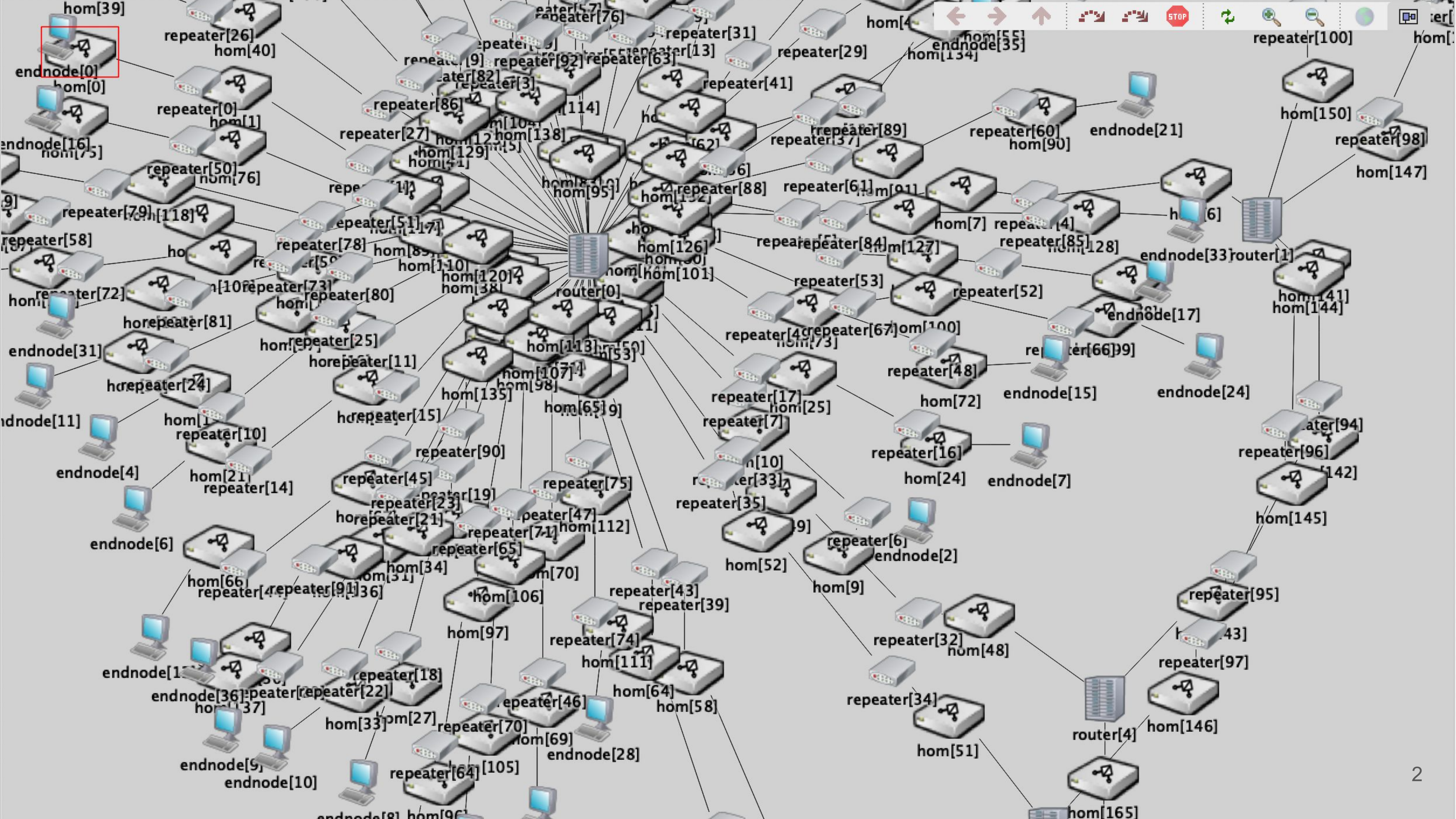
QuISP: Quantum Internet Simulation Package (open source!)

Rod Van Meter

QIRG virtual meeting 2020/4/8

https://aqua.sfc.wide.ad.jp/quisp_website/


hom[39]
repeater[26]
hom[40]
endnode[0]
hom[0]
repeater[0]
hom[1]
endnode[16]
repeater[50]
hom[76]
repeater[79]
repeater[58]
repeater[72]
endnode[31]
repeater[81]
repeater[25]
repeater[24]
repeater[11]
repeater[10]
endnode[4]
repeater[14]
endnode[6]
repeater[15]
repeater[90]
repeater[45]
repeater[23]
repeater[21]
repeater[19]
repeater[75]
repeater[47]
repeater[71]
repeater[65]
hom[34]
hom[66]
repeater[91]
hom[106]
hom[97]
endnode[36]
hom[33]
hom[27]
repeater[18]
repeater[22]
endnode[9]
endnode[10]
repeater[64]
hom[105]
repeater[70]
repeater[46]
hom[69]
endnode[28]
repeater[74]
hom[111]
hom[64]
hom[58]
repeater[43]
repeater[39]
hom[112]
hom[70]
hom[135]
hom[98]
hom[65]
hom[107]
hom[113]
hom[120]
router[0]
hom[101]
hom[126]
hom[95]
hom[129]
hom[138]
repeater[27]
repeater[86]
repeater[3]
repeater[92]
repeater[63]
repeater[13]
repeater[31]
repeater[76]
repeater[41]
repeater[29]
repeater[88]
repeater[61]
repeater[37]
repeater[89]
repeater[84]
repeater[53]
repeater[52]
repeater[67]
repeater[17]
hom[25]
repeater[7]
repeater[33]
repeater[35]
hom[52]
hom[9]
repeater[6]
endnode[2]
repeater[32]
hom[48]
repeater[34]
hom[51]
router[4]
hom[165]
hom[146]
repeater[97]
repeater[95]
hom[145]
repeater[96]
repeater[94]
router[1]
hom[141]
hom[144]
endnode[33]
endnode[17]
endnode[24]
endnode[15]
repeater[48]
hom[72]
repeater[16]
hom[24]
endnode[7]
hom[100]
hom[127]
hom[128]
repeater[85]
hom[7]
repeater[60]
hom[90]
endnode[21]
hom[150]
repeater[100]
repeater[98]
hom[147]
endnode[35]
hom[134]
repeater[80]
repeater[78]
repeater[73]
repeater[51]
hom[114]

Research Questions

- Emergent behavior
  - quantum congestion collapse?
- Protocol design
  - condition-action (like SDN match-action)
  - emphasis on classical messaging, eliminating latencies
- Connection architecture and performance prediction
  - studies of 2G & 3G networks, evolving technology, logical & physical heterogeneity
- Dynamic behavior
  - link state changes, traffic pattern changes

Repeater Generations

- 1G: Entanglement ACKnowledged link layer,
  purification (error detection),
  entanglement swapping
- 2G: Entanglement ACKnowledged link layer,
  quantum error correction (QEC),
  entanglement swapping
- 3G: Un-acknowledged link layer,
  quantum error correction,
  store-and-forward
- https://www.nature.com/articles/srep20463

Writing It Down: Quantum State Representations

Representation	Description	Scaling
Full state vector	every entry 000...0 to 111...1; pure states (no error) only	O(2^n)
Dirac's ket notation $\|\psi\rangle$	sparse representation of state vector (also used for variable names)	<< O(2^n) sometimes
von Neumann's density matrix	pure or mixed (error) states (sparse representations also possible)	O(4^n)
stabilizer	shorthand for specific states, specifies *constraints* on states (eigenoperators)	O(n) to O(n^2)
tensor networks	tree-based, memoization-like	dependent on the amount of entanglement: up to 56 qubits, maybe 100 for *very* special cases achievable
error basis	**track only errors, not states (useful for developing quantum error correction)**	**O(n) for Pauli (symmetric) errors; complex processing for others**

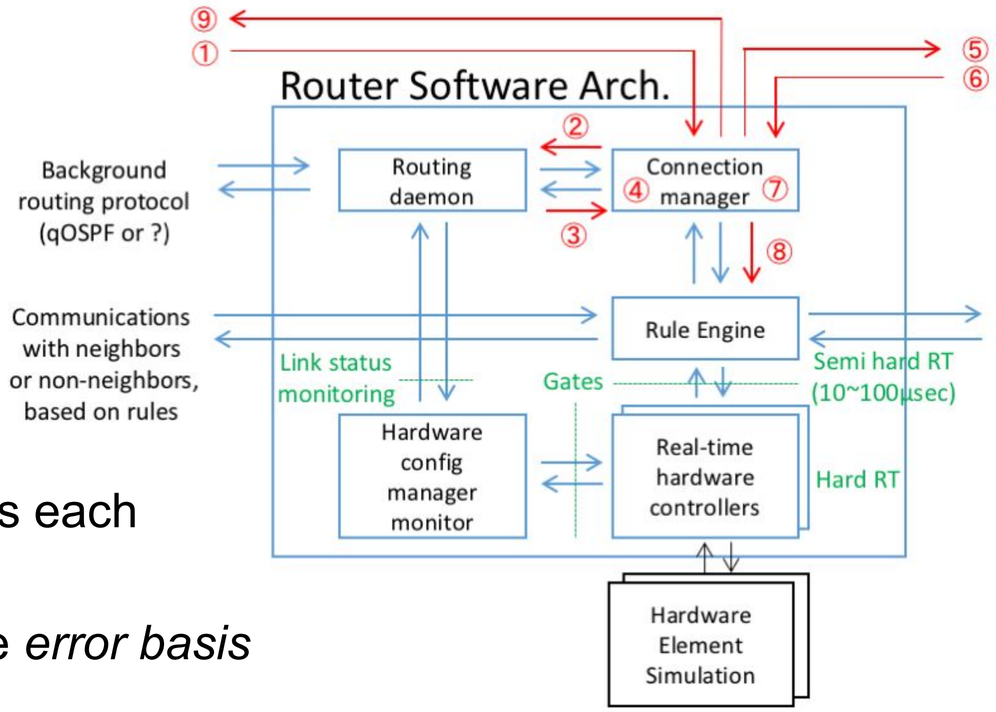
Scaling Quantum Simulation

If you want physical simulation, including asymmetric error processes, you need *density matrix* sim. # of qubits in a single entangled state gives exponential memory growth (16*2^(2n) bytes):

# qubits in state	density matrix size
2 (e.g., Bell pair, simplest two-qubit entangled state)	128B
7 (simple error corrected state)	8KB
14 (Bell pair over simple error correction)	256KB
28 (two Bell pairs over simple error correction)	64PB (7.2E16 Bytes)
825 (application qubits for Quantum Byzantine Agreement, 5 nodes)	3.6E249 Bytes
5,000 (Bell pairs over advanced QEC across 100 hops)	3.2E3011 Bytes (not a typo)

n.b.: many caveats, shortcuts for special cases; this is worst case

QuISP Strengths



- Scalability: ultimate target is
  100 networks of 100 nodes, 100 qubits each
  = 1 million qubits
  - made possible by operating in the *error basis*
- Clear node internal software structure
  - excellent for working on classical protocols
  - good for repeater/router software development
- Endless configurability
- Animations, inspector, etc. all built on OMNeT++ capabilities

QuISP Weak Points

- not tuned for very low-level simulation of physical processes
  (but does have model of both “Pauli” (symmetric error channel) and
  “non-Pauli” (loss, asymmetric error channel) errors)
- steep learning curve
- installation is a pain (mostly due to OMNeT++)
- many features still in development

Not-Really-A-Comparison

Name	focus	availability
SimulaQron	intro to concepts	via web
NetSquid	building up from solid physical model	open source (pip) coming?
SQUANCH	distributed app development	open source (pip)
SeQueNCe	?similar to QuISP?	?
QuNetSim	good for app prototyping (pure states only)	open source (pip)
QuISP	scalability, heterogeneity, protocols	open source (github)

n.b.: other low-level design/sim tools for quantum optics, simulators for QKD exist

Clone away, come join the Slack!
https://aqua.sfc.wide.ad.jp/quisp_website/
https://github.com/sfc-aqua/quisp
https://arxiv.org/abs/1908.10758