Rate-distance Tradeoff and Resource Costs for All-Optical Quantum Repeaters

arXiv:1603.01353

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The limit of repeaterless QKD

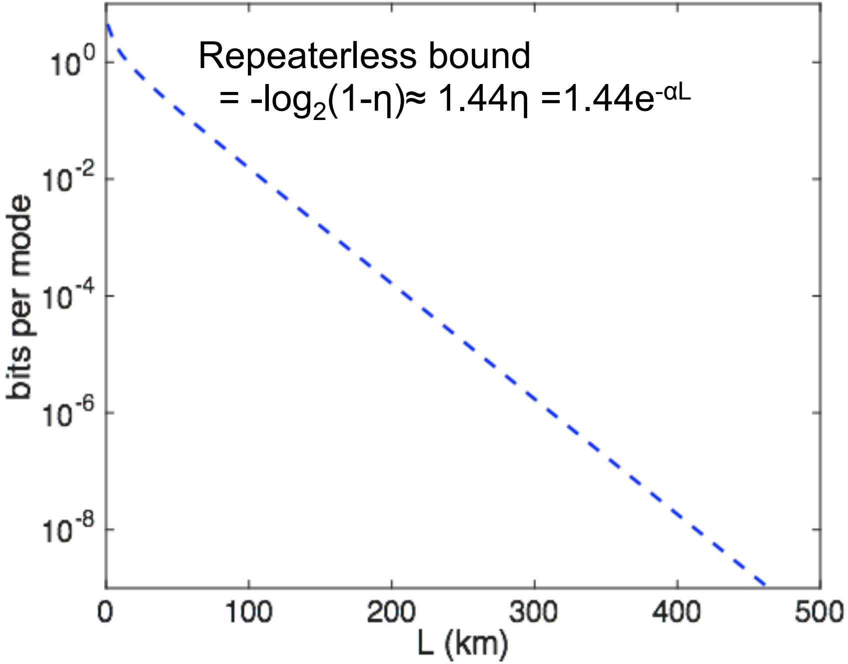
1000 km

Alice

200 dB loss

Bob

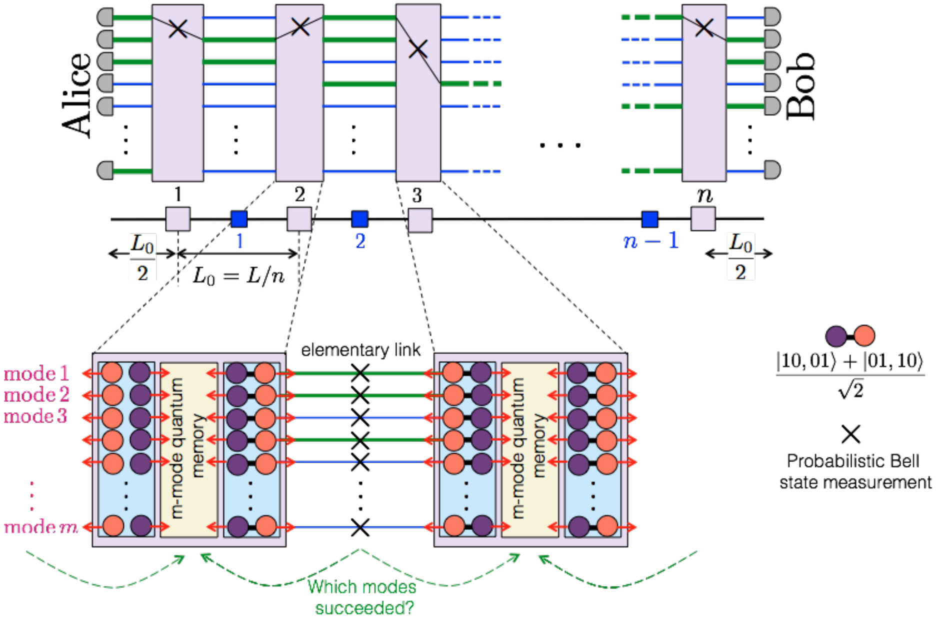
1.44×10^{-20} bits/mode or 1 bit/2000y with 10^9 modes/s

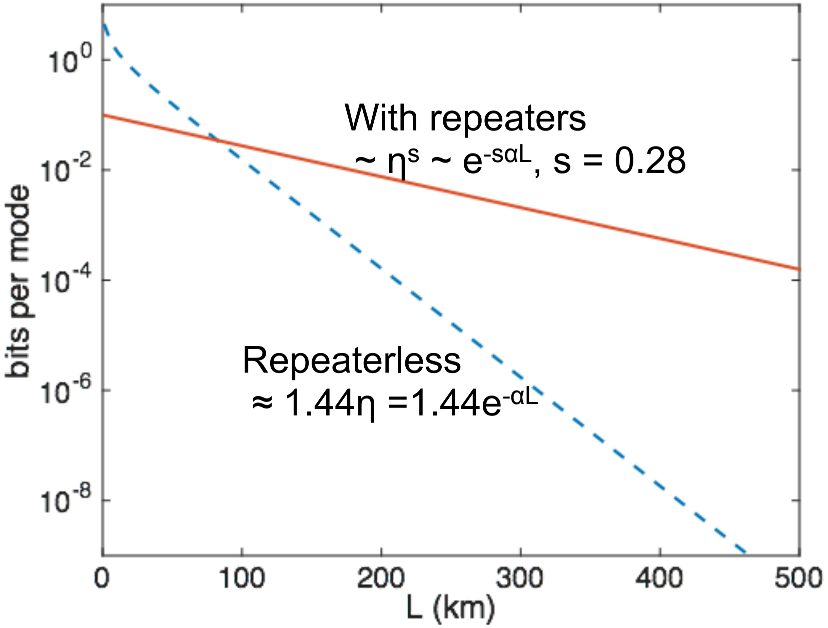


Pirandola, S., Laurenza, R., Ottaviani, C., & Banchi, L. Fundamental limits of repeaterless quantum communications. October 2015. *arXiv preprint arXiv: 1510.08863*.

Takeoka, M., Guha, S., & Wilde, M. M. (2014). Fundamental rate-loss tradeoff for optical quantum key distribution. *Nature communications*, *5*.

Quantum Repeaters



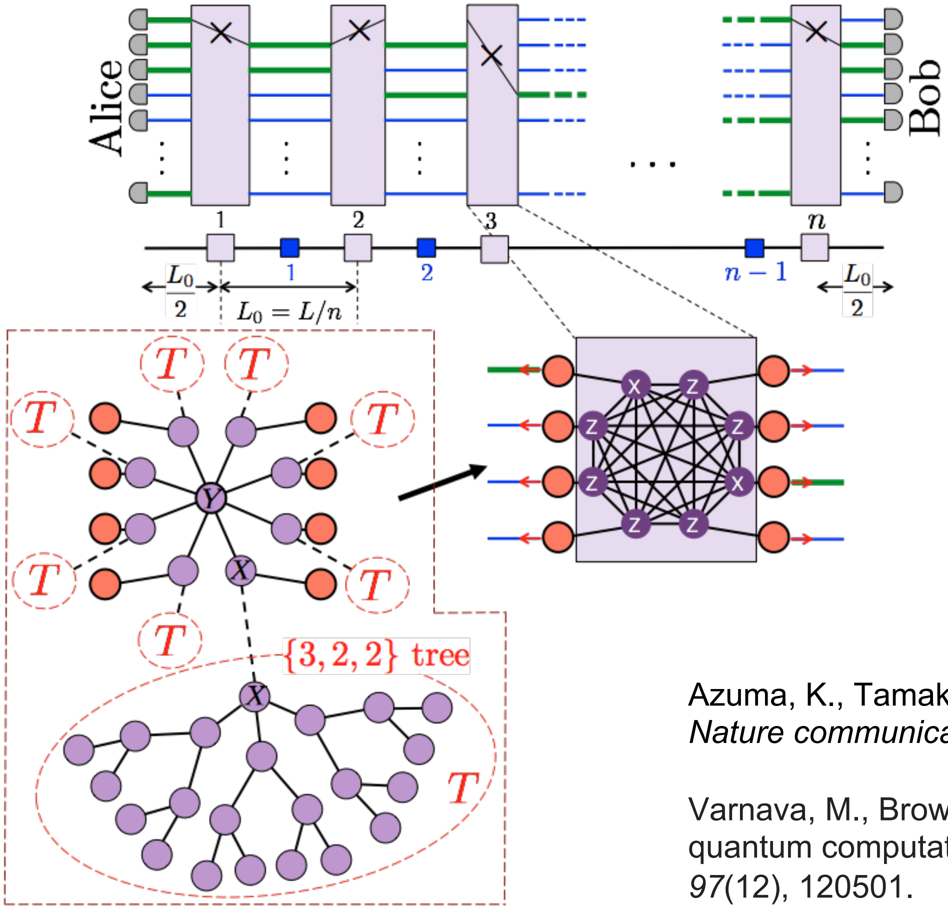


Challenges with Quantum memories

- Coupling with photonics
- Dilution fridge
- Error Corrected Memories

Sinclair et. al., *Physical review letters*, *113*(5), 053603 (2014).
Guha et. al., *Physical Review A*, *92*(2), 022357 (2015).

All-Optical Repeaters



Simpler components

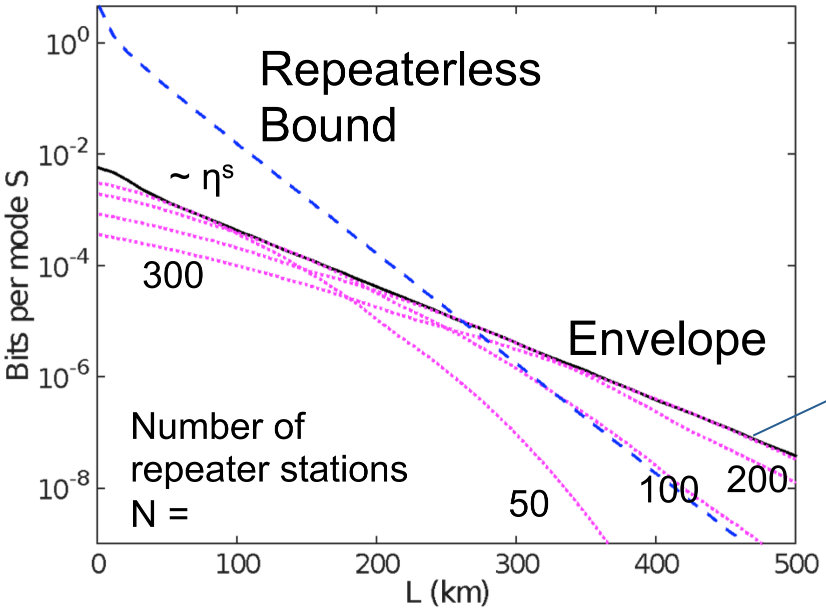
- Sources
- Detectors
- Beamsplitter
- Phase Shifters

But how practical is it?

Azuma, K., Tamaki, K., & Lo, H. K. (2015). All-photonic quantum repeaters. *Nature communications*, *6*.

Varnava, M., Browne, D. E., & Rudolph, T. (2006). Loss tolerance in one-way quantum computation via counterfactual error correction. *Physical review letters*, *97*(12), 120501.

Detailed analysis of the Scheme



Account for losses in all components

Optimize number of repeaters, number of communication channels

Smallest cluster that beats the repeaterless bound: **208 photons**

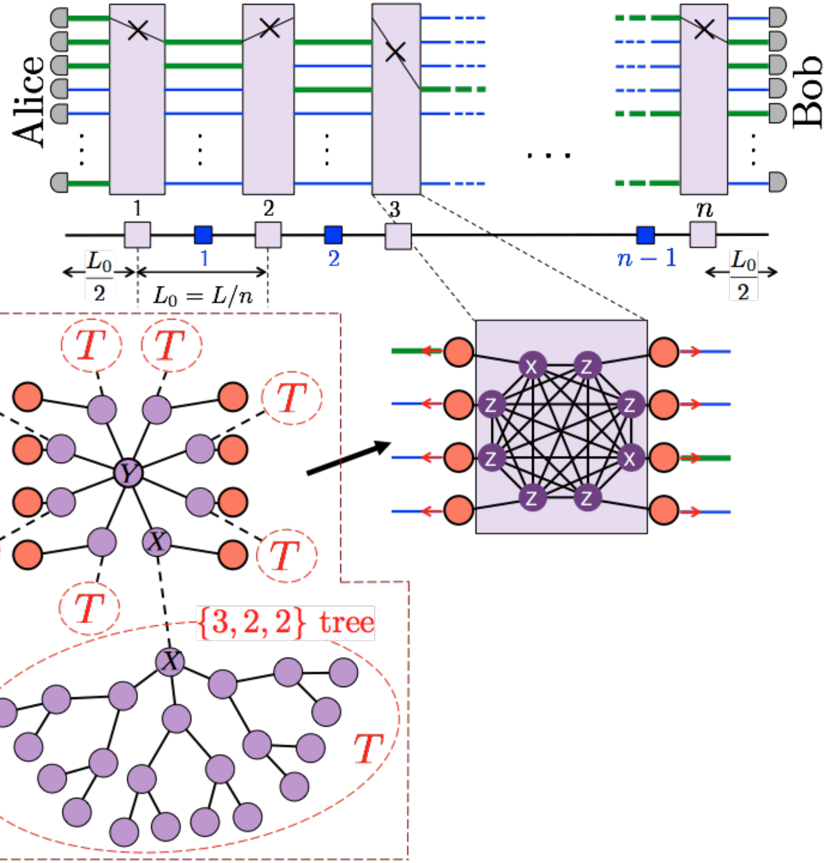
BUT

10^{11} photons required for cluster creation
200 parallel communication channels

Can this be made practical?

Pant, M., Krovi, H., Englund, D., & Guha, S. (2016). Rate-distance tradeoff and resource costs for all-optical quantum repeaters. arXiv preprint arXiv:1603.01353.

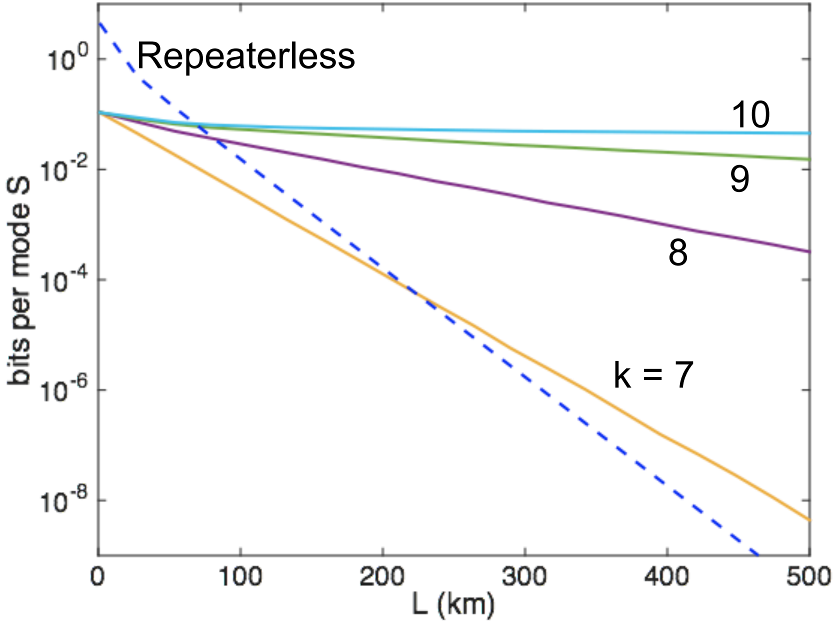
Improvements



- Store “memory” photons locally
- “Boosted” Bell measurement
  - Increasing success probability of Bell measurement to 75% using ancilla single photons*
- Better multiplexing
- Applying measurements in the beginning

Ewert, F., & van Loock, P., *PRL*, *113*(14), 140403 (2014)

Improved performance



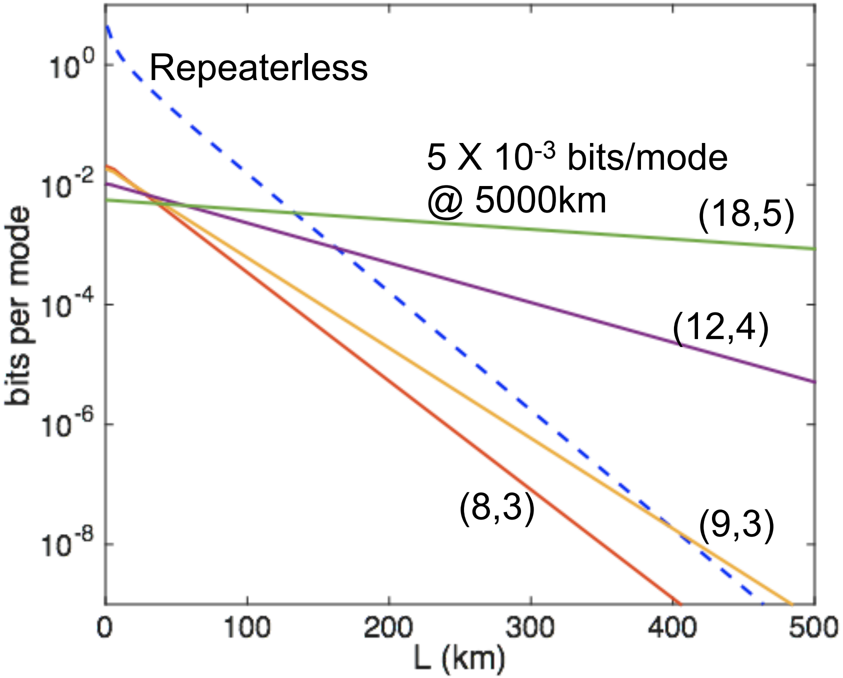
k	size of state	# of single-photon-sources	# 3-GHZ state sources
7	113	3 M	15 k
8	237	10 M	50 k
9	489	36 M	180 k
10	993	120 M	600 k

Analytical Result: Optimum repeater spacing independent of total distance

Pant, M., Krovi, H., Englund, D., & Guha, S. (2016). Rate-distance tradeoff and resource costs for all-optical quantum repeaters. arXiv preprint arXiv:1603.01353.

One way repeater based on Quantum Parity Code

$$|\pm\rangle^{(n,m)} = \left(\frac{|0\rangle^{\otimes m} \pm |1\rangle^{\otimes m}}{\sqrt{2}}\right)^{\otimes n}$$



Bell measurement success probability = $1-1/2^n$

Ewert, F., Bergmann, M., & van Loock, P. (2015). arXiv preprint arXiv: 1503.06777.

(m,n)	size of state	# of single-photon-sources	# 3-GHZ state sources
(8,3)	48	200k	1k
(9,3)	54	700k	3.5k
(12,4)	96	2M	10k
(18,5)	180	4.4M	22k

with Sreraman Muralidharan and Liang Jiang (in preperation)

Conclusion

- A **48 photon** entangled state source can beat the repeaterless bound
  - Reduction from **10^{11} to 10^{5}** single photon sources (**1000 3 photon GHZ sources**): lots of room for further improvement
    - Better error correction,
    - Efficient cluster creation
    - Fair comparison: error corrected quantum memory
  - Similar ideas would also be useful for reducing resource costs in LOQC in general
    - Li, Benjamin: 10^{10} components/logical qubit
    - Repeaters: a nearer term target compared to full blown LOQC