Optical-Relayed Entanglement Distribution Using Drones as Mobile Nodes

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Hua-Ying Liu et. al., PhysRevLett 126 020503

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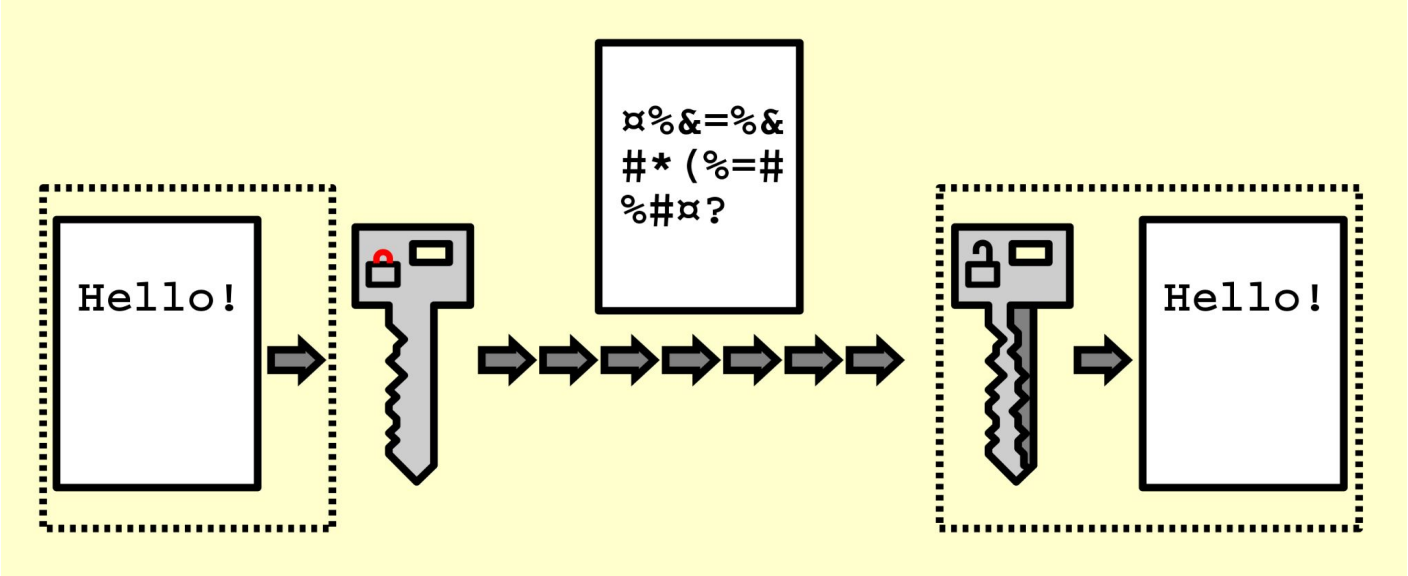
Uses for Quantum Networks

- The topic of this paper is a technical achievement in the realization of quantum networks.
- They allow transport of quantum information
- Why might people be interested in making quantum networks?
  - Quantum secured communication
  - Transfer of quantum memories
  - Allowing distant states to interact

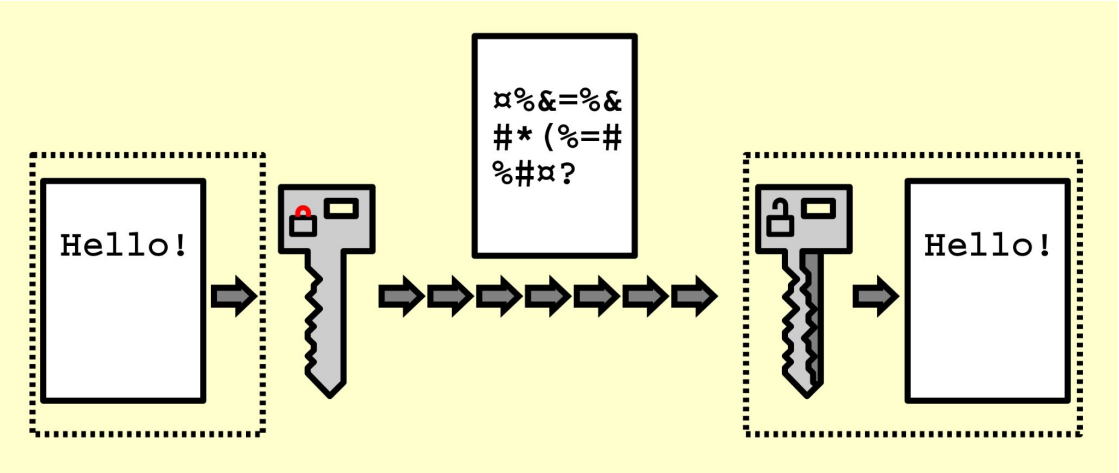
Quantum Secured Communication

- One of the biggest “killer apps” for a quantum network
- Modern asymmetric encryption could be broken by quantum computers
  - Asymmetric encryption: one password encrypts, one password decrypts
  - Symmetric encryption: same password encrypts and decrypts



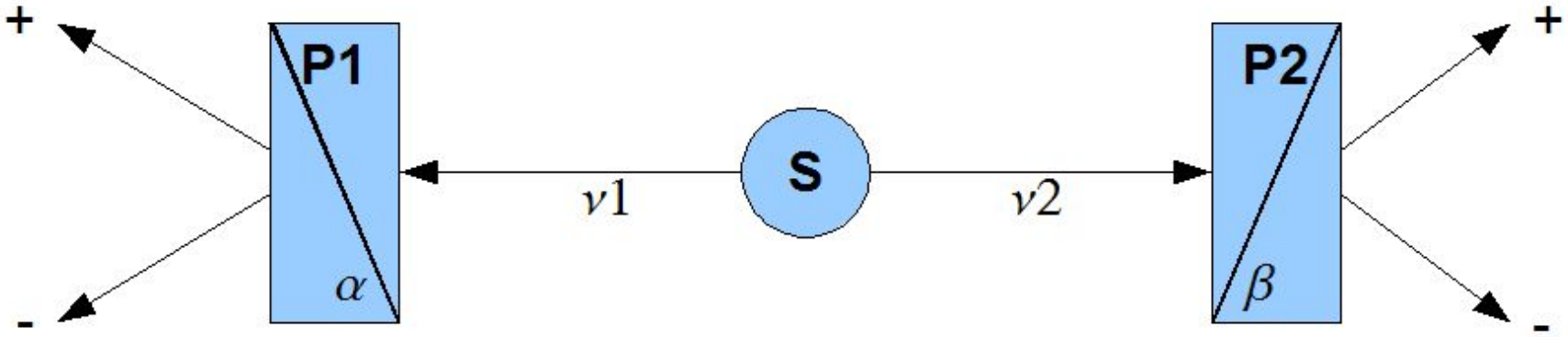
Quantum Secured Communication

- Most secure communication uses asymmetric encryption to exchange a symmetric key
  - Shor's algorithm: Asymmetric encryption could be broken by quantum computers
  - Replacing it with Quantum Key Distribution (QKD) is a solution to this
    - Done by transporting entangled states
    - Needs a reliable quantum network
    - Less reliability can compromise security



Entanglement Experiments

- A key feature of a quantum network for many applications is sending entangled states
- To determine the reliability of a quantum network with respect to this, one can measure the Clauser-Horne-Shimony-Holt (CHSH) S parameter
  - Realistic formulation of Bell's inequality
    - If S > 2, then inequality violated, therefore nonlocal effects
    - If S≤2, then inequality not violated, therefore too lossy for quantum states



Previous QKD proofs of concept

- Optical fiber[1]
  - First QKD system able to distribute provably secure keys over 307 km of **optical fiber**
  - Demonstrates the feasibility of **long-distance QKD** based on fiber-optic telecom
- Satellite-to-ground[2]
  - QKD from satellite to ground over **1,200 km**
  - Larger distance than possible with optical fiber network
- Initial groundwork for free-space optical network[3]
  - First attempt at drone-based entanglement distribution network
  - Ground stations separated by **200 m**

1) B. Korzh et. al., Nat. Photonics 9, 163 (2015).
2) S.-K. Liao et. al., Nature (London) 549, 43 (2017).
3) H.-Y. Liu et. al., Natl. Sci. Rev. 7, 921 (2020).

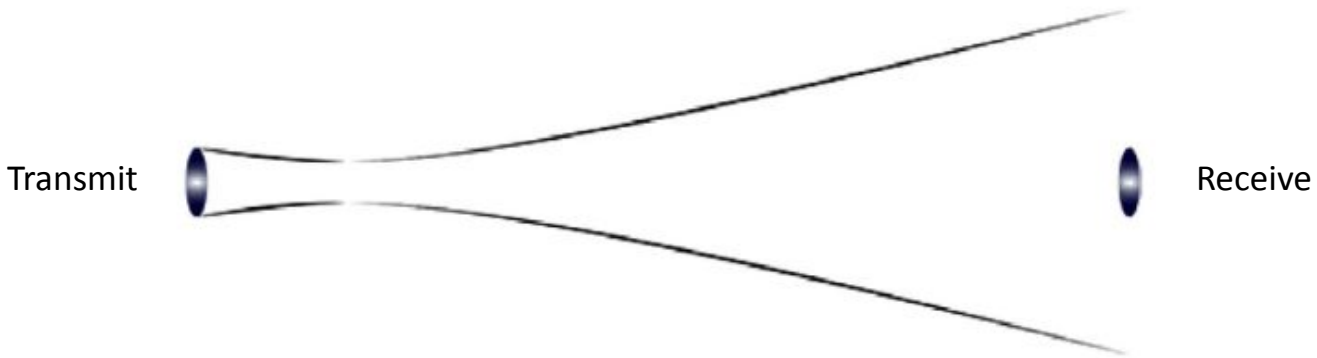
Local vs. Wide area scale mobile quantum network

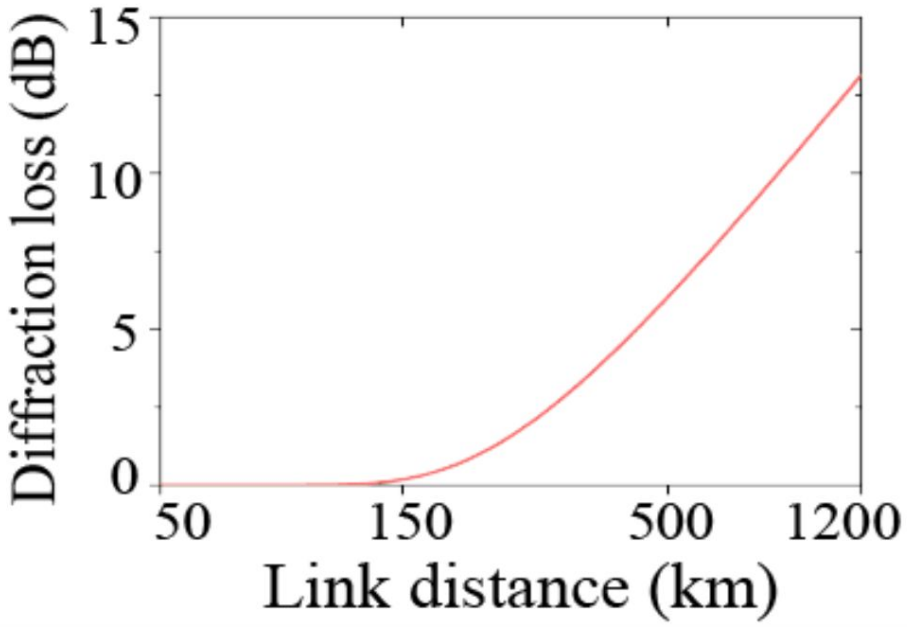
Beam Diffraction: Problem

- link distance > Rayleigh length ⟶ divergent beam

  ⇒ beam aperture > receiver telescope aperture

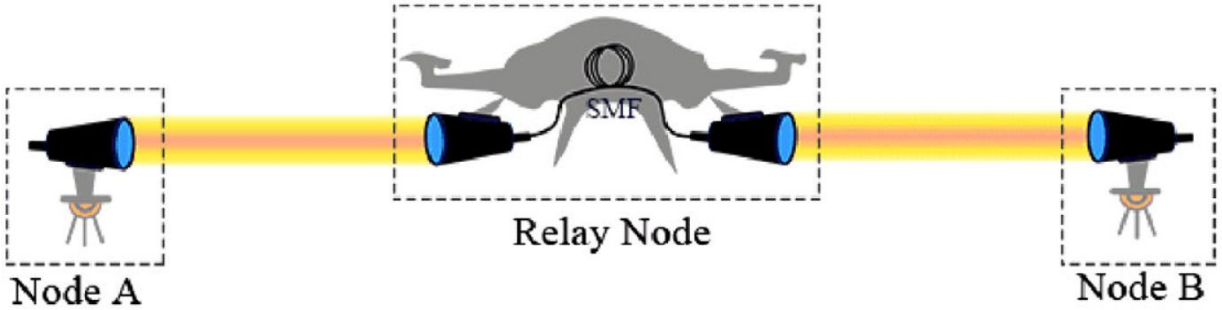
  ⟶ diffraction loss





Beam Diffraction: Solution

- Relay transceivers
  - Additional drone(s)



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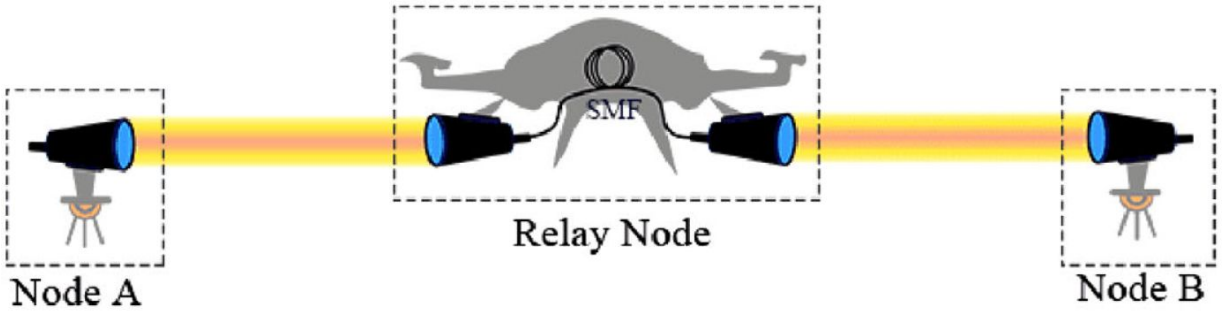
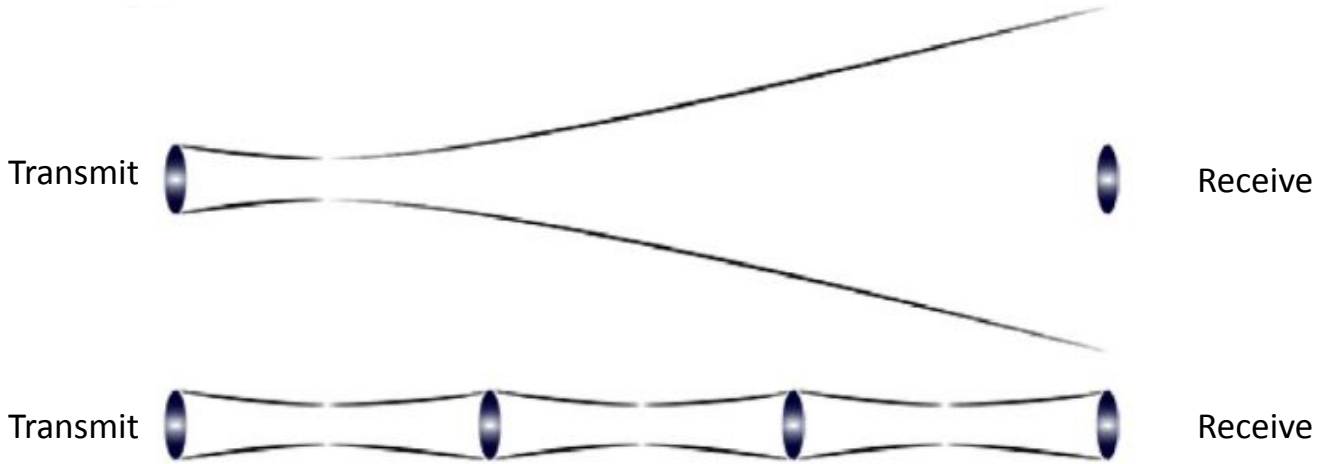
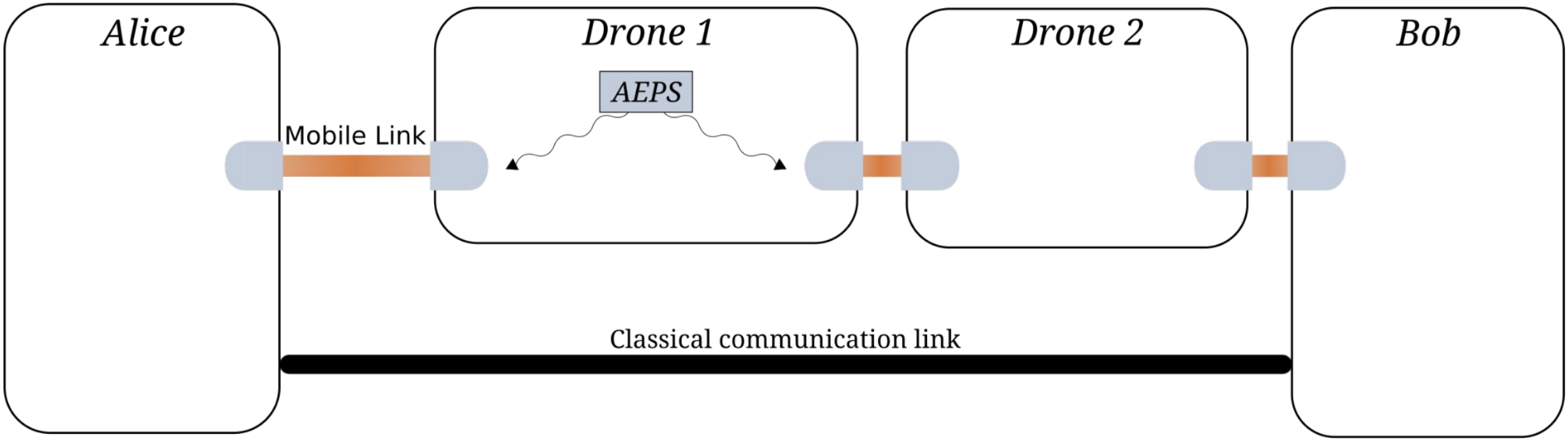


- Emulate collimating lens
- Minimize diffraction loss by re-transmitting signal



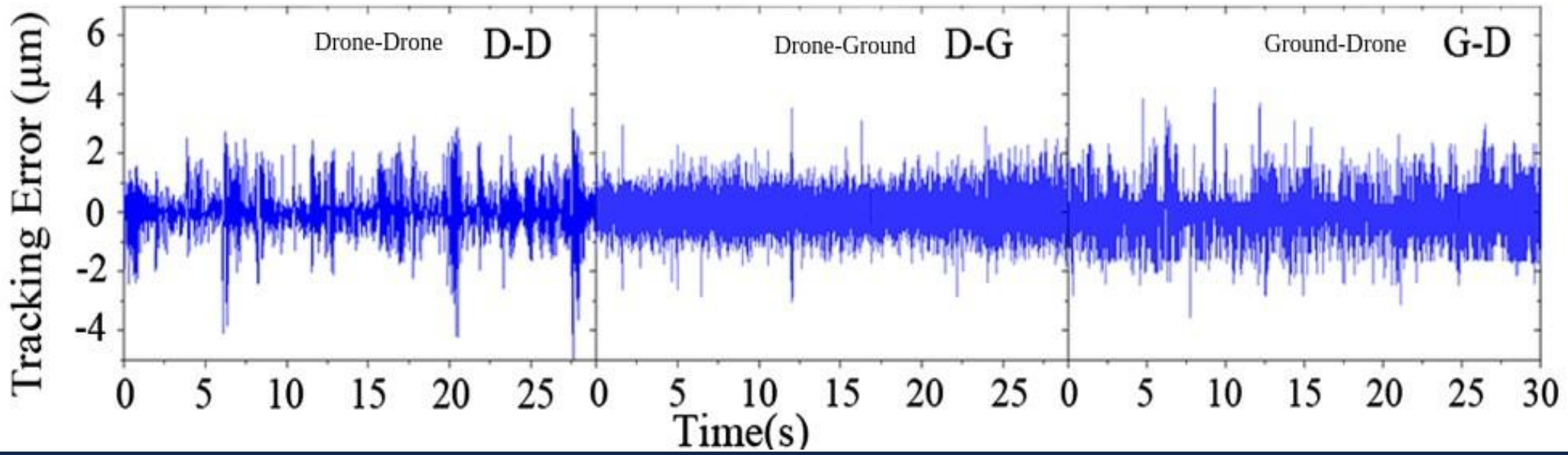
Entanglement Distribution Experimental Setup

AEPS: Airborne Entangled Photon Source



Analysis: Impressive Micron Order Error

- Bell's inequality test (S parameter = 2.29±0.11) confirm that the photons remain entangled
- Minimal tracking error (µm) for both drone to drone and ground to drone links

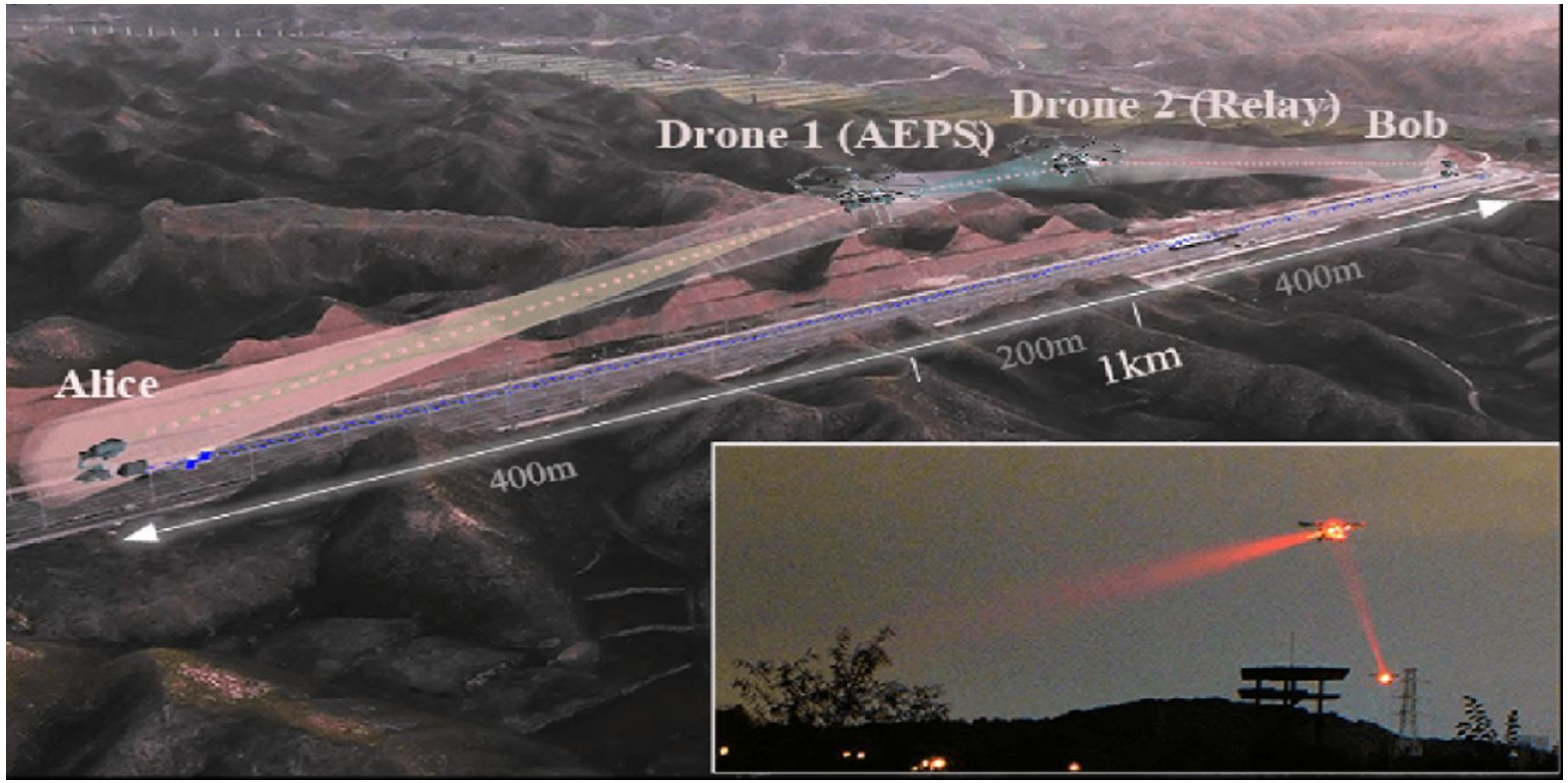


Analysis: Impressive Low Loss

- Link losses : Drone to Drone = 8dB; Drone to Ground = 6dB ⟶ Lowest values for the free space quantum link yet
- These technical losses are due to imperfect manual optical alignment
- But can be reduced more with finer optical alignment approach

What's New?

- First to send entangled particles between two moving devices.
- Used mobile drones, which are more resilient against weather conditions and more secure as compared to towers.
- Large scale application could lead to drone-based quantum network in a city or rural area.



- Done for just 1km, but authors suggest that moving the drones higher can allow transmission upto 150 km.

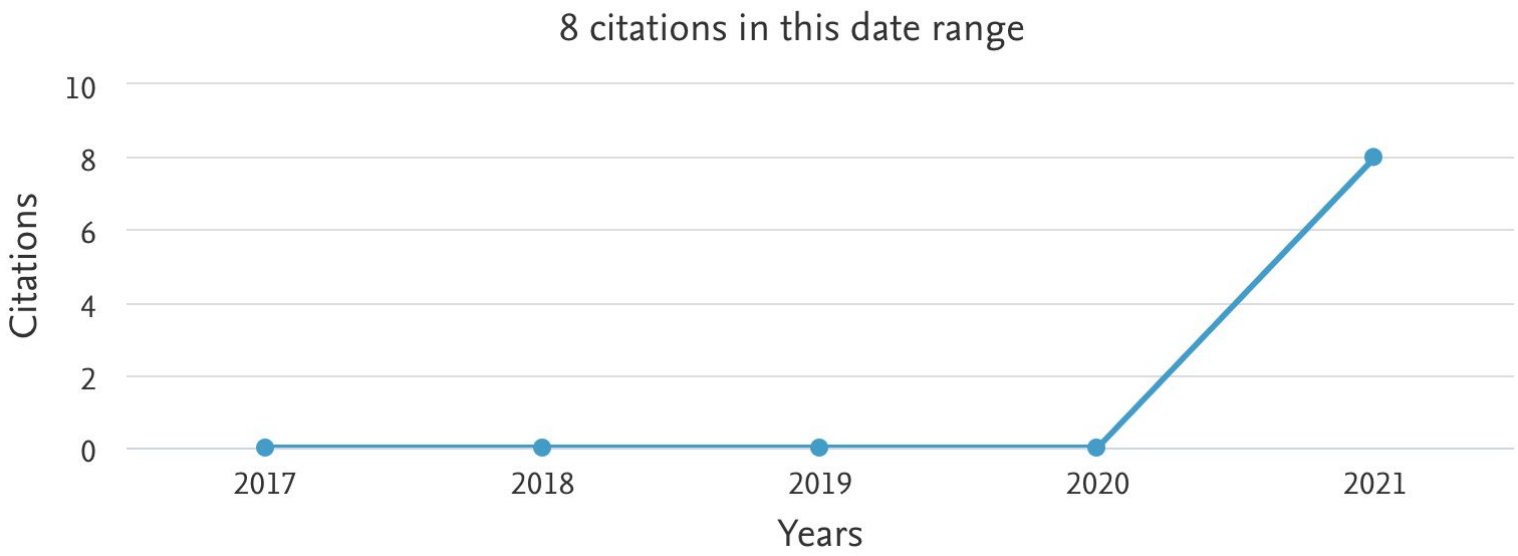
Analysis: Complex Base Stations

- Indeed, the drones are simple, but the base stations are complex and expensive.
- More weight can be reduced by designing the special drones and transceivers, as the authors have used the commercial ones for the purpose.
- Application: To use multidrone system to cover the quantum communication of a city.
- Photon transmission losses need to be reduced to achieve a multidrone relay system to cover an entire city.

Citation Evaluation

8 citations in Scopus (97th percentile)

Field-Weighted Citation Impact*: 7.36



* "Field-Weighted Citation Impact shows how well cited this document is when compared to similar documents. A value greater than 1.00 means the documents is more cited than expected according to the average."

Most Recent Work in Field

- Experimental work / simulations
- Improving quantum technologies
  - Unmanned aerial vehicle (UAV), military applications
- Most interested in future applications...

In the longer term, the structure of optical relay can be used for more than entanglement distribution, such multinode mobile link architecture can find application by hosting the quantum repeaters and rouging and multiplexing [23] the quantum information, for quantum key distribution [24], quantum teleportation [25], and quantum direct communication [26–28]. Additionally, such technology can be used in other area besides quantum communication, such as large-size distributed quantum computation [29], accurate timekeeping [30], and fundamental physics experiments such as quantum nonlocality [31] and quantum gravity [32].

Main Points in Paper

- Demonstrates “first quantum link between mobile nodes using any known platform”
  - Optical relay for entanglement distribution
- CHSH *S* parameter 2.29 ± 0.11
  - Violation of Bell inequality: 5.4 standard deviations
- Practical, portable system

Summary - Our Thoughts

- Figures used well to layout/explain challenging concepts
- Complicated schematics, i.e. MANY acronyms
- Adapts existing concepts to operate on a drone
- More of an engineering advancement rather than an advancement in physics
- Drone-based network allows for coverage of greater terrestrial distances