High-precision distributed sensing using an entangled quantum network

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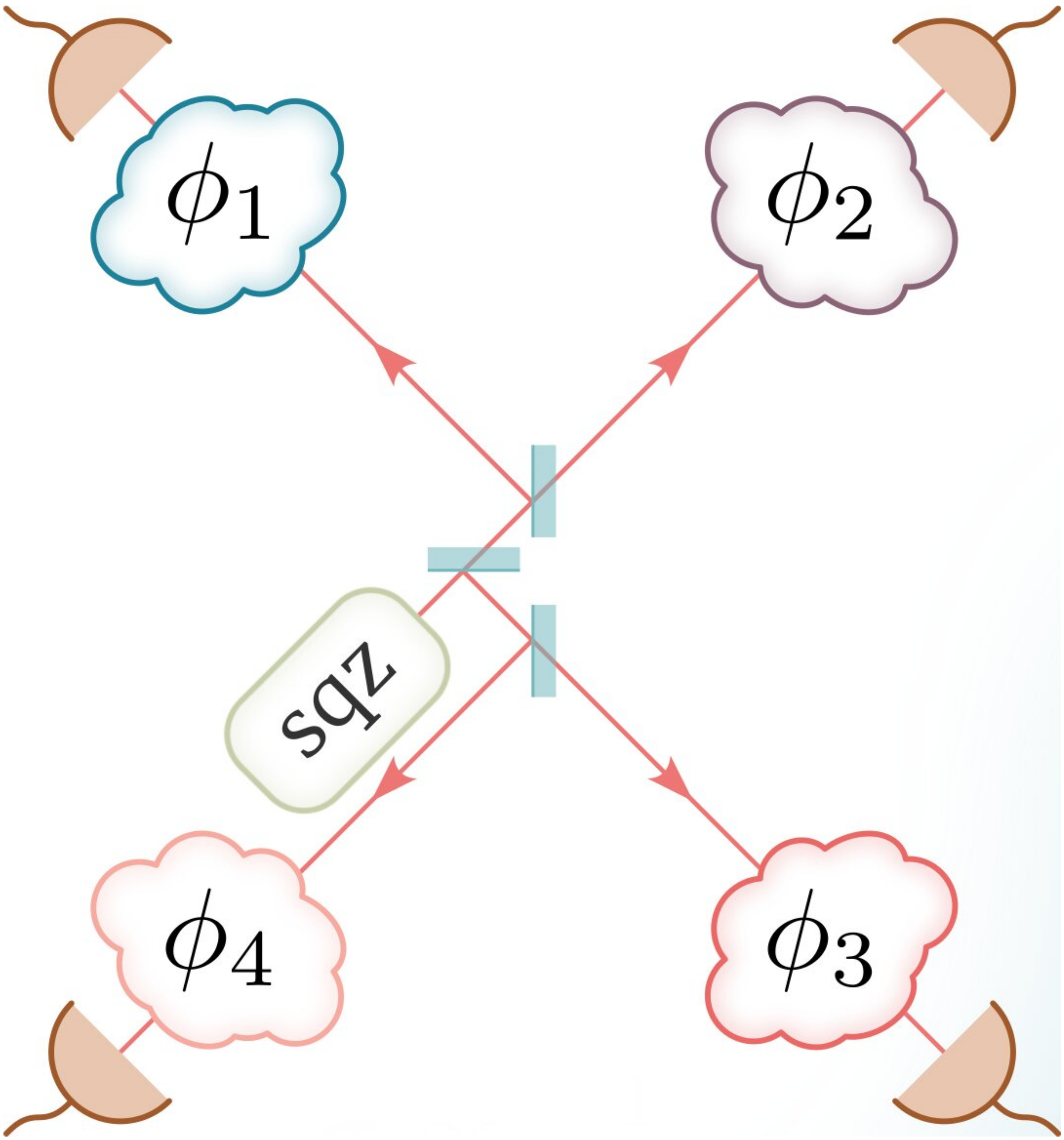
The experimental setup used in the study. Credit: Jonas S. Neergaard-Nielsen.

Quantum-enhanced metrology has been an active area of research for several years now due to its many possible applications, ranging from atomic clocks to biological imaging. Past physics research established that having a non-classical probe, such as squeezed light or an entangled spin state, can have significant benefits compared to classical probes. This idea was explored further in several recent works, some of which also considered the benefits of examining multiple distinct samples with non-classical probes.

Inspired by these studies, researchers at the Technical University of Denmark and the University of Copenhagen have recently carried out an experiment investigating the advantages of using an entangled quantum network to sense an averaged phase shift among multiple distributed nodes. Their paper, published in *Nature Physics*, introduces a series of techniques that could help to collect more precise measurements in a variety of areas.

"Recent studies showed that having non-classical correlations between probes addressing different samples could lead to a gain compared to having non-correlated probes," Johannes Borregaard, the researcher who initiated the project, told Phys.org. "This inspired us to investigate whether such advantages could be demonstrated already using present technology."

In their study, Borregaard and his colleagues focused on squeezed light and homodyne detection, which are now established sensing techniques. The overall goal of the experiment was to measure a global property of multiple spatially separated objects and investigate whether probing these objects simultaneously with entangled light led to more precise results than probing them individually. The researchers found that the use of a quantum network to probe the objects simultaneously enabled phase sensing with far higher precision than that attainable when examining probes individually.



Outline of the scheme for distributed phase sensing. Squeezed light (sqz) is distributed via beam-splitters to the phase samples under study. The phases imprinted on the squeezed probes are detected with homodyne detectors and these measurements are subsequently combined to form the average phase shift. Due to the quantum correlations between the probes, this average phase shift can be obtained with higher precision than if the samples were probed independently. Credit: Jonas S. Neergaard-Nielsen.

"In this particular demonstration, we wanted to estimate the average of multiple optical phase shifts," Xueshi Guo, lead author of the paper, told Phys.org. "We measured the phase shifts (which we set with wave plates to a known value) by sending a weak laser beam through and detecting the change in the light's phase quadrature with homodyne detectors."

To generate entangled light and distribute it among different sites, the researchers used a fairly simple method. First, they created a phase-squeezed state of light, which is a standard non-classical quantum state. Then they divided it into multiple beams using beam splitters.

This resulted in light probes with reduced noise in the phase quadrature, but only when all probes were measured simultaneously. This is precisely the property required to attain a better signal-to-noise ratio in the estimation of the average phase without increasing the energy (i.e., number of photons) in the probe states.

"In the experiment we had four phase samples in total," Guo explained. "The gain that can be achieved by using entanglement is then theoretically limited to a factor of 2. However, as the number of samples increases, so does the achievable gain."

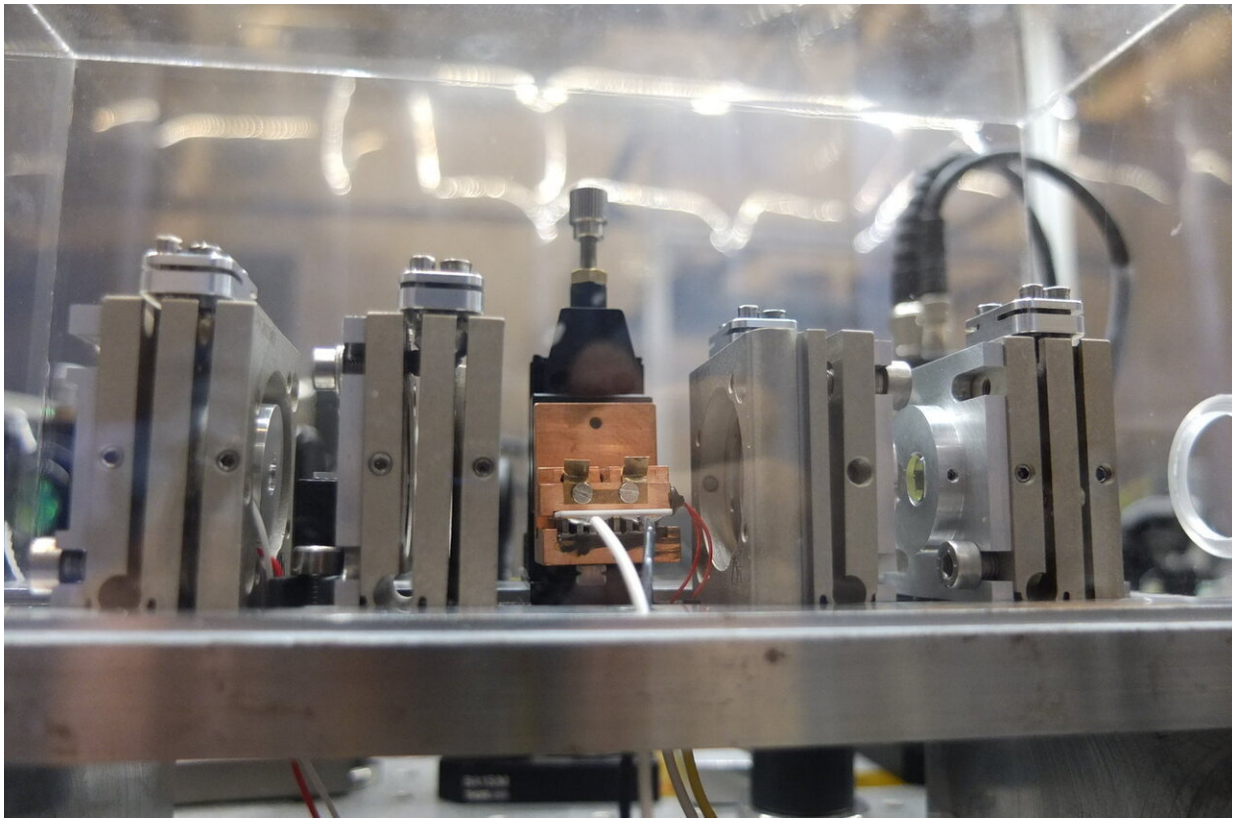


Image showing the source of squeezed light in the experiment (i.e., an optical parametric oscillator). Credit: Jonas S. Neergaard-Nielsen.

The researchers found that the advantage of using distributed quantum sensing truly becomes significant when a property of many objects connected in an optical network is to be measured. To successfully attain an increase in precision, however, the losses in the network and detectors need to be kept low, otherwise the quantum advantage vanishes.

"The key achievement of our study is the experimental demonstration of the advantages associated with using multi-mode entanglement for distributed sensing," Borregaard said. "Previous theoretical studies had predicted such advantages, but they often considered highly idealized scenarios and experimentally very challenging probe states or detection techniques. Our work cements that such advantages are accessible even with present noisy technology."

In the future, the techniques demonstrated by Borregaard, Guo and their colleagues could have important implications for a number of different areas of research and technology development. For instance, they could help to enhance the sensitivity of molecular tracking tools, atomic clocks, and optical magnetometry techniques.

Although only further investigations will determine how much each of these applications can benefit from the methods introduced by the researchers, this recent study offers valuable insight into how quantum-enhanced metrology can be achieved using readily available technologies, such as squeezed light generation and homodyne detection. In their future work, the researchers plan to continue investigating the use of multi-mode squeezed light in other contexts, in particular for optical quantum computing applications.

"In our experiment, we did not actually use the optimal probe states and measurement methods allowed by quantum theory, so it would be exciting to demonstrate the distributed sensing problem with those resources," Jonas S. Neergaard-Nielsen, another researcher involved in the study, told Phys.org. "Furthermore, it could be interesting to distribute the entangled light to far-away locations in an installed fiber network to show the real-world applicability of the scheme."

More information: Xueshi Guo et al. Distributed quantum sensing in a continuous-variable entangled network, *Nature Physics* (2019). DOI: 10.1038/s41567-019-0743-x