MON 17: Quantum Communication and Networks: Theory

Time: Monday 16:30–18:30 Location: ZHG006

MON 17.1 Mon 16:30 ZHG006

Resolution of Holevo's Conjecture on Classical-Quantum Channel Coding via Uncertainty Relations — •Joseph M. Renes — Institute for Theoretical Physics, ETH Zurich, Switzerland

The notion of complementarity is fundamental to quantum theory, as evidenced by the uncertainty principle. In quantum information theory complementarity and uncertainty relations have become important tools in designing and analyzing information processing protocols, e.g. in quantum key distribution. Here I report on another use, in determining the error exponent of classical-quantum (CQ) channels.

The error exponent of a given channel W and rate R is the constant $E(W,R)$ which governs the exponential decay of decoding error when using ever larger optimal codes of fixed rate R to communicate over ever more (memoryless) instances of a given channel W. Here I show a lower bound on the error exponent of communication over arbitrary CQ channels which matches Dalai's sphere-packing upper bound for rates above a critical value, exactly analogous to the known results for the case of classical channels. This resolves a conjecture made by Holevo in 2000 from his investigation of the problem.

Unlike the classical case, however, the argument does not proceed via a refined analysis of a suitable decoder, but instead by leveraging a bound by Hayashi on the error exponent of the cryptographic task of privacy amplification. This bound is then related to the coding problem via tight entropic uncertainty relations, providing another illustration of their use in quantum information theory.

MON 17.2 Mon 16:45 ZHG006

No-Go Theorem for Generic Simulation of Qubit Channels with Finite Classical Resources — •Sahil Gopalkrishna Naik[1], Nicolas Gisin[2,3,4], and Manik Banik[1] — [1]S. N. Bose National Center for Basic Sciences, Kolkata, India — [2]University of Geneva, 1211 Geneva 4, Switzerland. — [3]Constructor University, Bremen, Germany. — [4]Constructor Institute of Technology, Geneva, Switzerland.

The mathematical framework of quantum theory, though fundamentally distinct from classical physics, raises the question of whether quantum processes can be efficiently simulated using classical resources. For instance, a sender (Alice) possessing the classical description of a qubit state can simulate the action of a qubit channel through finite classical communication with a receiver (Bob), enabling Bob to reproduce measurement statistics for any observable on the state. Here, we contend that a more general simulation requires reproducing statistics of joint measurements, potentially involving entangled effects, on Alice's system and an additional system held by Bob. We establish a no-go result, demonstrating that such a general simulation for the perfect qubit channel is impossible with finite classical communication. Furthermore, we show that entangled effects render classical simulation significantly more challenging compared to unentangled effects. On the other hand, for noisy qubit channels with depolarizing noise, we demonstrate that general simulation is achievable with finite communication. Notably, the required communication increases as the noise decreases, revealing that large classical resources are necessary for its classical simulation.

MON 17.3 Mon 17:00 ZHG006

Extending Entropic Uncertainty Relations in QKD to multiple measurements — •Maik Romancewicz and Ramona Wolf — Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Straße 3, 57068 Siegen, Germany

Uncertainty is a fundamental property of quantum mechanics, and entropic uncertainty relations (EURs) provide a means to quantify and use it for various applications. EURs play a central role in analysing the security of quantum key distribution (QKD) protocols, especially in the finite-size regime. For the case of two different measurement settings, many useful relations are well-established and have been used to analyse QKD protocols such as BB84, obtaining high key rates and strong security guarantees. However, their applicability to study more complex QKD protocols, employing multiple measurements, such as the six-state-protocol, or higher dimensional systems, remains limited. In this work we study how to extend these relations, aiming to provide new results that can be useful in analysing the security of more complex QKD protocols.

MON 17.4 Mon 17:15 ZHG006

Quantum Conference Key Agreeement with Pre-shared Basis Choice — •Yien Liang, Anton Trushechkin, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, Universitätsstraße 1, 40225 Düsseldorf, Germany

Quantum conference key agreement is a quantum protocol that distributes a secret key among more than two parties. The participants of the protocol share an entangled quantum state and they measure it in the same basis to obatin the secret key. However, as the number of parties increases, the probability of all participants independently randomly choosing the same basis decreases exponentially. In previous literature, key pre-sharing is mentioned as a possible solution to increase the output of the protocol: here, the participants share a secret basis choice. However, no details were given about how to perform basis pre-sharing. In our work, we show how we can securely perform practical basis-sharing without introducing loopholes in the security proof.

MON 17.5 Mon 17:30 ZHG006

Quantum conference key agreement in pair-entangled networks: Fundamental bounds — •Anton Trushechkin, Justus Neumann, Hermann Kampermann, and Dagmar Bruss — Heinrich Heine University Düsseldorf, Faculty of Mathematics and Natural Sciences, Institute for Theoretical Physics III, Universitätsstr. 1, Düsseldorf 40225

Networks of nodes connected by sources of bipartite entangled states are in focus. The nodes can perform collective measurements on the particles coming from different sources. After many repetitions of such rounds, the nodes postprocess the obtained data to agree on a secret conference key. This scenario is relevant to future quantum networks. We derive fundamental bounds on the conference key generation rate based on properties of the graph of the network. In particular, the bounds can reveal global bottleneck structures in the network, i.e., node partitions that set tightest restrictions the conference key rate.

MON 17.6 Mon 17:45 ZHG006

Merging-based Quantum Repeater — Maria Flors Mor-Ruiz[1], Jorge Miguel-Ramiro[1], •Julius Wallnöfer[1], Tim Coopmans[2,3], and Wolfgang Dür[1] — [1]Institute for Theoretical Physics, University of Innsbruck, Austria — [2]QuTech, Delft University of Technology, The Netherlands — [3]EEMCS, Delft University of Technology, The Netherlands

We introduce an alternative approach for the design of quantum repeaters based on generating entangled states of growing size. The scheme utilizes quantum merging operations, also known as fusion type-I operations, that allow the reintegration and reuse of entanglement. Unlike conventional swapping-based protocols, our method preserves entanglement after failed operations, thereby reducing waiting times, enabling higher rates, and introducing enhanced flexibility in the communication requests. Through proof-of-principle analysis, we demonstrate the advantages of this approach over standard repeater protocols, highlighting its potential for practical quantum communication scenarios.

MON 17.7 Mon 18:00 ZHG006

Unlocking Quantum Advantage in Distributed Communication Networks — •Ananya Chakraborty[1], Ram Krishna Patra[1], Kunika Agarwal[1], Samrat Sen[1], Pratik Ghosal[1], Sahil Gopalkrishna Naik[1], Manik Banik[1], Mir Alimuddin[3], Edwin Peter Lobo[2], and Amit Mukherjee[4] — [1]Department of Physics of Complex Systems, S. N. Bose National Center for Basic Sciences, Block JD, Sector III, Salt Lake, Kolkata 700106, India. — [2]Laboratoire d'Information Quantique, Universite libre de Bruxelles (ULB), Av. F. D. Roosevelt 50, 1050 Bruxelles, Belgium. — [3]ICFO-Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, Av. Carl Friedrich Gauss 3, 08860 Castelldefels (Barcelona), Spain — [4]Indian Institute of Technology Jodhpur, Jodhpur 342030, India

In this work (Phys.Rev.A,vol.111,032617(2025)), we show a quantum advantage in multipartite communication complexity using n+1 partite GHZ states, enabling perfect evaluation of a global Boolean function with an n-1 bit reduction over classical protocols. Even for noisy

GHZ states this advantage persists.For n = 3 and 4, genuine multipartite entanglement is necessary; for n greater than 4, inseparable states can suffice, broadening the range of useful quantum resources. In this work(New J. Phys. 27 023027), we show that qubit communication can outperform classical strategies in simulating MACs, without shared entanglement, bypassing the Frenkel-Weiner bound via joint quantum decoding. Our protocol links to nonlocality without entanglement,semi-device-independent certification of entangled measurements.

MON 17.8 Mon 18:15 ZHG006

Emergent statistical mechanics in holographic random tensor networks — •Shozab Qasim, Alexander Jahn, and Jens Eisert — Dahlem Center for Complex Quantum Systems, Freie Universitat Berlin, 14195 Berlin, Germany

Random tensor networks, formed by contracting locally random tensors chosen from the unitary Haar measure, define a class of ensembles of quantum states whose properties depend on the tensor network geometry. Of particular interest are random tensor networks on hyperbolic geometries, leading to properties resembling those of critical boundary states of holographic bulk-boundary dualities. In this work, we elevate this static picture of ensemble averages to a dynamic one, leveraging earlier work on random matrix product state to show that random tensor network states exhibit equilibration of time-averaged operator expectation values under a highly generic class of Hamiltonians with non-degenerate spectra. We show that random tensor networks on hyperbolic geometries equilibrate faster than on flat ones, consistent with the expectation that the former describe highly chaotic holographic boundary theories, and that equilibration is further accelerated by the insertion of high- bond dimension black hole tensors in the network, consistent with previous holographic constructions. These results show that random tensor network techniques can describe aspects of holographic boundary dynamics without the explicit construction of a boundary Hamiltonian.