Gaussian benchmark for optical communication towards ultimate capacity

Jaehak Lee,[1] Se-Wan Ji,[1] Jiyong Park,[1] and Hyunchul Nha[1,2]

[1] *Department of Physics, Texas A & M University at Qatar, P.O. Box 23874, Doha, Qatar*

[2] *School of Computational Sciences, Korea Institute for Advanced Study, Seoul 130-722, Korea*

We establish the fundamental limit of communication capacity within Gaussian schemes under phase-insensitive Gaussian channels, employing multimode Gaussian states and collective Gaussian operations and measurement. We prove that this Gaussian capacity is additive so that a single-mode communication suffices to achieve the largest capacity under Gaussian schemes.

Sending and receiving signals via optical channels, e.g. optical fiber networks, is a crucial basis of communication. Employing protocols like intensity modulation and phase-shifting in optical communication, there eventually arises a question of fundamental importance—how quantum mechanics sets bound on communication capacity achievable using light beams. A remarkable result was recently established by proving the minimum output entropy conjecture [1], i.e., the ultimate capacity under phase-insensitive Gaussian channels is achieved by using coherent states as information carriers (encoding). However, there still exists an outstanding problem on what quantum receivers (decoding) can practically be used to obtain ultimate capacity. The Holevo-Schumacher-Westmoreland theorem states that the ultimate capacity can be achieved *asymptotically* with a certain joint measurement [2], which however requires highly nonlinear, so very demanding, operations. It is therefore important to identify quantum receivers achieving high communication rates practically.

In this talk, we identify the capacity achievable within *Gaussian communication schemes* [3] employing Gaussian states, operations, and measurements readily available in laboratory. It is unknown to what extent general Gaussian schemes particularly using entangling operations can improve capacity in contrast to separable schemes. So far there are two well-known Gaussian communication schemes, coherent-state scheme with heterodyne detection and squeezed-state scheme with homodyne detection, studied under an ideal situation or channel noises. We recently extended study to general *single*-channel Gaussian communications with arbitrary inputs and measurements and showed that the optimal strategy among them is either coherent-state scheme or squeezed-state scheme [4]. As for multimode scenario, with inputs restricted to coherent states, Takeoka and Guha showed that the optimal Gaussian receiver is a separable one [5]. Since Gaussian receivers with coherent-state inputs do not saturate the ultimate channel capacity although the channel capacity is obtained with coherent-state inputs, their work provides an evidence for the gap between the capacity of Gaussian schemes and the ultimate channel capacity. However, the restriction to coherent-state inputs is not sufficient as other inputs can yield higher capacity under some Gaussian channels [4].

We establish the ultimate limit of Gaussian schemes under phase-insensitive Gaussian channels in a general multimode scenario using arbitrary N-mode Gaussian input states and collective Gaussian measurements. We prove that its upper bound is achieved by separable inputs and separable measurements (additivity of Gaussian communication). The highest capacity of Gaussian schemes is thus obtained by the optimal *single-channel* protocol, i.e., either coherent-state scheme or squeezed-state scheme [4]. As the capacities of those two schemes do not achieve the Holevo bound, we characterize the exact gap between the ultimate channel capacity and the capacity within Gaussian communication. Our results identify an optimal protocol when resources are confined to Gaussian operations and Gaussian receivers. Until now, coherent-state and squeezed-state schemes were used as standard protocols due to simple applicability. We now show that they actually attain the upper limit of capacity within Gaussian resources. This work also establishes a benchmark to rigorously assess enhanced performance of non-Gaussian schemes in terms of mutual information—a central quantity of interest in communication theory. Furthermore, we suggest a non-Gaussian receiver of [6] combined with an appropriate encoding method as a feasible scheme for higher communication rate than Gaussian limit.

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