Compensating the cross-talk in two-mode continuous-variable quantum communication

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Outline

- Motivation: why quantum communication?
- Continuous-variable entanglement distribution
- Role of linear cross-talk
- Compensation by local manipulations
- Unbalanced channels
- Summary

Quantum communication

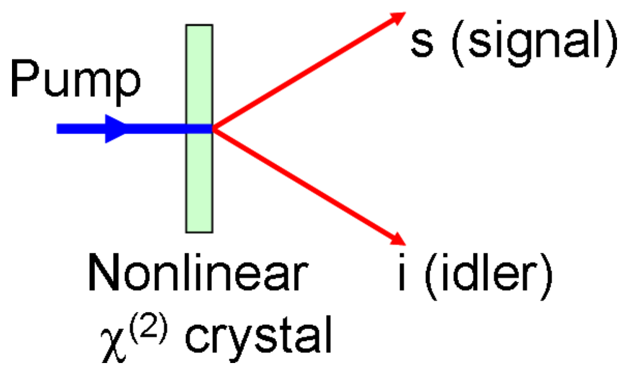
• Distribution of quantum states (typically photonic), with non-classical properties, for specific quantum tasks (e.g., *quantum key distribution, quantum teleportation, distributed quantum computing* etc)

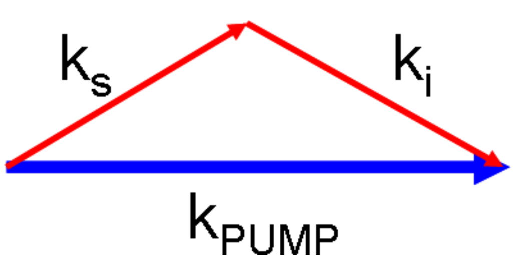
• Is well known for *discrete-variable* systems (e.g., *single photons* or *entangled photon pairs* with *direct photodetection*)

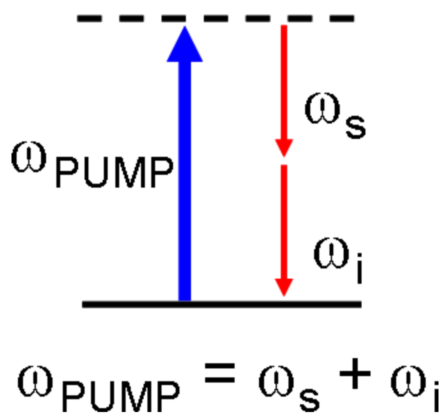
• Novel methods are based on continuous-variable systems (e.g., *coherent shot-noise limited states* of light or *entangled beams* with *homodyne detection*)

Continuous-variable entanglement

Typical CV entangled states – *twin beams*
a.k.a. *two-mode squeezed vacuum states* (TMSV)







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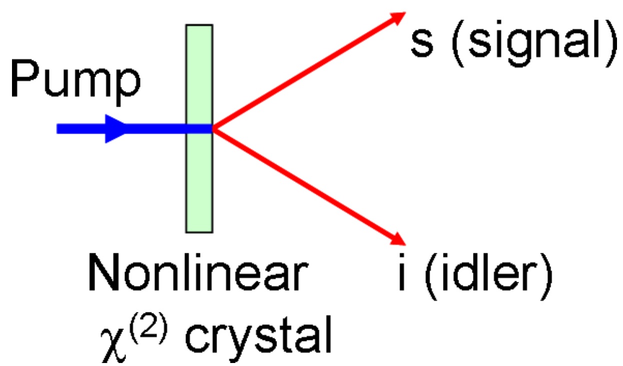

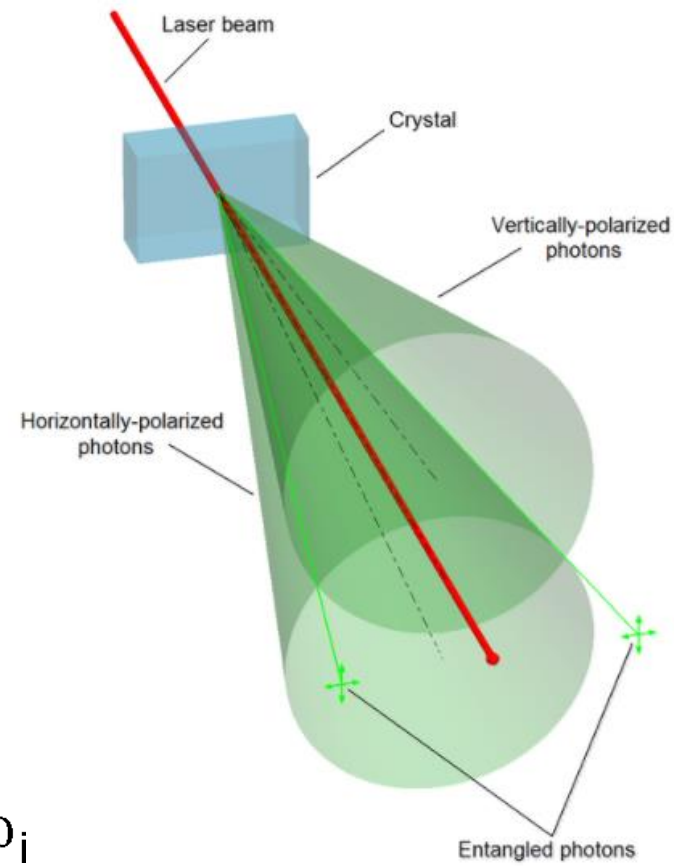

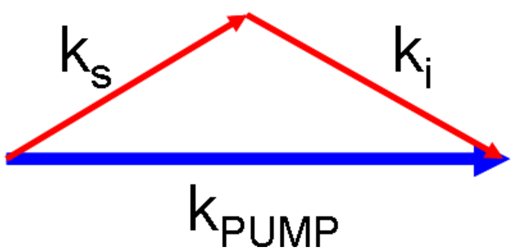

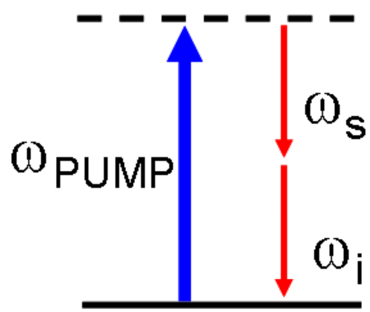

$$\omega_{PUMP} = \omega_s + \omega_i$$

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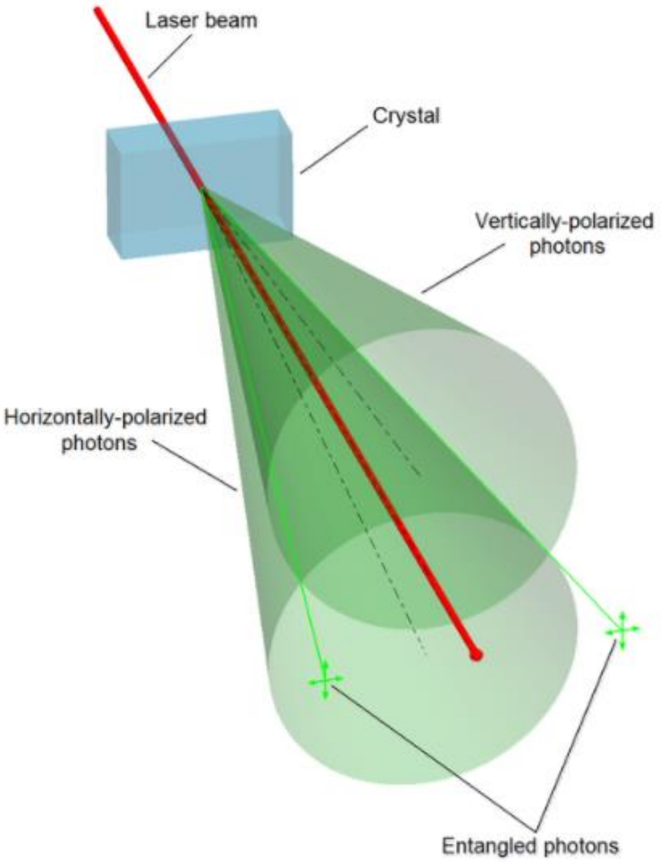


In the Fock (number) basis:

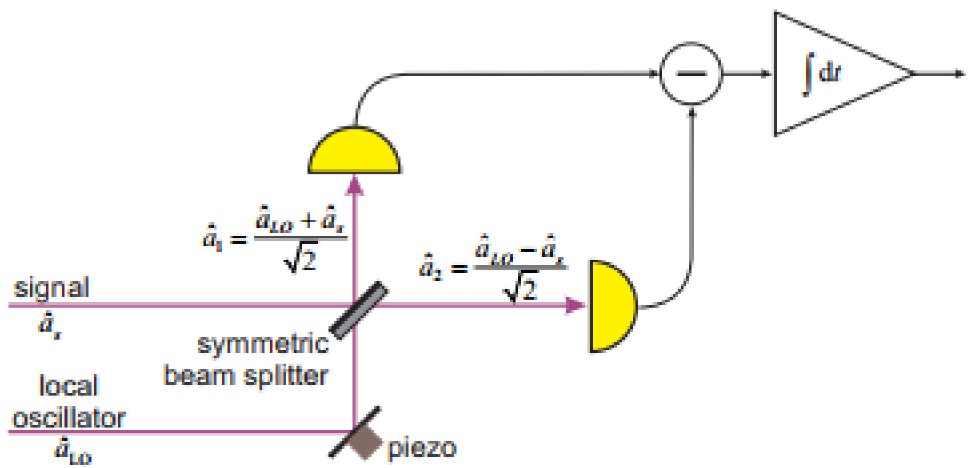
$$|x\rangle\rangle = \sqrt{(1-x^2)}\sum_n x^n\,|n,n\rangle\rangle$$

Continuous-variable entanglement

Entanglement between *field quadratures*:

$$\boxed{x = a^{+} + a, \quad p = i(a^{+} - a)}$$

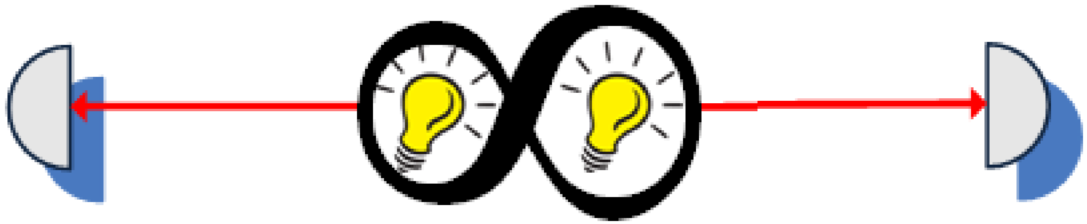
Quadratures can be measured using *homodyne detector*:

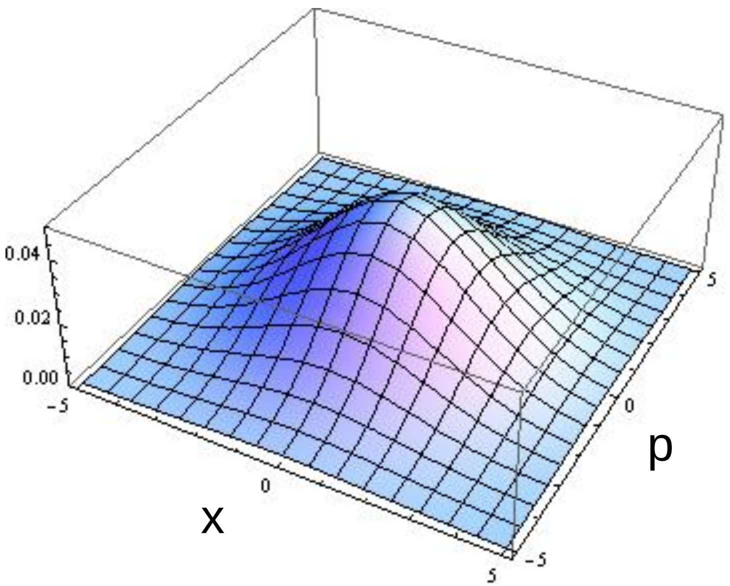


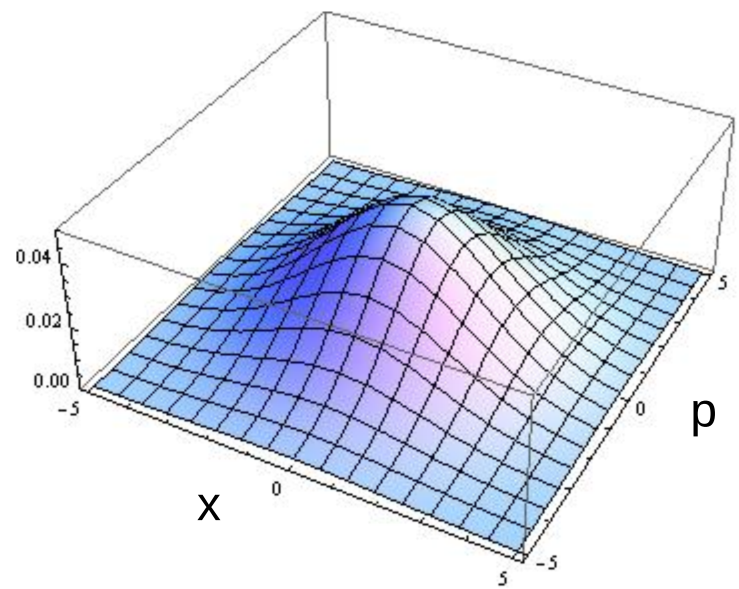
Depending on the phase-shift of the *local oscillator*, x or p quadrature is measured: $\hat{X}_\theta = \hat{X}\cos\theta + \hat{P}\sin\theta$

Continuous-variable entanglement

TMSV (produced by type-II SPDC) and measured by homodyne detectors:







Continuous-variable entanglement

TMSV characterization using *covariance matrices*

$$\gamma_{AB} = \begin{pmatrix} V\mathbb{I} & \sqrt{V^2-1}\sigma_z \\ \sqrt{V^2-1}\sigma_z & V\mathbb{I} \end{pmatrix}$$

$$\mathbb{I} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \text{ and } \mathbb{Z} = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

Continuous-variable entanglement

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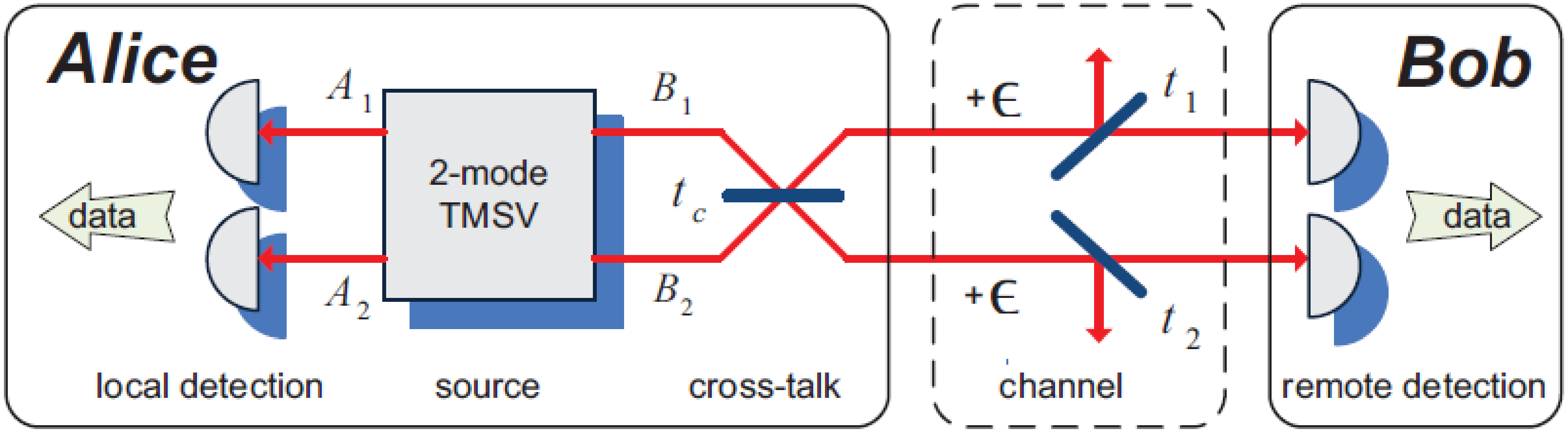
TMSV entanglement characterization using *logarithmic negativity*

$$LN = \max\{0, -\log_2 \nu\}$$

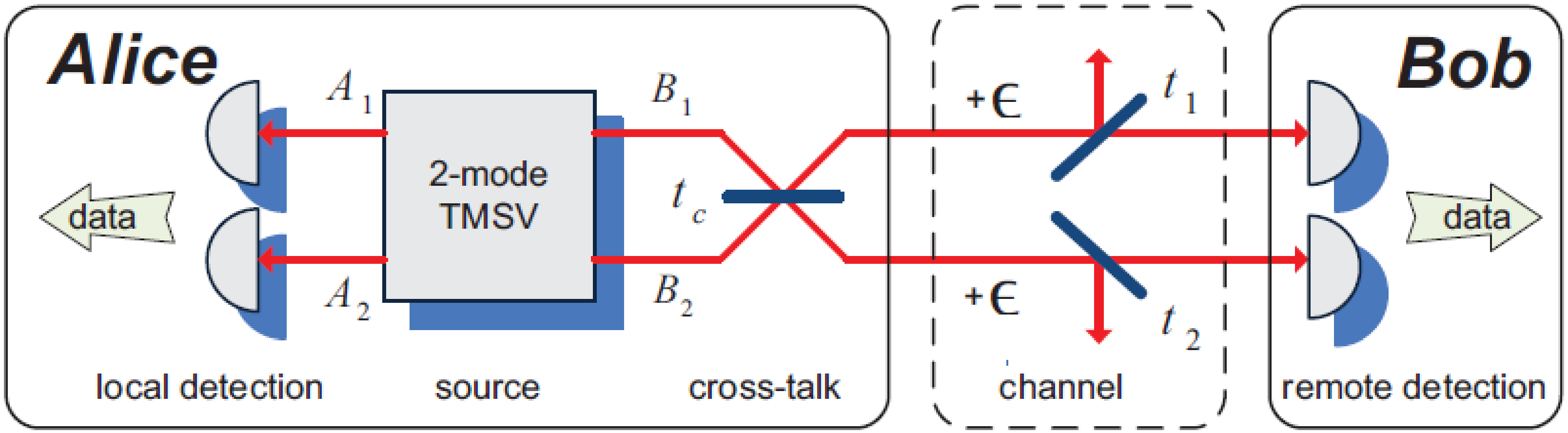
[G. Vidal and R. F. Werner, “Computable measure of entanglement,” Phys. Rev. A, vol. 65, no. 3, p. 032314, 2002]

Multimode CV entanglement distribution



Two-mode entanglement distribution scheme over noisy and lossy quantum channel with cross-talk in the source

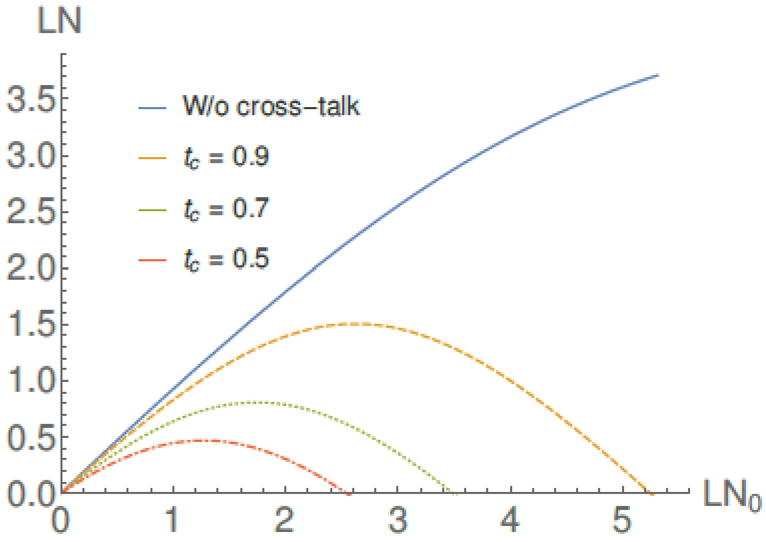
Multimode CV entanglement distribution

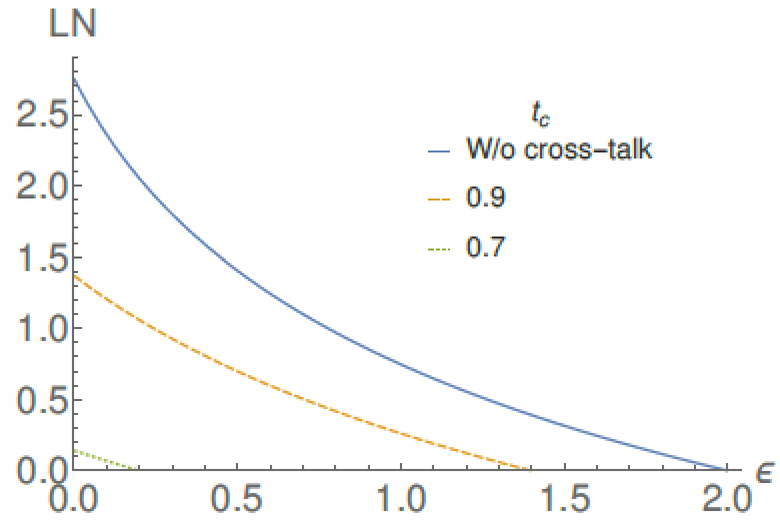


Two-mode entanglement distribution scheme over noisy and lossy quantum channel with cross-talk in the source. Covariance matrix of the resulting state:

$$\gamma_{A_1A_2B_1B_2} = \begin{pmatrix} V\,\mathbb{I} & \sqrt{t_c\,T_1}\sqrt{V^2-1}\,\mathbb{Z} & 0\,\mathbb{I} & -\sqrt{r_c\,T_2}\sqrt{V^2-1}\,\mathbb{Z} \\ \sqrt{t_c\,T_1}\sqrt{V^2-1}\,\mathbb{Z} & [T_1(V-1)+1]\,\mathbb{I} & \sqrt{r_c\,T_2}\sqrt{V^2-1}\,\mathbb{Z} & 0\,\mathbb{I} \\ 0\,\mathbb{I} & \sqrt{r_c\,T_1}\sqrt{V^2-1}\,\mathbb{Z} & V\,\mathbb{I} & \sqrt{t_c\,T_2}\sqrt{V^2-1}\,\mathbb{Z} \\ -\sqrt{r_c\,T_1}\sqrt{V^2-1}\,\mathbb{Z} & 0\,\mathbb{I} & \sqrt{t_c\,T_2}\sqrt{V^2-1}\,\mathbb{Z} & [T_2(V-1)+1]\,\mathbb{I} \end{pmatrix}$$

Role of cross-talk





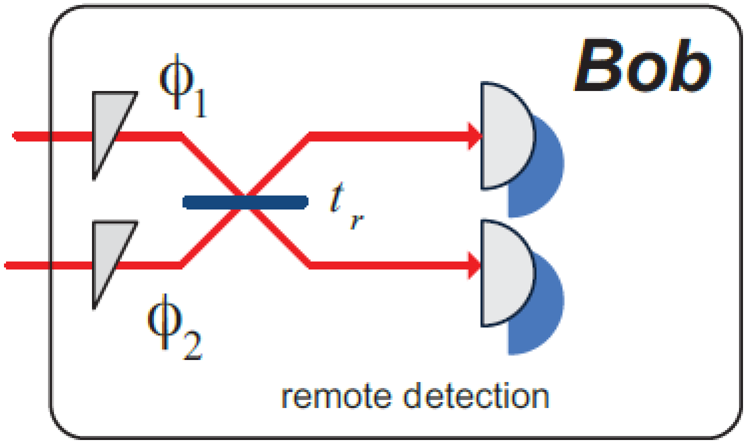
Effect of cross-talk on two-mode TMSV entanglement in dependence on the initial entanglement (left) and on the channel noise (right).

Initial entanglement must be drastically limited in the presence of cross-talk.

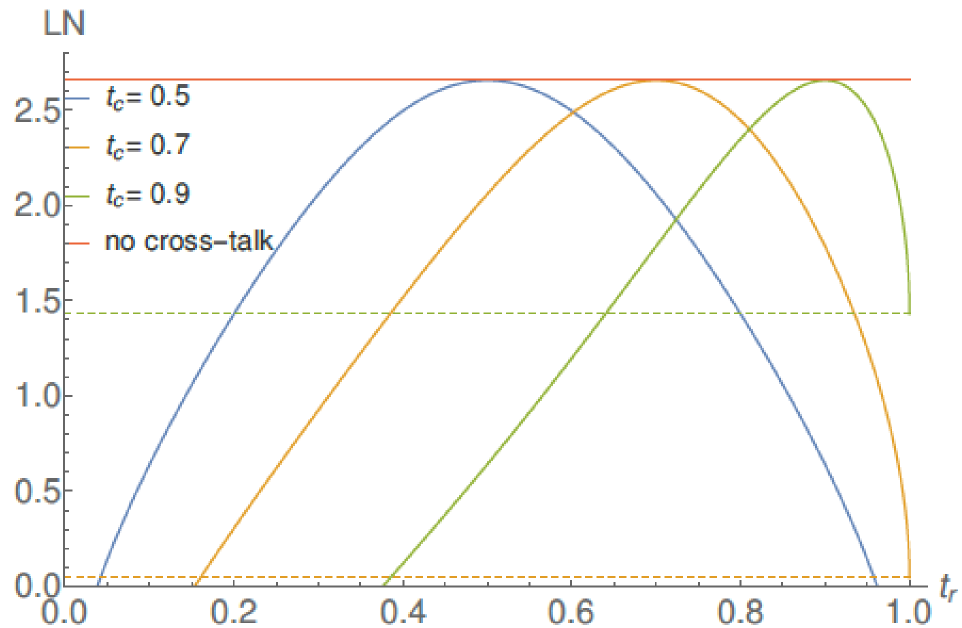
$$V_{max} = \frac{1 + t_c - \varepsilon}{1 - t_c}$$

The states become more sensitive to the channel noise.

Cross-talk compensation by local manipulations

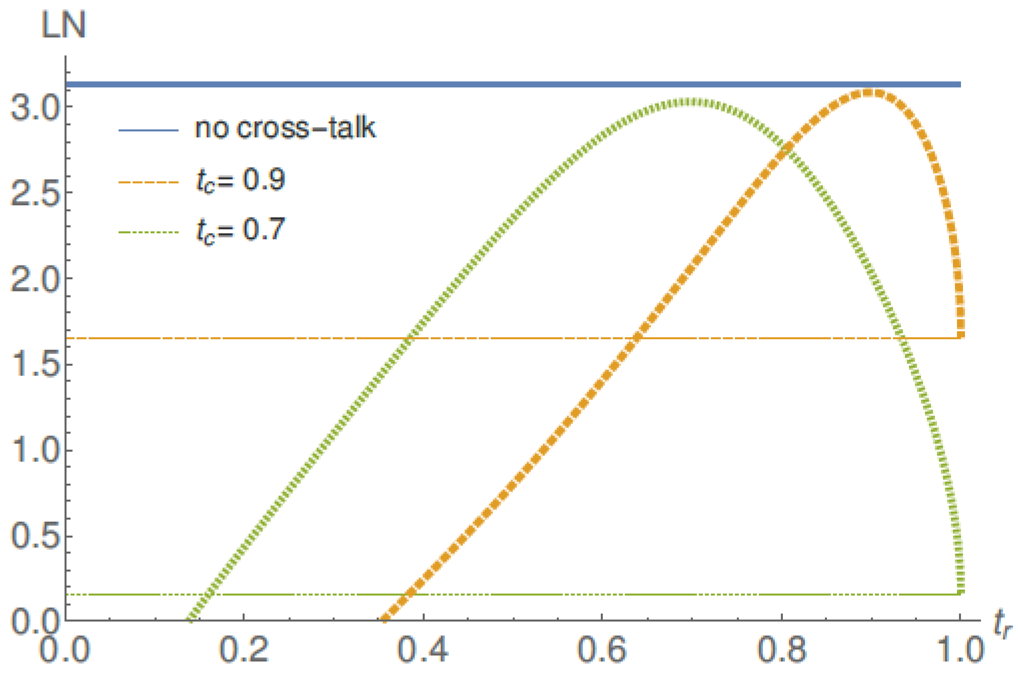


Phase shifts and linear coupling prior to detection on the remote side.



Entanglement restoration by optimal reverse coupling and phase flips.

Role of channel unbalancing



Possibility to restore entanglement in the case of unbalanced channels (transmittance of 0.9 and 0.7 for different modes)

Summary

- Linear cross-talk degrades entanglement of continuous-variable states;
- Cross-talk requires optimization (reduction) of the initial entanglement and makes the states more sensitive to the channel noise;
- We suggest the method of phase shifts and linear coupling on the remote side prior to detection;
- In the optimal setting, the method can fully restore the entanglement in the case of balanced channels (with the same transmittance for both the modes);
- For the strongly unbalanced channels the method is limited, but is still close to full reconstruction of entanglement.

Thank you for attention!

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