Optimizing Quantum Subchannel Discrimination:

One-Way Communication and Device-Independent Security

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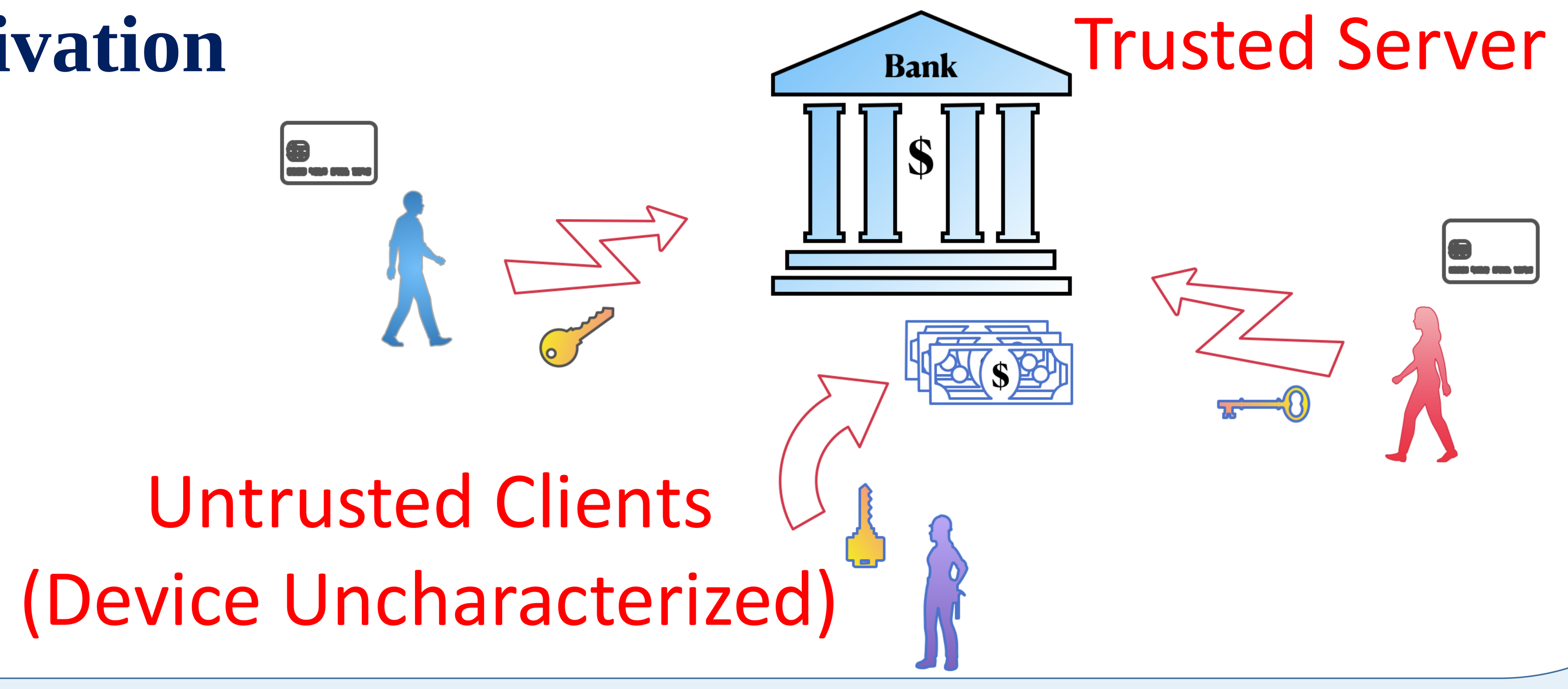
Abstract

Steerable states provide a quantum advantage in subchannel discrimination tasks. In this work, we experimentally demonstrate a discrimination task with high-dimensional entanglement and show how local filtering operations can enhance its success probability. By distilling the steerable states, we boost the discrimination probability close to **100%**. Our work also confirm the generality of this approach, which is valid across any dimension with appropriately chosen filters. This study establishes subchannel discrimination as a practical application of partially untrusted devices, deepening our understanding of their operational significance.

Motivation

In many real-world applications, certain schemes cannot be fully trusted. A typical example is a server-client model, such as online banking, where the **client-side devices are often untrusted or uncharacterized**. Subchannel discrimination plays a fundamental role in this one-sided device-independent (1S-DI) framework, making it one of the most practical applications of quantum information processing under untrusted conditions.



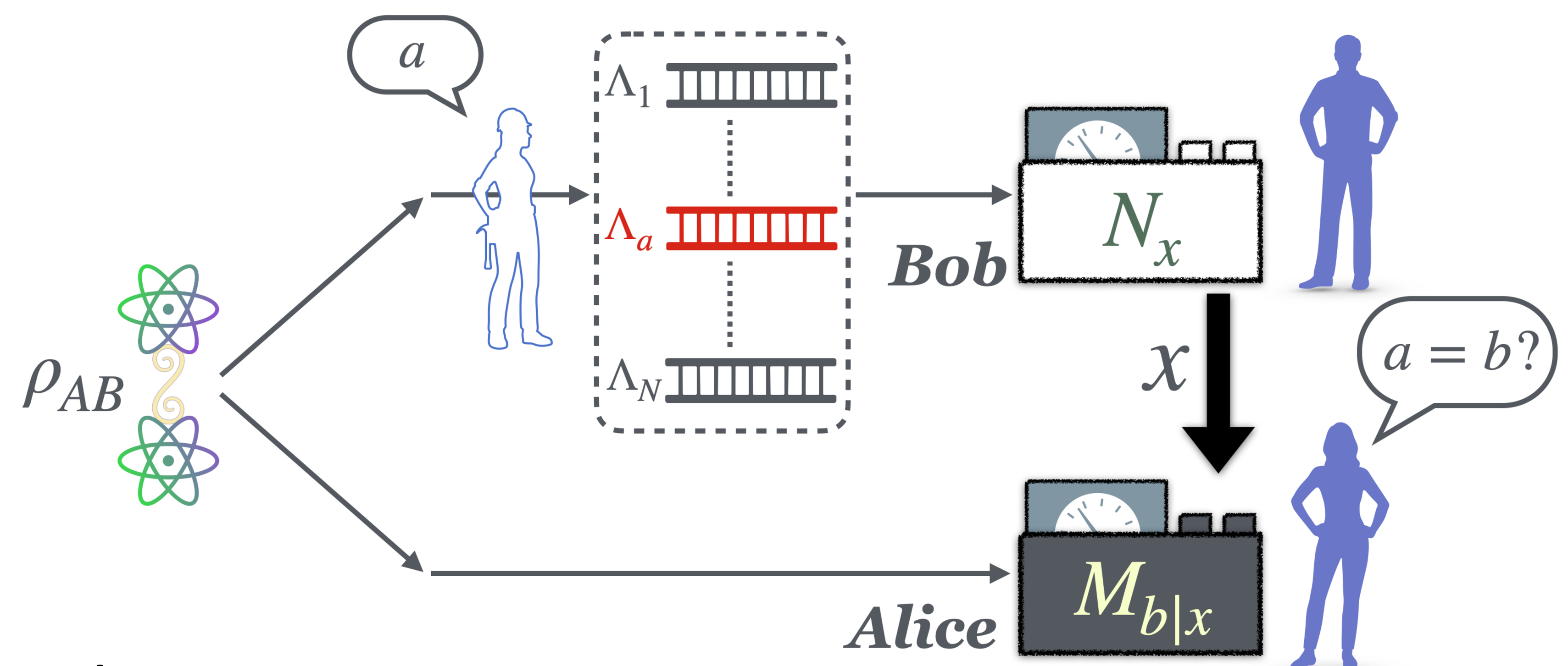
Subchannel discrimination task

Game Setup:

Alice and Bob share a bipartite state, A referee prepares a set of subchannel on Bob's side and randomly selects one subchannel

Objective:

Their goal is to **identify a** using **1W-LOCC operations**.



Game Process:

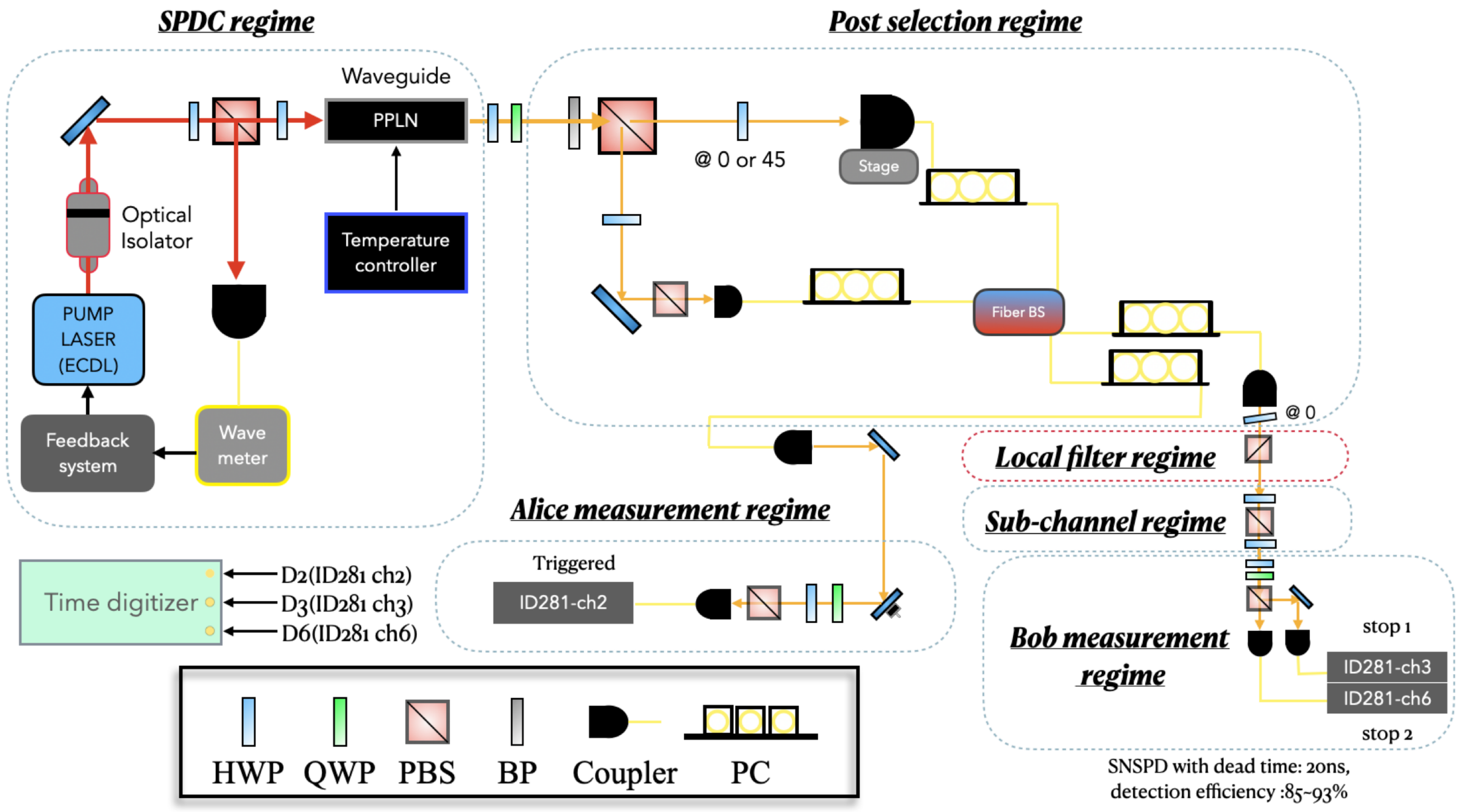
For Bob

1. Bob performs a measurement {Nx}x
2. Obtains an outcome x
3. Then sends x to Alice via classical communication.

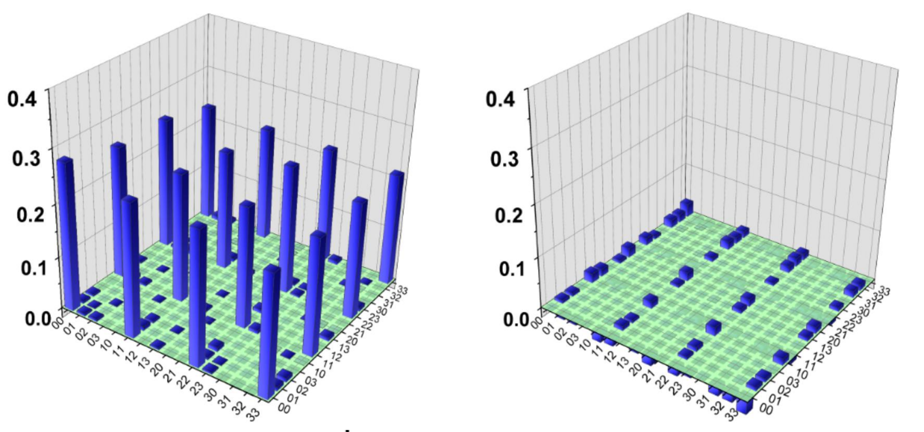
For Alice

1. Upon receiving x from Bob
2. Alice performs a conditional measurement
3. Then uses the measurement outcome b as final guess for a.

Experimental setup



High dimension state & sub-channels:



$$|\Phi^+_{AB}\rangle \otimes |\Phi^+_{AB}\rangle = \frac{1}{2}(|H_A H_B H_A H_B\rangle + |H_A V_A H_B V_B\rangle + |V_A H_A V_B H_B\rangle + |V_A V_B V_A V_B\rangle)$$

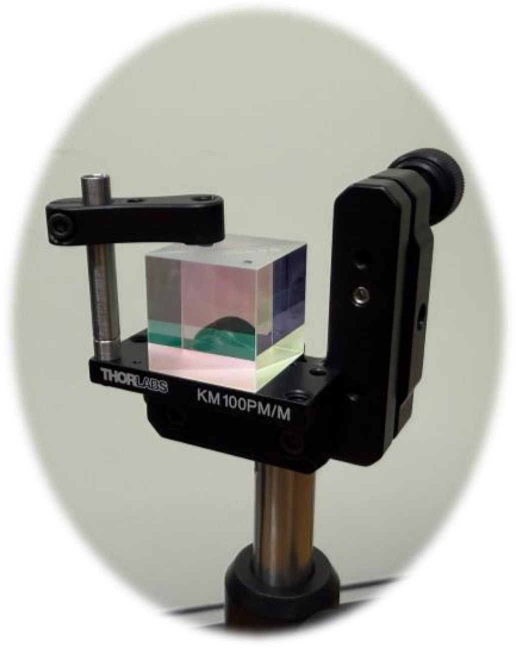
The task involves two subchannels (a=2), each composed of four Kraus operators (i=4).

$$\Lambda_a(\rho) = \sum_i K_{a,i} \rho K_{a,i}^\dagger$$

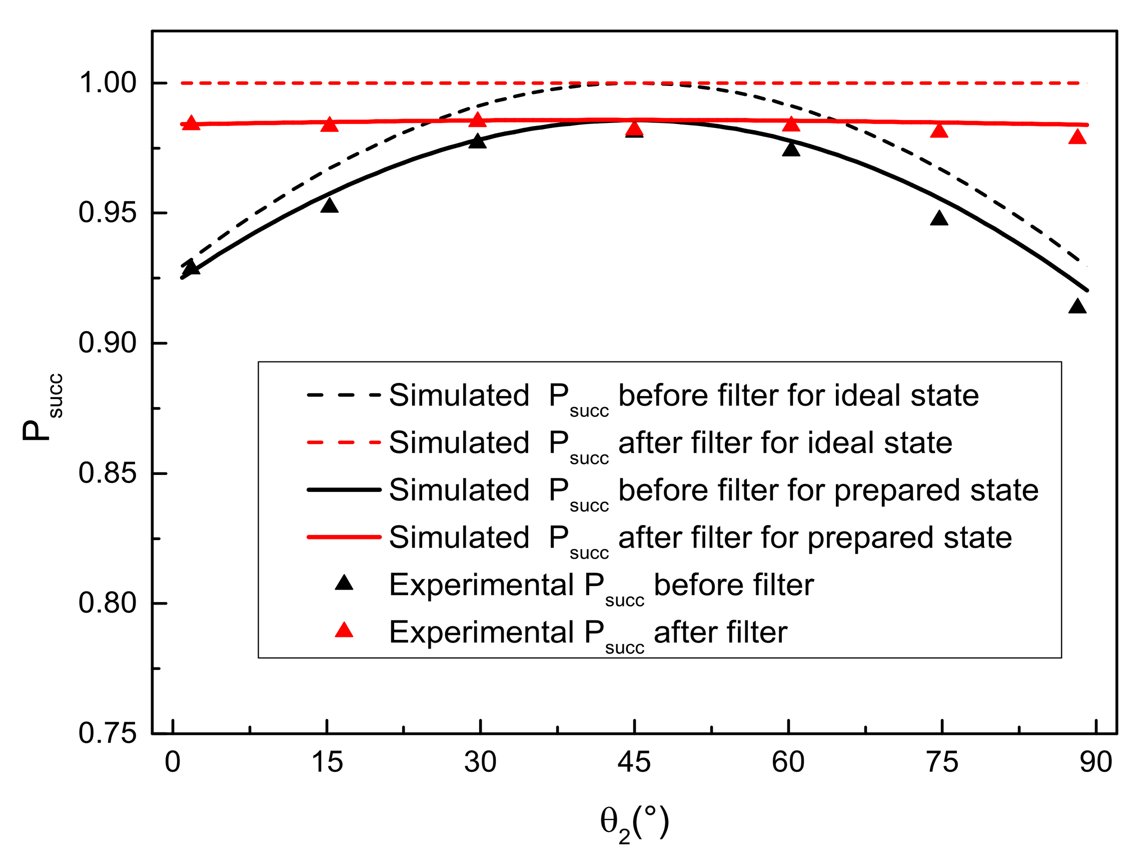
$$K_{a,i} = A_i \otimes B_i$$

$$\text{Ex:}\quad K_{a,1} = \begin{pmatrix} 0 & 1 \\ 0 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & 0 \\ -0.6490 & -0.2808 \end{pmatrix}$$

Results



Local filter



The guessing probability (P_{guess}) of SCD task is given by

$$\begin{aligned} P_{\text{guess}} &= \sum_{a,b} \text{Tr}\left[Q_a \Lambda_b(\rho)\right] \delta_{ab} \\ &= \sum_a \text{Tr}\left[Q_a \Lambda_a(\rho)\right] = \text{Tr}\left[Q_0 \Lambda_0(\rho)\right] + \text{Tr}\left[Q_1 \Lambda_1(\rho)\right] \qquad \textit{where}, Q_a = \sum_x M_{a|x} \otimes N_x \\ &= (M_{00} \otimes N_0 + M_{01} \otimes N_1) \left[\sum_m (I_{4x4} \otimes K_{0|m})\, \rho\, (I_{4x4} \otimes K_{0|m})^\dagger\right] \\ &\quad + (M_{10} \otimes N_0 + M_{11} \otimes N_1) \left[\sum_m (I_{4x4} \otimes K_{1|m})\, \rho\, (I_{4x4} \otimes K_{1|m})^\dagger\right] \end{aligned}$$

Reference

[1] Marco Piani, and John Watrous, Phys. Rev. Lett. 114, 060404 (2015)
[2] Cyril Branciard, Eric G. Cavalcanti, Stephen P. Walborn, Valerio Scarani, and Howard M. Wiseman, Phys. Rev. A 85, 010301(R) (2012)
[3] Huan-Yu Ku, Chung-Yun Hsieh, Shin-Liang Chen, Yueh-Nan Chen & Costantino Budroni, Nature Communications 13(1) : 4973 (2022)