High Dimensional Quantum Key Distribution System Using Structured Light

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Aim

Practical Implementation of HD QKD system based on higher dimension QKD protocol (KMB09).

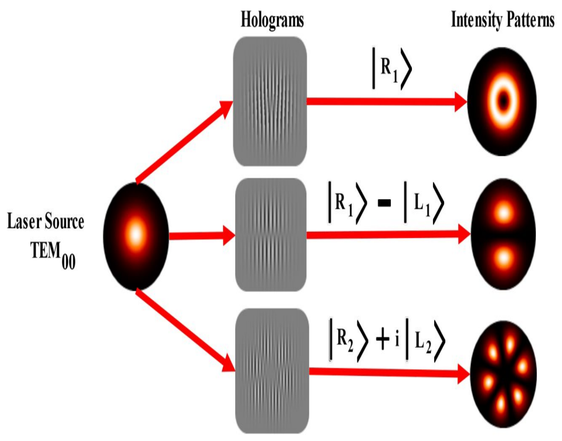
Basic Principles of QKD

Uncertainty Principle
– The state of a quantum system cannot be determined unless it is measured.

No Cloning Theorem
– Impossible to copy unknown pure quantum states.

Structured Light

- Light carrying orbital angular momentum (OAM) forms the structured light.
- Laguerre gaussian modes normally contain the OAM number associated with twist or rings.
- OAM modes can be directly created from laser using SLM driven by computer generated complex binary holograms.



Decoy State Scheme

- We also incorporate a decoy-state scheme to improve the QKD system efficiency on a secure transfer of secret keys.
- We utilized vacuum plus weak coherent pulses to avoid the Photon Number Splitting (PNS) attack.

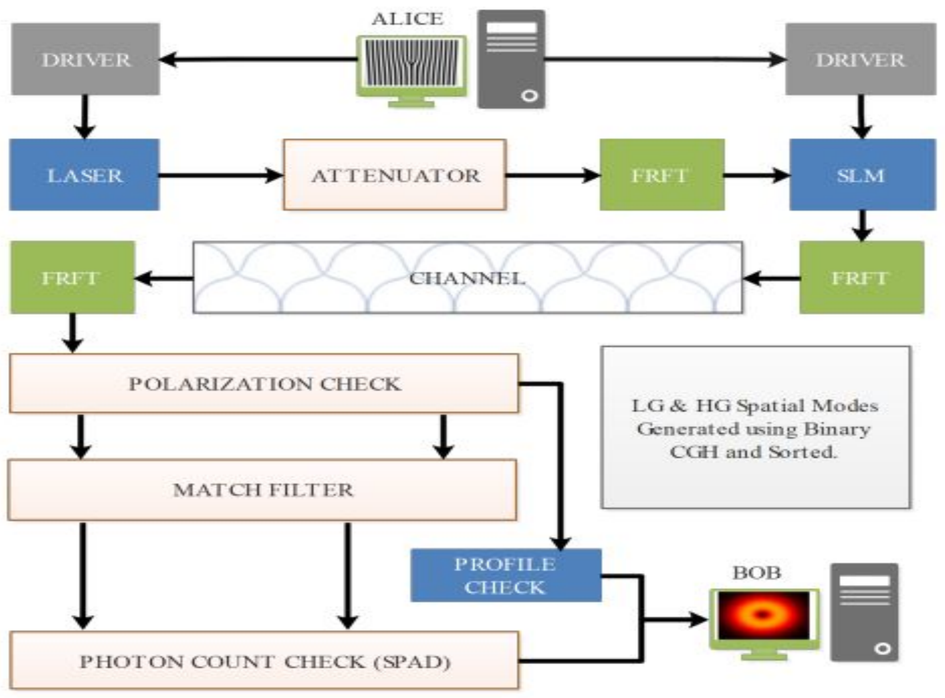
HD-QKD Protocol

- A high dimensional QKD protocol proposed in 2009 with two different eavesdropping error-rates.
  i. The Quantum Bit Error-rate (QBER).
  ii. The Index Transmission Error-rate (ITER).
- Bits are encoded in bases instead of dimensions.
- Improved eavesdropping detection.

Index By Alice	Measurement By Bob (bits)											
	$\|\tau_1\rangle$	$\|\tau_2\rangle$	$\|\tau_3\rangle$	$\|\tau_4\rangle$	...	$\|\tau_N\rangle$	$\|v_1\rangle$	$\|v_2\rangle$	$\|v_3\rangle$	$\|v_4\rangle$	...	$\|v_N\rangle$
1	×	1	1	1	...	1	×	0	0	0	...	0
2	1	×	1	1	...	1	0	×	0	0	...	0
3	1	1	×	1	...	1	0	0	×	0	...	0
4	1	1	1	×	...	1	0	0	0	×	...	0
...	...	...	...	...	...	...	...	...	...	...	...	...
N	1	1	1	1	...	×	0	0	0	0	...	×

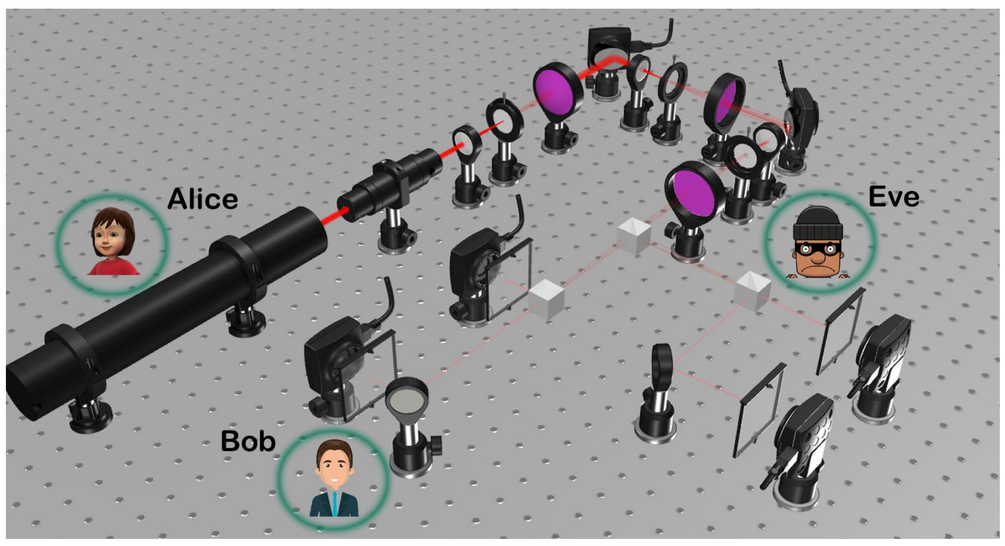
HD-QKD System Design

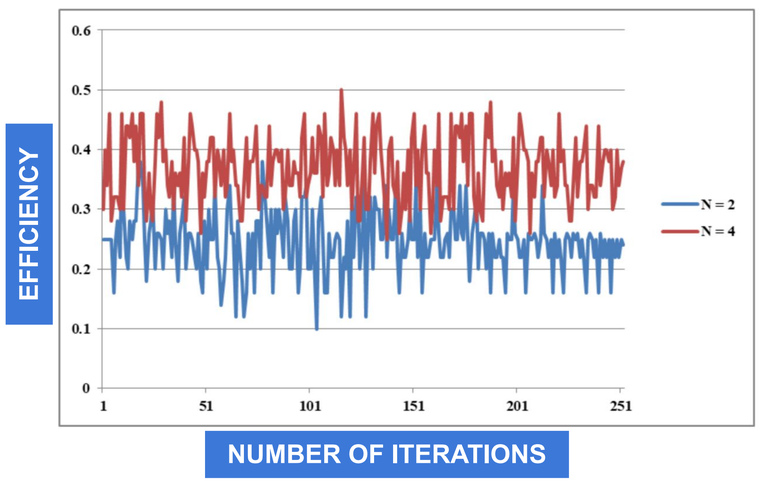
- QKD system comprises of Alice and Bob.
- Laser is the main source of photons having standard TEM_{00} Gaussian mode.
- Attenuator is used to limit μ per pulse.
- Beam expansion is done using 4f system.
- Spatial modulation is done with SLM by imposing holograms of LG modes.
- Higher order filtering is done using 4f system.
- First determine polarization of OAM mode.
- Second to use Match filter (SLM with fiber-coupler) for determining incoming photon mode carrying OAM.
- SPADs modules are used for photon counting.
- CMOS camera is used for profile checking.

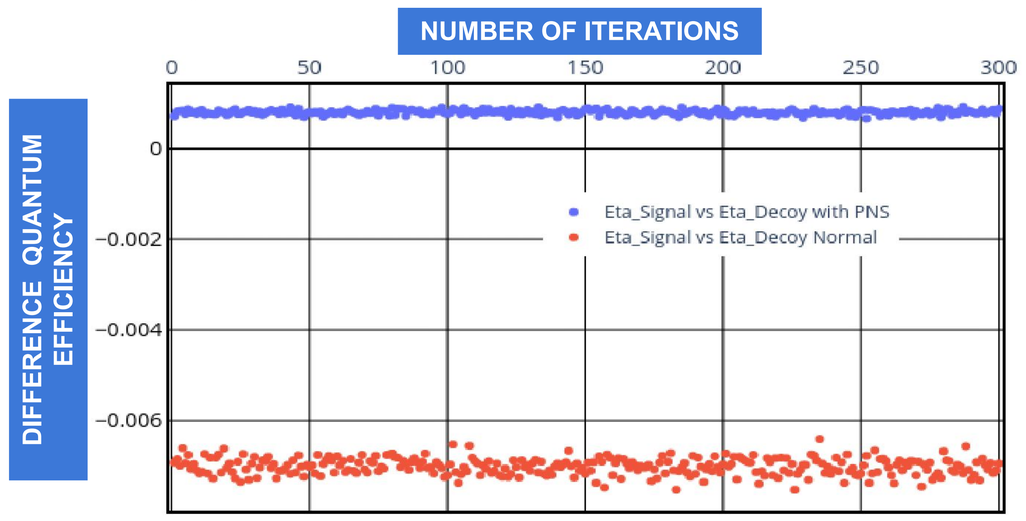


HD-QKD System Simulation

- Simulation is carried out on open source platform (python 3.7).
- SLM libraries and image processing (SSIM) schemes are mainly utilized in over-all simulation.
- Cartoon setup is developed using online 3D optical simulation tool.
- Graph shows the system simulation results in 2 and 4 dimensions in terms of efficiency and their absolute error w.r.t analytical results.







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Future Research Challenges

- Handling of attacks using protocol error rates i.e., QBER & ITER.
- Analysis of QKD system efficiency due to turbulence in quantum channel.

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