UNIVERSIDAD TECNICA
FEDERICO SANTA MARIA

DETECTING A SPY WITH QUANTUM COMPUTING

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(Universidad Técnica Federico Santa María, 2024)

CONTENT

- Conceptual Foundations
- State of Art
- Implementation
- Conclusions

CONCEPTUAL FOUNDATIONS – QUANTUM COMPUTING

A Quantum Computer(Qc):

- Solve problems out of reach for Classical Computing.
- Use Qubits and follows the next principles:
  - Superposition
  - Entanglement
  - Decoherence
- Actual State: Noisy Intermedite Scale Quantum (NISQ).
- Utility: Optimization, machine learning, cryptography and more.

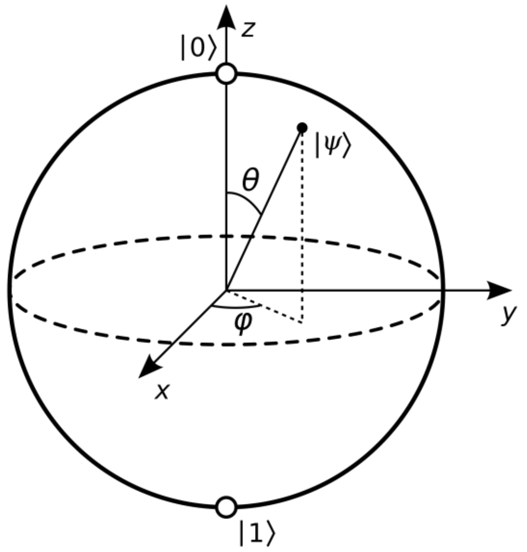
CONCEPTUAL FOUNDATIONS

- Quantum's states Representation:
  - 1 Qubit
  - 2 Qubits Superposition

$$|a\rangle = v_0|0\rangle + v_1|1\rangle \to \begin{bmatrix} v_0 \\ v_1 \end{bmatrix} \quad |0\rangle = \begin{bmatrix} 1 \\ 0 \end{bmatrix} \quad |1\rangle = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

$$|\psi\rangle = \alpha\,|00\rangle + \beta\,|01\rangle + \gamma\,|10\rangle + \delta\,|11\rangle$$

- Bloch's Sphere.
- Quantum Gates
  - NOT $X := \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$ $\quad X|0\rangle = |1\rangle \quad X|1\rangle = |0\rangle$
  - Pauli-Y $Y := \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}$ $\quad Y|0\rangle = i|1\rangle \quad Y|1\rangle = -i|0\rangle$
  - Pauli-Z $Z := \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$ $\quad Z|0\rangle = |0\rangle \quad Z|1\rangle = -|1\rangle$
  - CNOT $CNOT = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$
  - Hadamard $H = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$ $\quad H|0\rangle = \frac{|0\rangle + |1\rangle}{\sqrt{2}} \quad H|1\rangle = \frac{|0\rangle - |1\rangle}{\sqrt{2}}$
- Noise
- Quantum Error Correction(QEC)



(Esfera de Bloch, 2024)

STATE OF ART

Date	**Main Advances**
1970	James Park articulates The Non-Cloning Theorem (20).
1973	A. Holevo articulates the Holevo and Bennet theorem's revealing that the computing can be done in a reversible manner.
1980	Paul Beinoff describes the first model of QC Computer (21), Tomasso Toffoli presents the Toffoli's Gate (22).
1985	David Deutsch describes the first QC universal.
1992	D. Deutsch and R. Jozsa propose computational problem that can be solved efficiently in a QC.
1993	Dan Simon invents an oracle problem, for which a QC would be exponentially faster than an algorithm in a QC.
1994	Peter Shor publishes Shor's algorithm.
1995	Shor propose the first schemes for QEC (23).
1996	Lov Grover invents the quantum DB search algorithm.
2000	Pati and Braunstein proved the quantum non-elimination theorem.
2001	First execution of Shor's Algorithm
2003	Implementation of the Deutsch-Jozsa algorithm in a QC.

STATE OF ART

Fecha	Principales avances
2006	First QC of 12 Qubits.
2007	D-Wave system shows the use of a 28 Qubit annealing QC.
2009	Creation of the first electronic quantum processor.
2010	Development of the single-electron Qubit.
2014	Scientists transfer data by quantum teleportation over a distance of 3 meters with an error rate of 0% (24)
2017	IBM introduces the QC of 17 Qubits.
2018	Google announces the creation of a 72 Qubits quantum chip.
2019	IBM unveils its largest QC of 53 Qubits.
2020	Google reports the largest chemical simulation in a QC.
2021	IBM claims to have created a 127 Qubits processor.
2022	Google team creates a traversable wormhole in a QC.
2023	Researchers from Innsbruck entwined two ions at more than 230 meters.

STATE OF ART

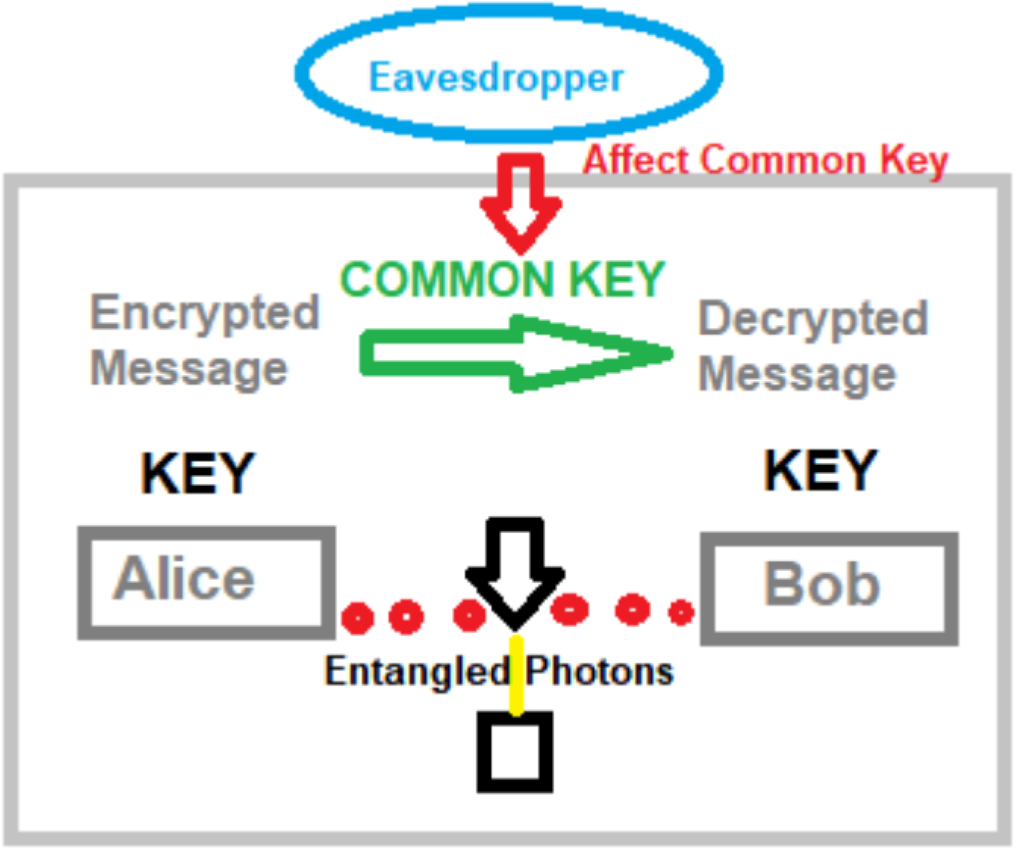
Ref	Contribución Realizada	Ventaja Comparativa
(25)	Propose of AES algorithm with more security using Quantum Random Walk	Post-Quantum propose of AES Algorithm
(26)	Quantum Key Distribution and experiments with eavesdropper.	State of Art of QKD and experiments with eavesdropper and quantity of photons.
(27)	Descripción general de QC en Ciberseguridad presentando varias soluciones.	Estado del arte sobre ataques con QC en contexto de Ciberseguridad
(28)	Propone parámetros y cambios a RSA en QC para hacerlos factibles en la actualidad.	Propone GEECM, versión cuántica de Lenstra Elliptic-Curve Factorization (ECM) y experimentación con escuchas de espías.

IMPLEMENTATION

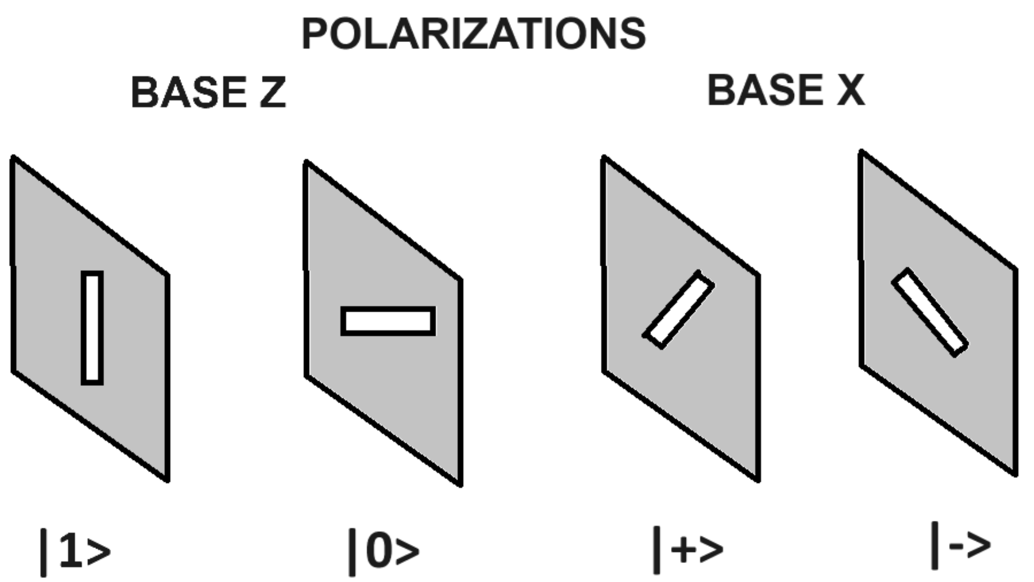
- **Purpose**: Send the next message to Bob:" 1 2 3 2 2 1" using Quantum Key Distribution and Quantum Circuit.
- **Libraries**: Qiskit, Cryptography Fernet.
- **Aim**: Send the next message with the creation of a Shared Key using Quantum simulation.
    - 1 2 3 2 2 1

      Binary: 0b01101110100 1
- **Situations**:
    - 1) No presence of a Spy.
    - 2) Presence of a Spy and detection.
- **Supositions**:
    - 1) No noise in the canal.

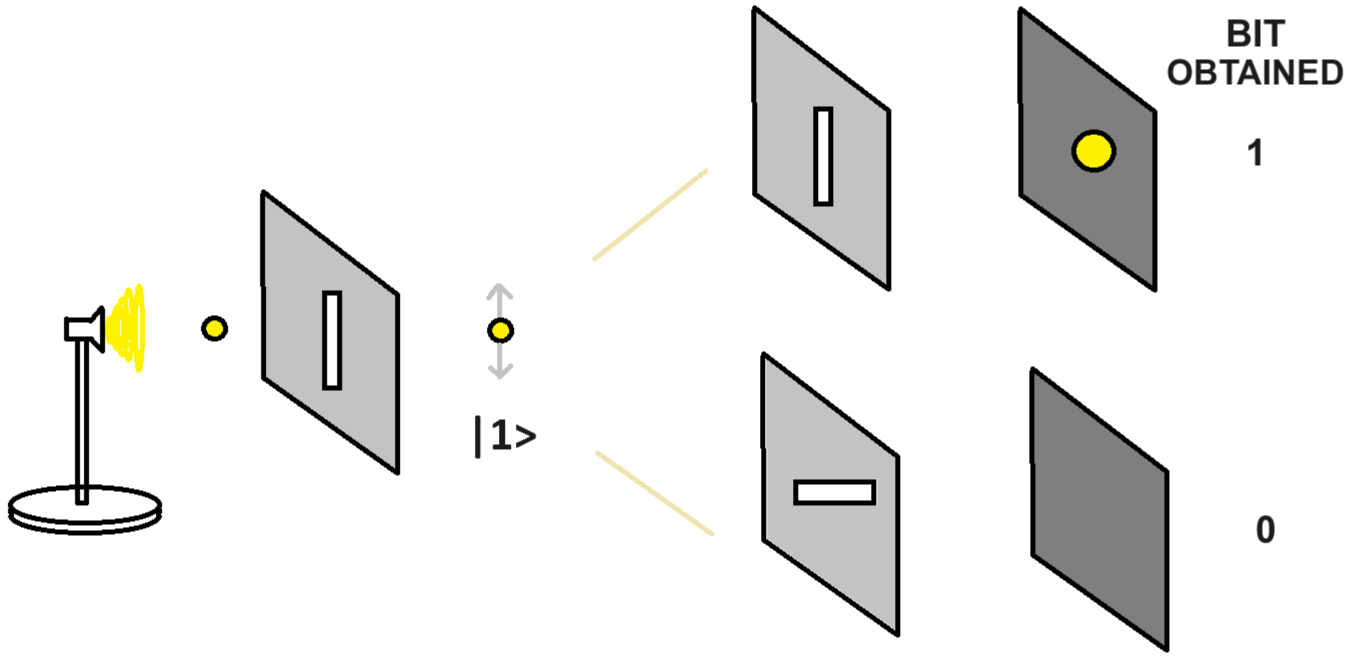
IMPLEMENTATION

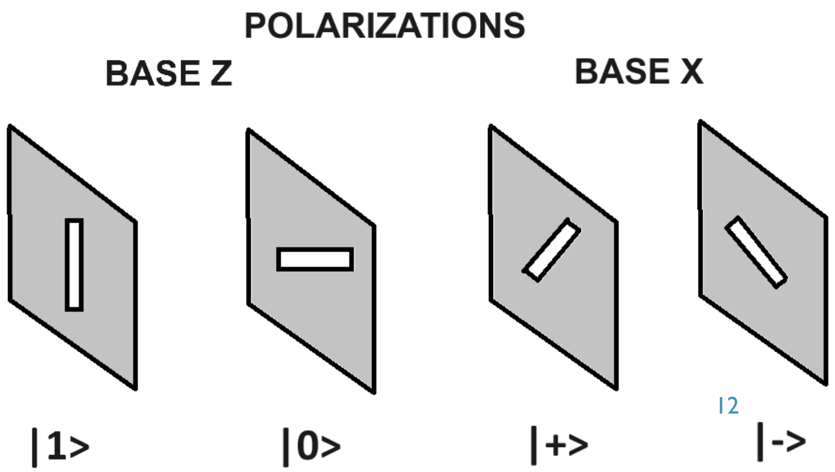


IMPLEMENTATION



IMPLEMENTATION

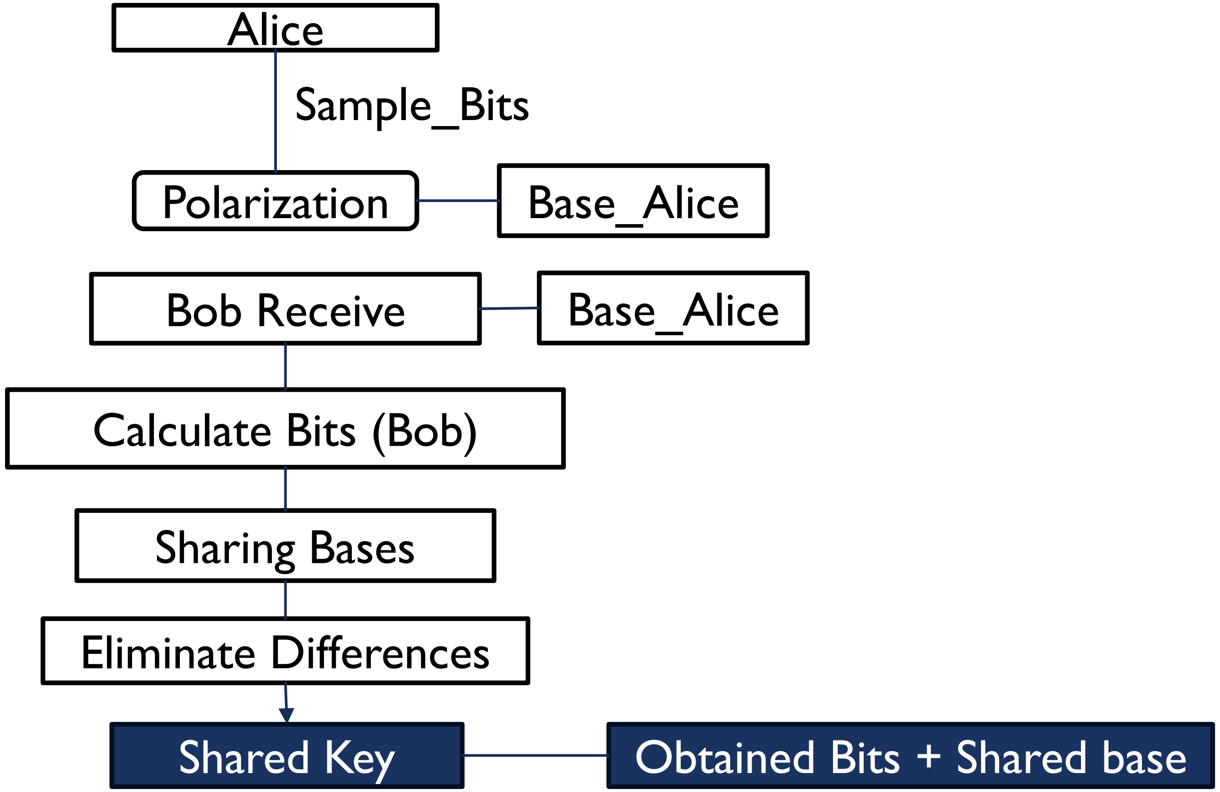




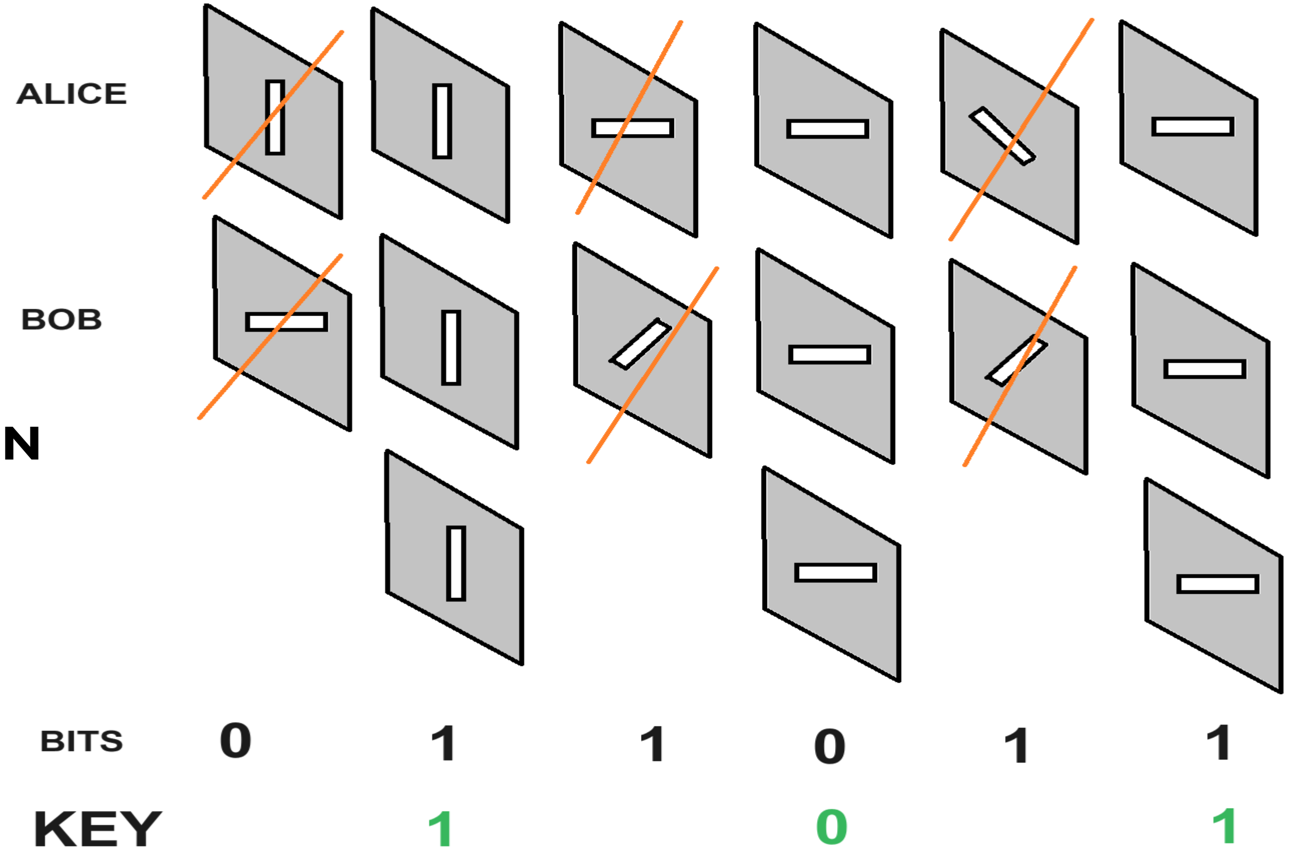
IMPLEMENTATION

- Situation 1) **No spy**:
  - **Generation of Bit String**(not message) **and arbitrary election of Basis:**

Random Generation:
Sample_Bits
Base_Alice
Base_Bob



- **SHARING BASES** (not Bits obtained)

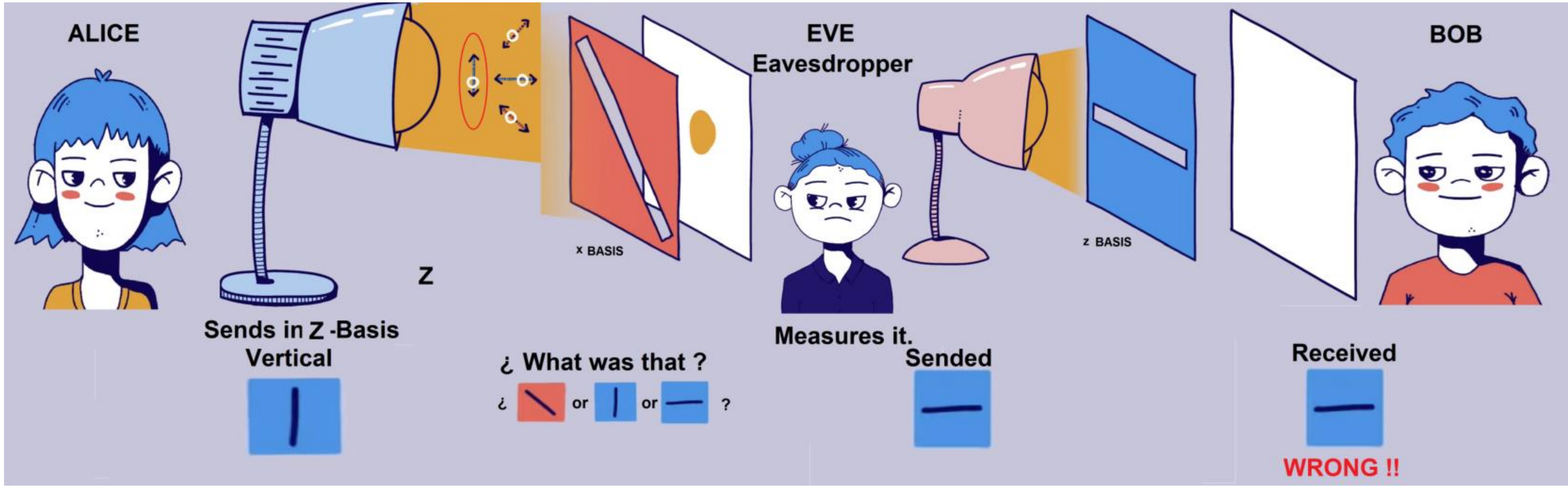


- **KEY OBTENTION**

- One Time Pad
- Cifrado simétrico
- MAC

IMPLEMENTATION

- **Situation 2:** Sending the message with Spy and Detecting.



Spy (EVE) can't know with 100% certainty the base used to replicate to Bob. Bob will realize that key generated is not working and it is reasonable think that the canal is compromised.

FUNCTIONS - IMPLEMENTATION

encode_message(bits, bases**)** , **measure_message(**message, bases**)** , **remove_no_coincidences(**a_bases, b_bases, bits**)**

```
def encode_message(bits, bases):
  message = []
  n=len(bases)
  for i in range(n):
     qc = QuantumCircuit(1,1)
     if str(bases[i]) == '0':
        if str(bits[i]) == '0':
           pass
        elif str(bits[i]) == '1':
           qc.x(0)
     else:
        if str(bits[i]) == '0':
           qc.h(0)
        elif str(bits[i]) == '1':
           qc.x(0)
           qc.h(0)
        qc.barrier()
     message.append(qc)
  return message
```

```
def measure_message(message, bases):
  backend = Aer.get_backend('aer_simulator')
  measurements = []
  n=len(bases)
  for q in range(n):
     if str(bases[q]) == '0': # base Z
        message[q].measure(0,0)
     if str(bases[q]) == '1': # base X
        message[q].h(0)
        message[q].measure(0,0)
     aer_sim = Aer.get_backend('aer_simulator')
     result = aer_sim.run(message[q], shots=1, memory=True).result()
     measured_bit = int(result.get_memory()[0])
     measurements.append(measured_bit)
  return measurements
```

```
def remove_no_coincidences(a_bases, b_bases, bits):
  good_bits = []
  n=len(bits)
  for q in range(n):
     if str(a_bases[q]) == str(b_bases[q]):
        good_bits.append(bits[q])
  return good_bits
```

IMPLEMENTATION

- **Results**

```
Bases
Alice_Base: [0 0 1 0 0 1 1 0 1 1 0 1 0 1 0 0 1 0 0 0 0 0 0 1 1 1 1 0 0 0]
Eva_Base:    [1 1 1 0 1 1 1 0 0 1 0 0 1 1 1 0 1 1 1 1 0 1 1 1 1 1 1 0 0 0]
Bob_Base:    [0 1 1 0 1 0 1 0 1 1 0 1 0 1 0 1 0 0 0 1 0 1 0 0 0 1 1 0 1 0]
```

```
Alice_Key_with_interception: 11101001010001101110
Bob_Key_with_interception:    01111011100111110110
```

```
ERROR. Used key is not correct.
POSIBLE PRESENCIA DE UN ESPIA
  Clave: 01111011100111110110
```

CONCLUSIONS

- Implementation of Quantum Key Distribution Based on BB84 in Python using Quantum Circuits simulator Qiskit.
  - Useful to make a secret shared key with the capacity to detect Spies in the communication.
  - We observe that the apparition of a Spy causes an unmatched shared Key, which is a sign of compromised communication.
    - State's Superposition is a important principle here, only on Quantum Computing.
  - While larger is the Key, better are the chances to detect an Spy in the communication in this context.

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