Fast and Smart Disaster Recovery Networks Using 5G-Advanced and 6G Mobile Base Stations with Physical Layer Artificial Intelligence and Quantum Machine Learning

Assoc. Prof. Dr.Eng. Khoirul Anwar, ST., M.Eng.

Director, The University Center of Excellence for Advanced Intelligent Communications (AICOMS), Telkom University, Bandung, Indonesia
Vice-Chairman of Asia-Pacific Wireless Group (AWG), Bangkok, Thailand 2018—2025
Research Collaboration of Quantum Technology (PKR Kuantum 2.0)
Beyond 5.5G Laboratory
Vice Chairman of Indonesia Open RAN Task Force
E-mail: anwarkhoirul@telkomuniversity.ac.id

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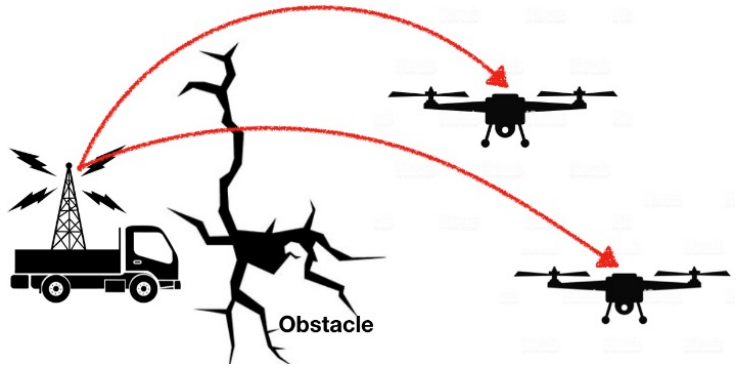
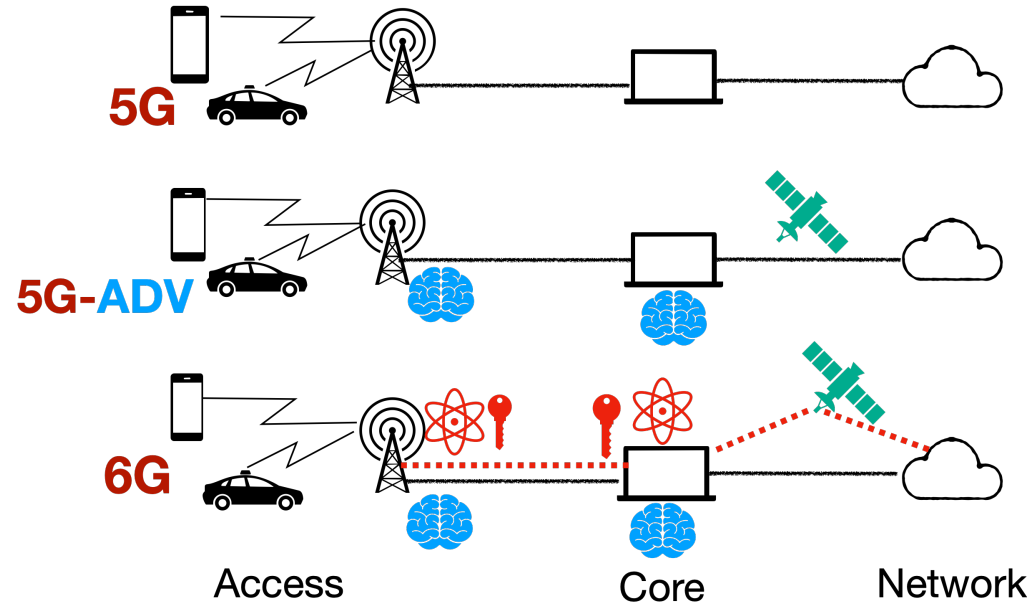
Background :

- After the disaster, telecommunication networks **cannot be recovered** soon and are **suffering from difficulties** of covering large areas.
- The rescue team and mobile base station are suffering from difficulties in finding the victims although the victim's mobile phones are active but is out-of-network range.
- The current telecommunication generation is towards 5G-Advanced and 6G

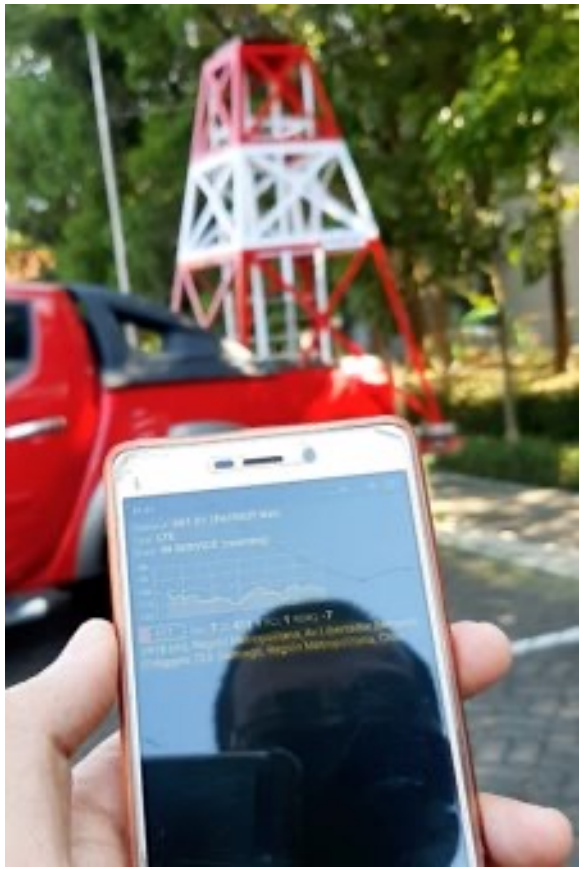


Targets:

- This project continues on the development of PATRIOT-Net with technology of 5G-Advanced and 6G
- Patent and publications for prototyping real-field parameters in high reputed IEEE magazines or similar.
  - Conference: 3
  - Patent: 2
  - Journal: 3
  - Standard body: 1 (Asia Pacific Wireless Group (AWG))



Experiment (Achievement 5): MCRBS and UAV

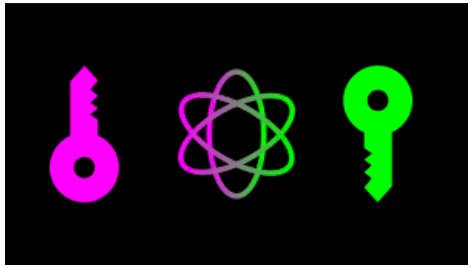


- Drone experiment in 2022 for communications over the cellular networks.

- We have proved to make connection with the mobile phone successfully in 2020.

Roadmap of PATRIOT-41R-Net

QUANTUM



ASEAN IVO Y5-Y6 (Expected):
MCRBS V (AI+Quantum) Becomes 6G

ASEAN IVO Y4 (Expected):
MCRBS IV (AI+Quantum) and UAV with Autonomous System for logistics

ASEAN IVO Y3 (Expected):
MCRBS III (AI) and UAV with Autonomous System

ASEAN IVO Y2:
MCRBS II and UAV over Cellular

ASEAN IVO Y1:
Coding and MCRBS

2019-2020

2021-2022

2023-2025

2026-2028

2028-2030

6G

5G ADVANCED

5G

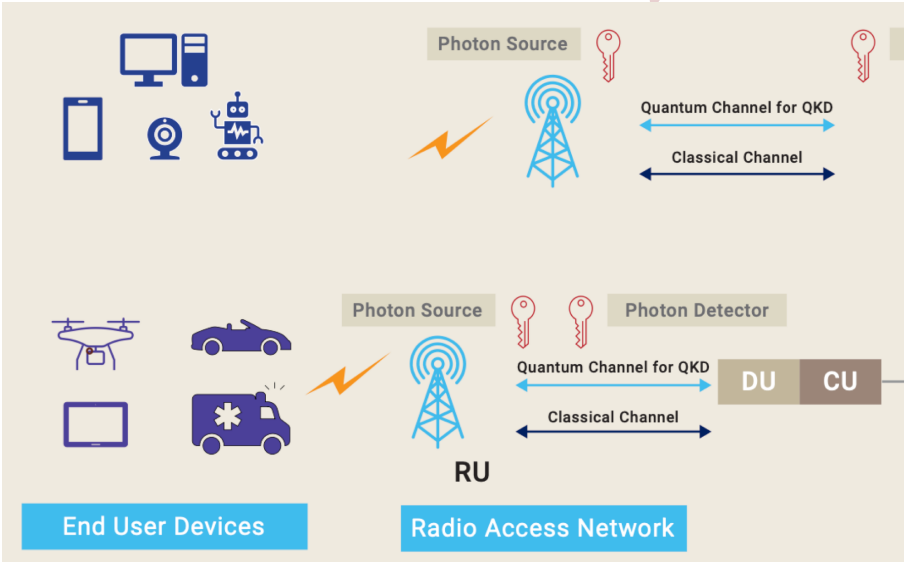


image: NEXTG Alliance, 2022.

Motivation on AI in 5G-Advanced and Quantum in 6G

- 6G has new and enchanced capabilities
- 6G has 6 use cases, where the new usecases are (1) Integrated AI and communications, (2) Ubiquitous connectivity, and (3) integrated sensing and communications.

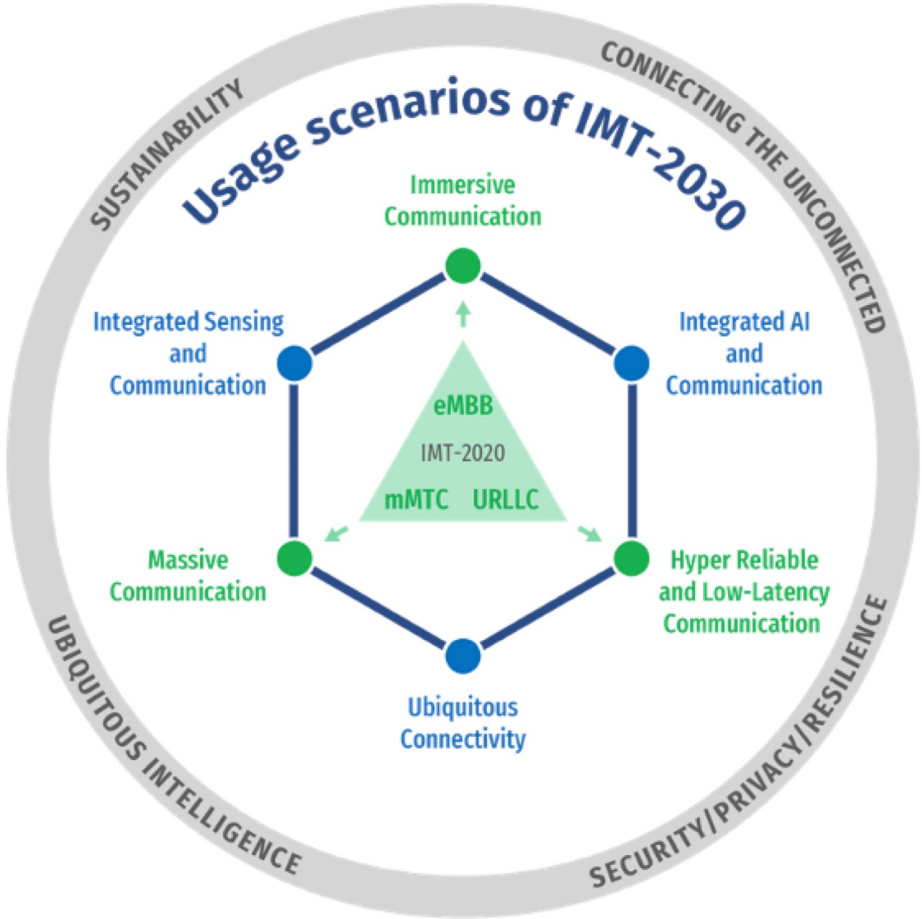
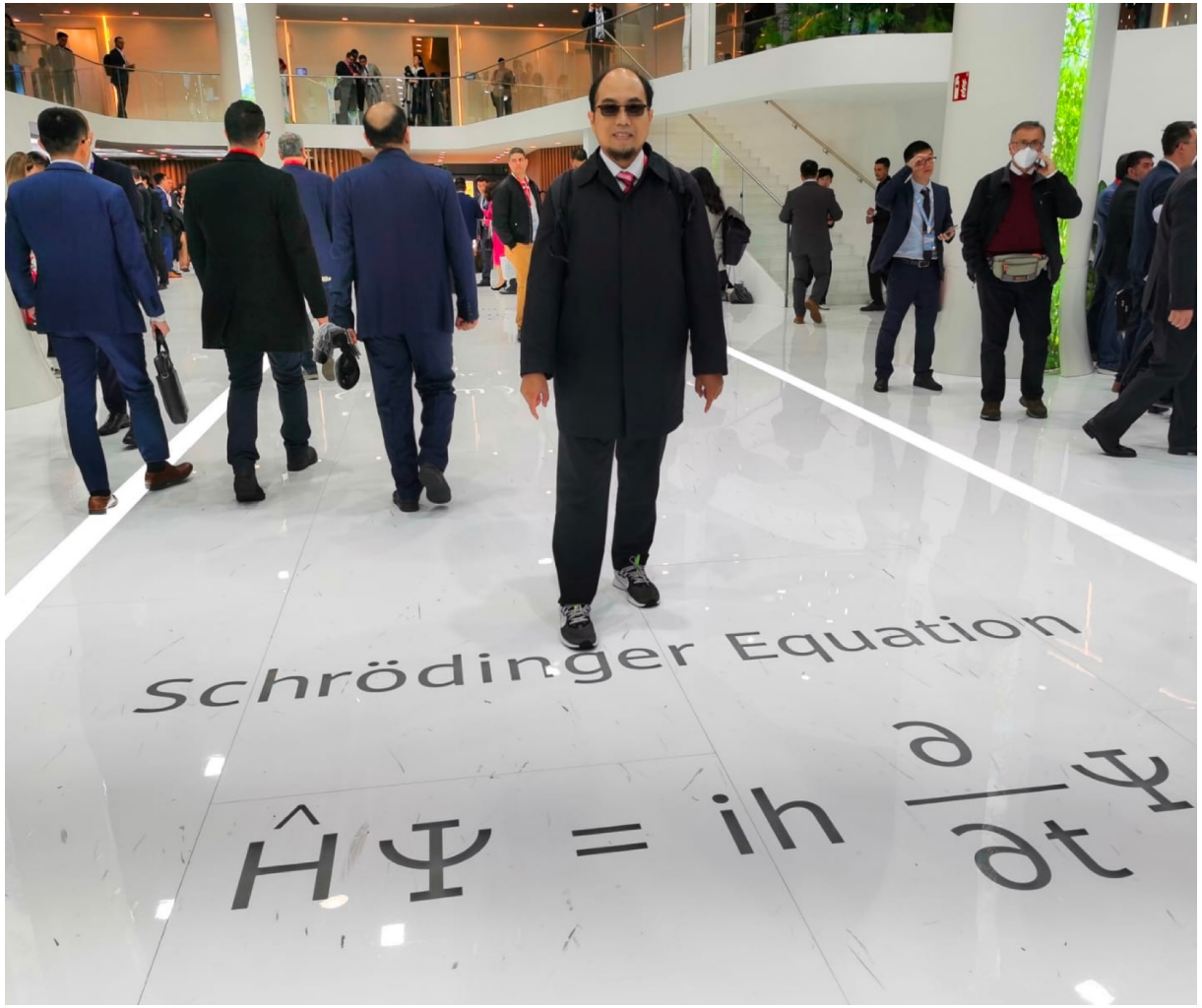


Image: ITU, WP5D

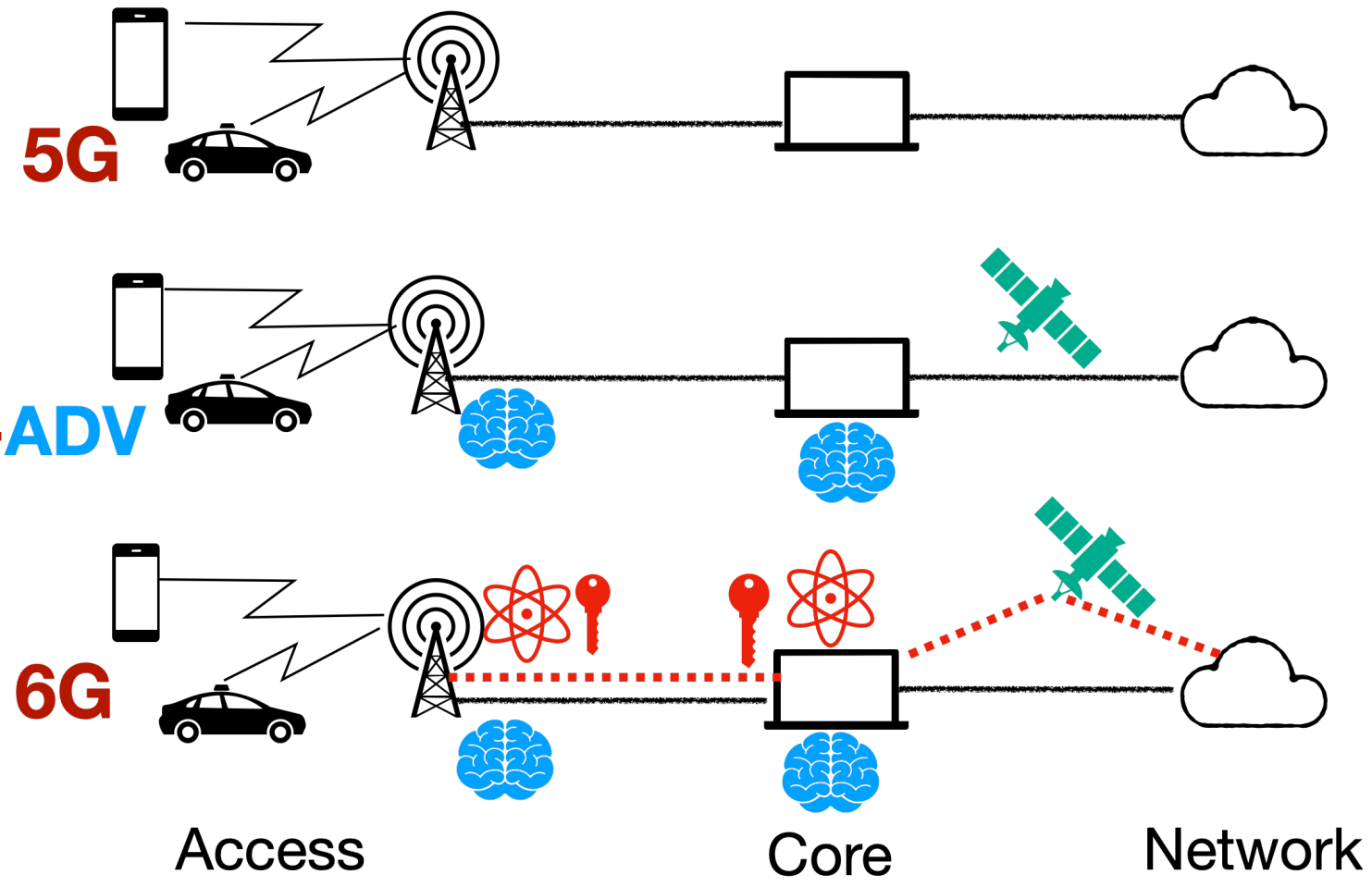
Motivation on AI in 5G-Advanced and Quantum in 6G



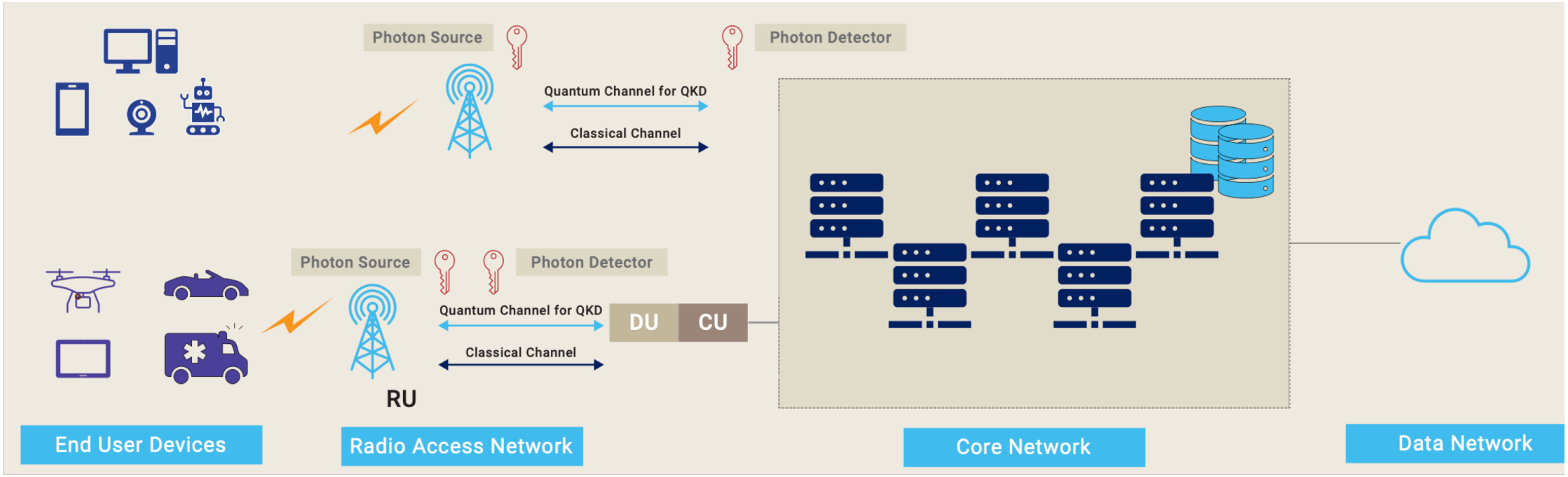
Updates from MWC23 Towards 6G in Barcelona, 27 Feb - 2 March 2023: AI and Quantum

Evolution of 5G to 6G and The Changes on Security and Satellite

- 5G increases throughput up to 20 Gbps
- 5G-Advanced has uniqueness on the artificial intelligence (AI)
- 6G has uniqueness on the AI and Quantum cryptography.
- The increases of local Base Station $Y_L$product is required to increase the economy of Indonesia from Infrastructure view point.
- The $Y_L^{5G} < Y_L^{5G-A} < Y_L^{6G}$ should be satisfied.



Quantum With Respect to RAN



- Physical layer processing of the user data plane in the RAN (**quantum Fourier transform** and quantum linear solver)
- Clustering for automatic anomaly detection in network design optimization (**quantum K-means algorithm**)
- Prediction of the quality of user experience for video streaming based on device and network level metrics (**quantum support vector machine**)
- Database search at the data management layer (**Grover's algorithm**)

image: NEXTG Alliance, 2022.

The Proposed Quantum QKD Testing in Bandung: Expecting more collaboration

⟨PKR|KUANTUM⟩

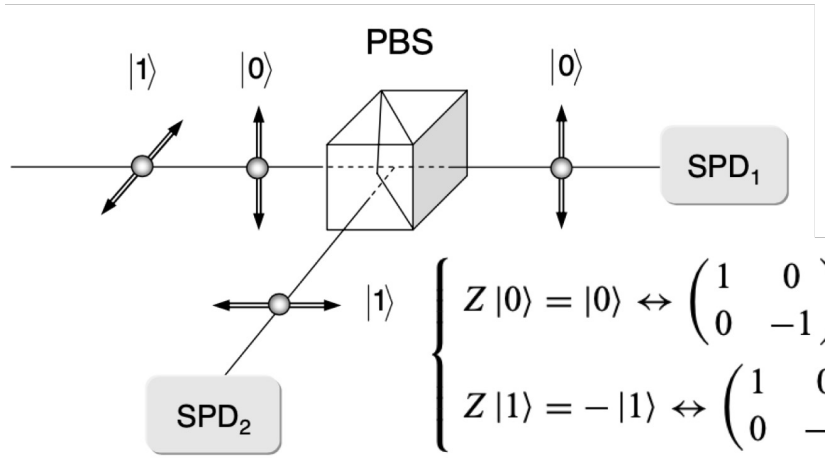
Pusat Kolaborasi Riset Teknologi Kuantum 2.0

(Research Collaboration Center for Quantum Technology 2.0)

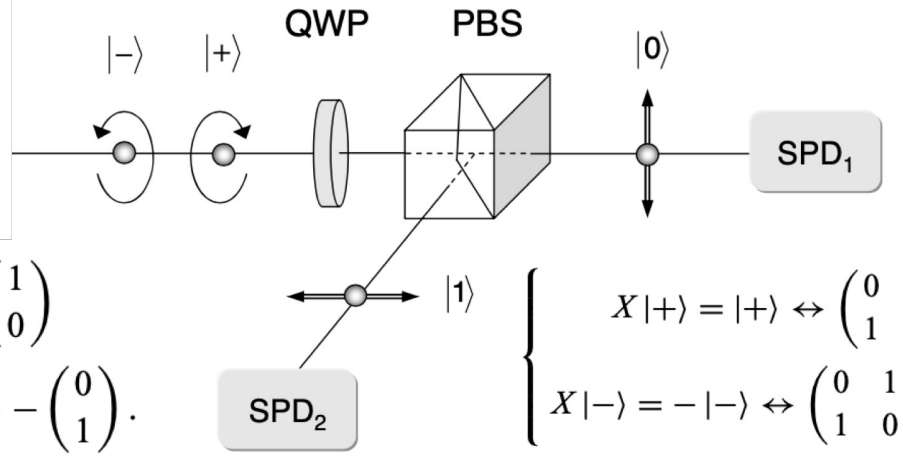
BADAN RISET DAN INOVASI NASIONAL – INSTITUT TEKNOLOGI BANDUNG – TELKOM UNIVERSITY

JL. GANESHA NO. 10, LABTEK V, BANDUNG 40132, INDONESIA

Collaboration with ITB and BRIN

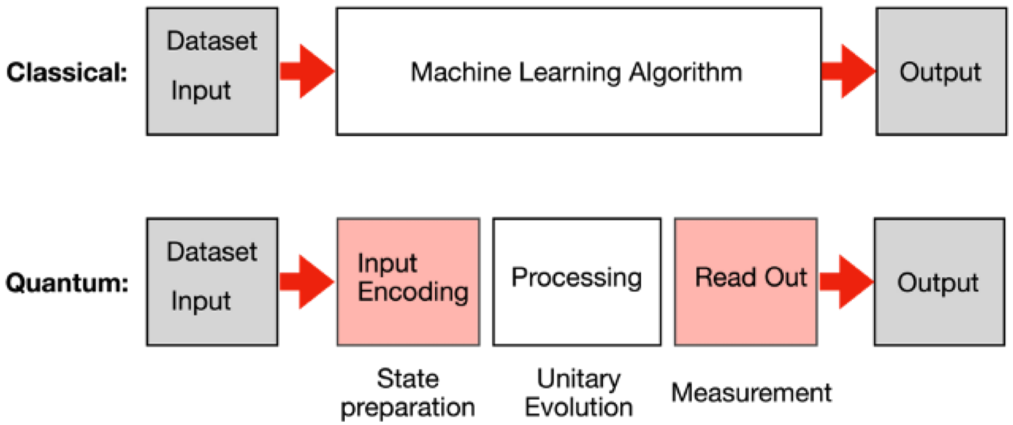


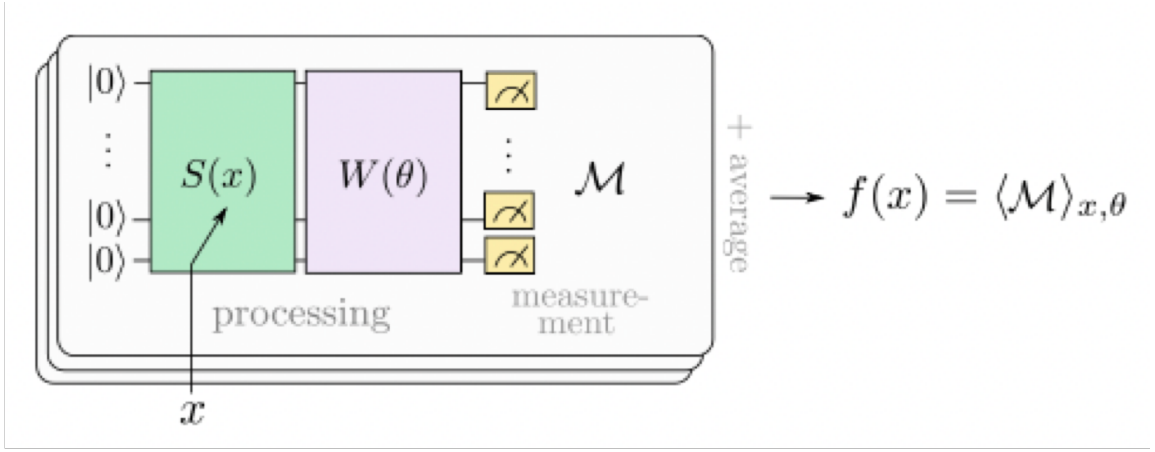
$$\begin{cases} Z|0\rangle = |0\rangle \leftrightarrow \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\begin{pmatrix} 1 \\ 0 \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \end{pmatrix} \\ Z|1\rangle = -|1\rangle \leftrightarrow \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\begin{pmatrix} 0 \\ 1 \end{pmatrix} = -\begin{pmatrix} 0 \\ 1 \end{pmatrix}. \end{cases}$$



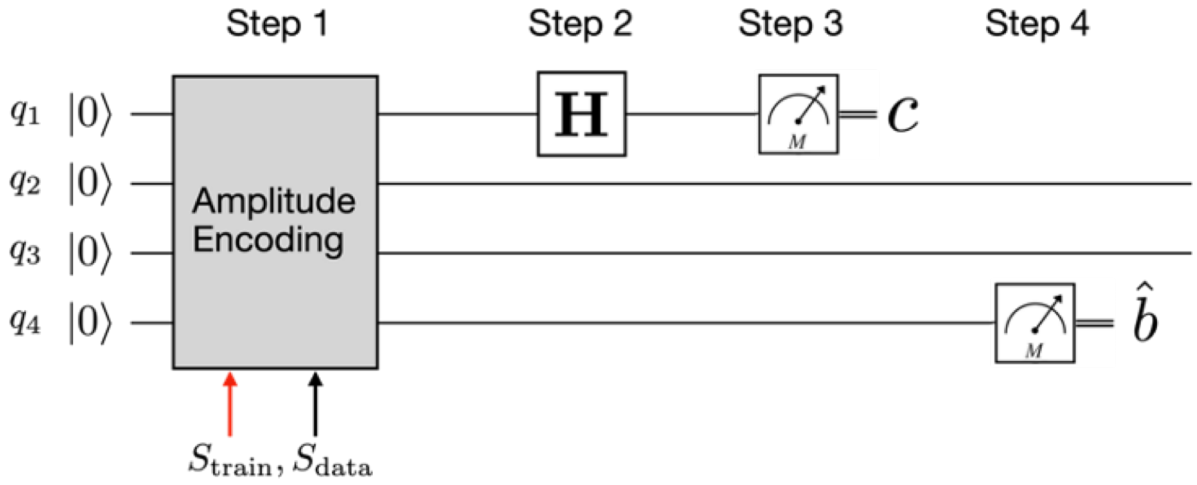
$$\begin{cases} X|+\rangle = |+\rangle \leftrightarrow \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\frac{1}{\sqrt{2}}\begin{pmatrix} 1 \\ 1 \end{pmatrix} = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 \\ 1 \end{pmatrix} \\ X|-\rangle = -|-\rangle \leftrightarrow \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\frac{1}{\sqrt{2}}\begin{pmatrix} 1 \\ -1 \end{pmatrix} = -\frac{1}{\sqrt{2}}\begin{pmatrix} 1 \\ -1 \end{pmatrix}. \end{cases}$$

The Proposed Developed Quantum Machine Learning for 5G and 6G





- A variational circuit can be used as a deterministic machine learning model that can be used for supervised learning.
- A popular model: U(x,θ) consists of a data embedding block S(x) and a parametrised block W(θ).
- An input x is encoded into a quantum state, which gets processed by a variational circuit.
- The expectation value of a measurement is interpreted as the output of the model



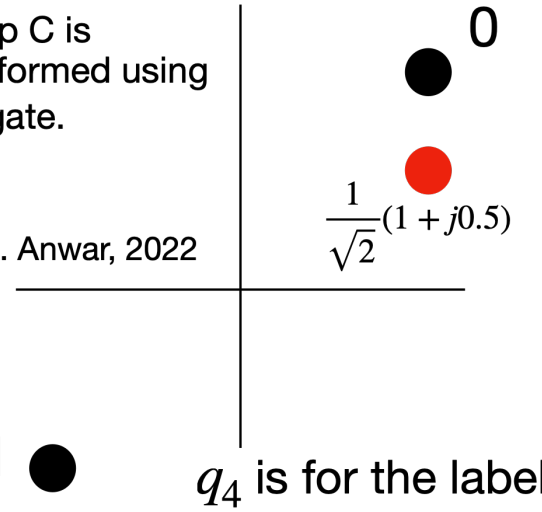
K. Anwar and M. Y. Alias, "Quantum Machine Learning for Demappers of Low Order Modulations of 5G and Beyond", CONQUEST, Nov. 2022.

Quantum Machine Learning for 5G NR CBPSK Demapper

Qubit state				Amplitude Step B	Amplitude Step C	Amplitude Step D
q_1	q_2	q_3	q_4			
0	0	0	0	$1/\sqrt{2}$	1.0000	0.7845
0	0	0	1		0	0
0	0	1	0	$1/\sqrt{2}$	0.7500	0.5883
0	0	1	1		0	0
0	1	0	0		0	0
0	1	0	1	$-1/\sqrt{2}$	0	0
0	1	1	0		0	0
0	1	1	1	$-1/\sqrt{2}$	-0.2500	-0.1961
1	0	0	0	$1/\sqrt{2}$	0	0
1	0	0	1		0	0
1	0	1	0	$0.5/\sqrt{2}$	0.2500	0
1	0	1	1		0	0
1	1	0	0		0	0
1	1	0	1	$1/\sqrt{2}$	-1.0000	0
1	1	1	0		0	0
1	1	1	1	$0.5/\sqrt{2}$	-0.7500	0

$$x(i) = \frac{1}{\sqrt{2}}\left[(1-2b(i)) + j(1-2b(i))\right]$$

Step C is performed using H gate.



q_4 is for the label

The real and imaginary parts are assumed as the feature.

$$p(q_4 = 0) = 0.7845^2 + 0.5883^2 = 0.9615$$

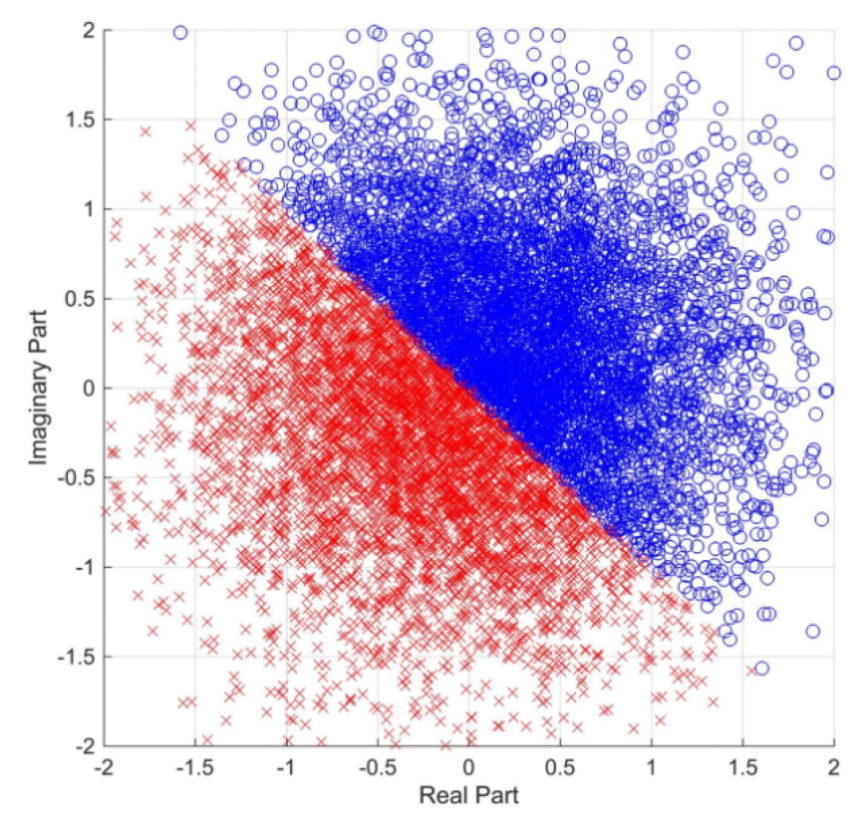
← Correct

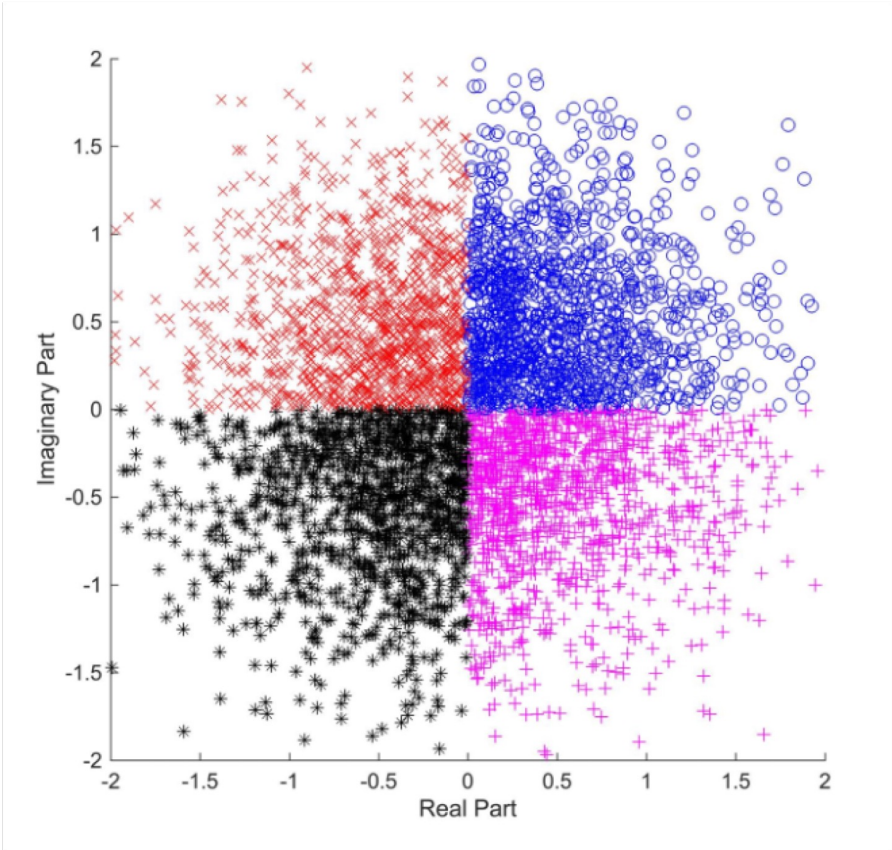
$$p(q_4 = 1) = 0^2 + (-0.1961)^2 = 0.0385$$

We can conclude that the bit is 0.

K. Anwar and M. Y. Alias, "Quantum Machine Learning for Demappers of Low Order Modulations of 5G and Beyond", CONQUEST, Nov. 2022.

Quantum Machine Learning for 5G NR CBPSK Demapper



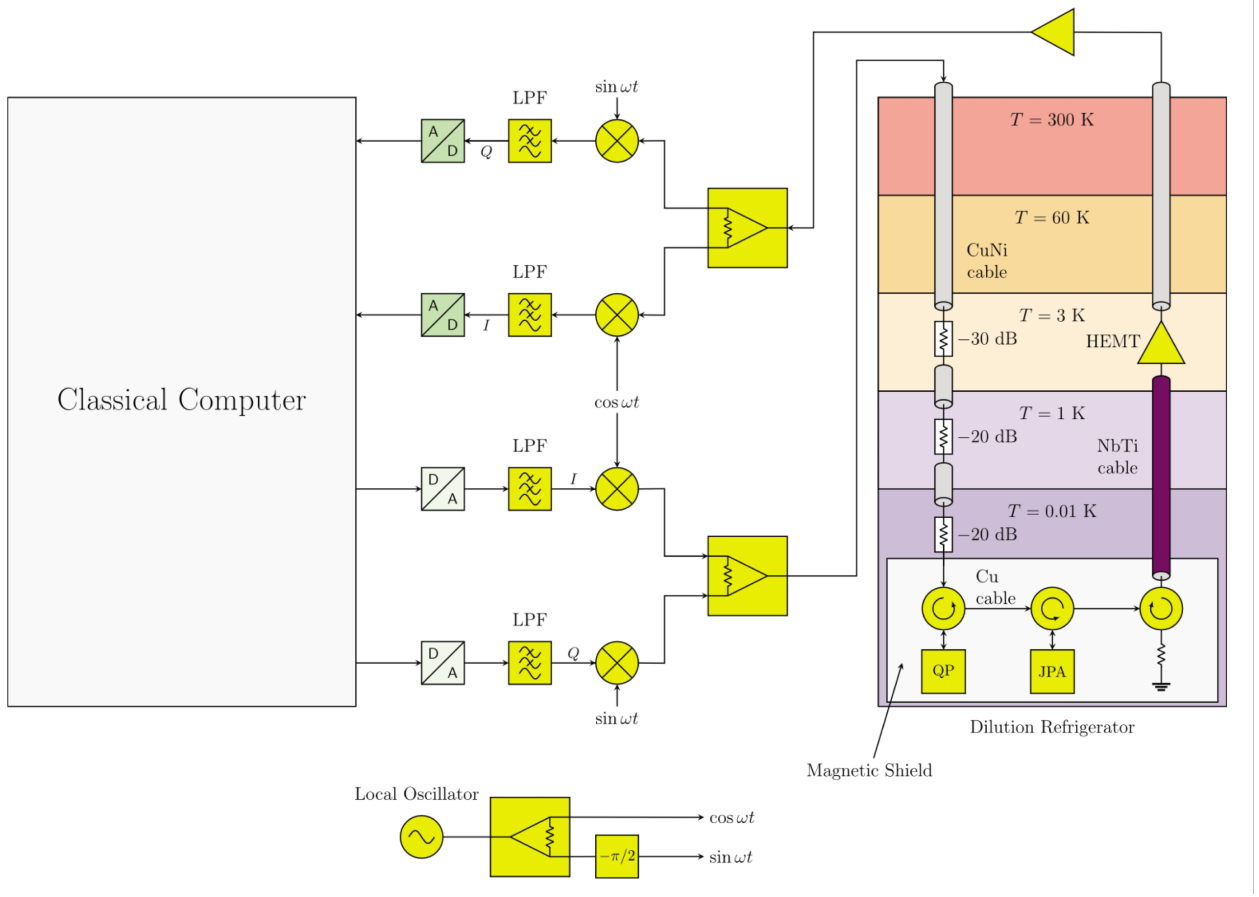


- QML can succesfully demap 5G CBPSK and 4-QAM by naturally creating the boundary of the areas.
- QML is potential for future M-QAM in 6G, where $M > 1024$, of which the classical computation is heavy.

K. Anwar and M. Y. Alias, “Quantum Machine Learning for Demappers of Low Order Modulations of 5G and Beyond”, CONQUEST, Nov. 2022.

Conclusions

- PATRIOT-41R-Net project has been successful and is formally commercialized in 2023, where further improvement is required.
- The proposed improvement is on:
  - Upgrade to 5G-Advanced with AI/ML
  - Upgrade to 6G with:
    - QKD and
    - Quantum Machine Learning
- We need further help either on the AI for classical or for Quantum



$$E = h\omega$$

$$f = 5\text{GHz}, \rightarrow T \leq 0.24K$$

image: Stancil and Byrd, Principles of Superconducting Quantum Computers, Wiley, North Carolina State University, 2022.