Hexa-X 2 online workshop

13 February 2024, online

6G-GOALS

6G GOAL-ORIENTED AI-ENABLED LEARNING AND SEMANTIC COMMUNICATION NETWORKS

Semantic and Goal-oriented Communications

The 6G-GOALS Approach

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GENERATIONS OF CONTENT BLIND COMMUNICATIONS

Current *content-blind transmit-without-understanding* approach:

data is transmitted without any prior **understanding** of how informative it is (**semantic**) to the receiver or useful (**pragmatic**) for the end-goal of communications

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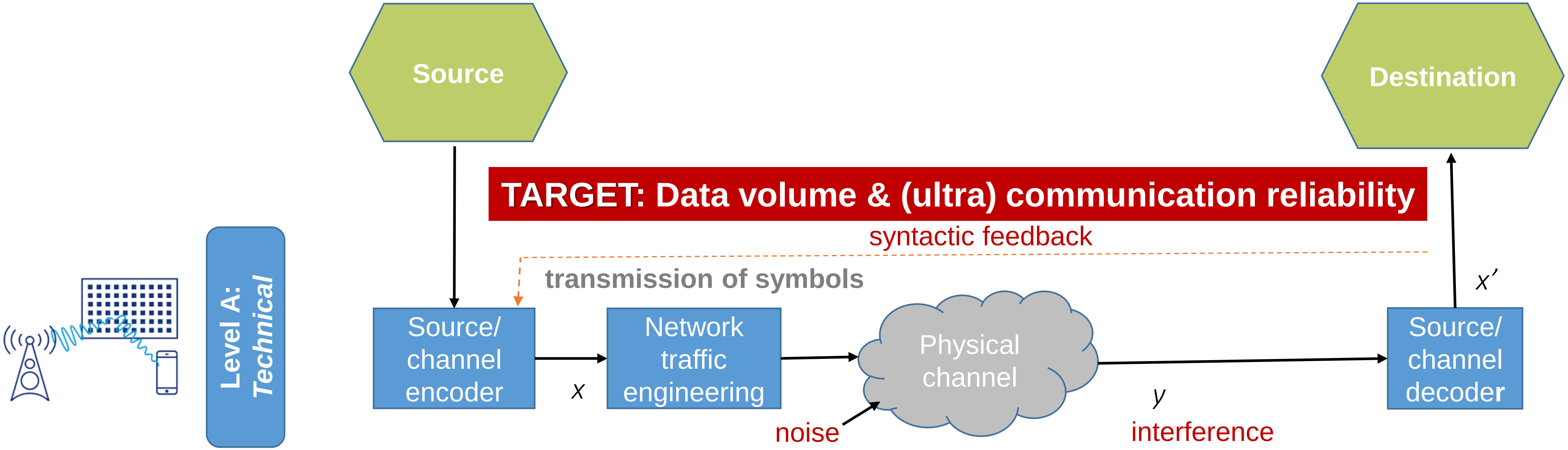
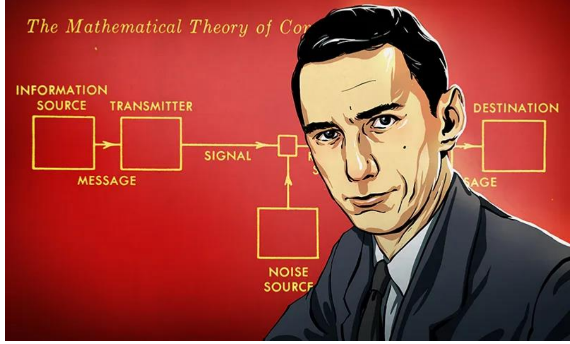
Shannon's approach (The **technical** problem):
How **accurately** can the symbols of communication be transmitted?



WHAT WE HAVE TARGETED SINCE 2G



Shannon Channel Information Capacity*

$$C = BW \times n \times \log_2(1+SNIR)$$

Capacity (bits/seconds)

Radio channel Bandwidth (Hz)

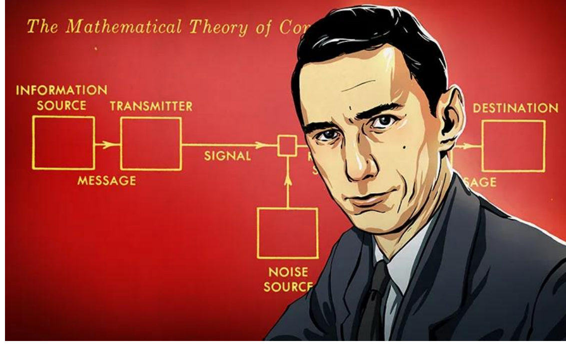
Number of uncorrelated signal paths

Signal to Noise + Interference Ratio

How to achieve a x1000 factor improvement in 6G?

* **Note** that this is the Shannon **capacity for single user AWGN channel** under **infinite code lengths** assumption. This formulation is not valid with other types of channels.

HOW 5G ACHIEVED X1000 FACTOR IMPROVEMENT



Shannon Channel Information Capacity

x1000 x10 x10 x10

$$C = BW \times n \times \log_2(1+SNIR)$$

Capacity (bits/seconds)

Radio channel Bandwidth (Hz)

- Spectrum Management
- Carrier aggregation
- New mmW Spectrum

Number of uncorrelated signal paths

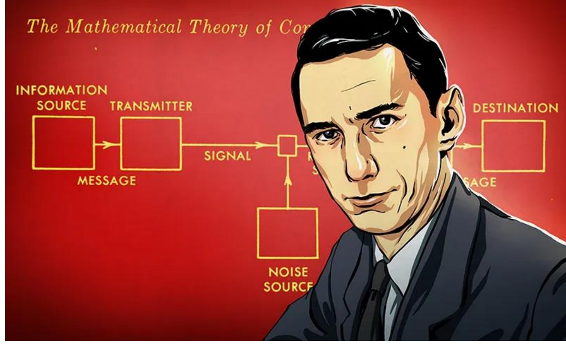
- (Ultra Massive) MIMO
- Network densification
- Small cells

Signal to Noise + Interference Ratio

Spectral efficiency:

- Beamforming & high dBi antennas
- new modulations & coding schemes
- new waveforms, full-duplex

HOW 5G ACHIEVED X1000 FACTOR IMPROVEMENT



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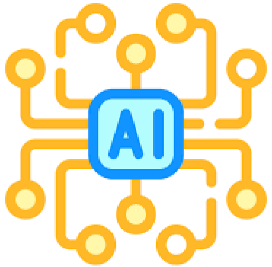
Why to target a x1000 capacity increas while technology should provide sustainability & be sustainable?

6G-GOALS WHAT IF WE COULD SAY LESS BUT UNDERSTAND MORE?

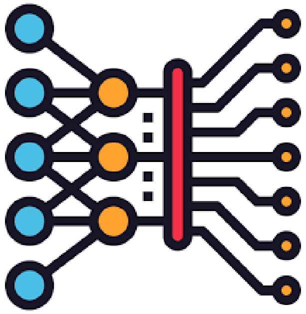
6G-GOALS: THE SEMANTIC & GOAL-ORIENTED COMMUNICATIONS OPPORTUNITY

6G-GOALS WHAT SEMANTICS & EFFECTIVENESS



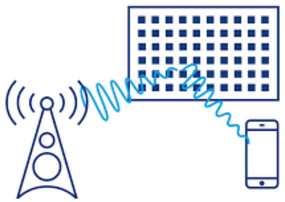
Level C: *Effectiveness*

3. **Level C:** How effectively does the received meaning affect conduct in the desired way?
   (The **effectiveness** problem)



Level B: *Semantic*

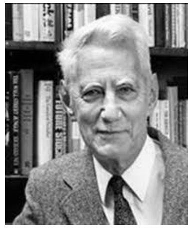
2. **Level B:** How precisely do the transmitted symbols convey the desired meaning?
   (The **semantic** problem)

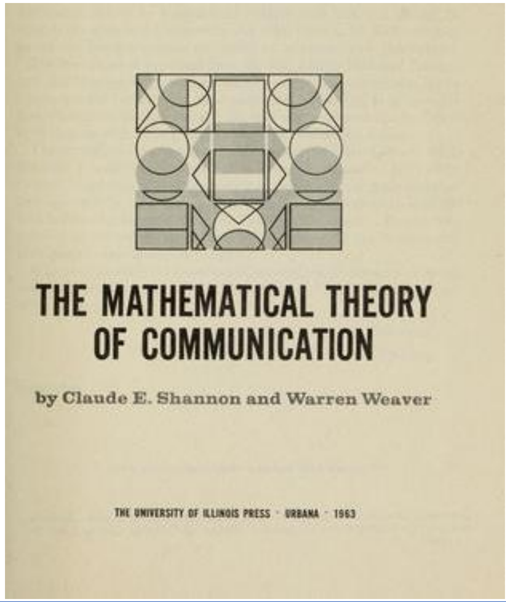


Level A: *Technical*

1. **Level A:** How accurately can the symbols of communication be transmitted?
   (The **technical** problem)

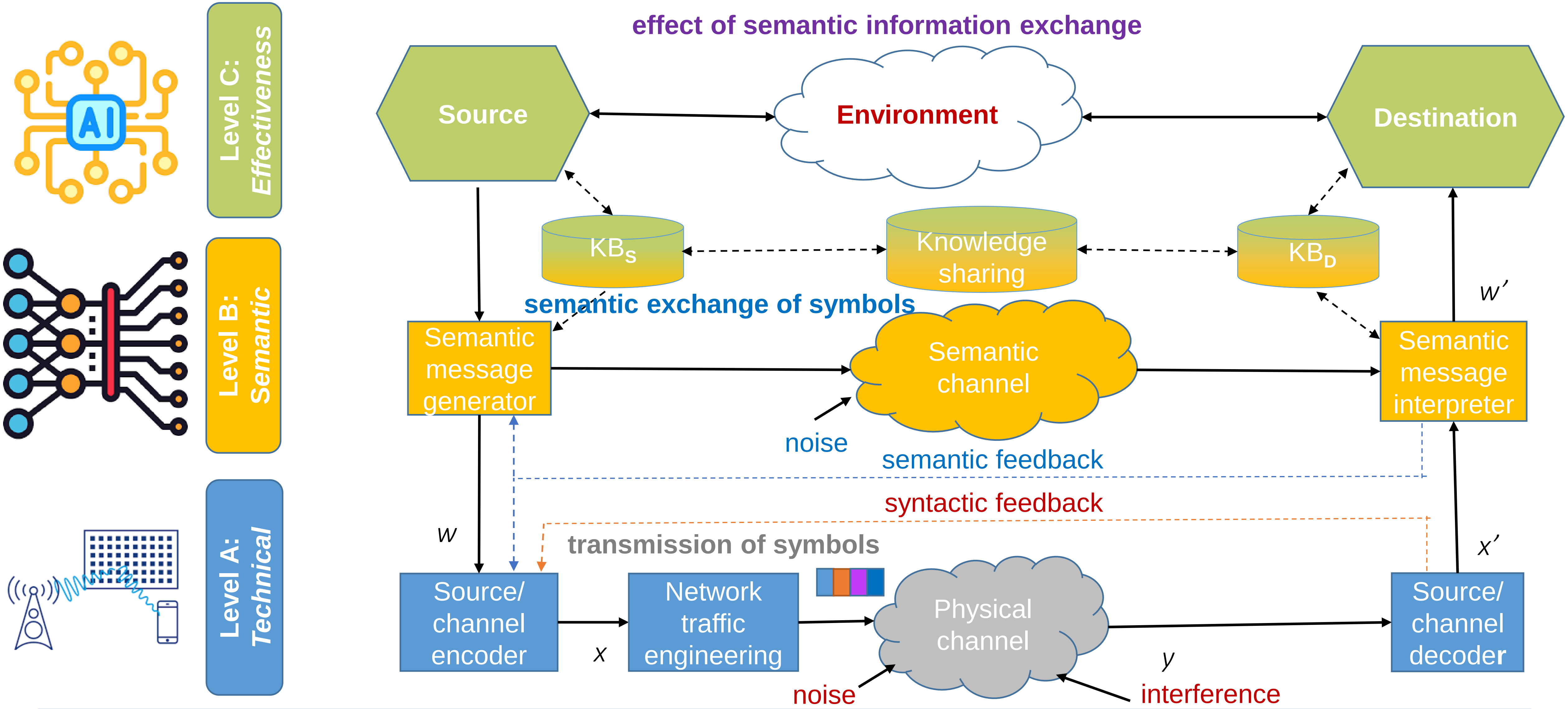
The broad subject of communication can be organized into **three levels**
[Shannon, Weaver, 49]





Source: E. Calvanese Strinati and Barbarossa.,"6G Networks: Beyond Shannon Towards Semantic and Goal-Oriented Communications". Computer Networks Journal, Feb. 2021.

6G-GOALS WHAT SEMANTICS & EFFECTIVENESS



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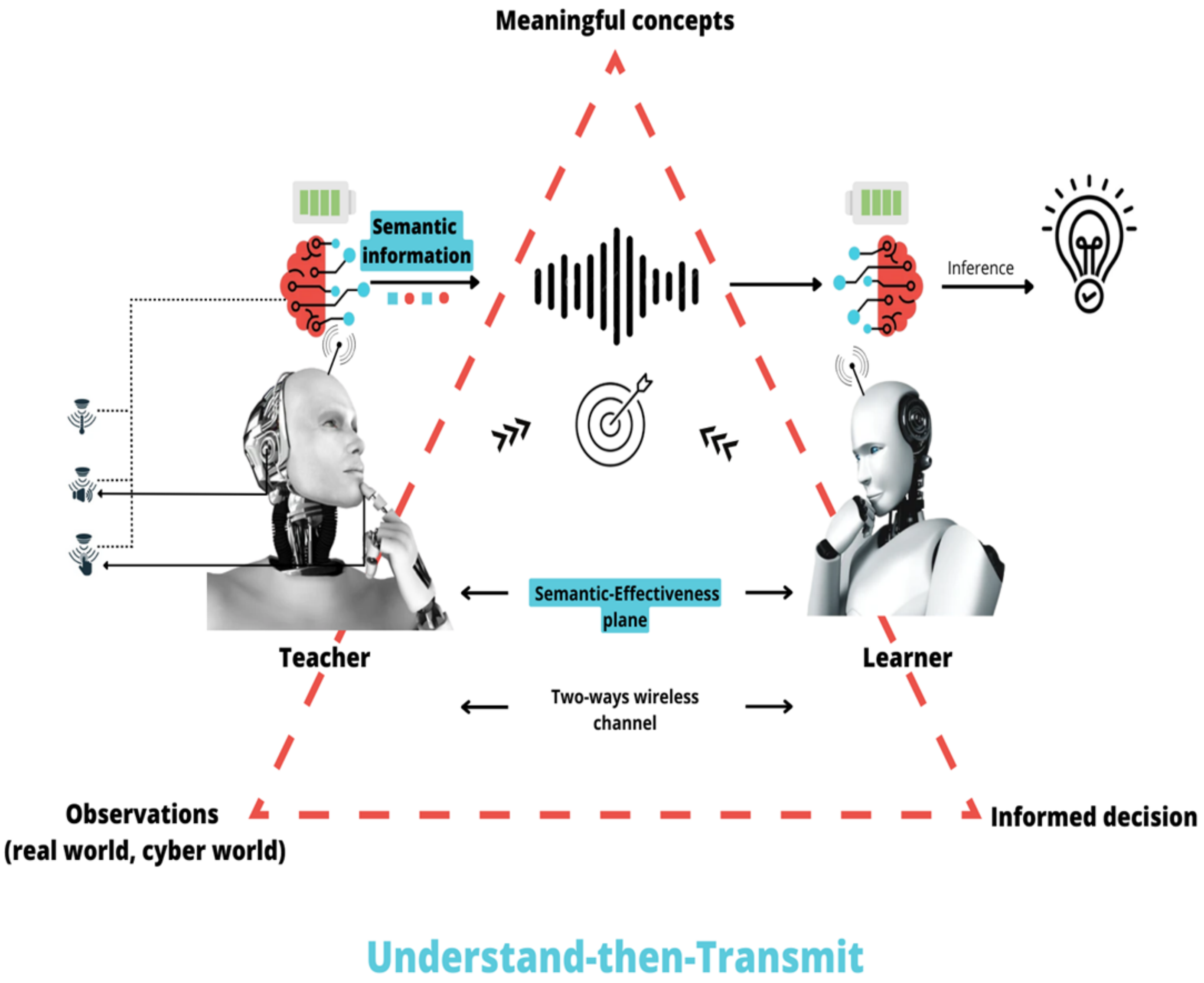
6G-GOALS WHAT (KEY PROJECT'S CONCEPTS)

Understand-then-transmit

- **Move beyond the established sense- compute- connect- control models** towards **semantic and goal-oriented communications** based on AI-enabled architectures, protocols and services.

- Lay the **theoretical**, **algorithmic** and **operational foundations** of a novel communication and networking paradigm



6G-GOALS WHAT IS A SEMANTIC COMMUNICATION

Ask chatGPT?

As of my last knowledge update, the term "wireless semantic communications" is not an established term in the field of wireless communication.

6G-GOALS **WHAT** IS A SEMANTIC COMMUNICATION

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Semantic communications

Communicate only what cannot be deduced or predicted by AI

- to facilitate knowledge sharing, consensus-building & the integration of diverse perspectives, distributed among AI systems

- to stimulate reasoning between intelligent agents rather than ensuring high bit accuracy of shared (raw) data at the receiver side

6G-GOALS WHY

Sustainability, Scalability, Interoperability

- (Edge) **AI/ML** and **5G/6G** systems are designed and operated as **separated silos**
- **Critical resources waste** due to **avoidable large volumes of data** being generated-communicated-processed-stored-recovered
  - costs and complexity rather than gains in accuracy in decision-making.
- **Reduce overall PHY layer complexity** by targeting lower spectrum, less antennas, less densification of the network, etc.
- … at the potential cost of increased AI related complexity and costs
- **distill the data that are strictly relevant to conveying the semantic meaning end effectively achieve goals**
- **focus only on relevant, valuable, and timely information**

6G-GOALS **HOW** PARADIGM SHIFT #1: GOAL-ORIENTED COMMS

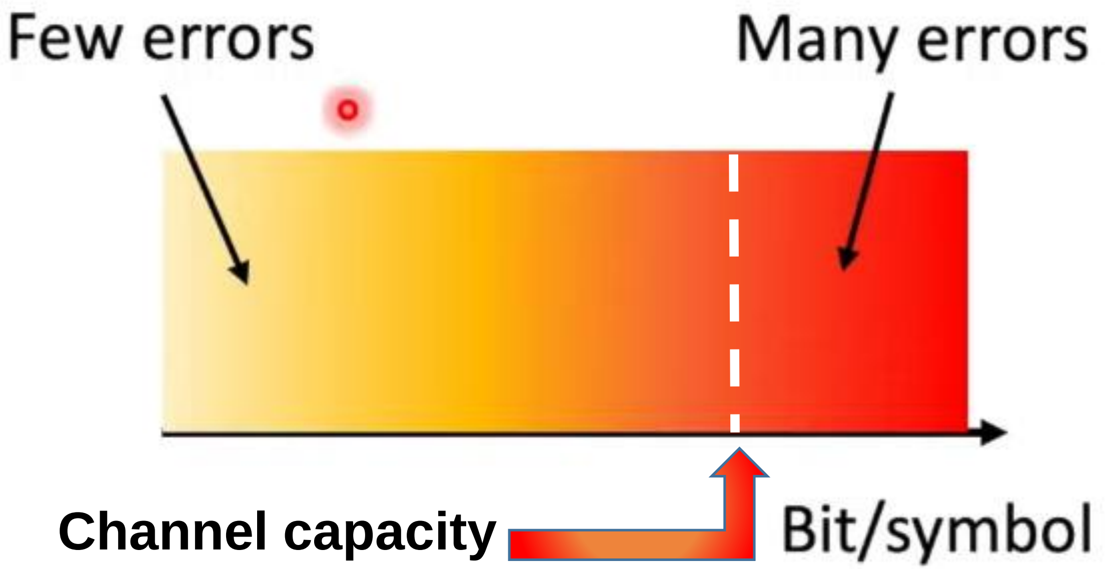
From: *Spectral Efficiency of Data-oriented Communications*

➔ Send more data over the available spectrum to use it efficiently

Send the maximum volume of data per second while maintaining a target QoS.

How to? Not just more antennas and/or network densification (interference issues)

(*Massive*) *MIMO*, *cell free*, *beamforming*, *new modulatoins*, *waveforms & coding schemes*, full-duplex, etc.



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To: Effectiveness *per Goal* of transmission strategy outcome

➔**identify the relevant needed information to recover the meaning intended by the transmitter(s) and/or to attain the goal at the receiver(s)**

But **focusing rather on the actual effect that the received information has on performing an action**!

Targeting inference/intelligence reliability rather than blind bit-fidelity

6G-GOALS HOW PARADIGM SHIFT #2: SEMANTIC COMMS

From: Moving (raw) data to feed ML & AI is all you need!

The data PARADOX: AI needs data but data needs AI.

ML/AI training, test and operation are known for **insatiable appetite** for **data**

The transmitter determines what to send

6G-GOALS HOW PARADIGM SHIFT #2: SEMANTIC COMMS

To: *Understanding & Effectively Conveying the Intended Meaning*

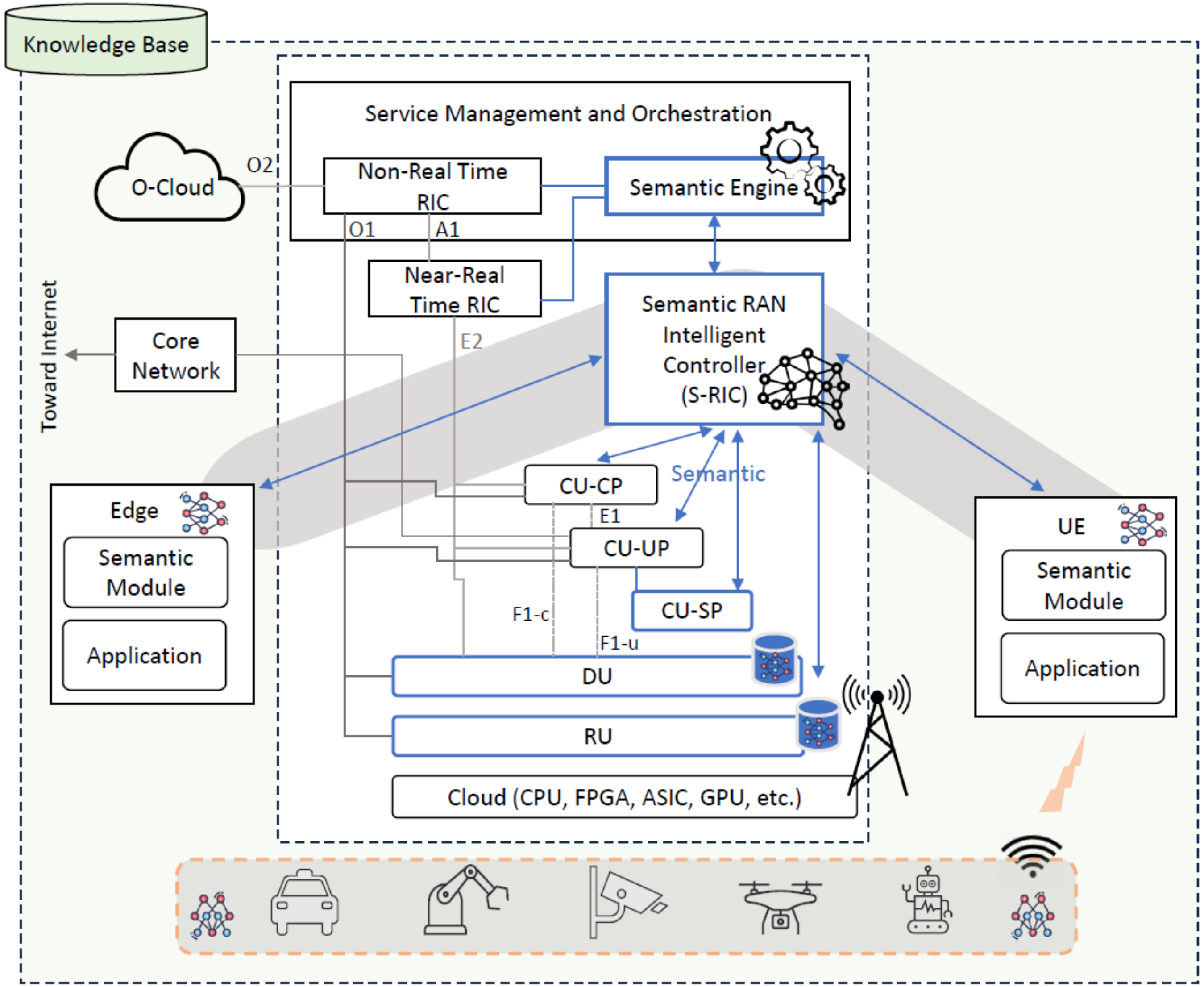
➔ Enabling more context-aware & meaningful interactions between Intelligent Agents.

Moving beyond the exchange of raw data towards communication that is context-aware, goal-driven, and capable of preserving and conveying the intended useful **meaning of information**

Share only knowledge that cannot be reliably deduced or inferred by the receiver (Generative) AI agent

Semantic communications to facilitate knowledge sharing, consensus-building & the integration of diverse perspectives, distributed reasoning & collaboration among AI systems

6G-GOALS HOW PROPOSED ARCHITECTURE



AI-native 6G system tailored for semantic and goal-oriented communications

Semantic plane that enhances both the user plane and the control plane

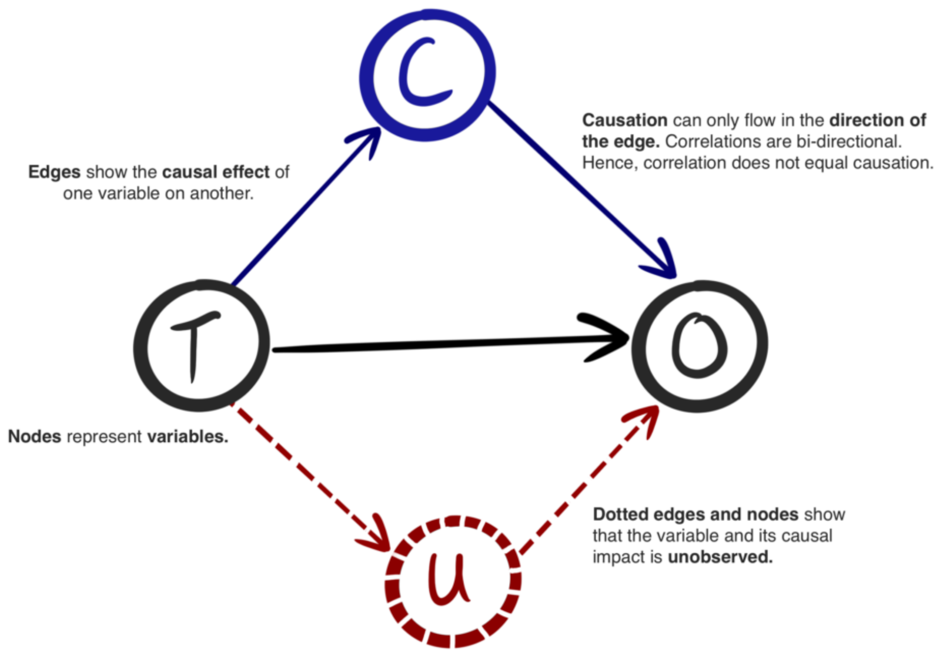
Open RAN to effectively handle semantic communications on a large scale

New intelligent semantic network functions responsible for semantic communication and resource management

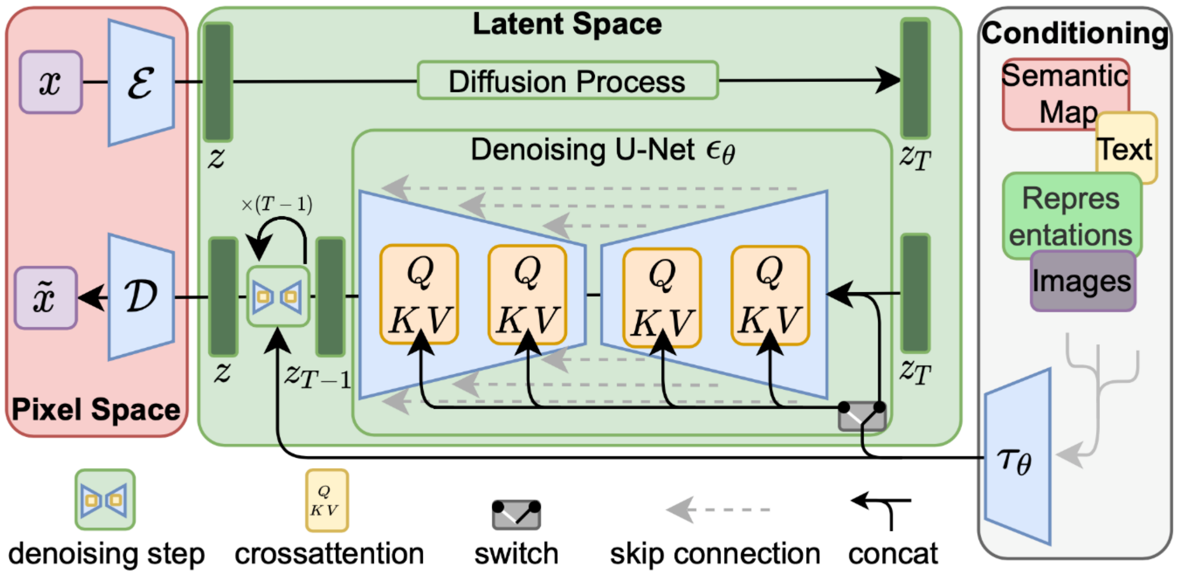
Coexistence & **inter-operability** with semantic-agnostic systems

6G-GOALS HOW DO WE EXTRACT, REPRESENT & USE SEMANTICS?

Causal representations



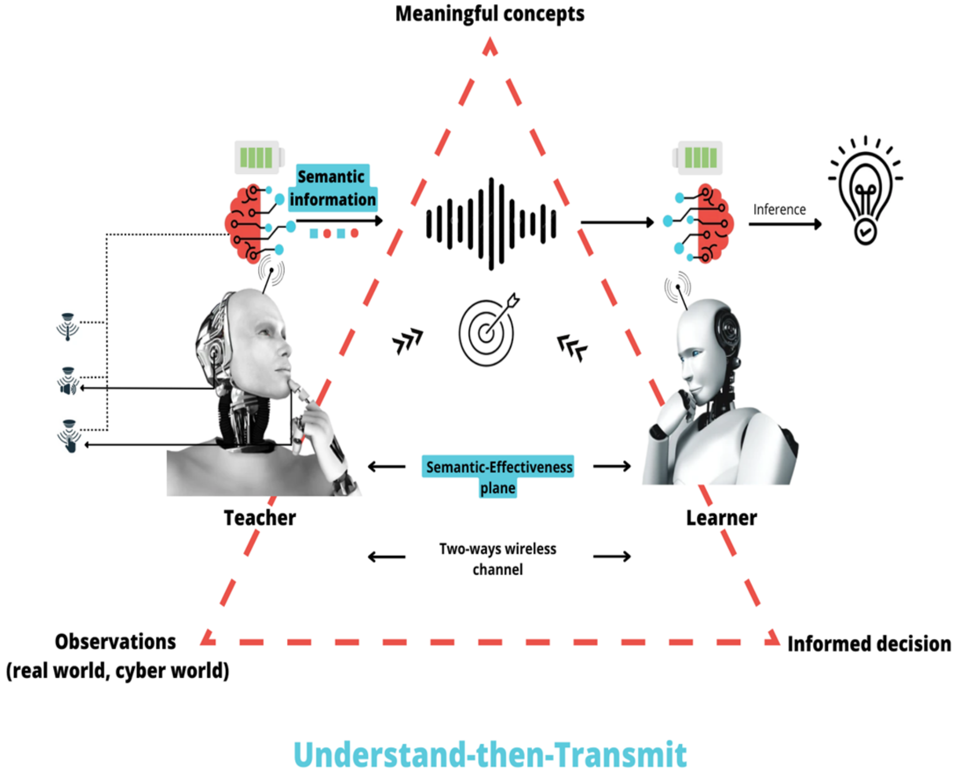
Generative AI



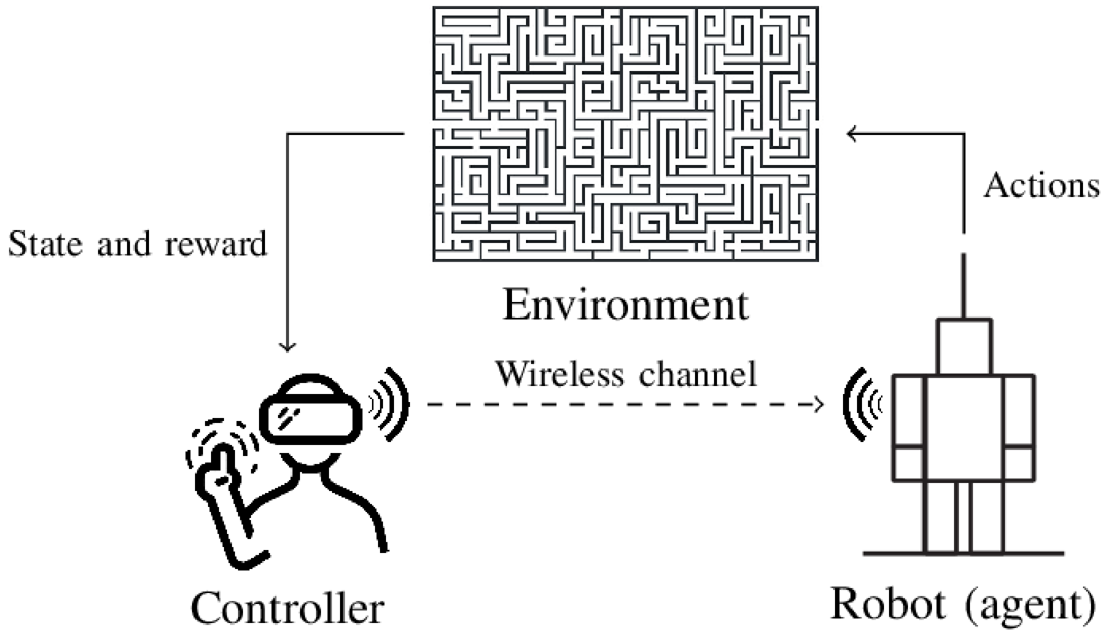
We use and study the term "semantic" in a very general sense :
any structural (topological), statistical, or causal relationship within the data to be communicated, assessed in relation to the desired reconstruction metric or desired actions to be taken at the receiver side.

6G-GOALS HOW DO WE EXTRACT, REPRESENT & USE SEMANTICS?

Reasoning through Semantic Communications



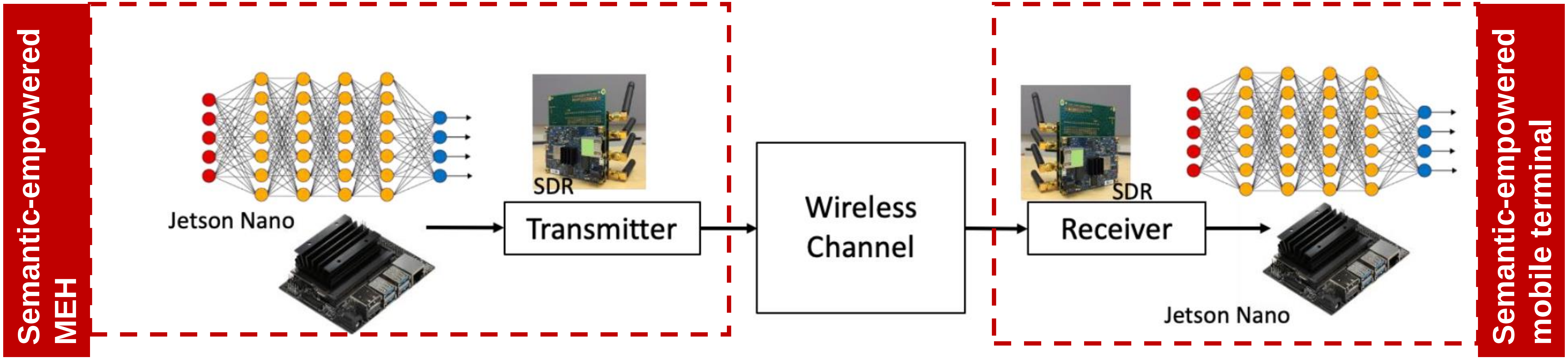
Pragmatic communications



6G-GOALS : **enable learning and reasoning** via **pragmatic communications**, incorporating **causal semantic data representations**, and **considering mismatches of languages and semantic rules** between sender(s) and receiver(s) & ensuring **backward compatibility with legacy** (data-driven) **systems**.

6G-GOALS HOW PROOF OF CONCEPTS #1:

IN-LAB DEMOS FOR SEMANTIC-ORIENTED COMMUNICATION



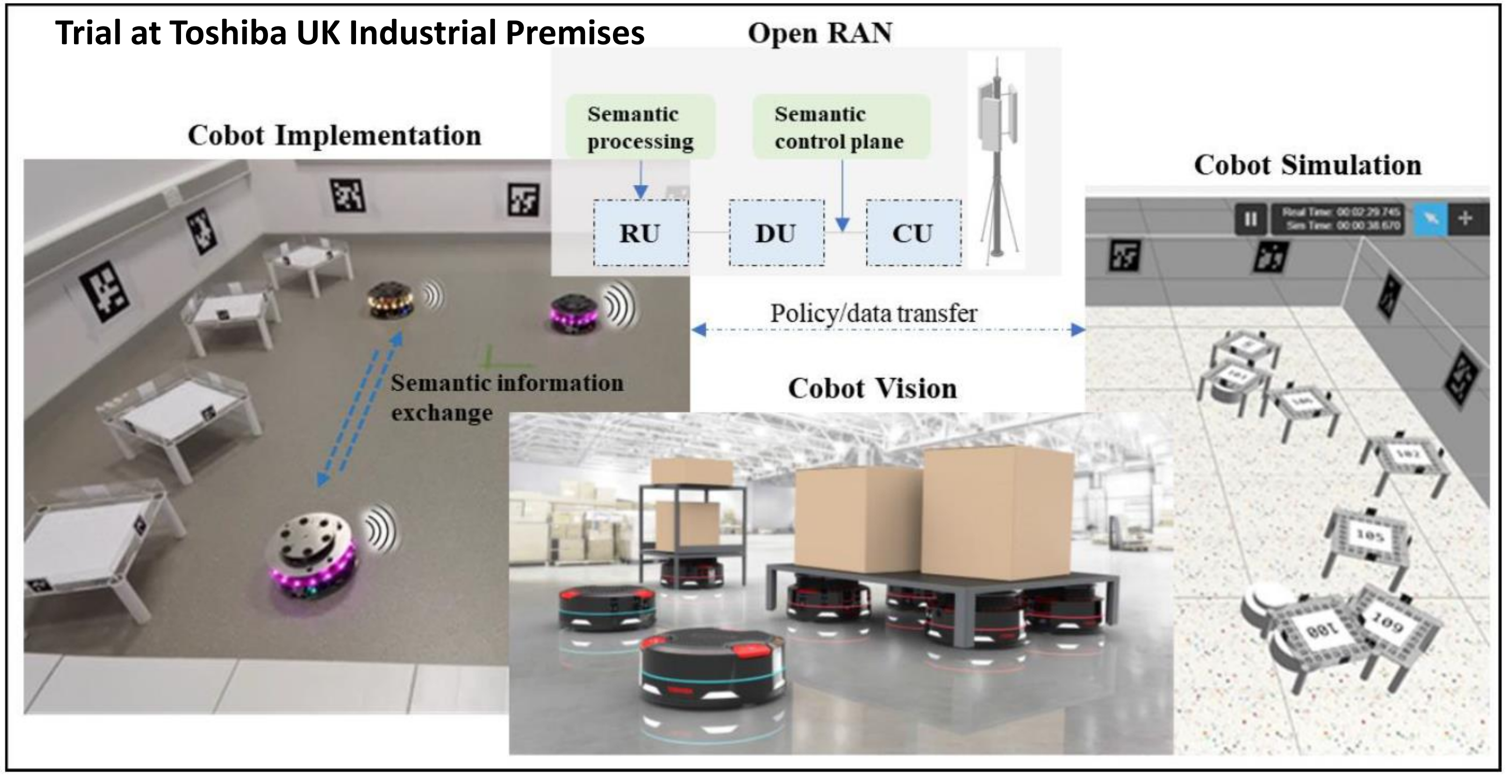
PoC implementation of the **delivery of large deep neural network** models over wireless links

- **Point-to-point scenario**:
  - the **transmitter** models the **edge server wherein the trained model is available**
  - the **receiver** (a **mobile terminal**): requests to download the model on-demand to carry out inference tasks locally within desired latency & energy budgets
- The In-LAb PoC will bring technology to a **TRL 4 maturity**

Goal: the recovered model can still serve its intended inference goal with high accuracy (robustness)

6G-GOALS HOW PROOF OF CONCEPTS #2:

SEMANTIC & GOAL-ORIENTED ENABLED COLLABORATIVE ROBOTS



Goal: To develop E2E robot control techniques that **use semantic communication to exchange sensing data**, and allocate tasks with a Goal-Oriented approach

Target: to reduce communication overhead while improving energy efficiency

The demo trial will bring technology to a **TRL 5 maturity**

6G-GOALS WHO

6GSNS
PHASE 2

G◎ALS

Project Coordinator:
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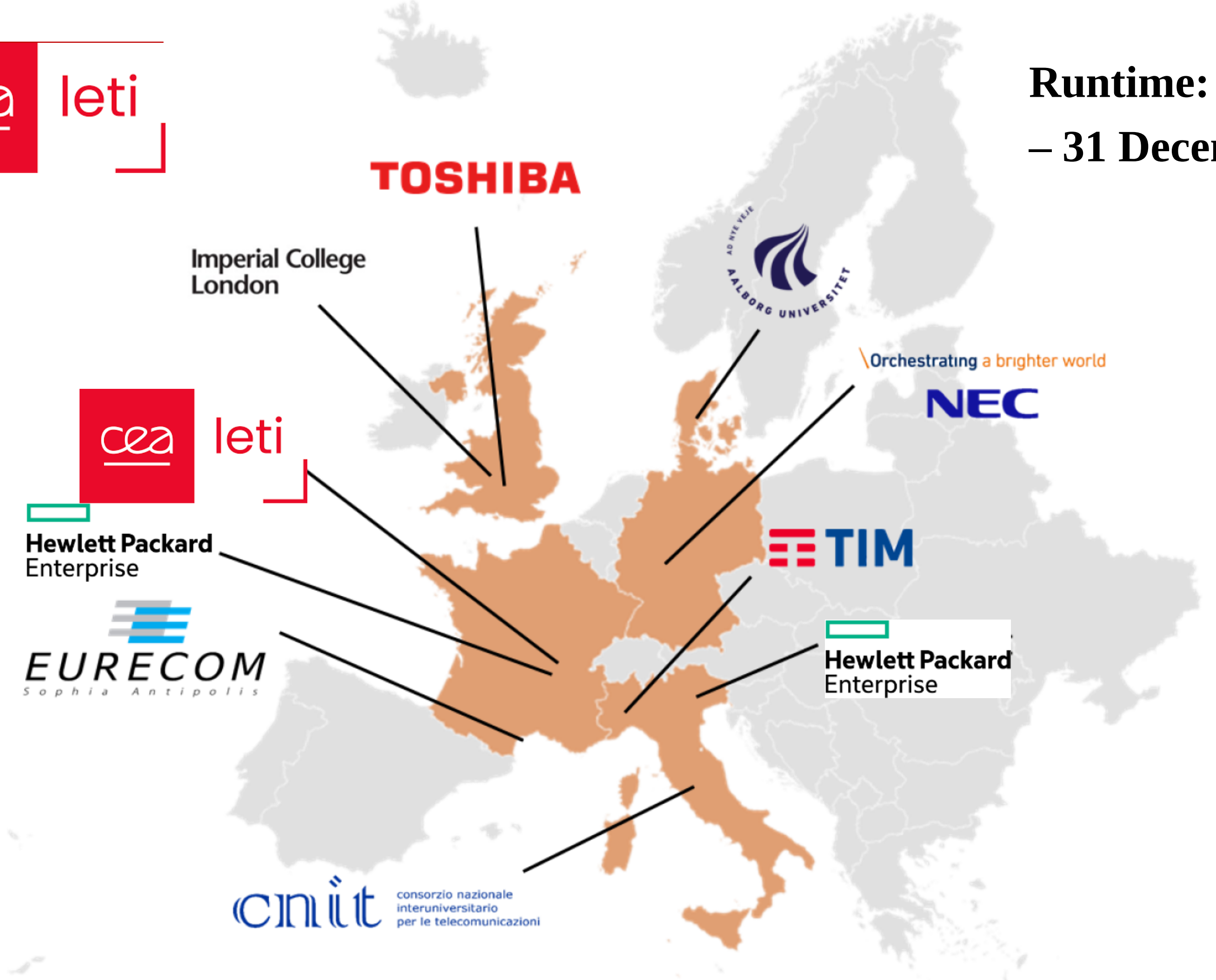
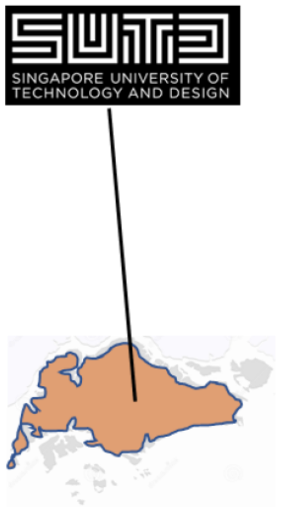
Technical Manager:
Paolo DI LORENZO
cnit

Runtime: 01 January 2024 – 31 December 2026





11 Consortium Partners

4 EU Member States

1 Asian Affiliated partner

5G PPP
PUBLIC-PRIVATE PARTNERSHIP

European Commission

Thank you!

MERCI !

謝謝

고맙습니다

ALOHA

Grazie!

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Goal-Oriented and Semantic Communication in 6G AI-Native Networks: The 6G-GOALS Approach

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[x] Hewlett Packard Enterprise, Italy, [xi] Hewlett Packard Enterprise, France

Abstract—**Recent advances in AI technologies have notably expanded device intelligence, fostering federation and cooperation among distributed AI agents. These advancements impose new requirements on future 6G mobile network architectures. To meet these demands, it is essential to transcend classical boundaries and integrate communication, computation, control, and intelligence. This paper presents the 6G-GOALS approach to goal-oriented and semantic communications for AI-Native 6G Networks. The proposed approach incorporates semantic, pragmatic, and goal-oriented communication into AI-native technologies, aiming to facilitate information exchange between intelligent agents in a more relevant, effective, and timely manner, thereby optimizing bandwidth, latency, energy, and electromagnetic field (EMF) radiation. The focus is on distilling data to its most relevant form and terse representation, aligning with the source's intent or the destination's objectives and context, or serving a specific goal. 6G-GOALS builds on three fundamental pillars: *i)* AI-enhanced semantic data representation, sensing, compression, and communication, *ii)* foundational AI reasoning and causal semantic data representation, contextual relevance, and value**

[1]. Despite the constant growth in data traffic, these measures have been successful in meeting the increasing demand so far. However, as we are going towards 6G networks, we are entering a new phase in communications geared to natively interconnect Artificial Intelligence (AI) modules [2], [3] in a sustainable way, i.e., by avoiding the paradox of increasing efficiency while experiencing a much higher increase of data traffic. The upcoming 6G networks are expected to create a network of networks through the convergence of communication, computation, control, and learning principles, supported by efficient interactions and exchange of knowledge among agents with diverse forms of intelligence [4], [5].

Project vision: The 6G-GOALS project aims to realize the potential of cutting-edge AI-native architectures along with new semantic and goal-oriented communication paradigms. The project challenges the prevalent method of transmitting data without understanding its relevance or informativeness for