

# 5G/6G Sensing - New Eyes For Robots

**Huawei**

**Oct 2024, Mobile Robot Summit 2024**

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# Industrial IoT Challenges for 5G/5G-A and beyond

## Brief C.V.



Munich Research Center since 2013

5G and 6G research

Focus on verticals: V2x, I4.0, e-health, Robotic



Founding member of 5G-ACIA

Board Member of 5G-ACIA since the beginning

Chief of Huawei delegation in 5G-ACIA

Active in different Work groups and Work Items



Founding member of one6g

Elected WG4 Chair (2<sup>nd</sup> term)

Member of the one6g board



Member of the ZVEI Steering Committee  
for industrial communication since 2019

# Robotic Categorization

Robots are a hot topic in many different domains e.g. industry, health, consumer, agriculture, etc

## Industrial robot (Inbot)



## E-health robot



## Service robot (Sobot)

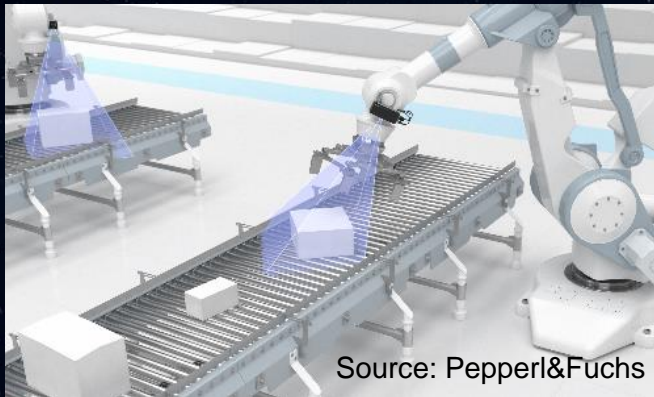


... and many more categories already today and in future \*)

\*) >15 types of robots are listed in <https://robots.ieee.org/learn/stem-resources>

# Robotic Applications Industry

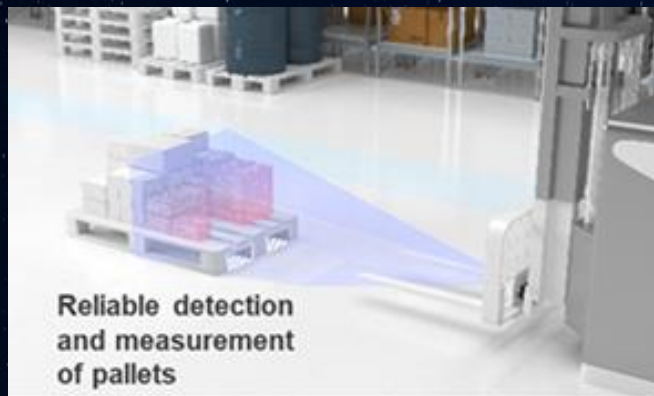
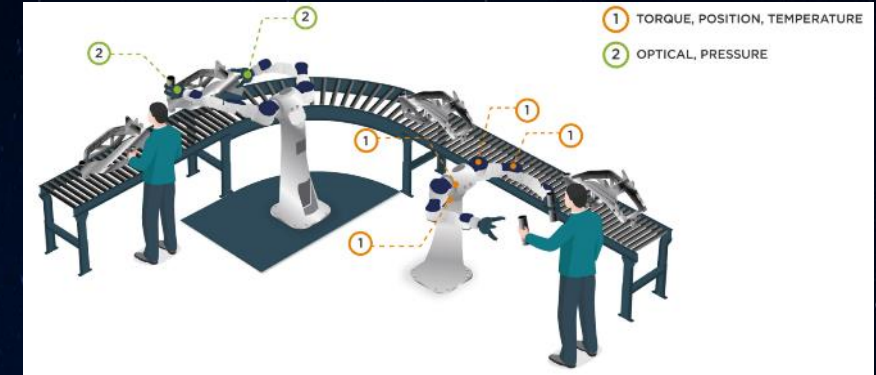
## Industrial robot (Inbot)



## Logistic



## Cobot



... and many more categories already today and in future

# Robotic Applications Logistics



<https://otsaw.com/>

**TransCar**

Automated Guided Vehicle for Material Transport

**O-R3**


Autonomous Security Patrol Robot

**O-RX**

World's First UV-C LED Disinfection Robot

**Camello**

Last Mile Delivery Robot



**StockBot**

The robotic solution to manage your inventory in a more intelligent and useful way



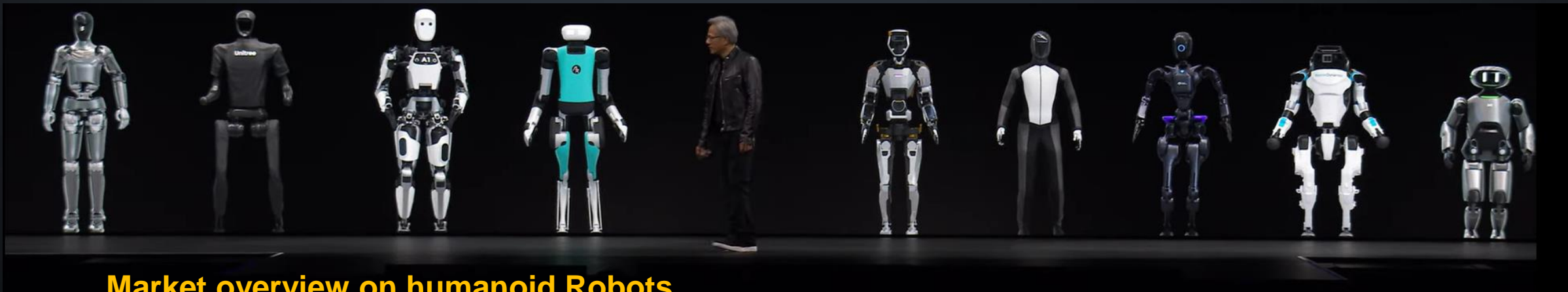
<https://www.realman-robotics.com/>

... and many more categories already today and in future

<https://www.hansonrobotics.com/sophia-2020/>  
<https://neuronmocap.com/pages/perception-neuron-3>  
<https://awakening.health/>  
<https://singularity.studio/>  
[lnmoov.fr](https://lnmoov.fr)  
<https://builtin.com/robotics/humanoid-robots>

# .... And in Future? – The Future starts already Now!

Recent NVIDIA Conference in 2024



## Market overview on humanoid Robots

Exhibit 15: China humanoid robot brands, their product specs and targeted applications

Manufacturer	China humanoid robots									
	UBTECH	Fourier Intelligence	AGIBOT	Unitree	Datas	Xiaomi	Dream	Chunmi	Leju Robot	KEPLER
Model	Walker S	Fourier GR-1	Expedition A1	H1	XR-4	CyberOne	Universal Humano Robot	DaQiang	KUAID	K1, S1, O1
Mass	n.a.	60kg	55kg	47kg	60kg	52kg	60kg	65kg	65kg	80kg
Height	1.70m	1.65m	1.75m	1.8m	1.65m	1.77m	1.70m	1.70m	n.a.	1.70m
Speed	n.a.	1.4m/s	1.9m/s	>1.5m/s	1.4m/s	1.0m/s	0.6m/s	0.6m/s	1.3m/s	n.a.
Degrees of freedom	41	44	45+	20	60+	21	44	36	26	28 + 12 (hands)
Continuous operating time	2hr	>1hr	n.a.	2hr	12hr	2hr	n.a.	n.a.	n.a.	n.a.
Country	China	China	China	China	China	China	China	China	China	China
Target applications										
Disaster rescue										
Special/hazardous applications										
Patrol										
Logistics										
Auto manufacturing										
Healthcare/elderly care										
Commercial applications										

Robot models are updated as of Jan 5, 2024.

Source: Company data, Data compiled by Goldman Sachs Global Investment Research

Exhibit 14: Existing global humanoid robot brands, product specs and their targeted applications

Manufacturer	Global ex-China humanoid robots									
	Boston Dynamics	Agility Robotics	Tesla	Apptronik	Kawasaki Heavy Industries	Rainbow Robotics	1X	Figure 01	Sanctuary AI	
Model	Atlas	Digit (Latest Gen)	Optimus Gen 2	Apollo	Kanoto	HUBO2	EVE	Figure 01	Phoenix	
Mass	85kg	<65kg	63kg	73kg	80kg	43kg	63kg	60kg	70kg	
Height	1.5m	1.75m	1.72m	1.73m	1.80m	1.20m	1.83m	1.70m	1.70m	
Speed	2.5m/s	1.5m/s	2.0m/s	1.0m/s	1.5m/s	0.5m/s	3m/s	1.2m/s	1.2m/s	
Degrees of freedom	28	18 + 8 (arms)	28 + 22 (hands)	c.30	34	32	74	41	74	
Continuous operating time	1hr	16hr (optimized for logistics)	4hr	4hr	n.a.	4hr	4hr	4hr	n.a.	
Country	USA	USA	USA	USA	Japan	Korea	Canada	US	Canada	
Target applications										
Disaster rescue										
Special/hazardous applications										
Patrol										
Logistics										
Auto manufacturing										
Healthcare/elderly care										
Commercial applications										

Robot models are updated as of Jan 5, 2024.

Source: Company data, Data compiled by Goldman Sachs Global Investment Research

**Bull Case:** we expect humanoid robot shipments to hit 1m units by 20231 accelerated by advancement in end-to-end AI  
**Blue-sky Scenario:** We expect humanoid robots to become the next commonly adopted technology after smartphones

Source: Goldman Sachs Equity Research, January 8<sup>o</sup>, 2024

# .... And in Future? – The Future starts already Now!

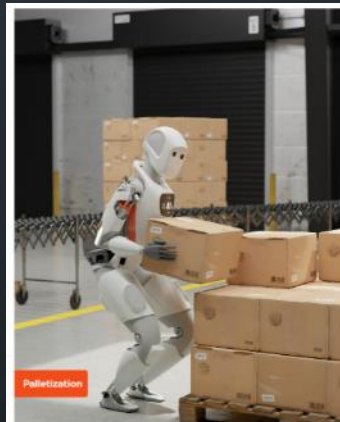
## The new Champs in industry



Digit, which can walk forwards, backwards and sideways and crouch, is 5ft 9in and carries up to 35lb. Photograph: Jason Redmond/AFP/Getty Images



Source: <https://agilityrobotics.com/>



Palletization



Machine Tending



Source: Aptronik - <https://aptronik.com>

## SEE FIGURE IN ACTION.



Introducing Figure 02



OpenAI Speech-to-Speech Reasoning



Real World Task



AI Trained Coffee Demo



Dynamic Walking

Source: <https://www.figure.ai/ai>



Source: unitree - <https://www.unitree.com/g1/>

# .... And in Future? – The Future starts already Now!

## The new Champs in industry

### Mercedes-Benz to pilot humanoid robots in its manufacturing facilities

The auto manufacturer plans to use the robots to perform physically demanding or repetitive tasks that are often more hazardous to humans.

Published March 20, 2024

“Mercedes plans to use robotics and Apollo for automating some low skill, physically challenging, manual labor – a model use case which we’ll see other organizations replicate in the months and years to come,” Apollo CEO Jeff Cardenas 2)

Tesla is also considering deploying its AI-powered, humanoid “Tesla Bot” in its factories to work alongside humans.

### Amazon Begins Using Humanoid Robot in Warehouse

March 4th, 2024, 2:39 PM GMT+0100

Amazon has begun using humanoid robot in a warehouse near Seattle. Called Digit, the machine is being used to move bins from a shelf to a conveyor. The maker, Agility Robotics, hopes to make 10,000 a year and deploy them to warehouses and storerooms all over the world. (Source: Bloomberg)

### BMW aims to deploy humanoid robots at its Spartanburg factory

The automaker is testing how general-purpose robots could improve factory productivity as part of a multi-stage deployment deal.

Published Jan. 29, 2024

- 2025 menschenähnliche Roboter für den industriellen Einsatz in Serie produziert werden
- Und bis 2030 sei der Reifegrad humanoider Roboter so weit fortgeschritten, dass sie in ihrer Bewegungsgeschwindigkeit, Flexibilität und Feinmotorik menschliche Fähigkeiten übertreffen. 1)

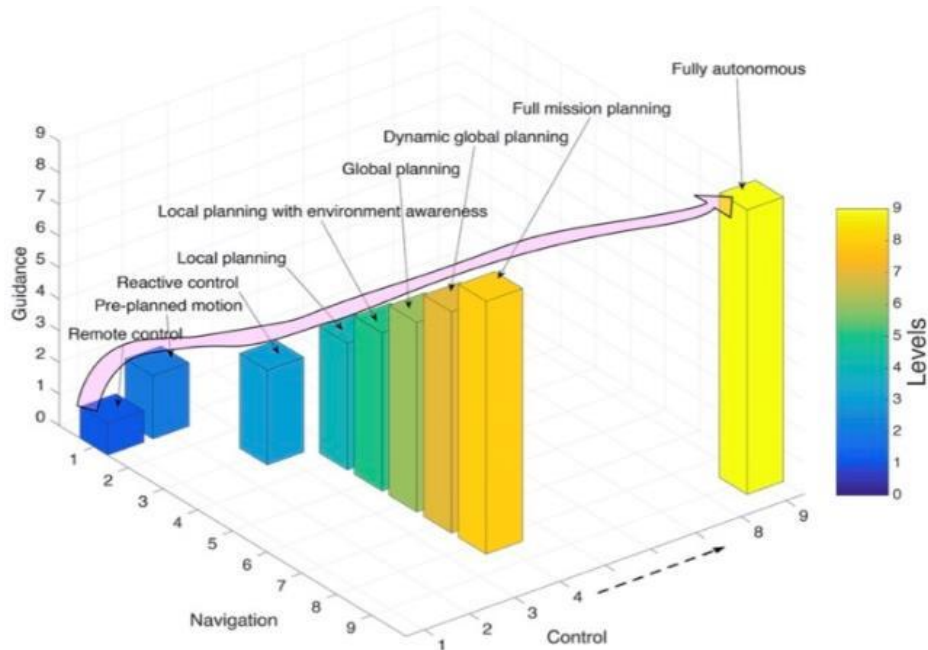
### Estimated ROI nach 1,36 Jahren

- 1) Source: <https://www.horvath-partners.com/de/media-center/studien/humanoide-roboter-in-operations>
- 2) Source: <https://www.automotivedive.com/news/mercedes-benz-approntion-humanoid-robots-apollo-manufacturing/710570/>



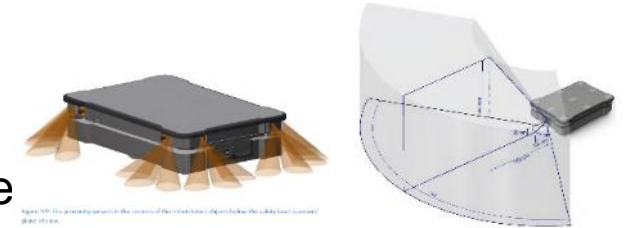
# Challenge: Robot Control depends on Perception

## Complex Motion Planning

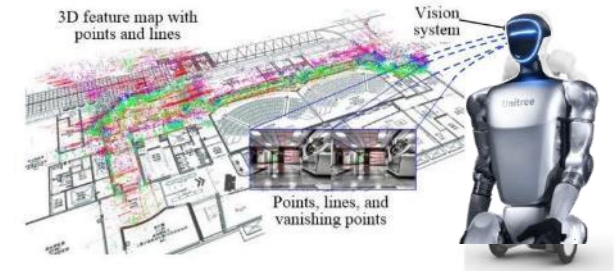


## State of the Art Sensorics

- 2-x LIDAR
- 2-x Radar
- 2-3 2D/3DCame
- 24 Proximity sensors



- Internal sensors



- Each Service Robot has at least one Camera

Complex sensorics'

Turtle view

Sources:

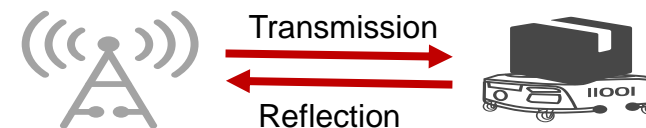
- 1) <https://www.mn.uio.no/ifi/studier/masteroppgaver/robin/uia-master-projects.html>
- 2) one6G whitepaper on Robotics
- 3) <https://www.quadruped.de/Unitree-G1>

# 5G Advanced 3GPP Rel 19 – Study on Sensing

Scenarios	Agreed Use Cases up to SA1 101
Intruder Detection	Highway, Railway, avoidance of UAV collision, UAV intrusion, inside/outside Home, manufactory, vehicle blind spot, smart grid
Tracking and Navigation	UAV, Vehicle
Smart Home	Sleep monitoring, immersive experience, gesture recognition
Smart City	Rainfall, city flood, spot traffic monitoring, parking space, public safety search and rescue
Sensing Functional Enhancement	Sensing Data Relay/aggregation, service continuity, service protection, fusion of 3GPP/non-3GPP data, privacy, roaming, high reliability

- 3GPP SA1: Study Item related to radio sensing
- 30 use cases for V2X, home, industry and city
- Only few use cases reflects the needs of industry !!!
- Sensing is one feature of 6G from ITU vision on 6G

## Example use case for logistic and robotic



- Beyond 5G system can be deployed in a factory to perform continues sensing measurements
- Detection of the presence or proximity of AGVs and humans.

## AGV detection and tracking in factories



## AMR collision avoidance in smart factories

- Continuously analyze and recognize situations with collision risk,
- e.g., estimating speed, distances between objects, etc.

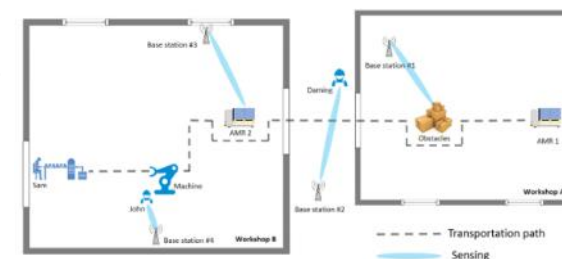
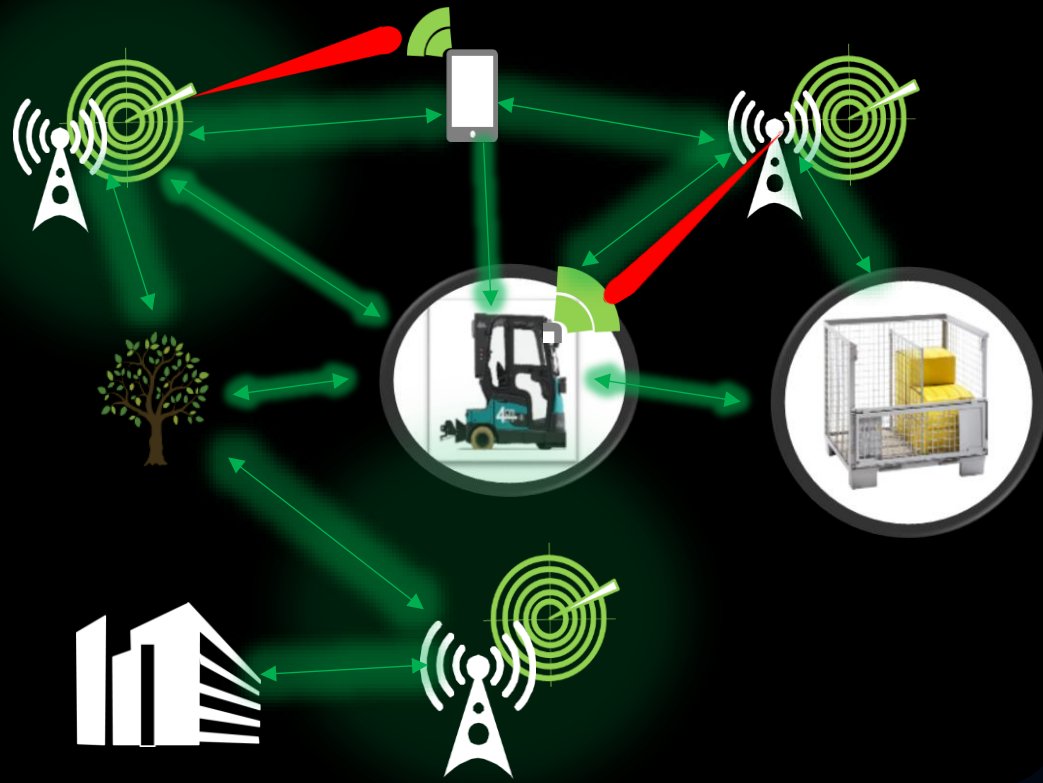


Figure 5.23.3-1: Sensing People or obstacles detection in smart factory

# 5G/6G sensing - new eyes for robots

## Networks as Sensors – new Eyes



— Data Link      ↔ Sensing Link

- Sensing assist Robotics
- Sensing assist Communication

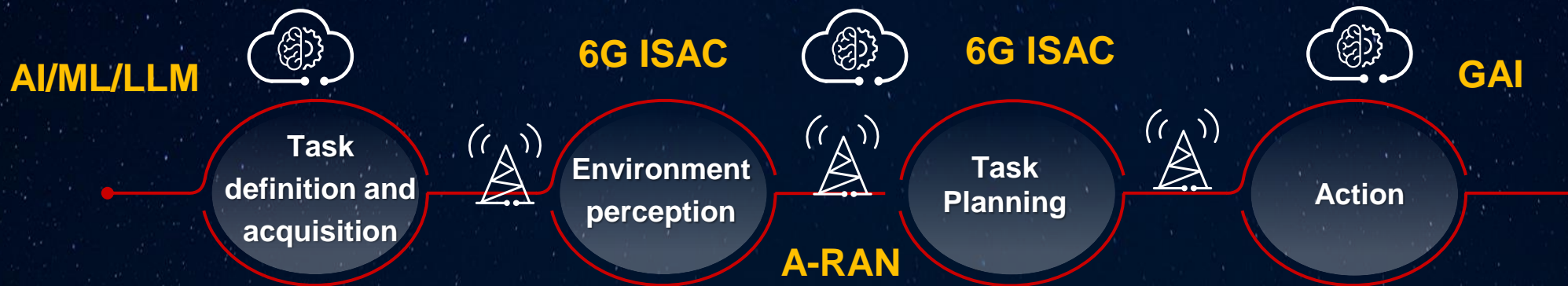
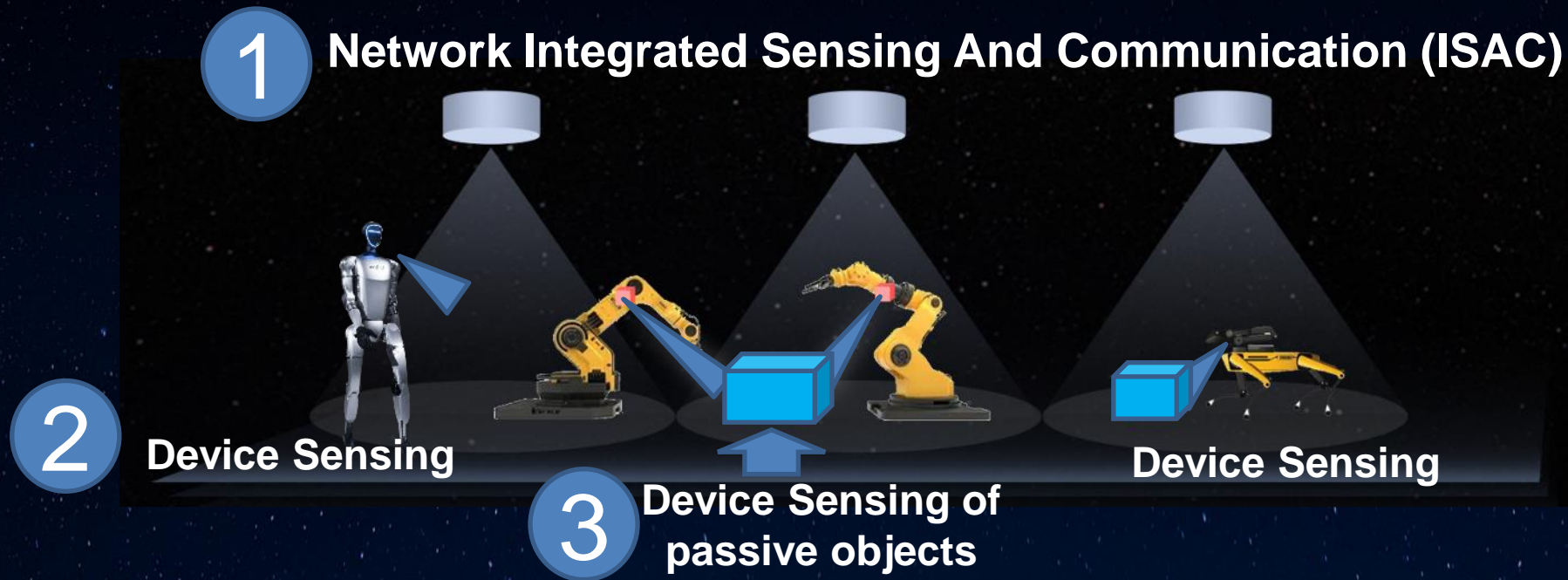
High accuracy localization and tracking

Simultaneous imaging, mapping and localization

Augmented human sense

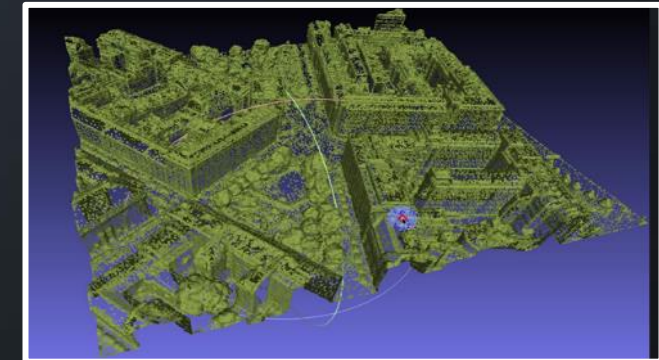
Gesture and activity recognition

# 5G/6G sensing - new eyes for robots

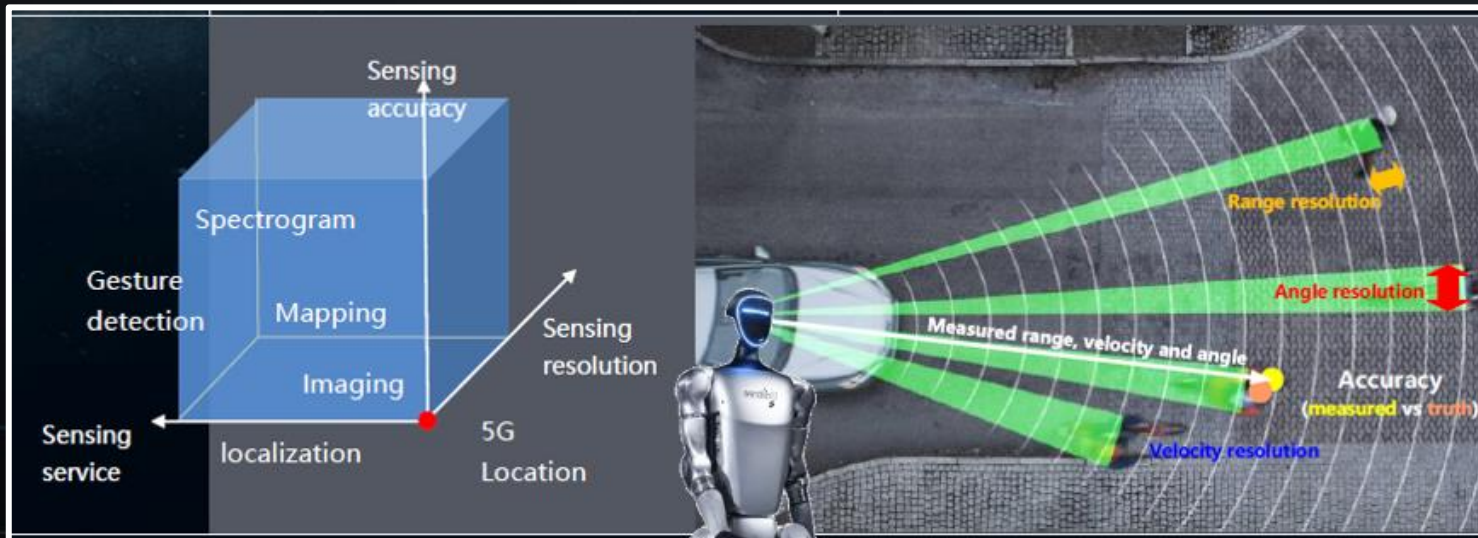
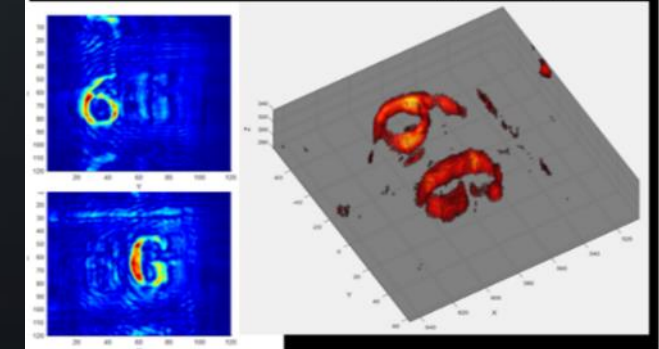


# Radio Sensing Principles and Theoretical limits

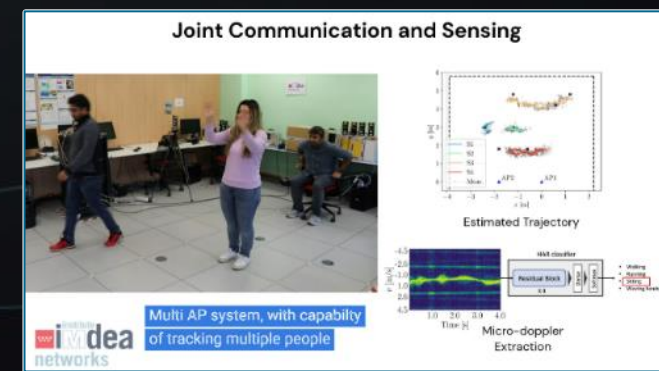
	Frequency	39GHz	71GHz	275GHz	1THz
	Bandwidth	5GHz	5GHz	20GHz	50GHz
	Distance Resolution Limit	3cm	3cm	7.5mm	3mm
	Imaging Resolution Limit	4.7mm	2.6mm	0.7mm	0.2mm
	Spectrogram Resolution Limit	2.4MHz	2.4MHz	9.6MHz	24.4MHz



3D Reconstruction with 3mm accuracy (130GHz, 8 GHz)

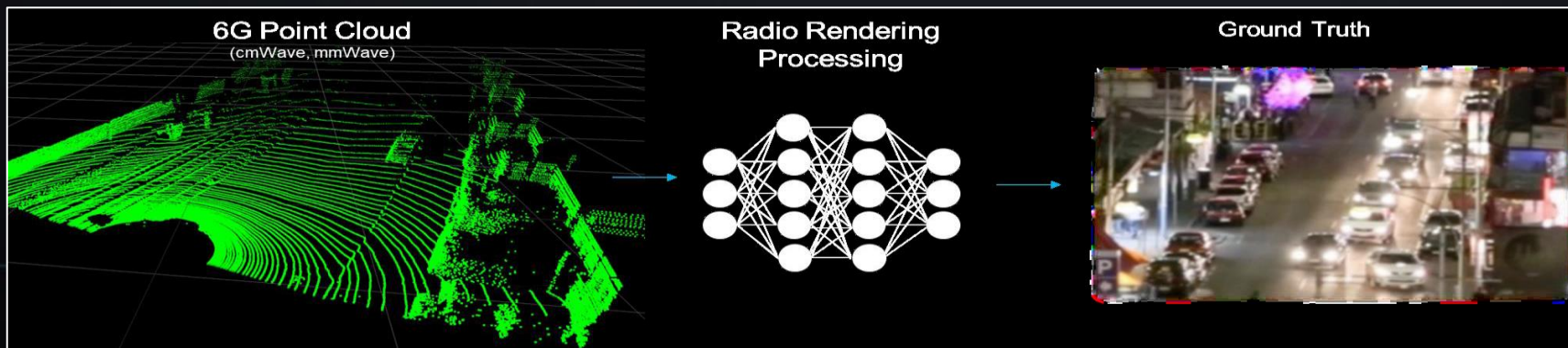


Source: Huawei

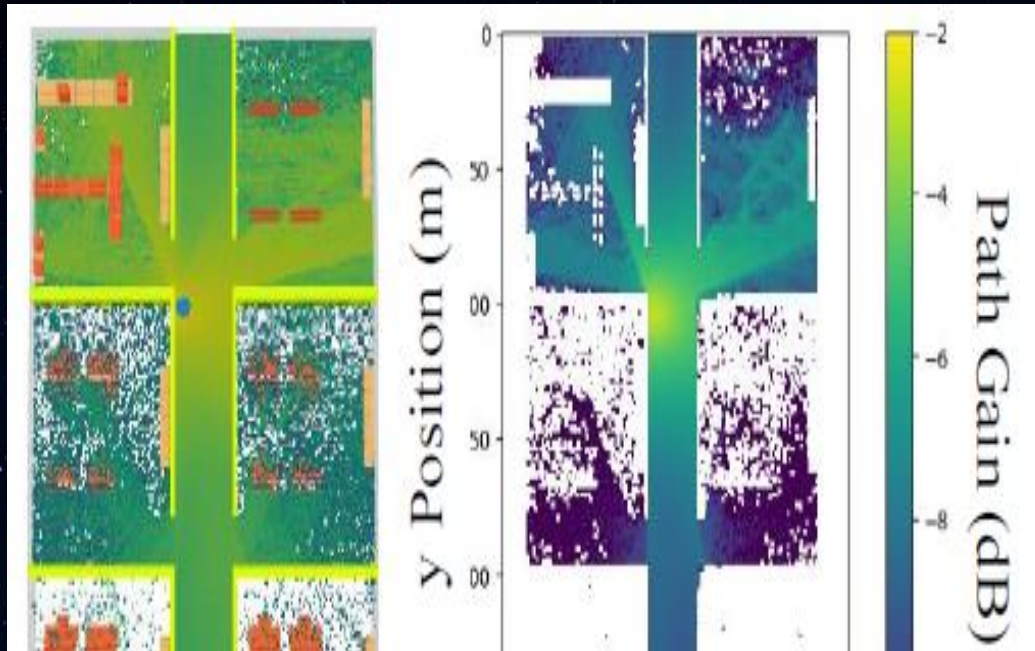


Source: one6G summit 2022

# All Spectrum and All Radio Node Sensing (network & device)



# Example: Communication-aware Motion Control for Mobile Robot



- Online updated Coverage map enables save path planning
- Radio connection depends on the height of the antenna (right picture, 1m)

**Source:** *Communication-aware Motion Control for Mobile Robot Applications*

Daniel F. N. Gordon, Yiqun Wu, Xueli An Huawei Munich Research Centre, Munich, Germany 4th IFSA Winter Conference on Automation, Robotics & Communications for Industry 4.0 / 5.0 (ARCI' 2024), 7-9 February 2024, Innsbruck, Austria

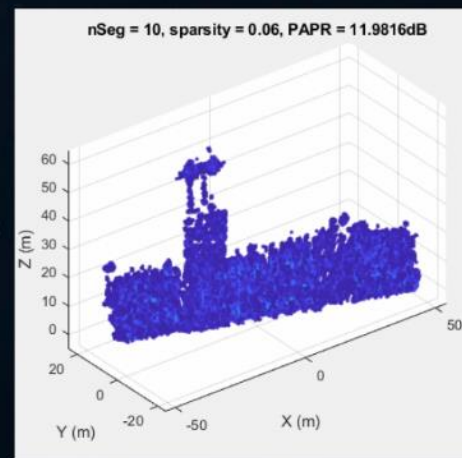
# Environment Reconstruction – BS/UE Collaboration



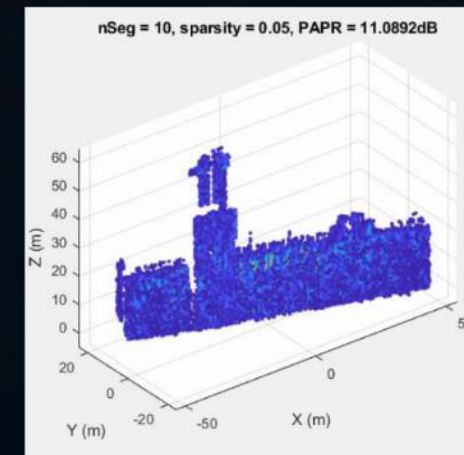
BS: ULA  $64 \cdot \lambda/2$   
UE: equivalent aperture  $128 \cdot \lambda/2$

Multi band Joint Sensing with gNB & UE

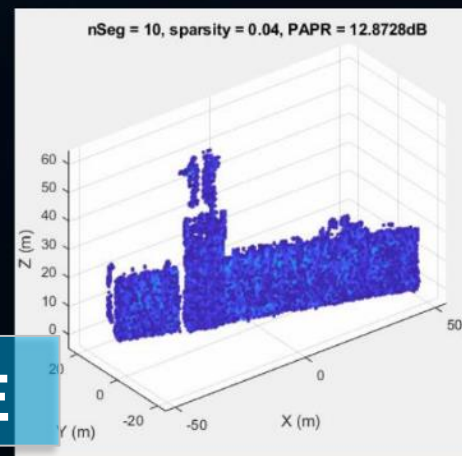
### 3.5GHz



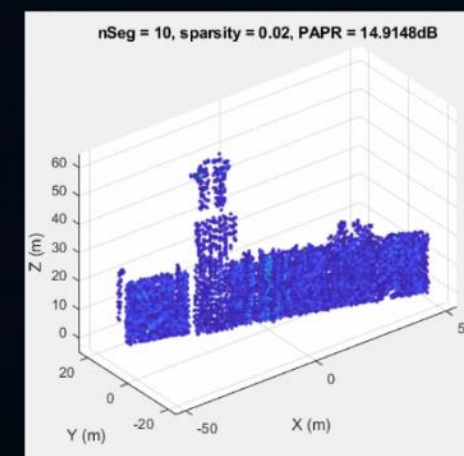
### 10GHz



### 26GHz

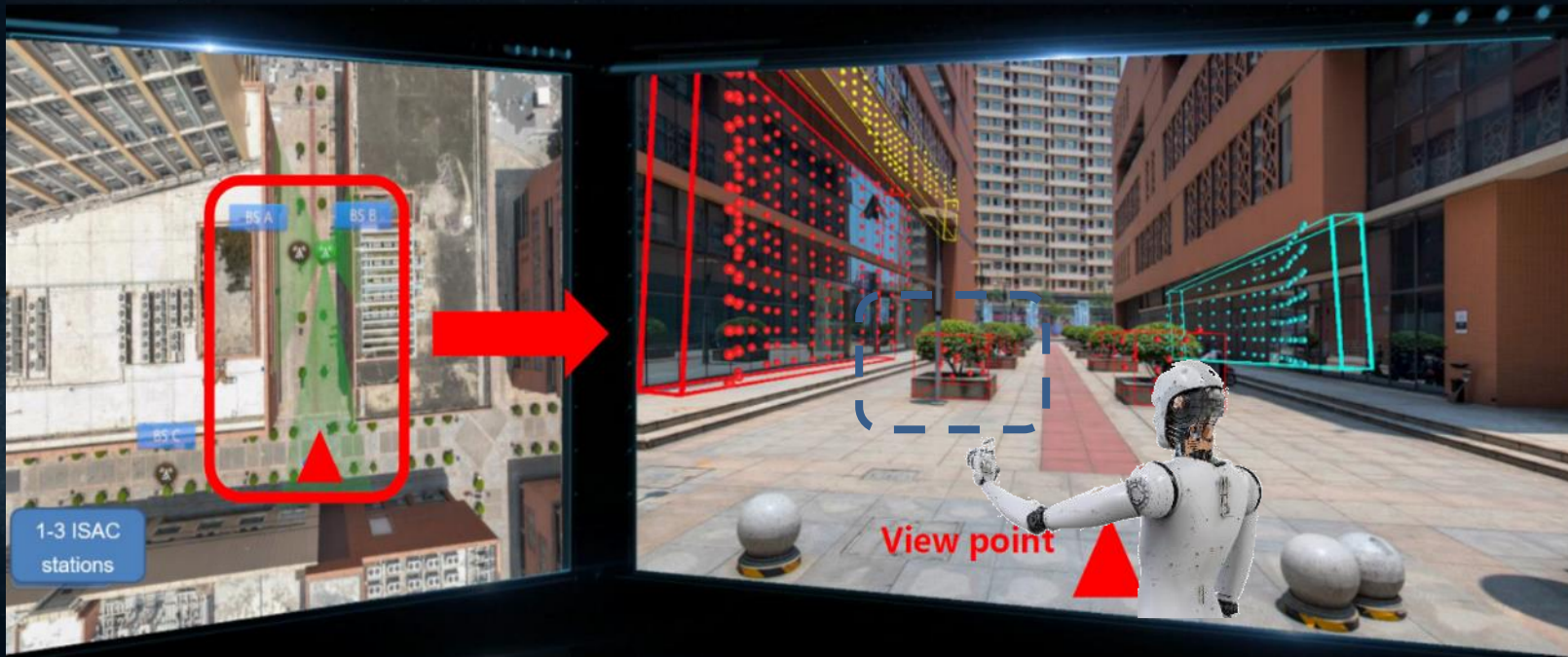


### 100GHz





# Real-Time Campus-Wide Digital Twinning at 10GHz



Building reconstruction KPI	BS A + BS B
Polygon distance error	8.3cm
Norm vector error	4.19°
Reconstruction ratio	50%

## New Services: autonomous Robot, Car, Mobile and Social Robots etc

- Sensing assisted communication
- Digital map reduce communication overhead & power consumption,
- Improve positioning accuracy (of any kind of object)

# 6G - Fusion of Physical and Cyber World

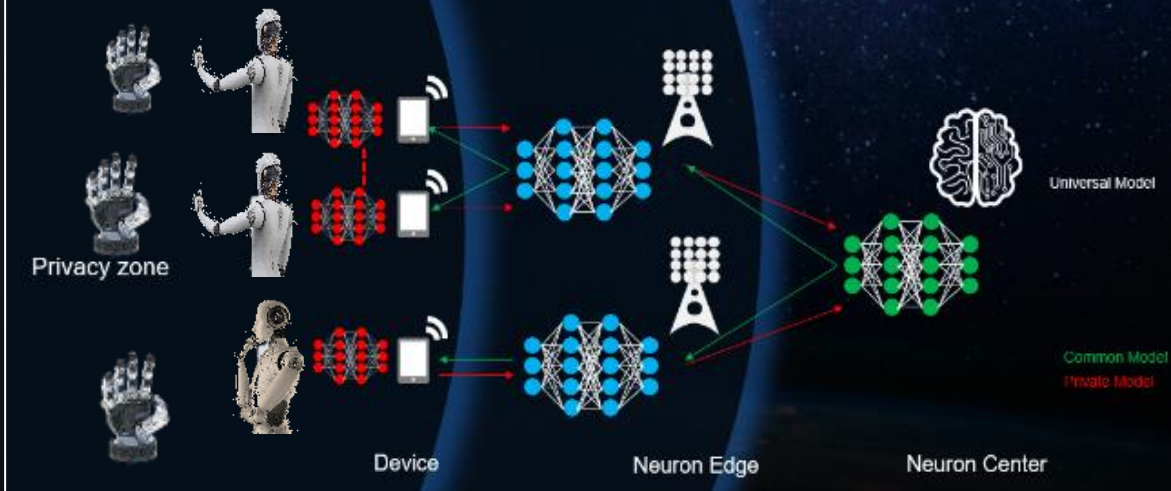


- 6G will go beyond communications to be a platform for AI and Sensing with key capabilities
- A global 6G standard is the key to the success of 6G. Industry consensus are building.

# 6G AI4Network – Network4AI

## 6G Distributed Learning Architecture

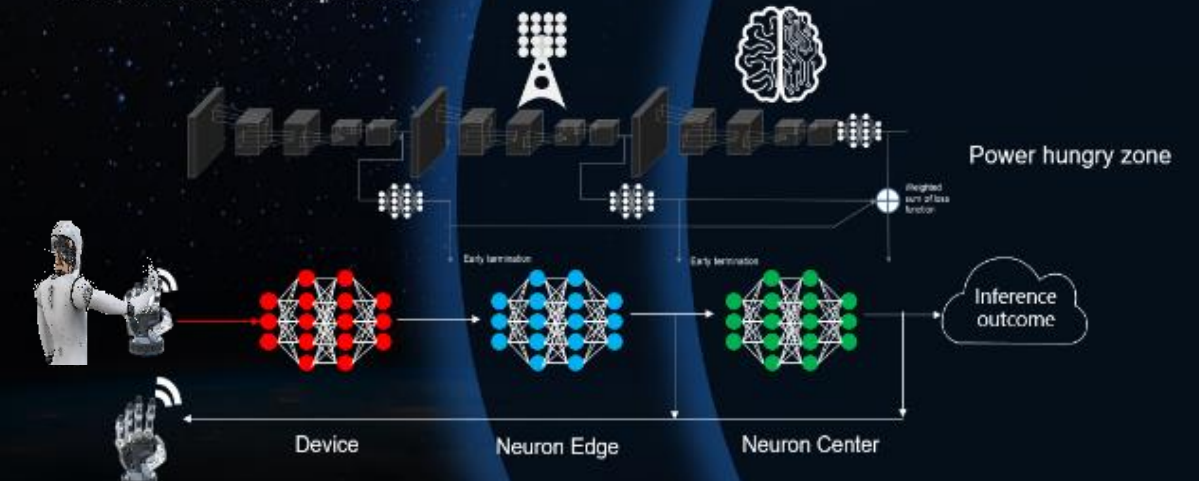
- **Privacy Protection:** Protects data privacy by not transmitting raw data
- **Energy Saving:** Moves computing closer to data for better energy efficiency



## 6G Distributed Inferencing Architecture



- **Terminal offloading computing and power burden to the network:** Proliferation of intelligence even when terminal computing capability is insufficient
- **Collaborative inference:** Data aggregation from different angles and joint inference for real-time intelligent services such as 3D interpretation



- AI resources used to improve the 6G network
- AI resources provide Sensing features
- 6G Network provides AI resources for 3rd party services e.g. Robotic

# When 6G Meets Robotic

## Enhanced Perception

- Network-based and/or device-based sensing
- Multi spectrum Network sensing
- Real-time digital twin of the physical world
- Develop new robotic capabilities



New Eyes for Robot  
Local and Remote Eyes



## New communication / compute capability

- Robotic internal and external communication
- On demand, flexible and modularized design
- Extreme performance
- Cloudification and distribution

## Enhanced Cognition and Control

- Digital twin, Data fusion,
- Continues fine tuning of AI/LLM models
- Comprehensive data management,
- Network AI as a Service for control & perception

Local vs edge based computing

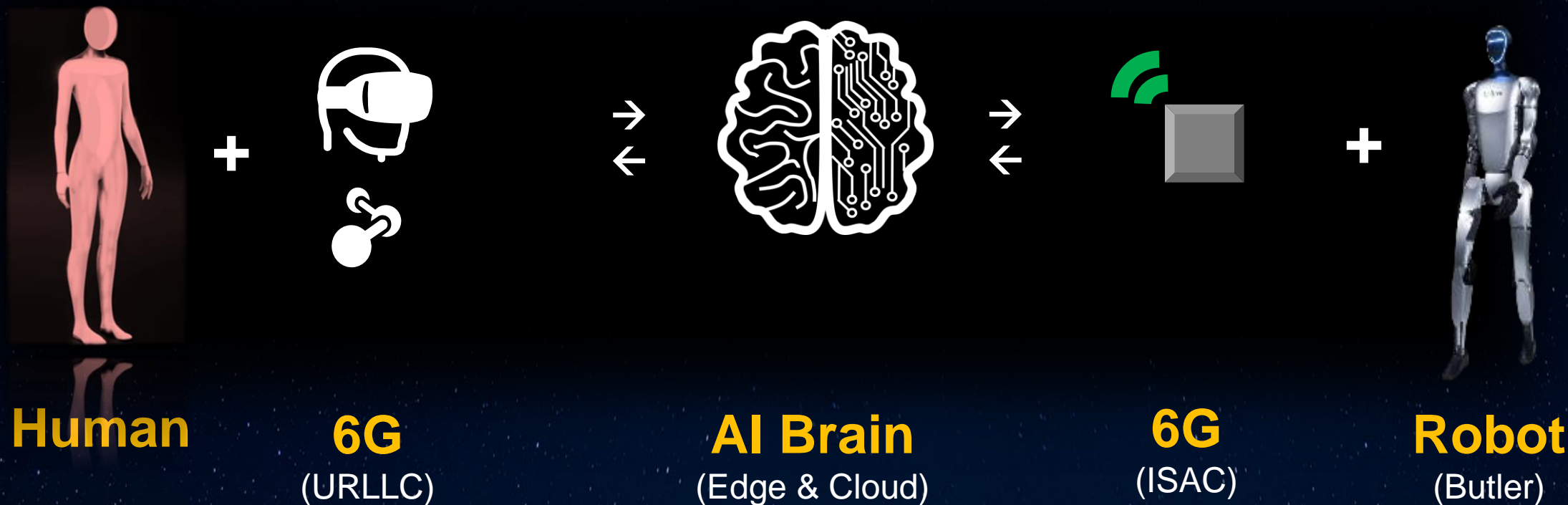


Computing and power restriction on the robot

Graceful degradation for local and edge compute functions

**6G will fundamentally change how robotics could be designed!**

# 6G - The Make of General Purpose Robot



Robot as “iPhone” for Consumers in 6G Era

# Thank you for your Interest

## Josef Eichinger

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5G-ACIA board member  
One6g WG4 Chair  
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**HUAWEI**