



NEXT FRONTIER FOR FUTURE NETWORKS:  
NOVEL APPLICATIONS AND DEVICES

*A “HIGH SPEED” OVERVIEW*

DR. IR. MICHAEL PEETERS—PROGRAM DIRECTOR CONNECTIVITY

## Let's stick to the 5G label

Any argument for 6G?

- 5G was quite conservative in the technology chosen
- 5G must deliver low latency communication NOW – 5G calls are lame

Computing will dominate the communication systems – MEC/AI the killer app

- Software will take over – update rate 1/day
- Hardware is still needed for RF/BB and acceleration in computing

Therefore 6G might be a great marketing tool, but technically we will focus on

Release 16, 17, 18, ...

**But the worst a 6G label could do, it could destroy the market**

THE WRONG ANGLES.

**Application**

**Network**

**Software**

**System**

**Package**

**Chip**

**Circuit**

**Process**

**Materials**

**Application**

**Network**

**Software**

**System**

**Package**

**Chip**

**Circuit**

**Process**

**Materials**

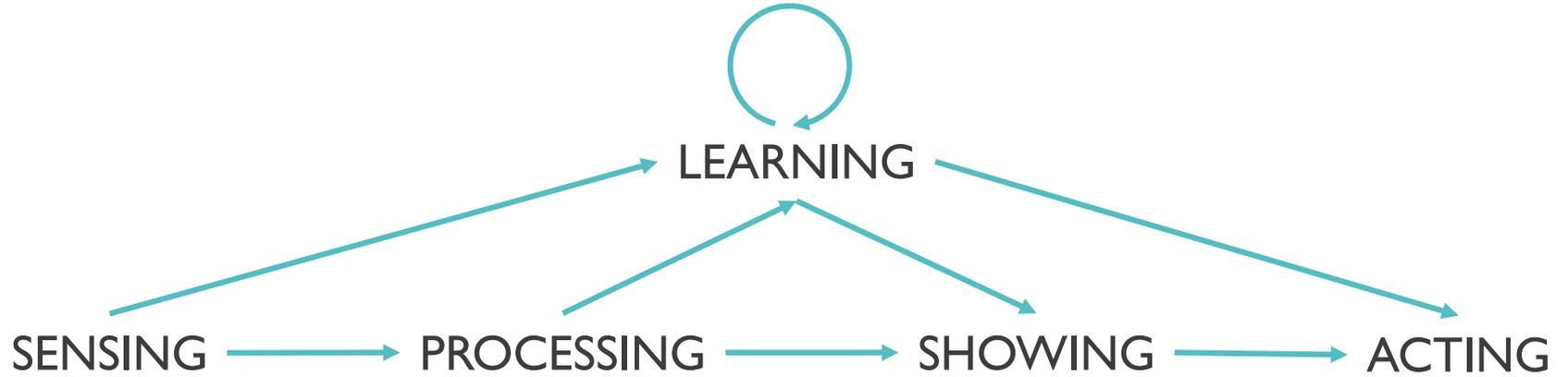
# THE ARGUMENTS

## OVERVIEW

- I—OT
- Applications
  - Priceable
  - Priceless
- Devices
- Summary

# THE I IN IOT

—————> CONNECTING



# APPLICATIONS (PRICEABLE)



**FWA**

**PROCESS  
AUTOMATION**

**RELIABILITY**

**NO**

**XR**

**SCADA**

**RAPID  
RESPONSE**

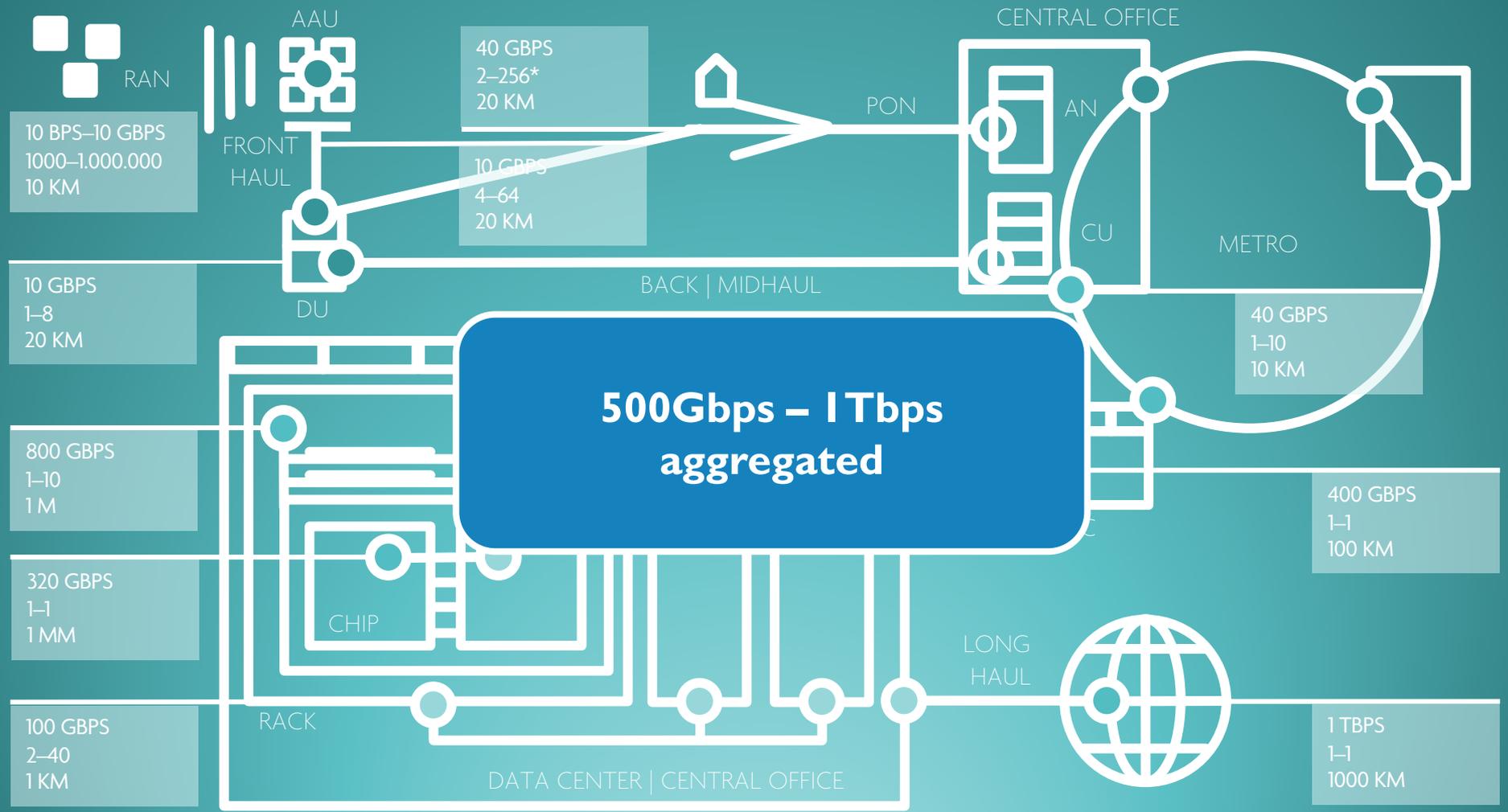
**LATENCY**

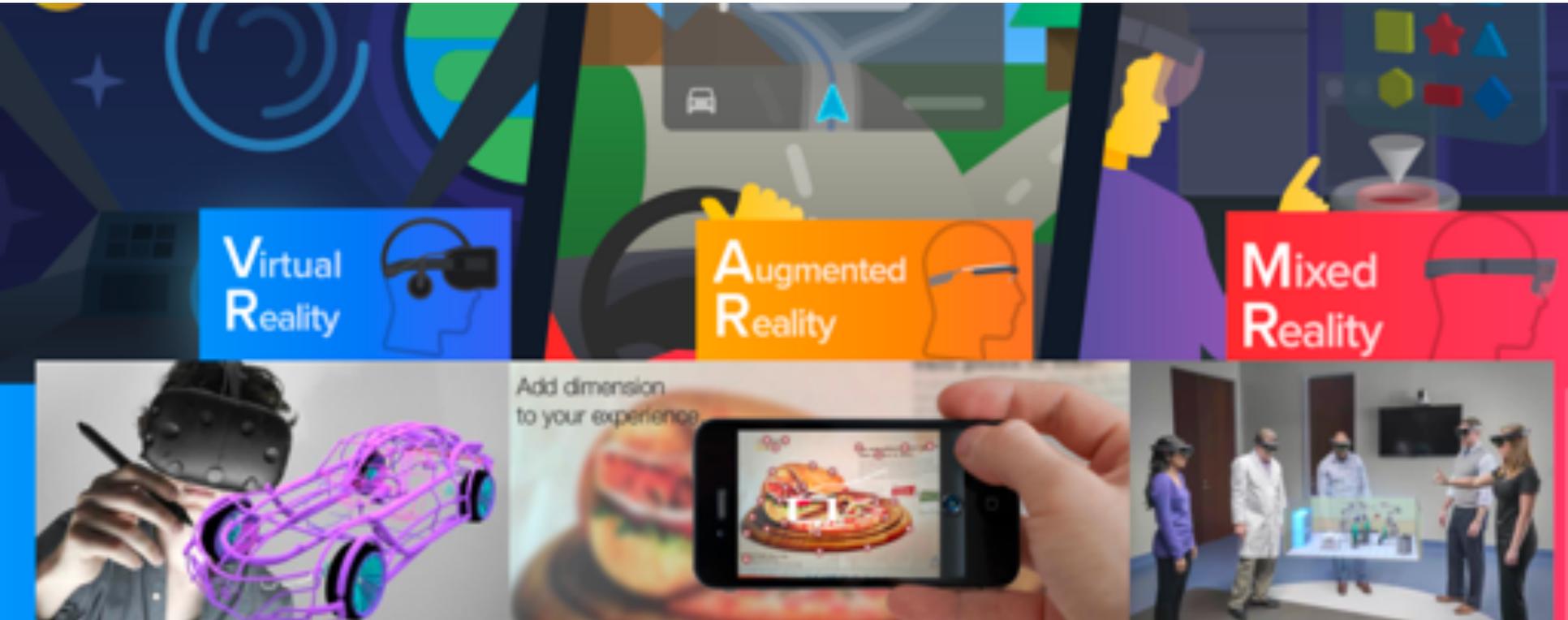
sense centric



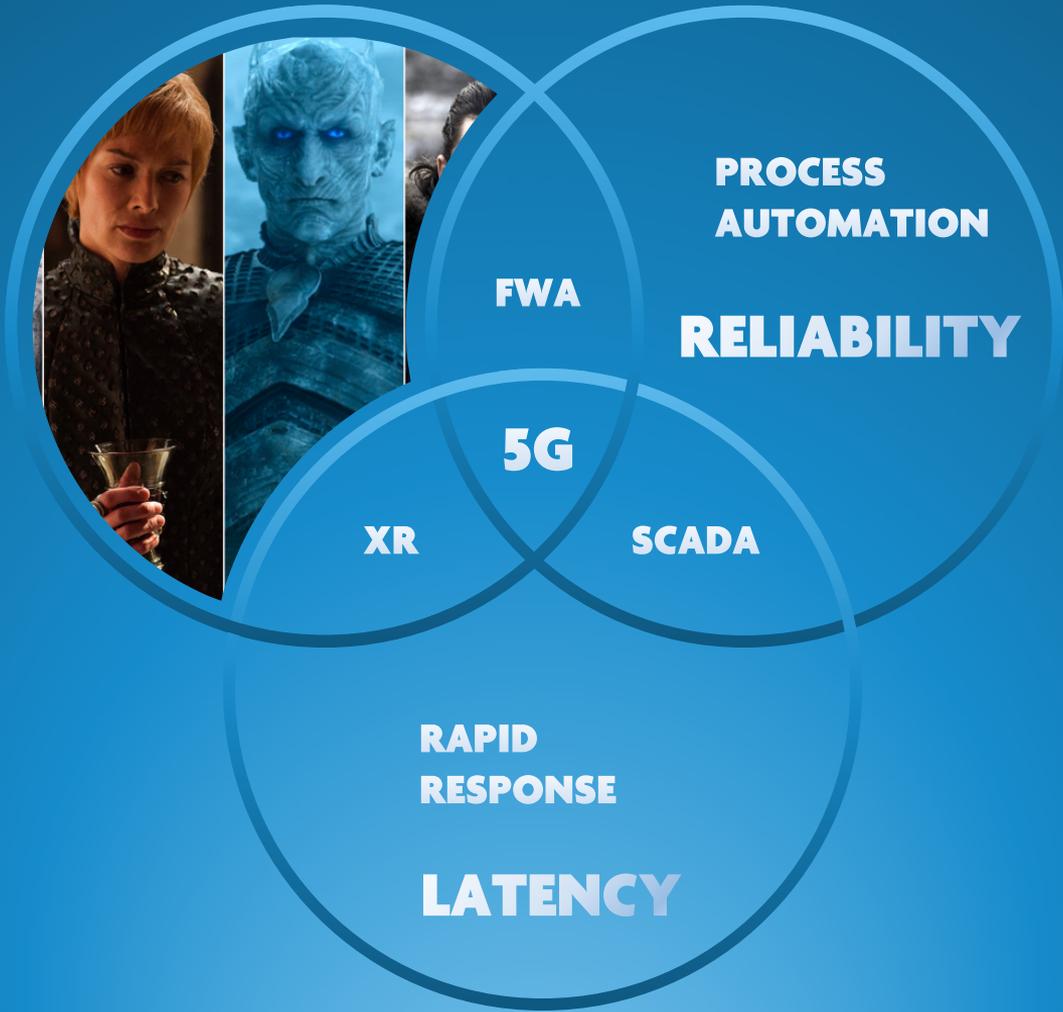
human centric

Combination of multiple media streams continues to push bandwidths.







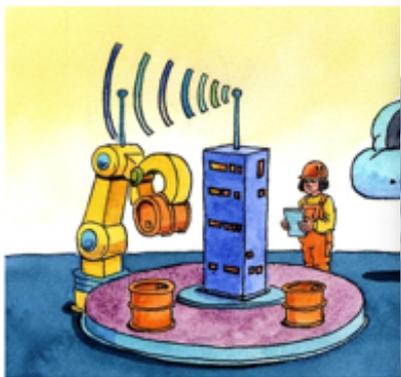




Life on the edge

## The era of the cloud's total dominance is drawing to a close

*The rise of the "internet of things" is one reason why computing is emerging from the centralised cloud and moving to an "edge" of networks and intelligent devices*



Print edition | Business >

Jan 18th 2018



McKinsey & Company  
High Tech

Our Insights

How We Help Clients

Our People

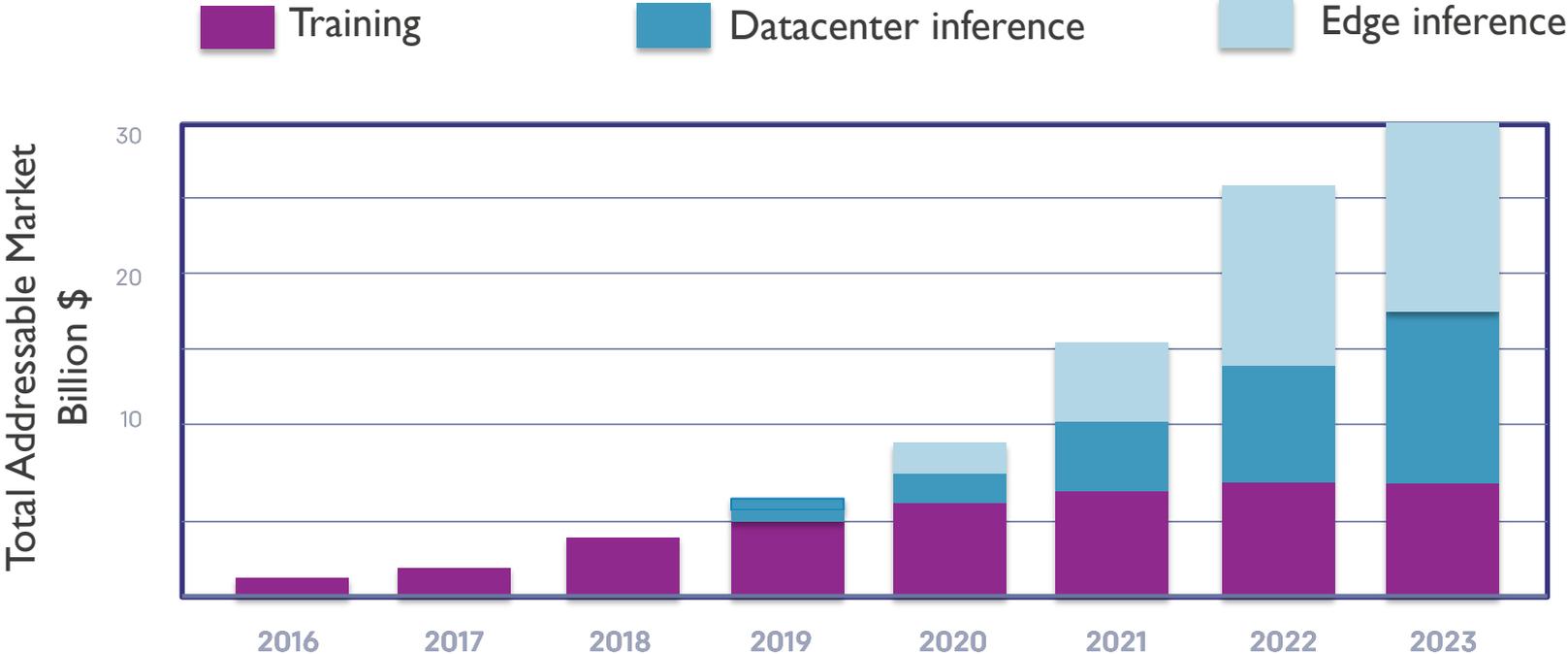
Contact Us

Article  
November 2018

# New demand, new markets: What edge computing means for hardware companies

By JM Chabas, Chandra Gnanasambandam, Sanchi Gupta, and Mitra Mahdavian

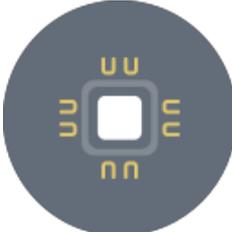
# EDGE AI IS THE GROWTH MARKET



1: Barclays Research, Company Reports May 2018

# EDGE AI – A WHOLE DIFFERENT BALLPARK

EVERYTHING BECOMES A BOTTLENECK



Terabytes

Gigabytes

Megabytes



Gbps

Mbps

Kbps



10,000 Watts

0.5-1 Watt

50 mWatt



person 0.99



chair 0.91 chair 0.90

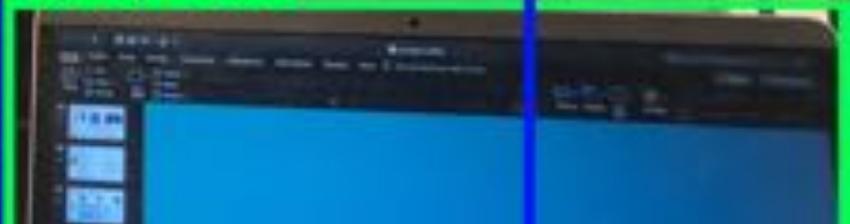
chair 0.96

chair 0.96

chair 0.96

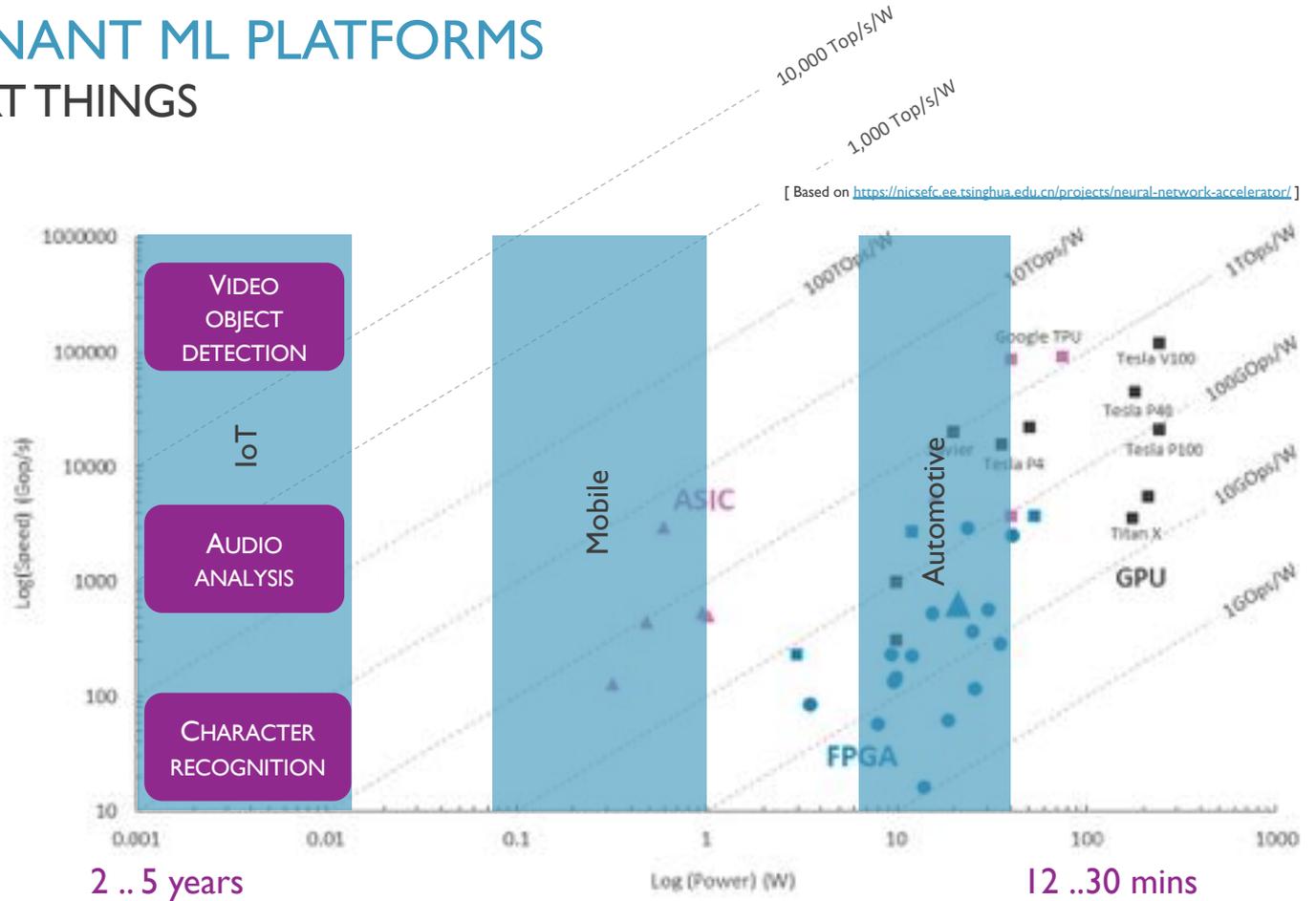


laptop 0.95



# TODAY'S DOMINANT ML PLATFORMS NOT FIT FOR SMART THINGS

- Intelligence at the extreme edge
  - 10 year autonomous operation
  - On a power-budget
- Below 1 mW



# IMPACT OF EDGE AI

## IMAGINE A WASTE MANAGEMENT SOLUTION

15

1

0.1



Radio  
1 Watt



Traditional  
embedded GPU  
15 Watt



“Sweet spot”  
0.1 Watt



# IMPORTANT EDGE AI MARKETS



## WEARABLES

Anomaly detection in movement of elderly people (e.g., fall detection)



## AR/VR

Low latency reaction speed on the device



## ASSET TRACKING

Movement prediction  
Tracking abnormal behaviour



## SMART CITIES

Automated monitoring of the city  
(video surveillance, waste, energy)



## INDUSTRY 4.0

Monitoring of critical infrastructure  
Monitoring of workers on site



## CONNECTED CARS

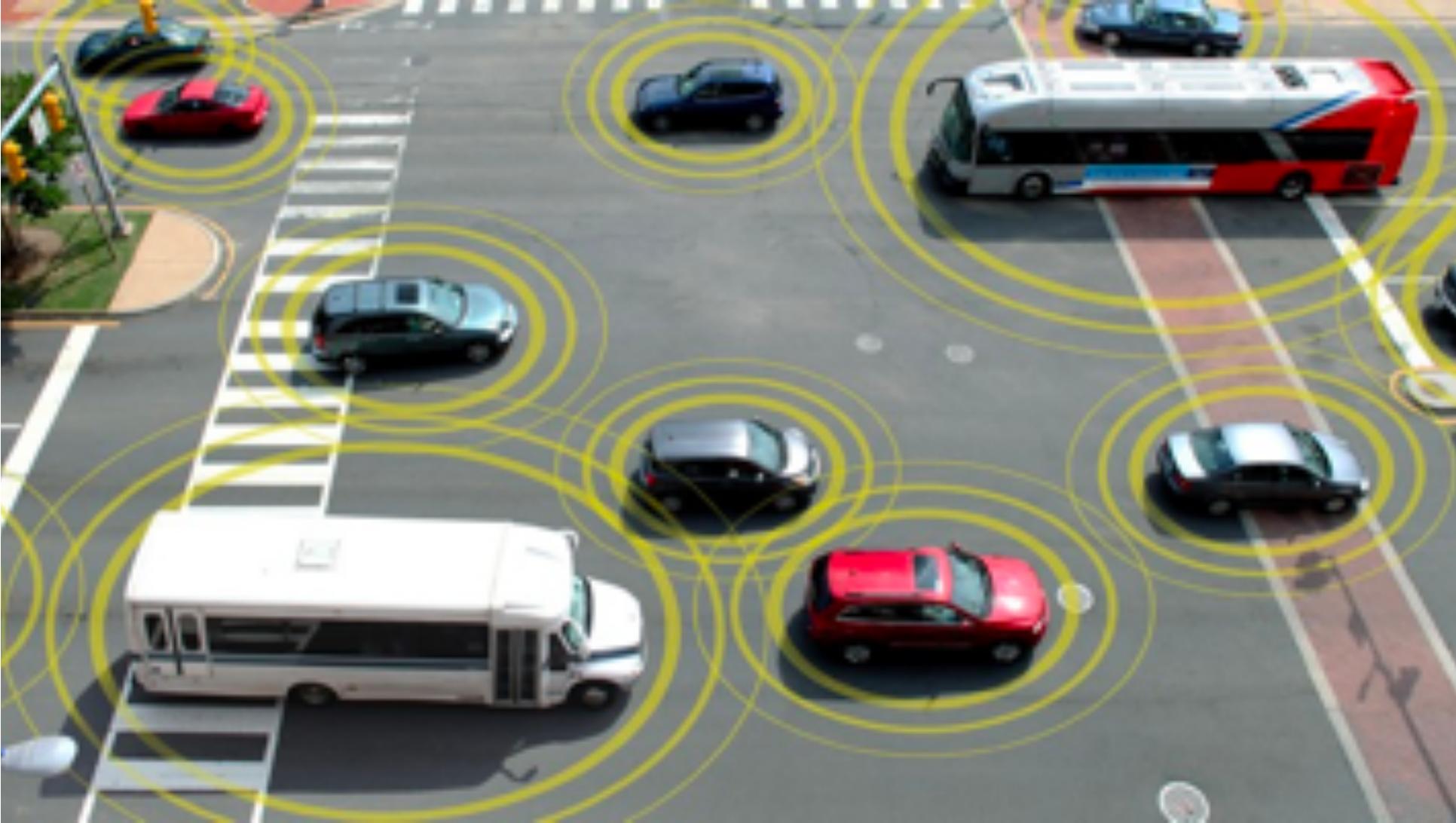
Low latency & proactive interaction between connected cars.



## DNA SEQUENCING

Lab on chip: Sequencing of cancer cells in the blood.

**AND MANY MORE...**







15 MIN

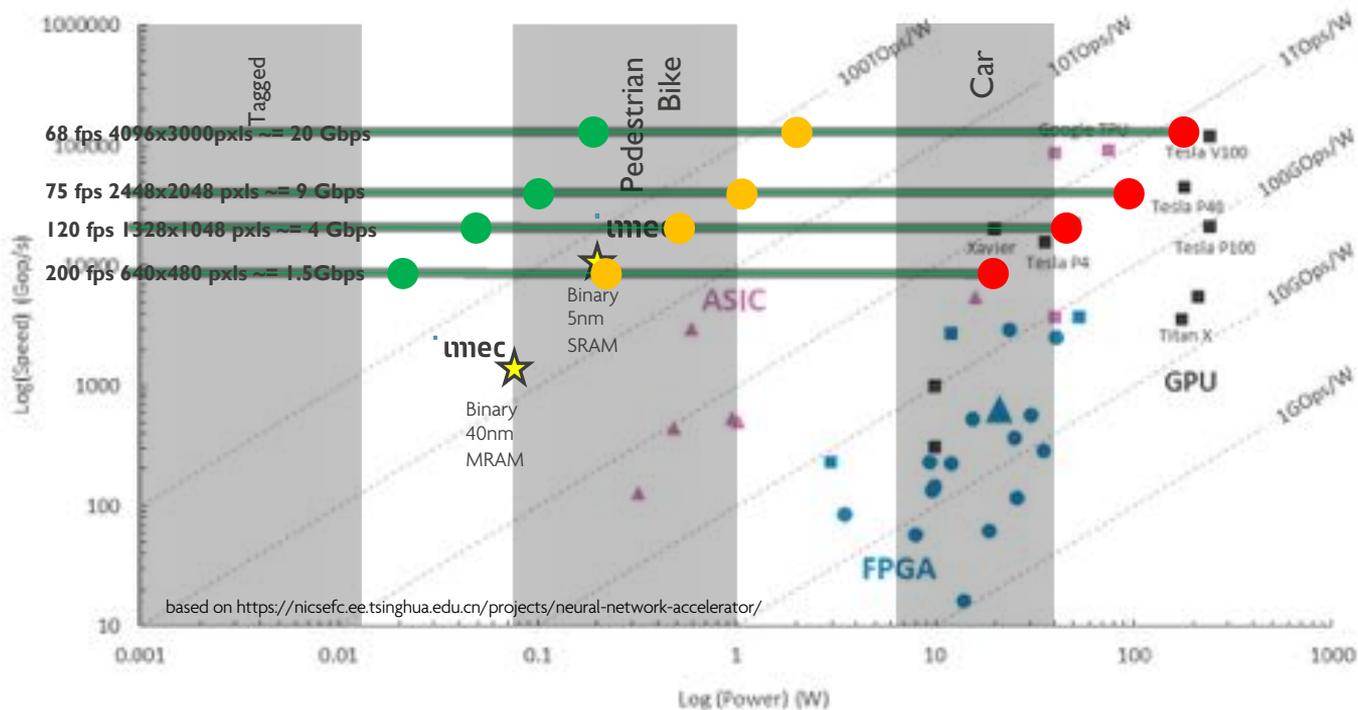


924 HOURS

NEED VERY FAST MACHINE LEARNING  
ON LARGE AMOUNTS OF DATA

# TRADING OFF PROCESSING WITH TRANSMISSION

BENCHMARK – TRANSMISSION OF IMAGE DATA VS PROCESSING



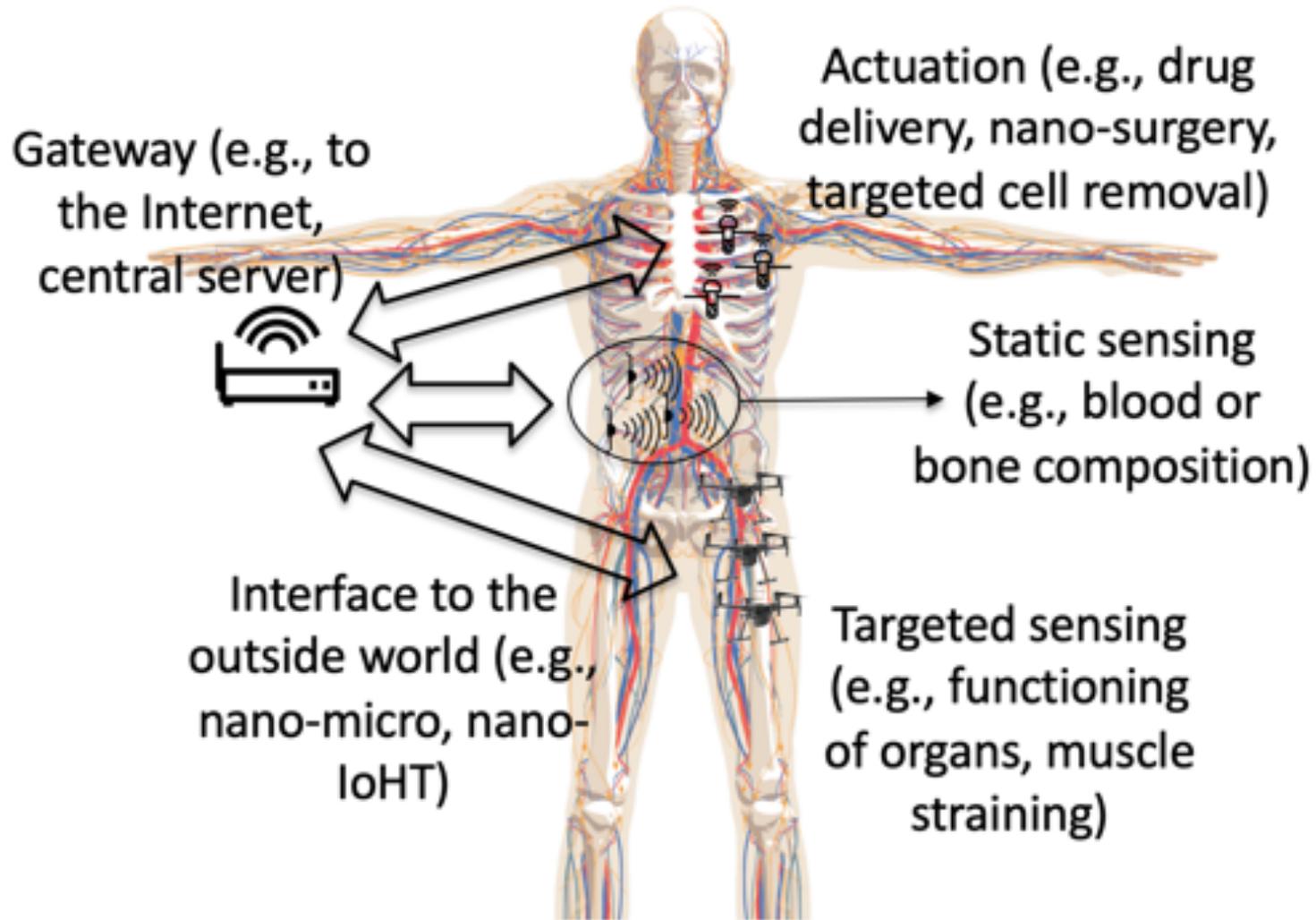
- Power requirement only to transmit the raw data (lowest latency), where we're using an (optimistic)  $10^{-8}$  J/bit average number. As can be seen, moving all processing to a central cloud can consume almost as much energy as the processing itself. Compression is equivalent to (partial) local processing with one key difference: latency. ●, ● are factor 1000 (HEVC target), 100

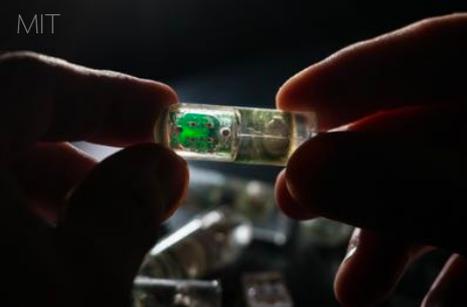
## KEY MESSAGE

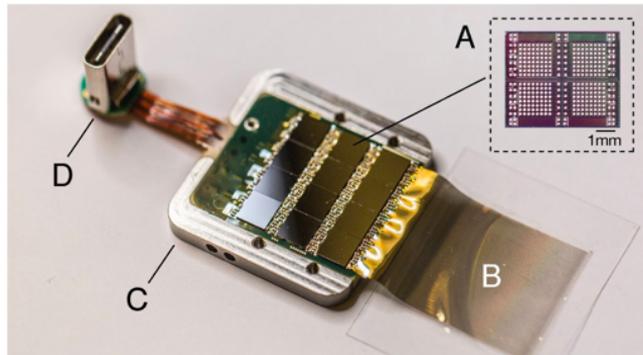
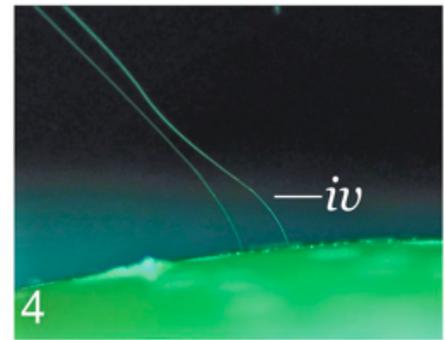
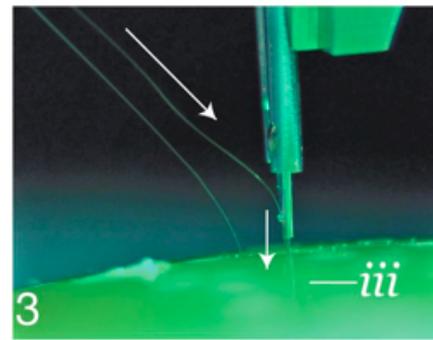
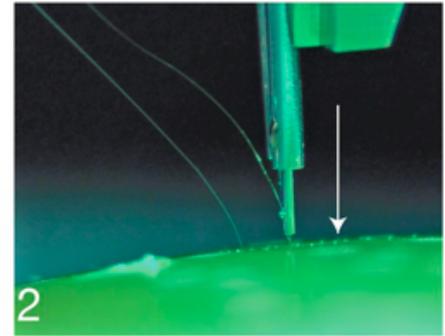
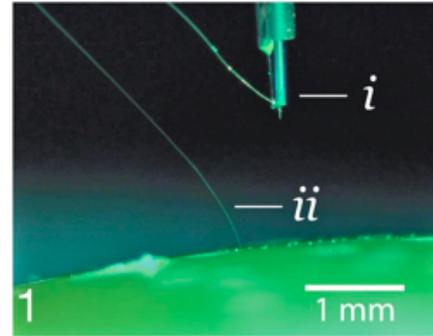
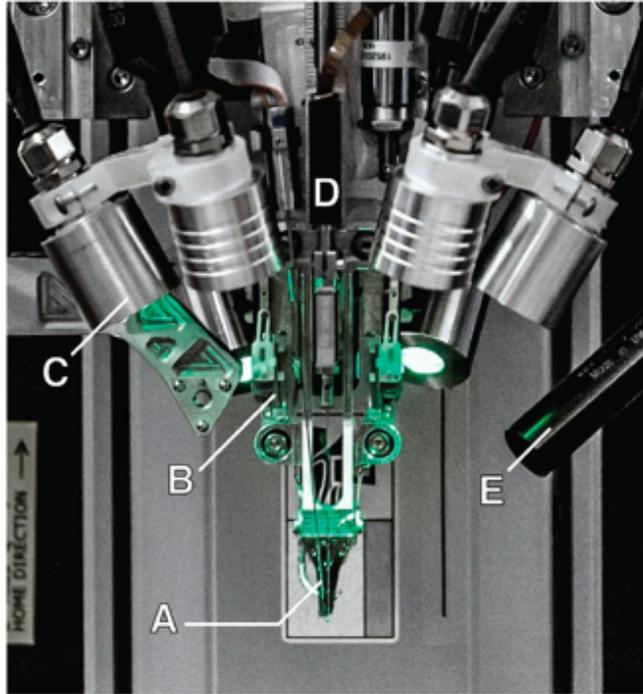
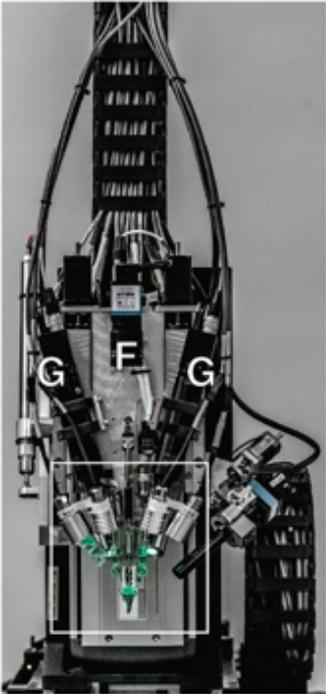
ORDER OF MAGNITUDE IMPROVEMENT (STILL) NEEDED  
IN COMPUTE, STORAGE AND COMMUNICATIONS.

# APPLICATIONS (PRICELESS)

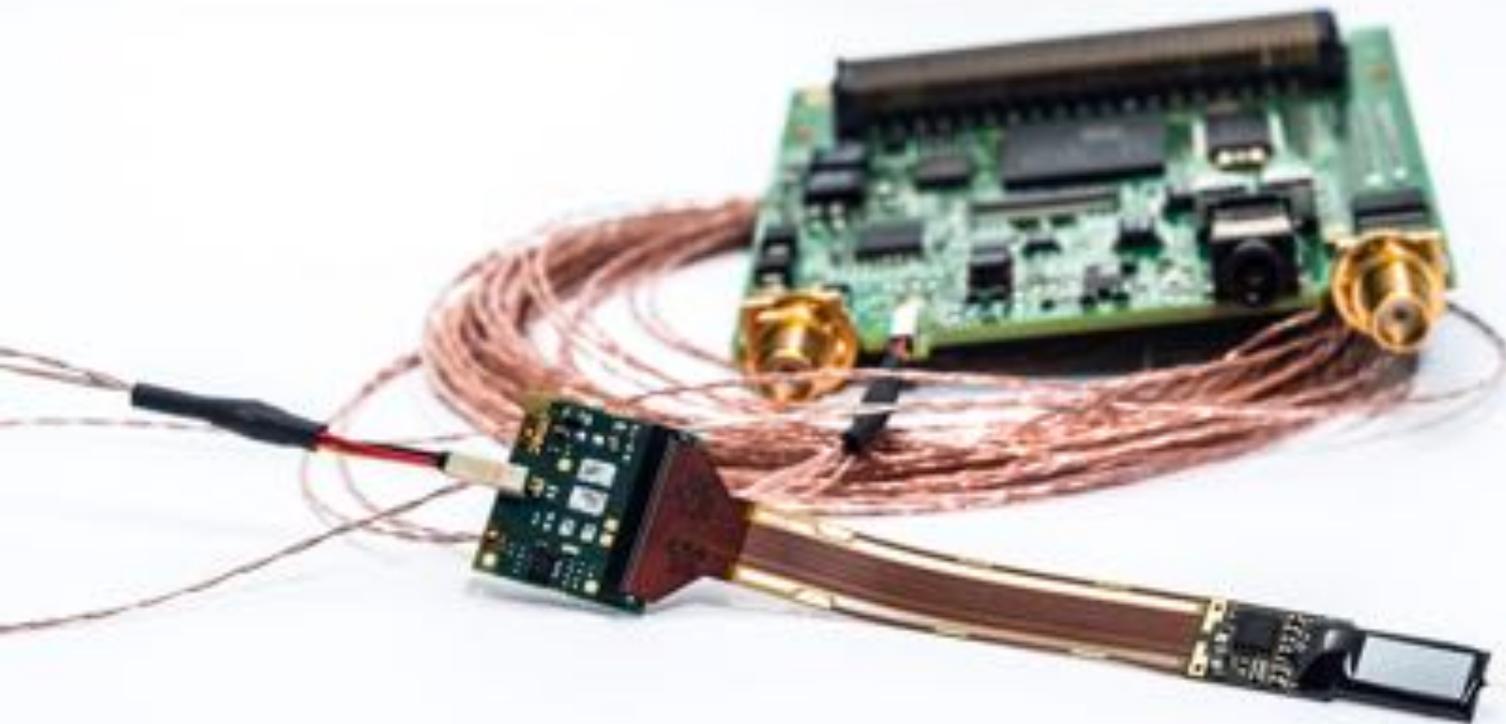
HEALTH





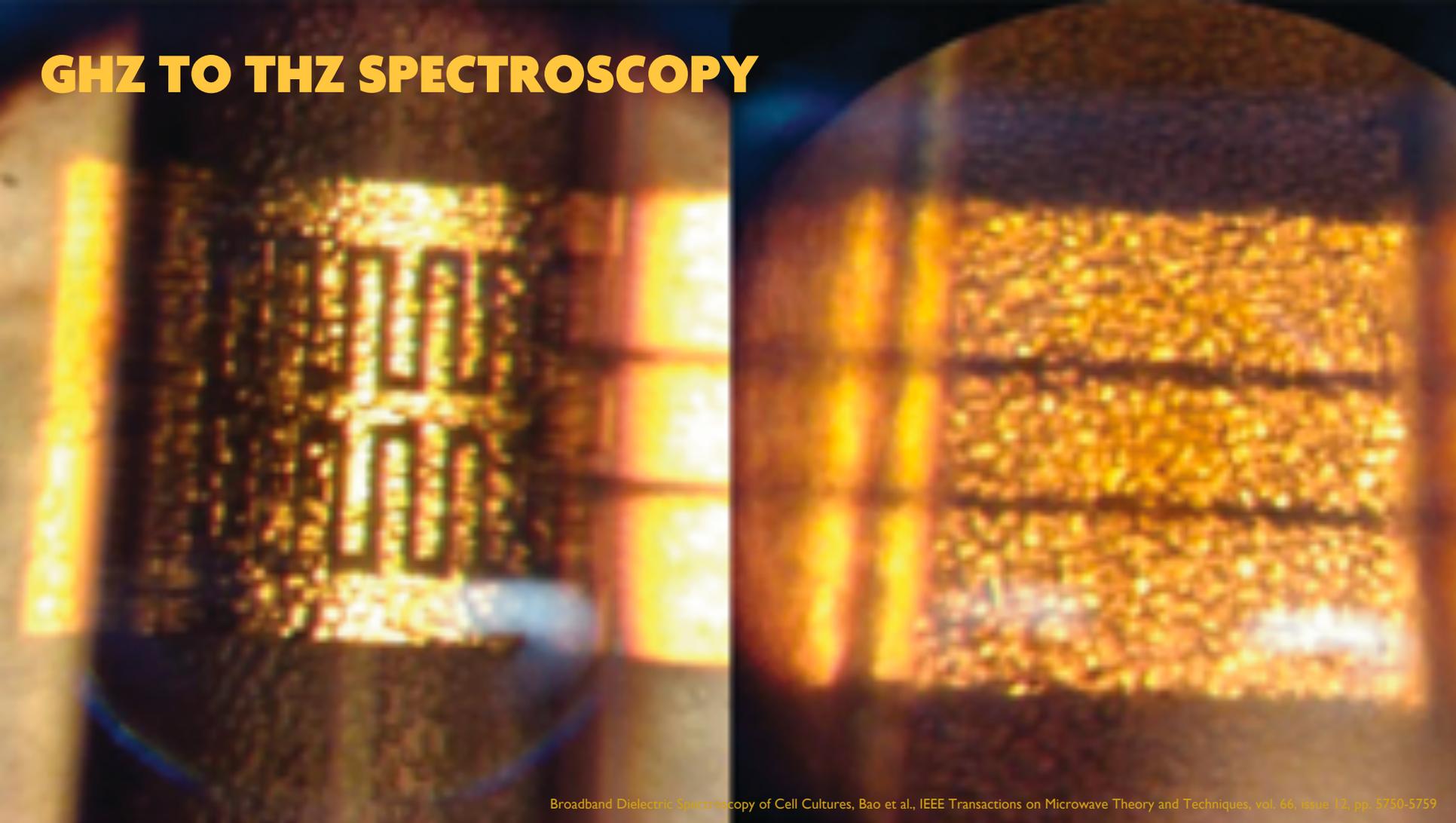


~500Mbps for 3000 electrodes



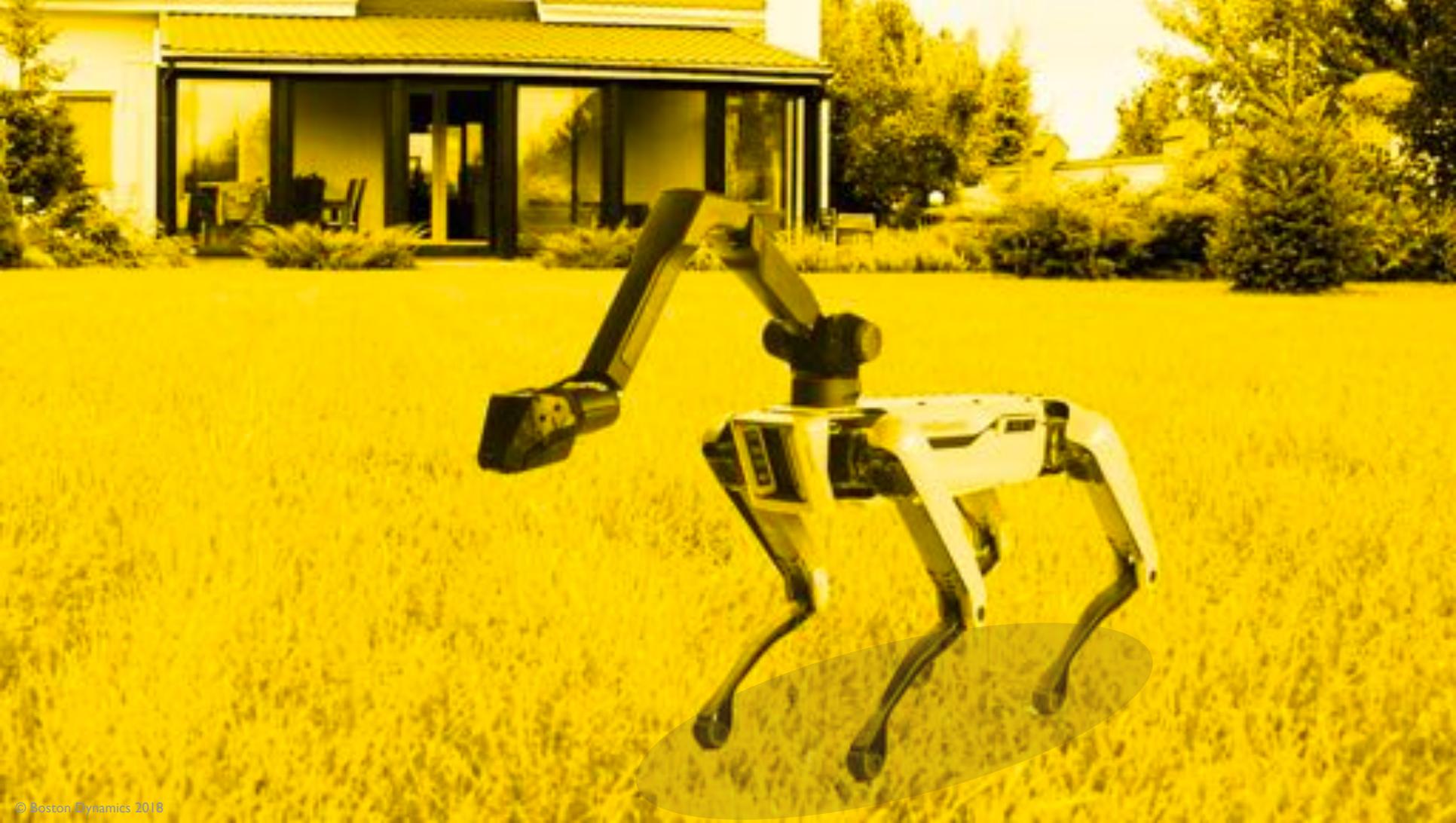
1 cm  
20x70 micron  
960 sensors

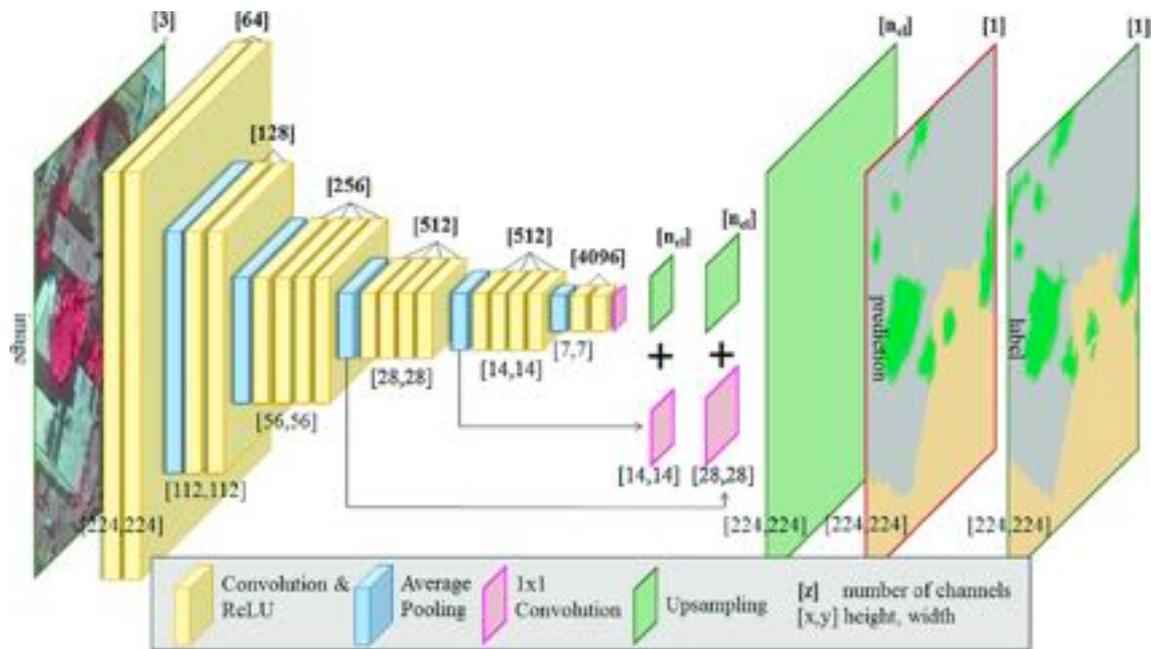
# GHZ TO THZ SPECTROSCOPY



HEALTH

TIME





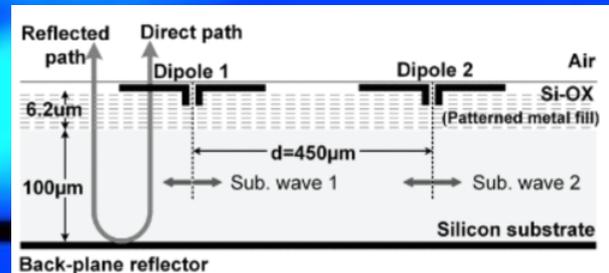
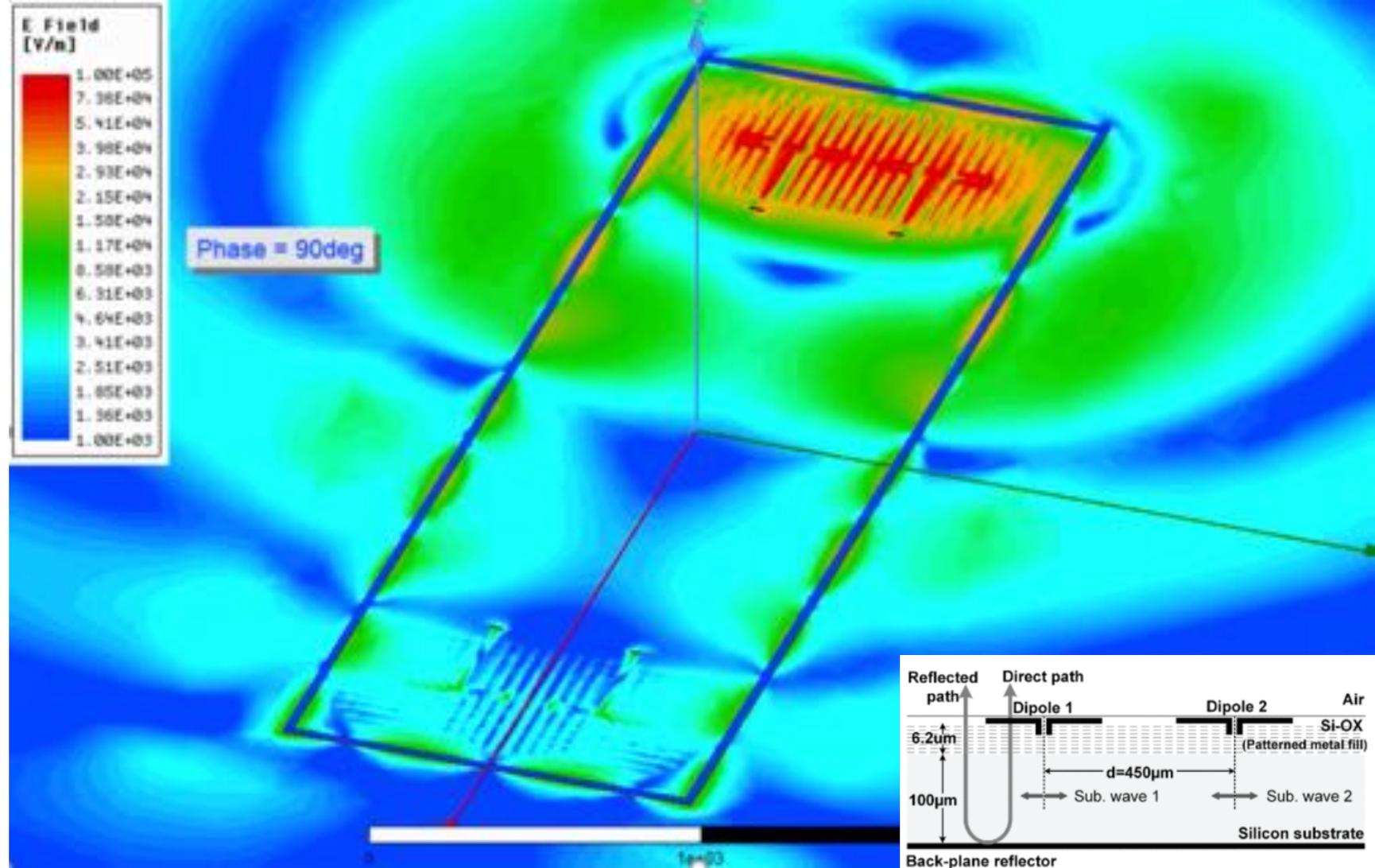
Layer name	#Filters	#Parameters	#Activations
input			150K
conv1.1	64	1.7K	3.2M
conv1.2	64	36K	3.2M
max pooling			802K
conv2.1	128	73K	1.6M
conv2.2	128	147K	1.6M
max pooling			401K
conv3.1	256	300K	802K
conv3.2	256	600K	802K
conv3.3	256	600K	802K
conv3.4	256	600K	802K
max pooling			200K
conv4.1	512	1.1M	401K
conv4.2	512	2.3M	401K
conv4.3	512	2.3M	401K
conv4.4	512	2.3M	401K
max pooling			100K
conv5.1	512	2.3M	100K
conv5.2	512	2.3M	100K
conv5.3	512	2.3M	100K
conv5.4	512	2.3M	100K
max pooling			25K
fc6		103M	4K
fc7		17M	4K
output		4M	1K

~150 million parameters





Phase = 90deg



HEALTH

TIME

PLANET

TreeWatchWUR (@TreeWatchWUR) x

twitter.com/treewatchwur?lang=en

Home About Search Twitter Have an account? Log in




Tweets 1,343 Following 5 Followers 4,425 Likes 11 Follow

**TreeWatchWUR**  
@TreeWatchWUR

I am the huge (popular) poplar tree (D = 95.8 cm) standing near the café The Spot in Orion at the Wageningen Campus in the Netherlands.

Wageningen, Nederland  
treewatch.net  
Joined May 2017  
6 Photos and videos

**Tweets** Tweets & replies Media

**TreeWatchWUR** @TreeWatchWUR · Aug 12  
Here is today's summary: shrunk 0 mm, transported 0 L of water at a maximum sap flow of 0 L/h.  
3 7

**TreeWatchWUR** @TreeWatchWUR · Aug 11  
Yesterday I've transported 0 L and today 0 L. My stomates are being regulated quite well.  
1 10

**TreeWatchWUR** @TreeWatchWUR · Aug 10  
Today I have shrunk 0 mm, transported 0 L of water at a maximum sap flow of 0 L/h.



HEALTH

BMI

body machine interfaces

TIME

AI

autonomous intelligence

PLANET

BIO

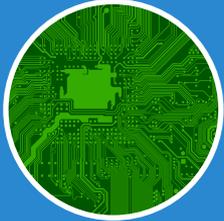
biological IO

## KEY MESSAGE

NEW “USES” AND “USERS” POSE EVEN GREATER CHALLENGES.

# DEVICES

# 100 GBPS COMMUNICATION REQUIRED



## Intra-Device Communication

- BMI
- Board to board communication, digital light processing projectors, inter-chip communication

100 Gbps

<10 cm



## Close Proximity P2P applications

- AI-2-AI
- Kiosk mode, **automotive data**, device-to-device, public transportation

100 Gbps

<1 m



## Multi-user AR/VR and holographic display

- Shopping mall, airport, **holographic displays**, football matches, virtual office, **multi-user AR/VR**

100 Gbps

<10 m



## Data Center

Rack to rack, intra-rack communication

100 Gbps

10 – 100 m



## Wireless Fronthaul/Backhaul

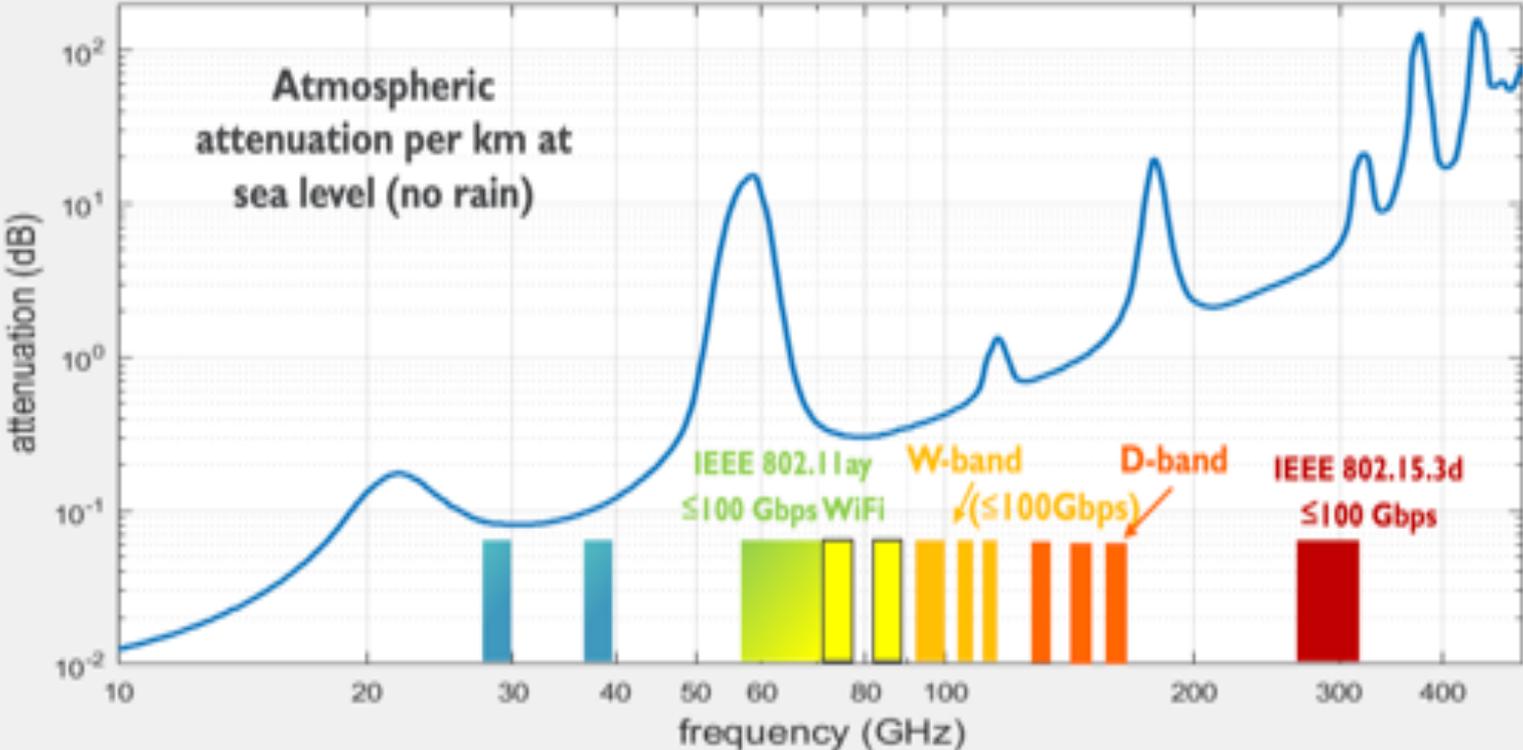
Biological IO

Fixed point-to-point links for cellular networks

1 Tbps/area

>100 m

# 100 GBPS WIRELESS COMMUNICATION REQUIRED

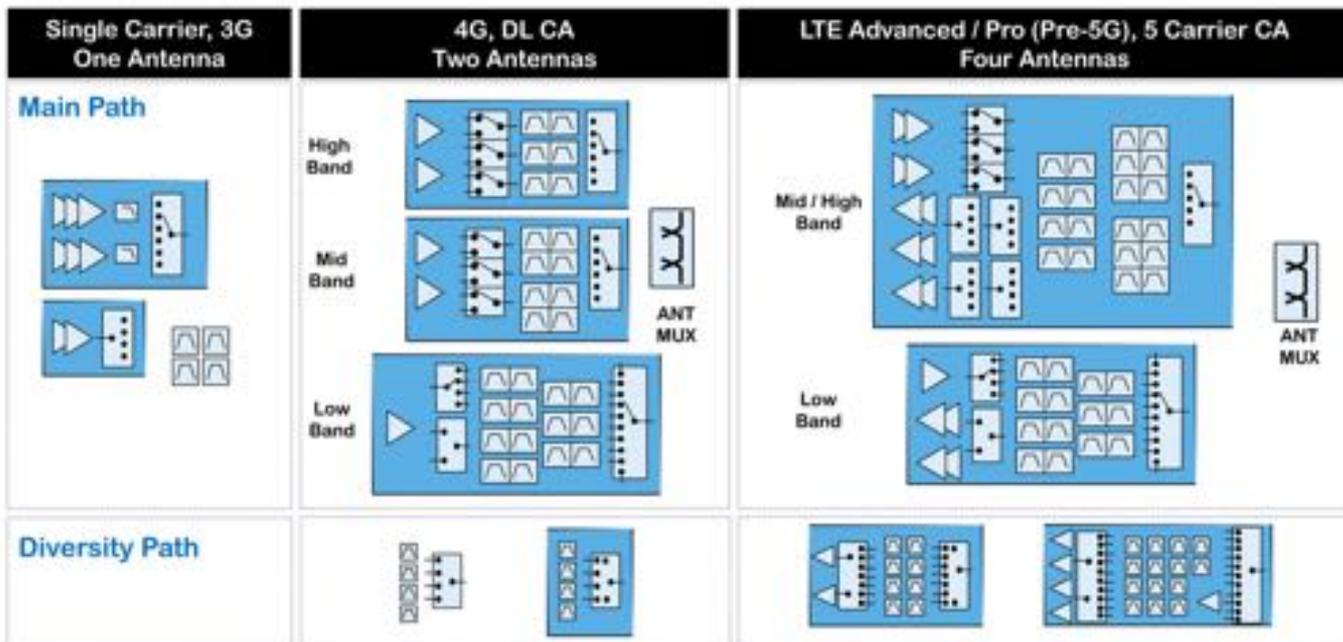


+ SENSING

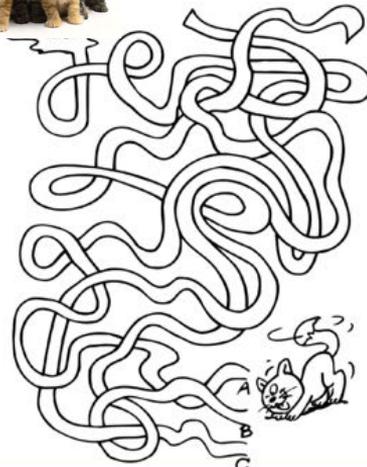


# 5G FRONT-ENDS BECOME EVEN MORE COMPLEX

## Evolution of the RF Front End

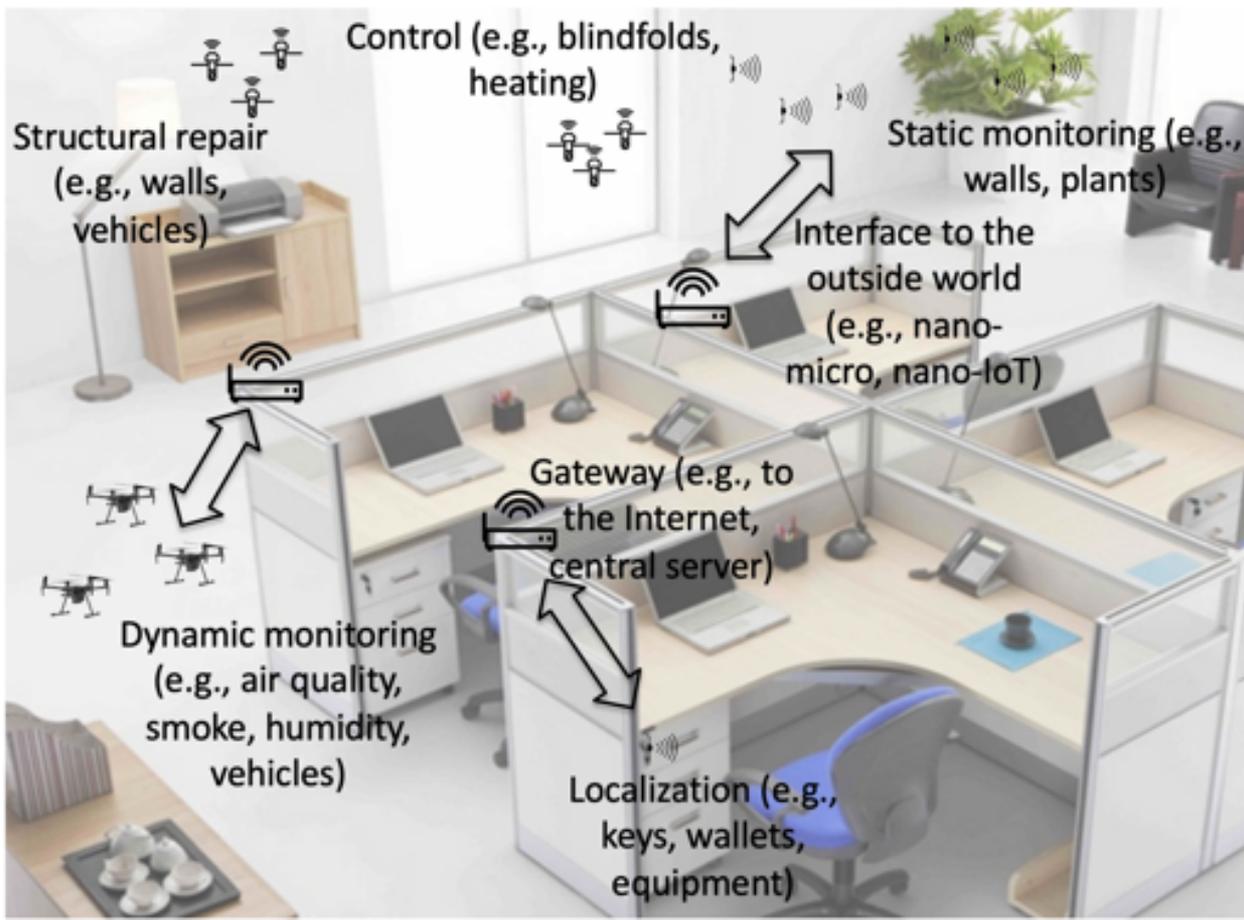


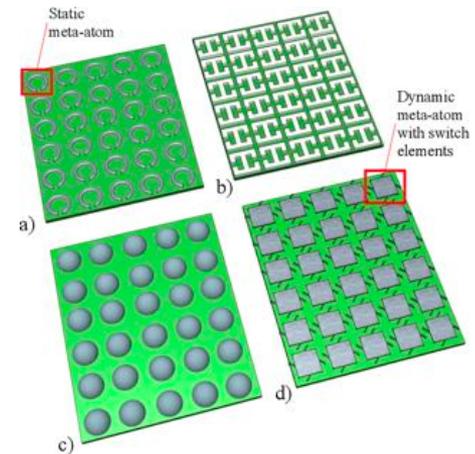
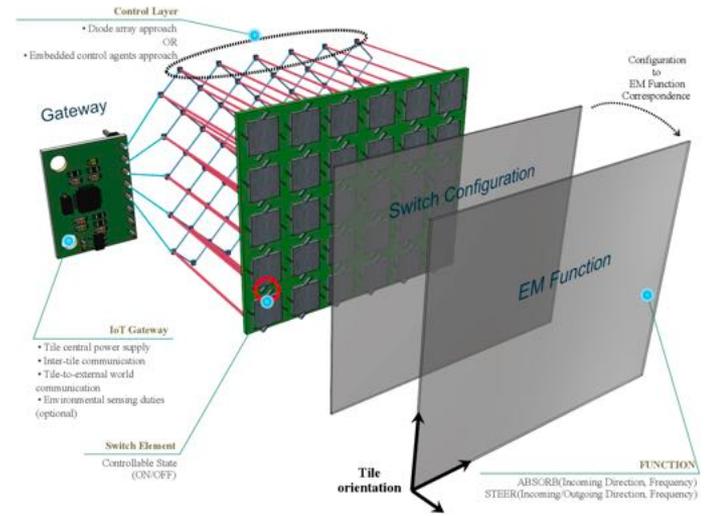
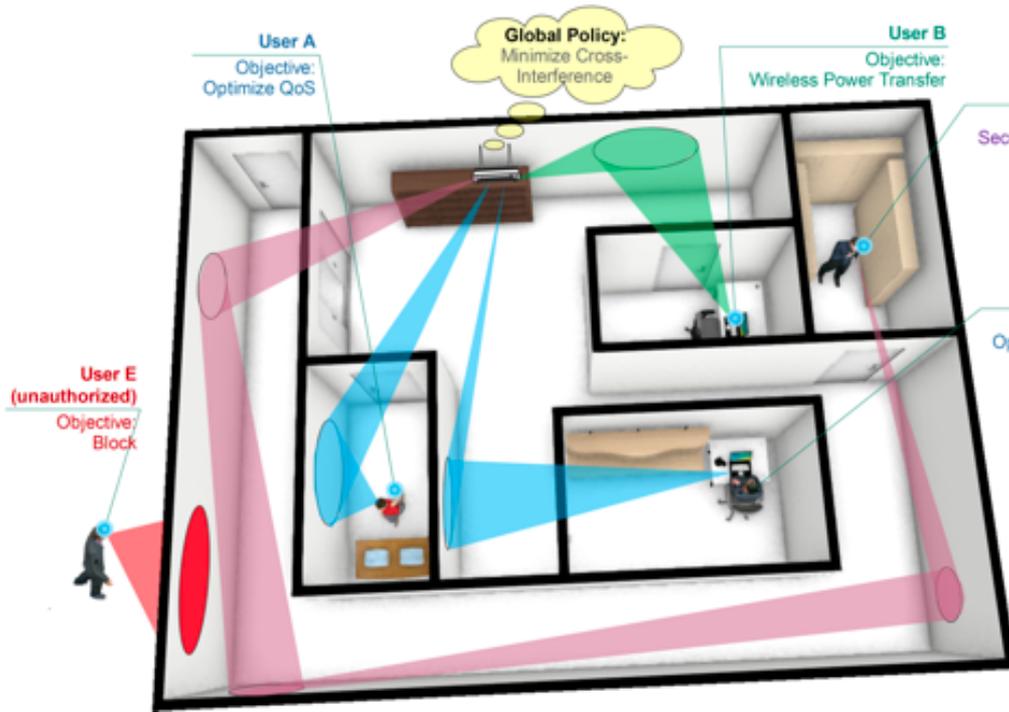
5G++



<https://ir.qorvo.com/node/17561/html>

# ENVIRONMENTS BECOMING EVEN MORE COMPLEX





Liaskos, Christos et al.. "A New Wireless Communication Paradigm through Software-Controlled Metasurfaces." IEEE Communications Magazine 56 (2018): 162-169.

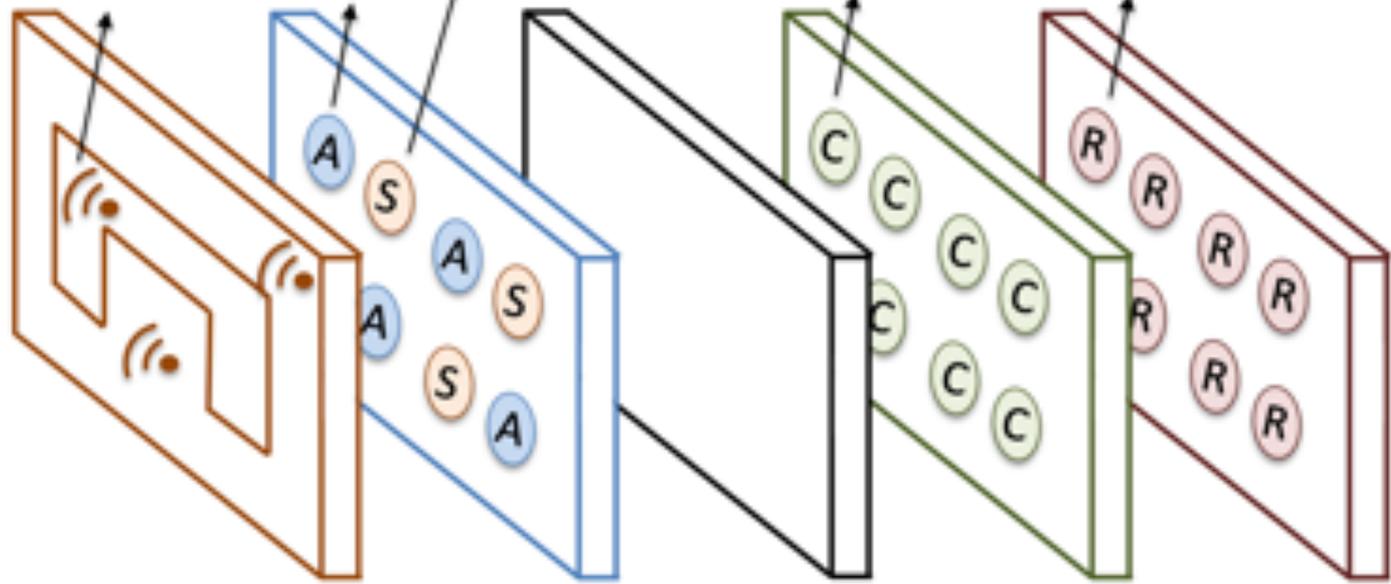
Reconfigurable EM behavior

Sensor

Controller

Router

Gateway



Metamaterial plane

Sensing and actuation plane

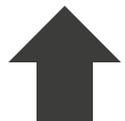
Shielding plane

Computing plane

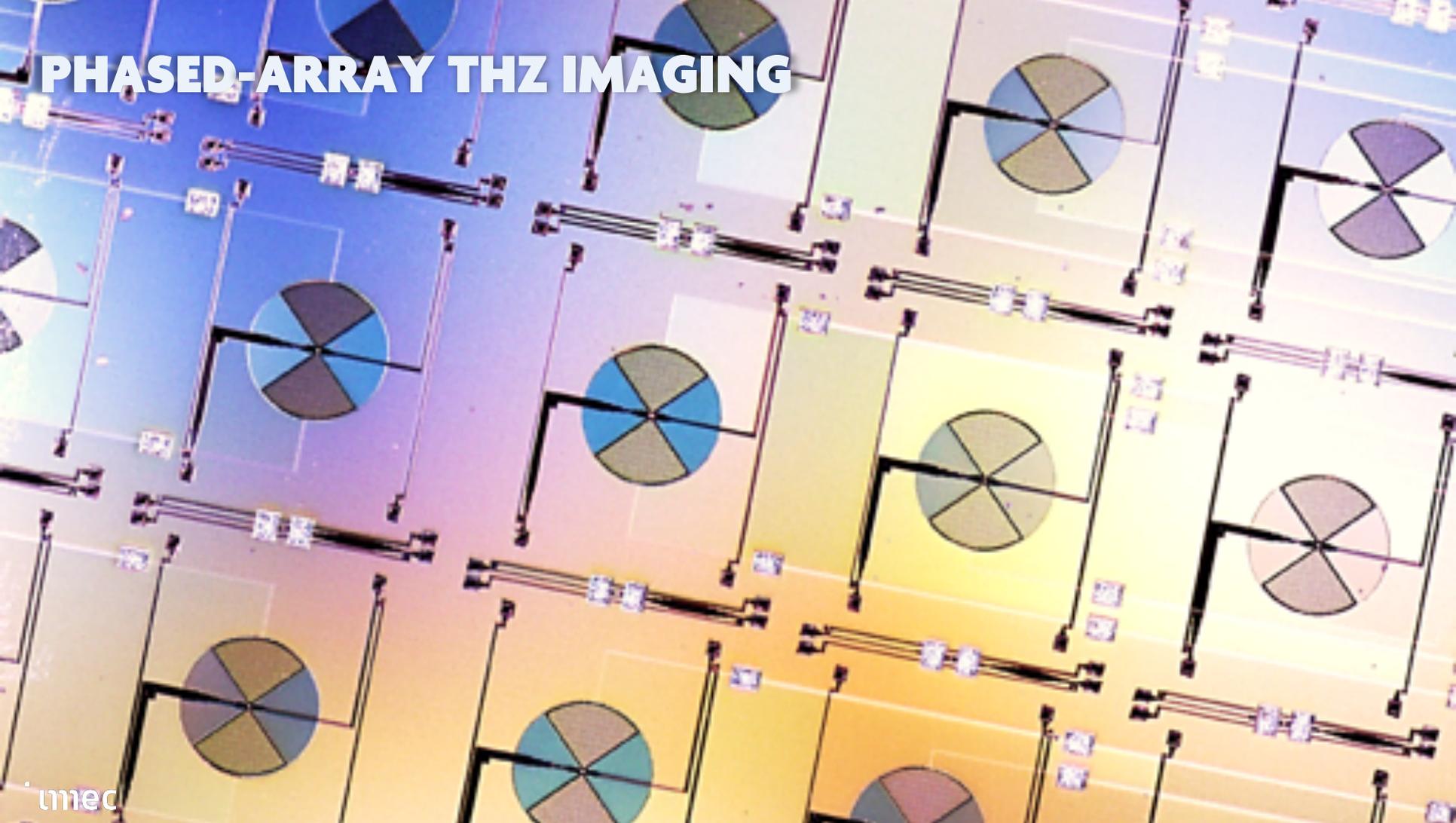
Communication plane



Interface to the outside world (e.g., nano-micro, nano-IoT)



# PHASED-ARRAY THZ IMAGING

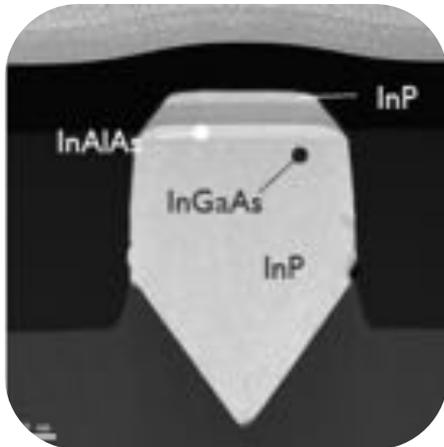


# ADVANCED CIRCUITS AND INTEGRATION

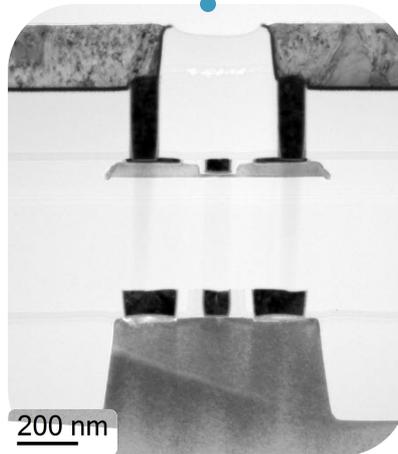
Monolithic  
integration

Sequential 3D

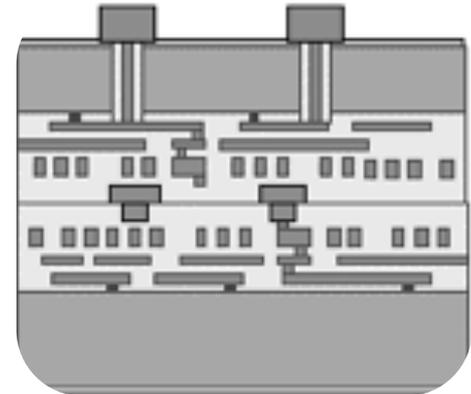
3D-SIC



[Waldron, VLSI'18]

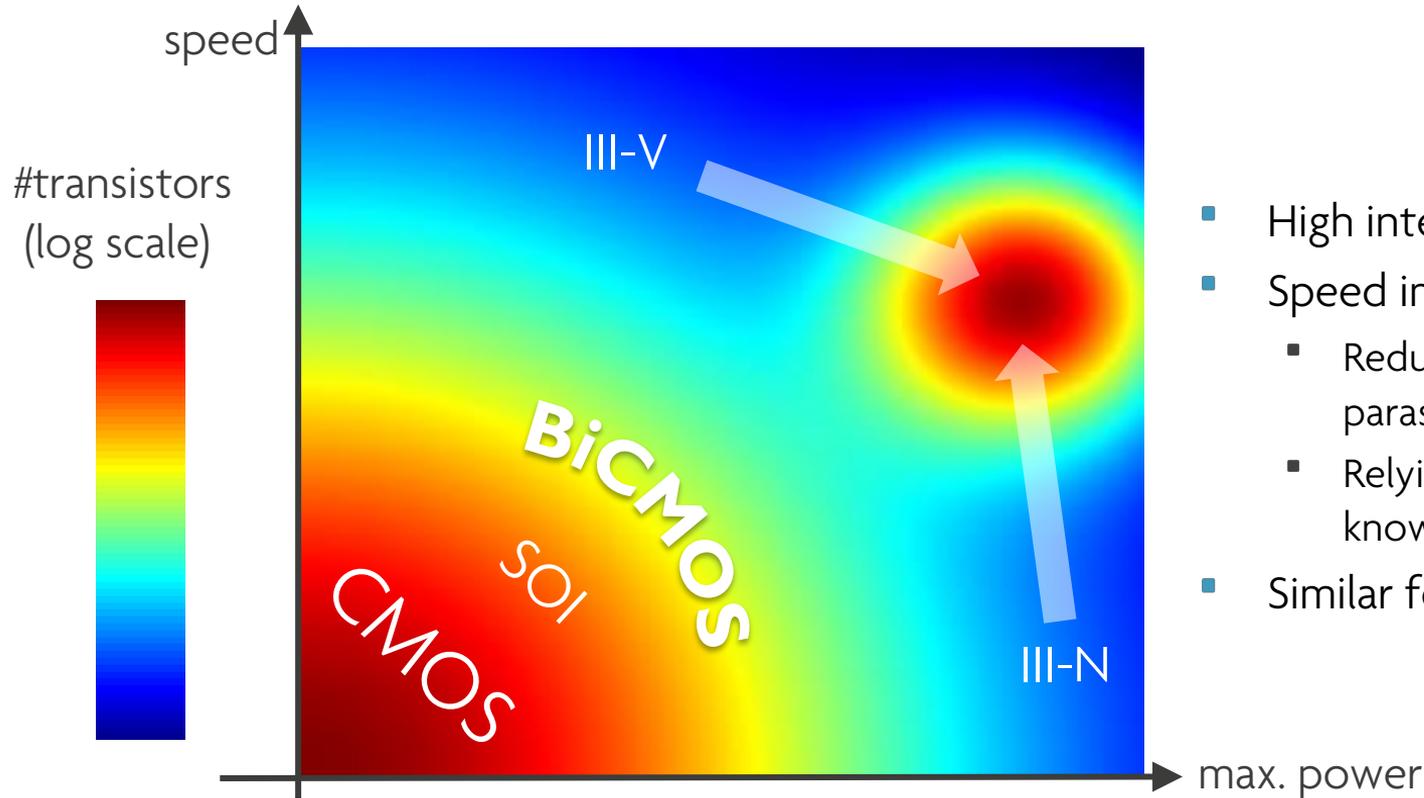


[Vandooren, VLSI'18]



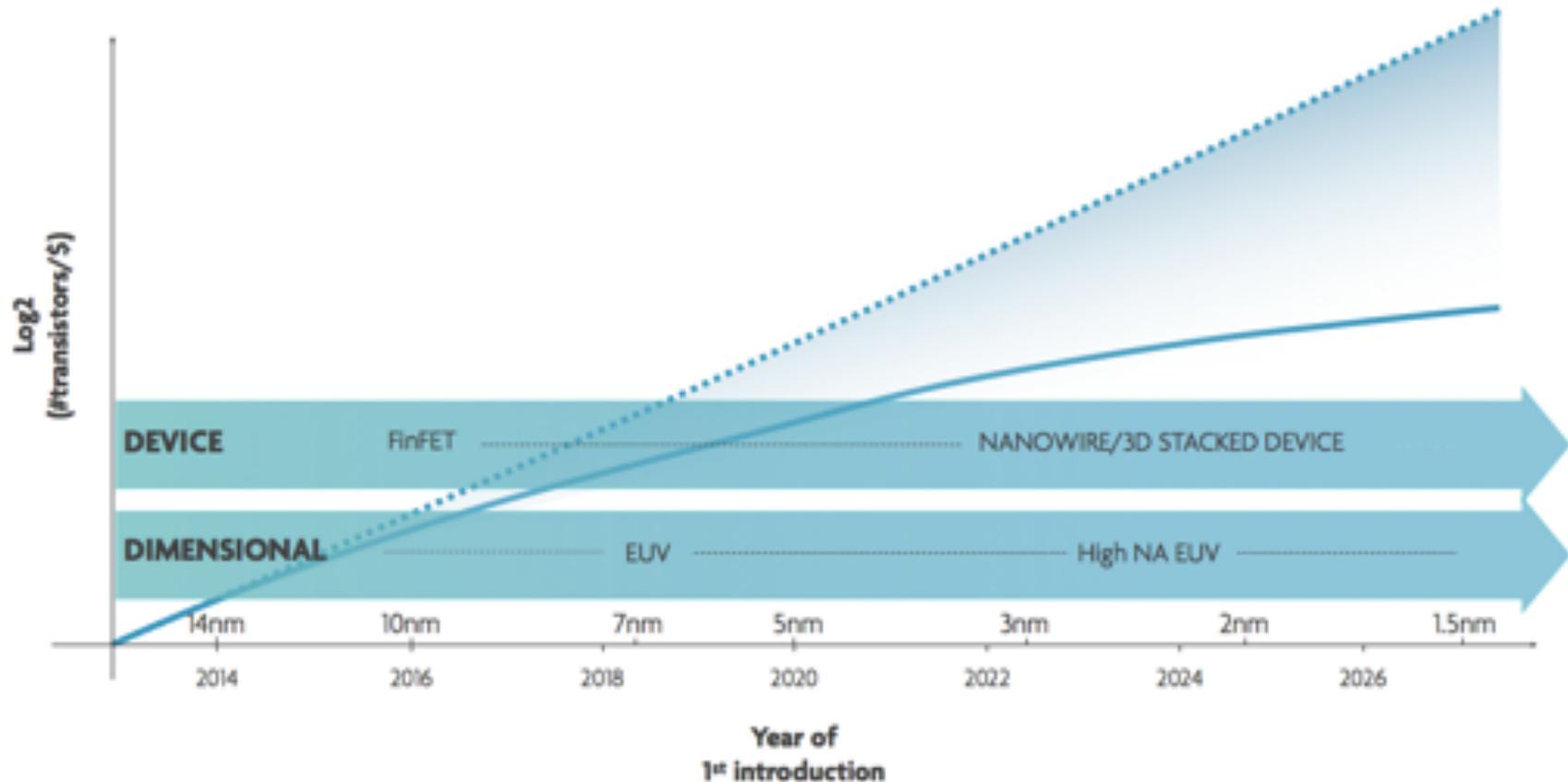
# OVERCOMING CMOS LIMITATIONS

ADDING III-V/III-N DEVICES WHILE MAINTAINING HIGH INTEGRATION DEGREE

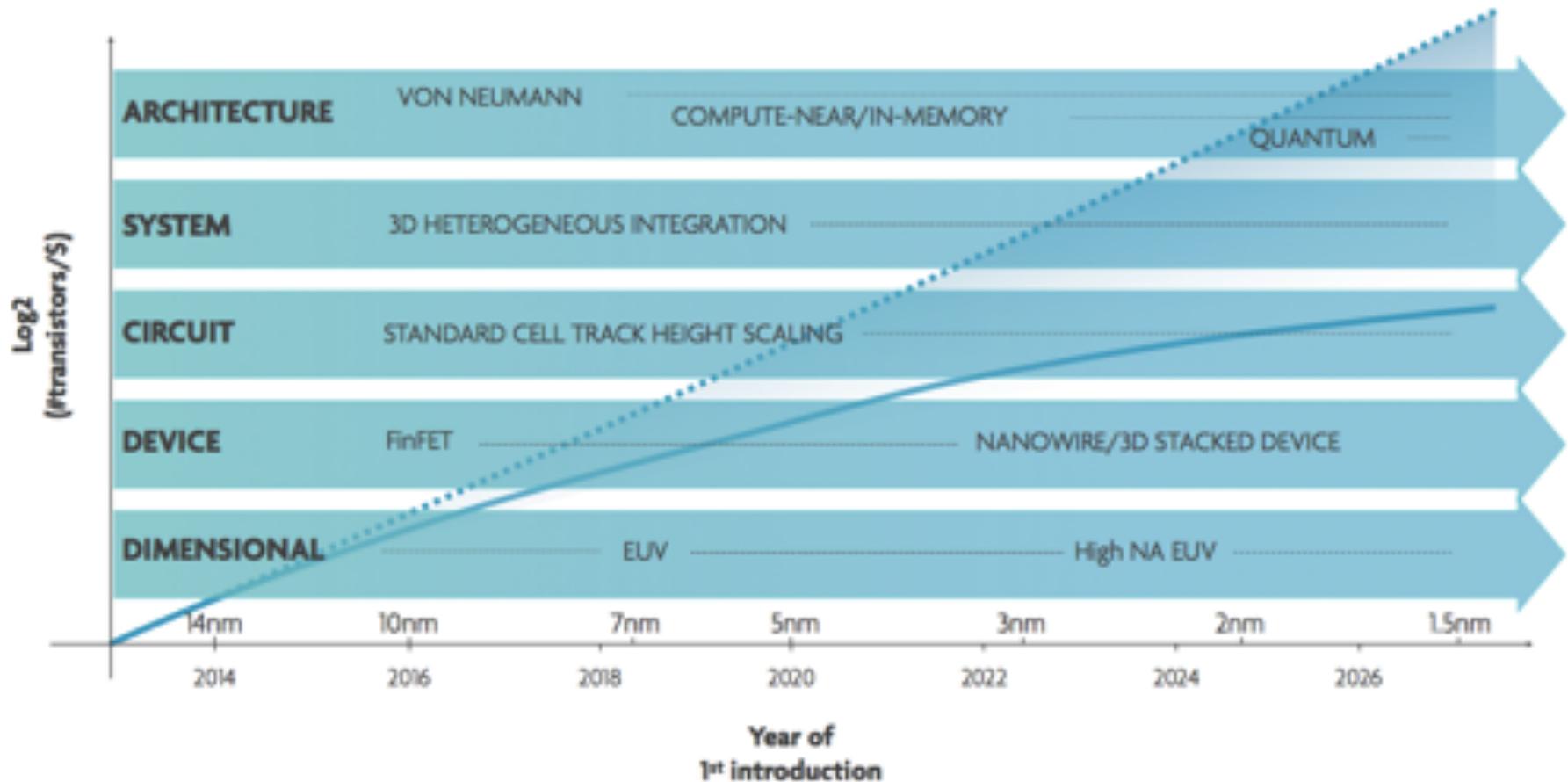


- High integration degree
- Speed improvement
  - Reduction of extrinsic parasitics
  - Relying on imec's CMOS knowhow
- Similar for GaAs and InP

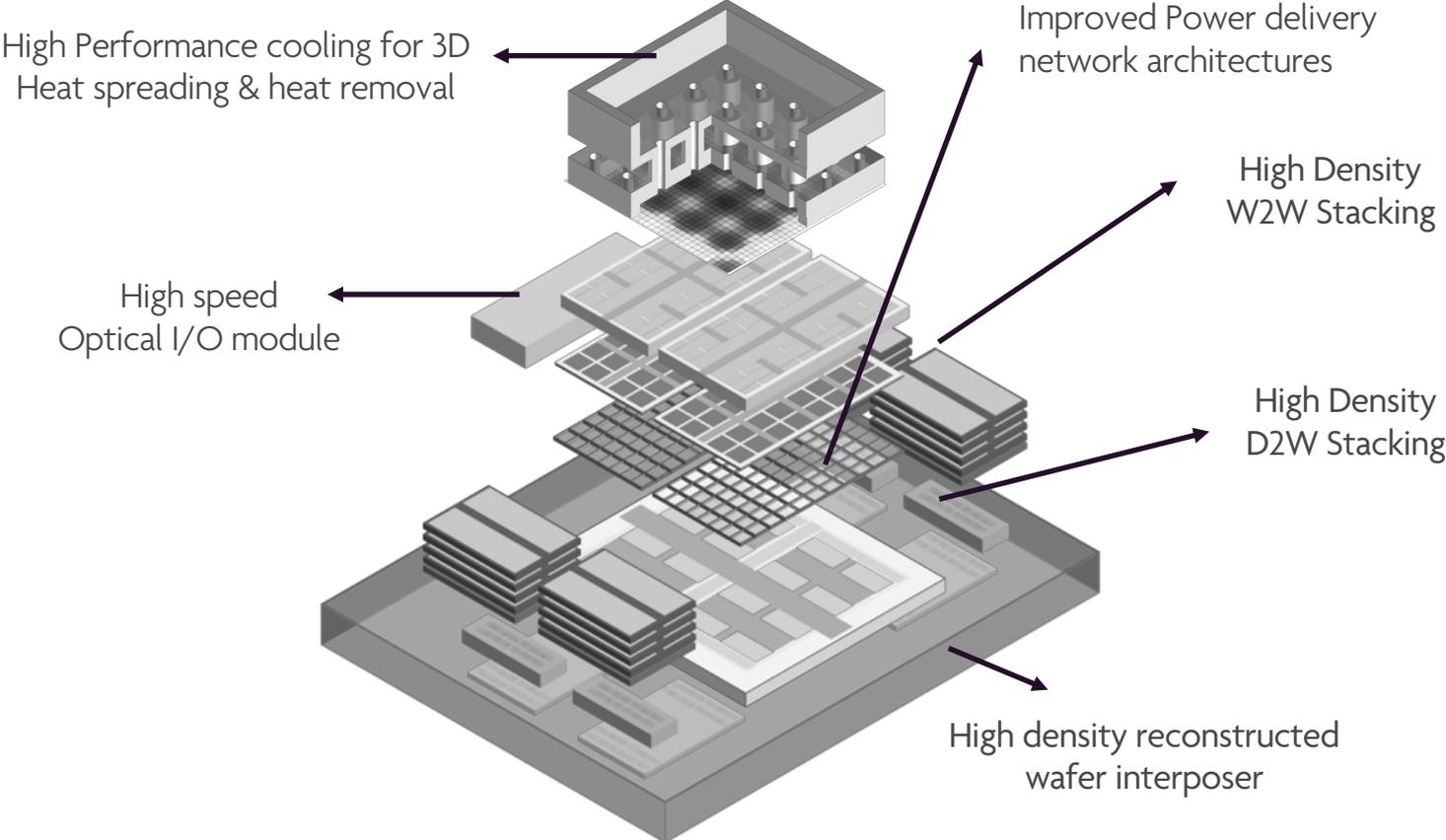
# Dimensional scaling and Device architecture



# High performance compute



# NEXT GENERATION “DEVICES”



# KEY MESSAGE

SMART NETWORKS BUILD ON SMARTER “DEVICES”,  
COMPONENTS  
MODULES SUBSYSTEMS

**Application**

**Network**

**Software**

**System**

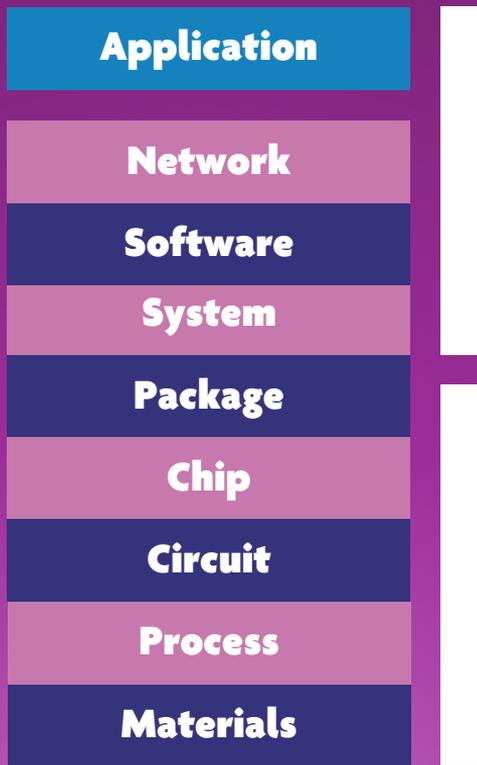
**Package**

**Chip**

**Circuit**

**Process**

**Materials**



HEALTHY ECOSYSTEMS

HEALTHY FUNDAMENTS

# KEY TAKE-AWAYS

- Networks and network infrastructure will become ever more important for competitiveness, given the shift to beyond human-sense-centricity: new “users”
- The number of bits per second is rising everywhere, and ever more processing is needed
  - New applications due to new challenges tackled by edge compute architectures
- Higher speeds are needed, but also higher efficiency and smaller form factors
  - No longer solveable by smartness at the network layer alone
- There is a gap in TRL, technology stack and availability that needs to be closed: new “devices” leveraging European strengths
  - Priceable and priceless uses

■  
mec

embracing a better life



Source: Counterpoint Research, 5G Ecosystem Update, July 2019

Counterpoint