Enabling Technologies and Scenarios for a 5G-Enabled Internet of Verticals and the Road to 6G

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Keynote
BCS Internet Specialist Group Meeting

Centre for Advanced Communications, Mobile Technology and IoT
University of Sussex, Brighton, UK

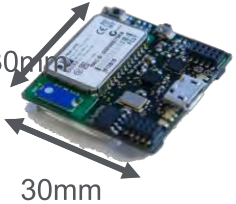
NetWorld 2020

5G PPP
The 5G Infrastructure Public Private Partnership

Horizon 2020

lte
lte
lte
5G

TELECOM INFRA PROJECT



THE ROYAL SOCIETY
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Content

- 5G and 6G projected timelines
- 6G Use Cases
- 6G enabling technologies
  - AI for 6G RAN, Core and Transport Design
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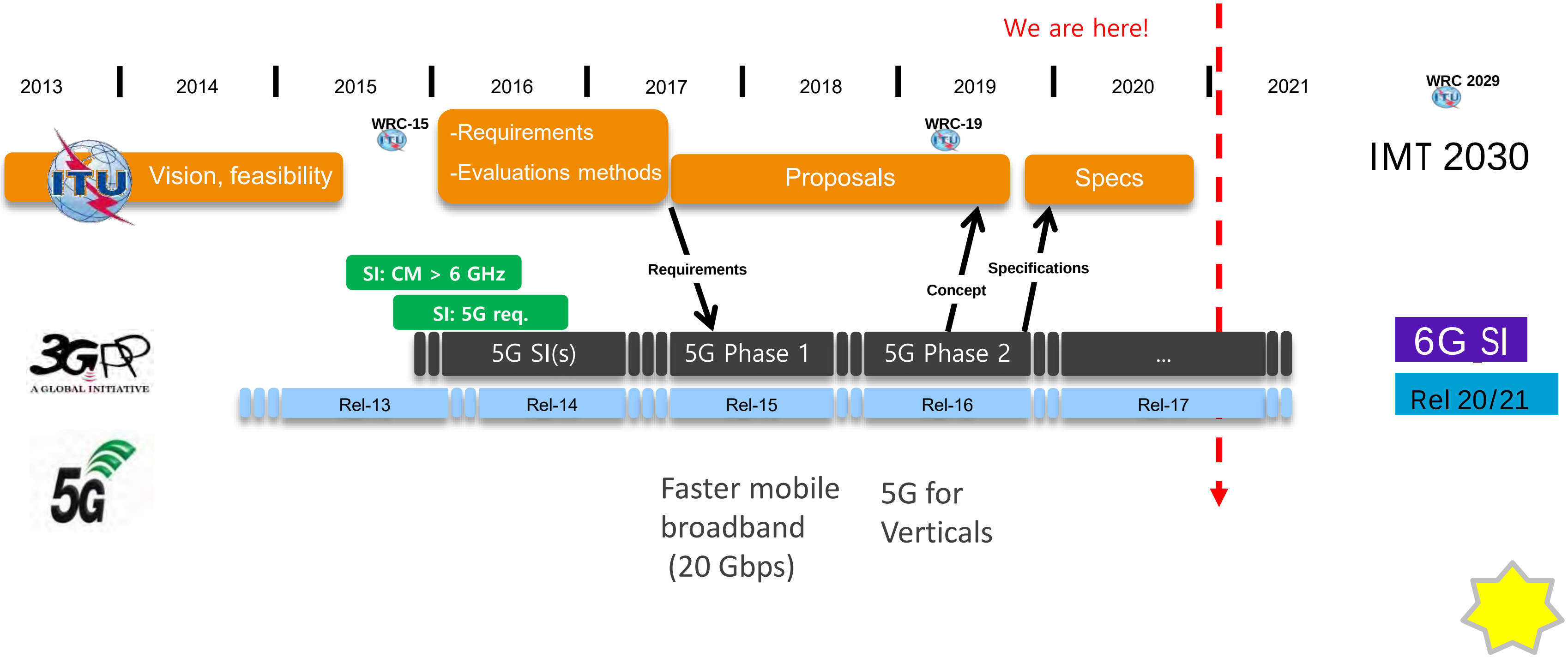
5G and projected 6G Timelines



- **6G standardization starts 2025/2026**
- **6G Commercialization starts 2029/2030**

5G use case families

Enhanced Mobile Broadband (eMBB)

- ❑ Augmented and Virtual Reality
- ❑ Ultra-High Definition videos, Streaming etc
- ❑ Gaming

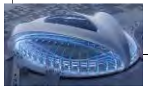
Ultra-Reliable Low Latency Communications – URLLC

- ❑ Industry robotic automation
- ❑ Tactile internet
- ❑ E-Health, tele-surgery
- ❑ Autonomous Vehicles communications, Vehicles to everything



Massive Machine Type Communications - mTTC

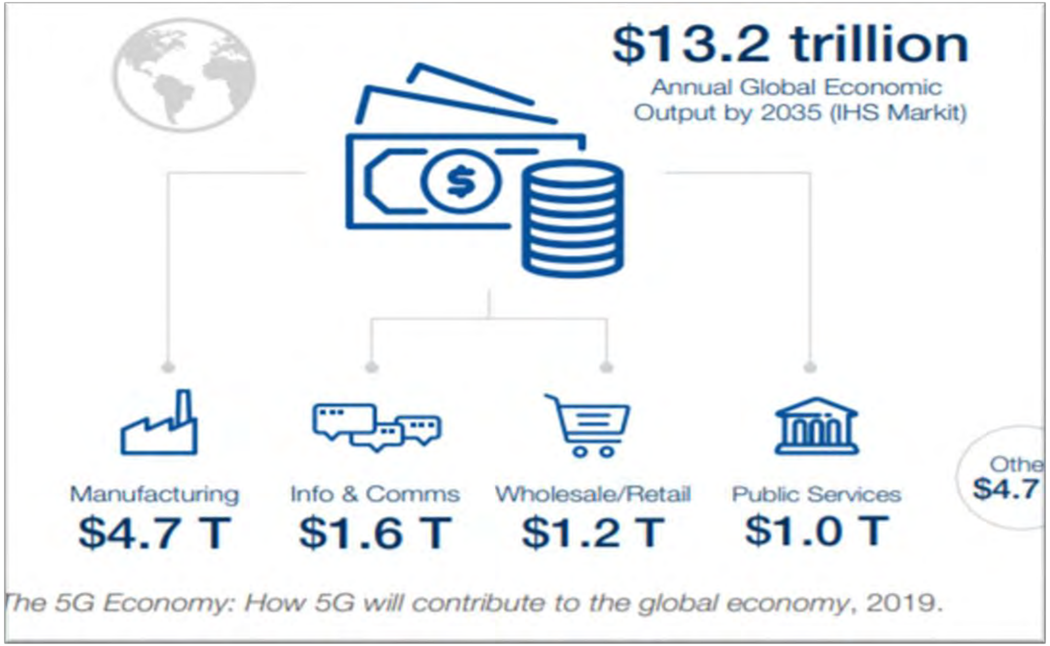
- ❑ Grid smart meters, utility monitoring
- ❑ E-Health wearable devices
- ❑ Connected Sensors, cameras on factory floor.
- ❑ Logistics, assets monitoring, tracking
- ❑ Remote sensing



Consumer Market

Vertical Markers (Emerging)

5G economics



Source: Qualcomm

Can 5G for verticals help operators close their revenue gap?

5G spectrum allocation

600 MHz	LTE/5G	North America
700 MHz	LTE/5G	APAC, EMEA, LatAm
3.3-3.4	LTE/5G	APAC, Africa, LatAm
3.4-3.6	LTE/5G	Global
3.55-4.2	LTE/5G	US
3.6-3.8	5G	Europe
4.5	5G	Japan China
28	5G	US, Korea Japan
39	5G	US
24.25-27.5	5G	WRC-19 band
31.8-33.4	5G	WRC-19 band (Fra, UK)
~40,~50,~70	5G	WRC-19 bands

3GPP Rel 17

Full coverage with <1 GHz

Dense urban high data rates at 3.5 – 4.5 GHz

Hotspot 10 Gbps at 28/39 GHz

Future mmwave options

IoT

Fixed-Wireless Access e.g. Verizon

Towards 6G

~Tbps peak data rate

6G Requirements

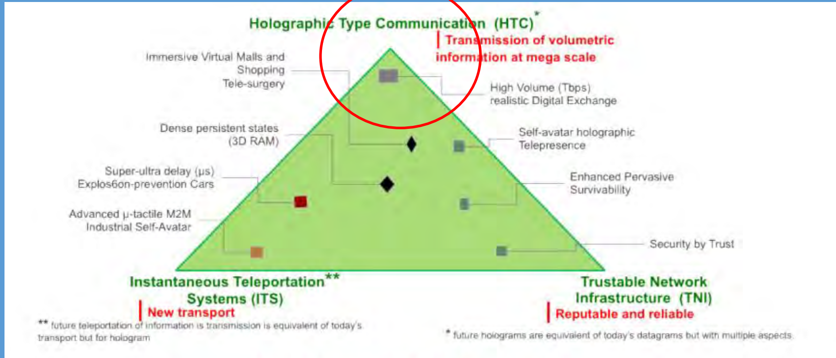
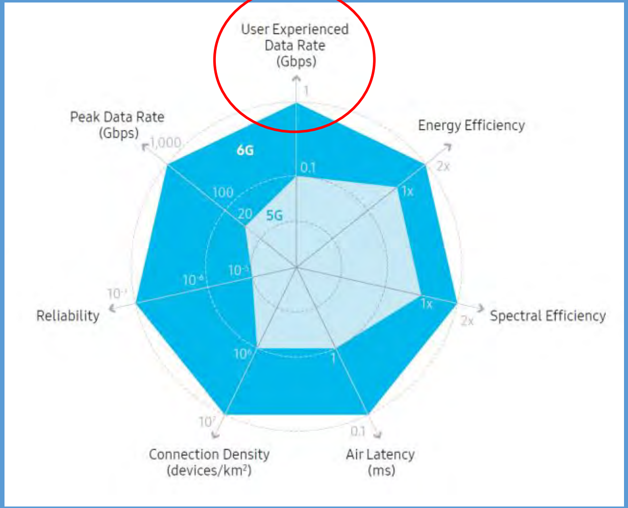


Figure 4: Capabilities for the Future applications



Source: Huawei Internet 2030 Vision (2019)

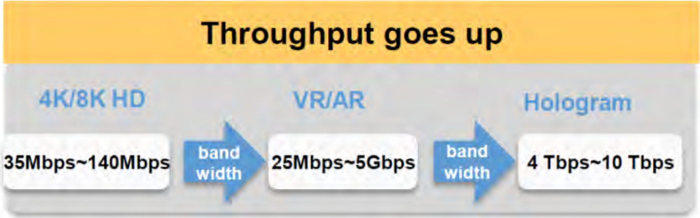
Source: Samsung 6G Vision (July 2020)

6G Use Cases (ultra high data rate)



Holographic Communications

Digital Triplet/Digital Human



To duplicate 1mX1m area for digital twin we may need 0.8Tbps assuming 100ms periodic updates

Horizon Europe

NetWorld 2020

New Technologies for “New Verticals”

Future Digital Health and Care

Future Transportation

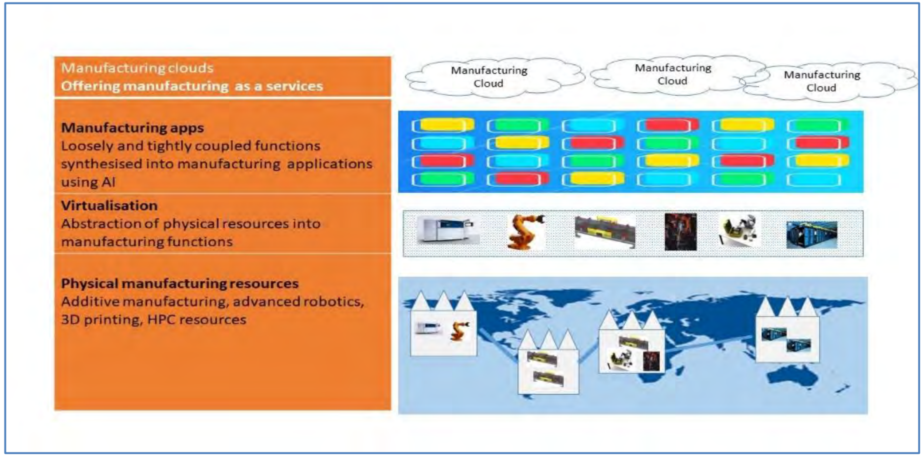
Future Robotics

Future interfaces

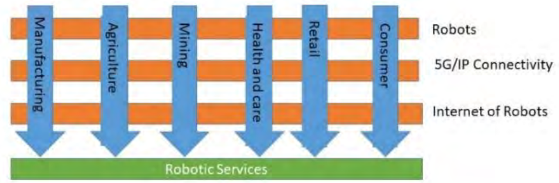
Smart Networks and Services

New Working Group
All welcome

Internet of Verticals (IoV) Vision enabled by 6G



6G enabled cloud-manufacturing



6G-enabled Internet of Robots

Ref: M. Nekovee, Z. Lou, Technologies and Scenarios for a 5G-enabled Internet of Verticals , IEEE Comm Magazine (submitted)

Robotic communication scenarios and requirments

Scenario	Purpose	Expected communication rate	Communication type
Robot-environment Communications Robot-Things Communications	Control of and adaption to Environment /exchange of sensory data with environment	Mbps/Gbps	data, Images, video, commands
Robot-Human Communications	Control, Cooperation/Coordination, Information sharing, Problem solving	Up to Gbps	data, images, video, voice, haptic, holographic
Robot-Robot Communications	Control, Cooperation/Coordination, Information Sharing, Problem solving	Up to Tbps	Data, images, voice, haptic, holographic, new forms of multi-sensory and multi-modal communications, semantic communication
Robot-Cloud Communications	Control, Information Sharing, Virtualization	Up to Tbps	Data and control

Ref: M. Nekovee, Z. Lou, Technologies and Scenarios for a 5G-enabled Internet of Verticals , IEEE Comm Magazine (submitted)

Our research on AI for Beyond 5G/6G

AI at the RAN:

- Intelligent initial access and handover
- Dynamic beam-management
- **Model-free PHY Design**

AI at the transport layer (Fronthaul, backhaul)

- Traffic pattern estimation and prediction
- **Flexible functional split...**

AI at the Core:

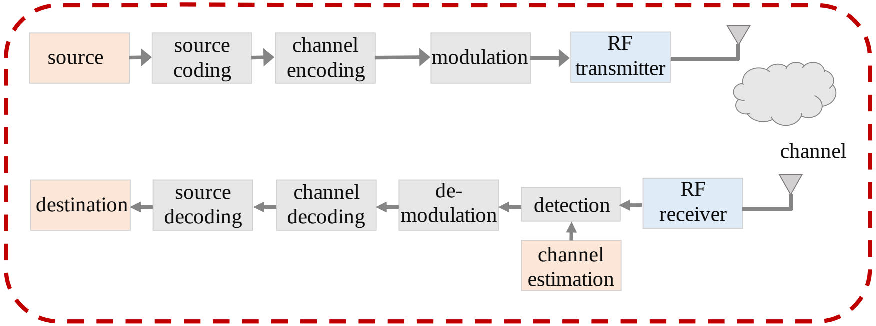
- **Next Generation NFV and SDN**
- Intelligent network slicing management
- service prioritization and resource sharing
- Intelligent fault localization and prediction
- Security and intrusion detection

Other areas of interest

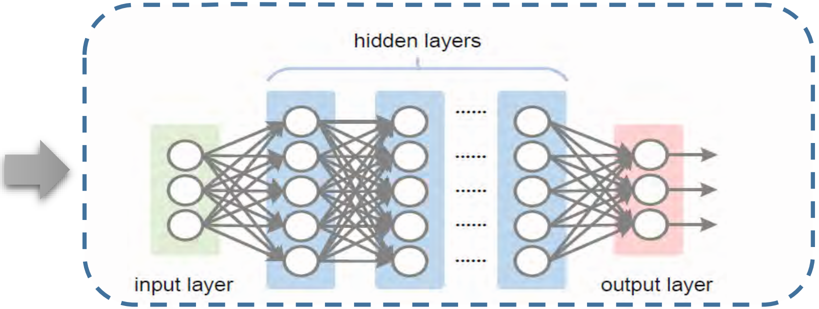
- TCP/IP suit of protocols.
- **Reconfigurable meta-surfaces for THz beamforming and beam-tracking technology**

Deep Learning approaches for beyond 5G/6G PHY Design

- **Conventional PHY Design (3G, 4G, 5G)**
  - 3G and 4G design was for known applications (voice, video, data) and deployment scenarios
  - 5G should work for yet unknown applications (verticals) and deployment



- **AI- Based PHY Design (beyond 5G/6G)**
  - Holistic optimization of the entire PHY processing blocks
  - Data-driven, end-to-end learning solution so reduces design cycle
  - Can adapt to changing applications and deployment environments (including channel)
  - Data-driven, end-to-end learning solution so reduces design cycle



T.O'Shea and J.Hoydis,"An introduction to deep learning for the physical layer, " IEEE Transactions on Cognitive Communications and Networking," IEEE Transactions on Cognitive Communications and Networking, vol. 3, no. 4, pp. 563-575, 2017.

Interference Channels – *Challenges and Potential Solutions*

Challenges

Multiple functional blocks *(optimisation)*

- Equalization
- Multi-objective optimization

DL based end-to-end optimisation

Strong and very strong interference *(Multiple users)*

- Online learning
- Adaptive algorithms

AE and DRL algorithm applied

Imperfection (hardware or channel model)

- Equalization
- Adaptive/advanced modulation
- Compensation

ML based Reconstruction

Data-driven

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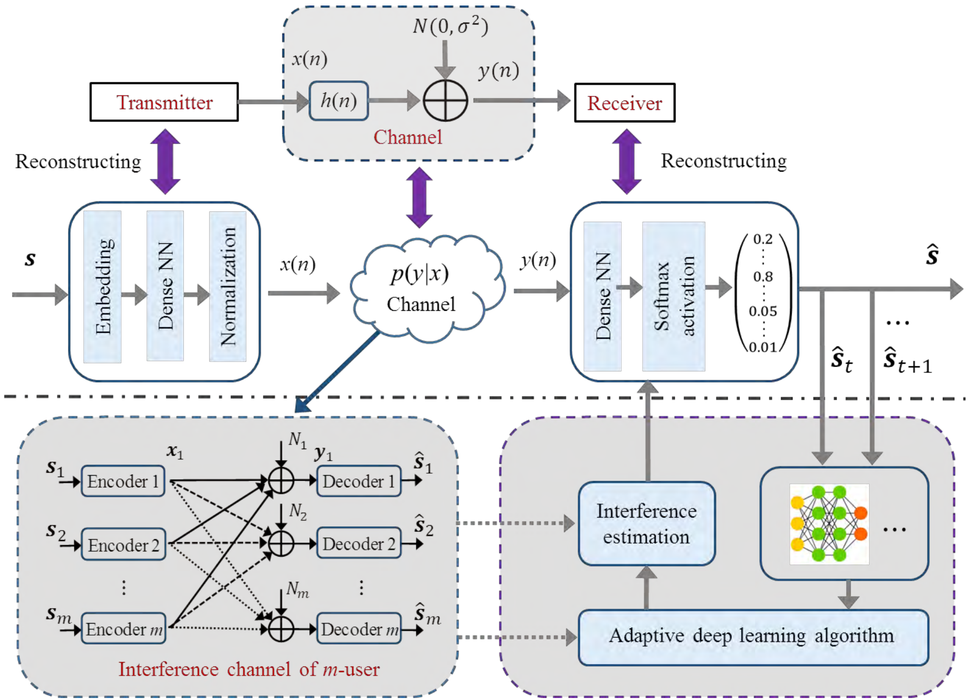
System overview



System block diagram of an adaptive deep learning (ADL) based AE for a wireless communication interference channel with *m*-user.

Ref: D Wu, M Nekovee, Y Wang, "An Adaptive Deep Learning Algorithm Based Autoencoder for Interference Channels" 2nd IFIP International Conference on Machine Learning for Networking (MLN'2019),; IEEE Access 2020

Algorithms

The structure of the AE:

Block name	Layer name	Output Dim
	input:	M
Block name	Dense+eLu	M
	Dense+Linear	$2n$
	nomalization	$2n$
Channel	Noise	$2n$
Decoder	Dense+ReLU	M
	Dense+Softmax	M

Name	$[\sigma(u)]_i$	range
ReLU	$\max(0, U_i)$	$[0, \infty)$
Tanh	$\tanh(U_i)$	(-1, 1)
Softmax	$\frac{e^{u_i}}{\sum_j e(u_j)}$	(0, 1)

The ARL algorithm estimates the interference (α).

With the predicted α, channel function is updated. Then signals are decoded.

The proposed ADL algorithm:

Algorithm 1: DRL to predict the interference

Input : • AE model and specifications: n, k, batch size, epochs number, optimizer, learning rate, etc
• the training data set l_{in}
• the variance of channel noise σ^2

Output: • the estimated interference parameter α

Initialize:
Set AE model parameters (e.g., $n \leftarrow 4$, $k \leftarrow 4$, $M \leftarrow 4$)
for i in range (training data samples) **do**
  Set $x = f(s_i) \in \mathbb{R}^{2n}$, $s_i \in \{1, 2 \ldots M\}$, encoding
  Create and Set $\hat{y}(n)$ for receiver layer
  for i in range (numble of guessing α) **do**
    DNN layer to training the data set
    Recovery pilot signal $\hat{s}_i$ according to a guessing α
    Calculate *reward* $\hat{R}_i$ according to Eqs. (5) and (6)
Set confidence interval of $\hat{R}_i$ and predict α
Update DNN layer with α according to Eqs. (7) to (10)

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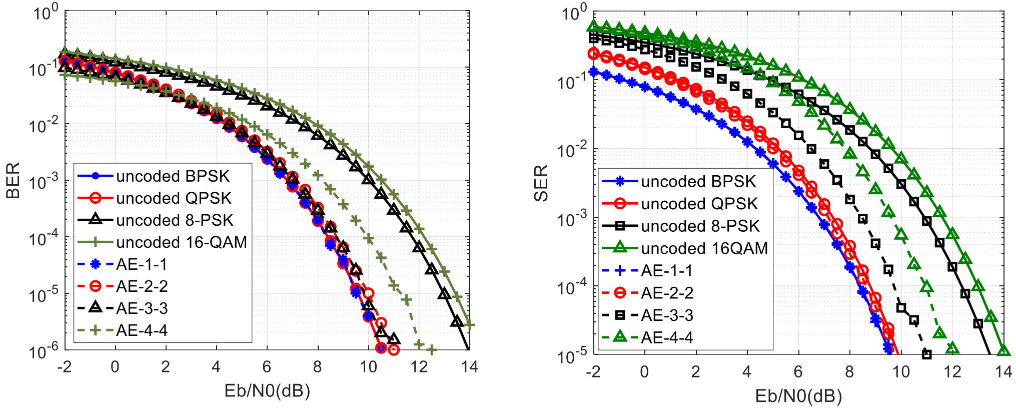
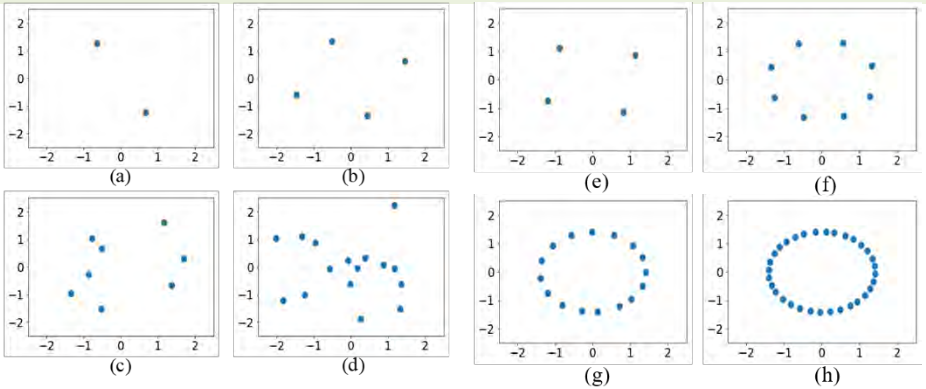
Numerical results and analysis (single user)



Bit error rate and symbol error rate vs SNR (E_b/N_0) for the AE and other modulation schemes (single user case).



Learned AE constellation produced by AE for single user case: (a) AE-1-1, (b) AE-2-2, (c) AE-3-3 and (d) AE-4-4. (e) AE-1-2, (f) AE-1-3, (g) AE-1-4, (h) AE-1-5.

Numerical results and analysis (multiple users)

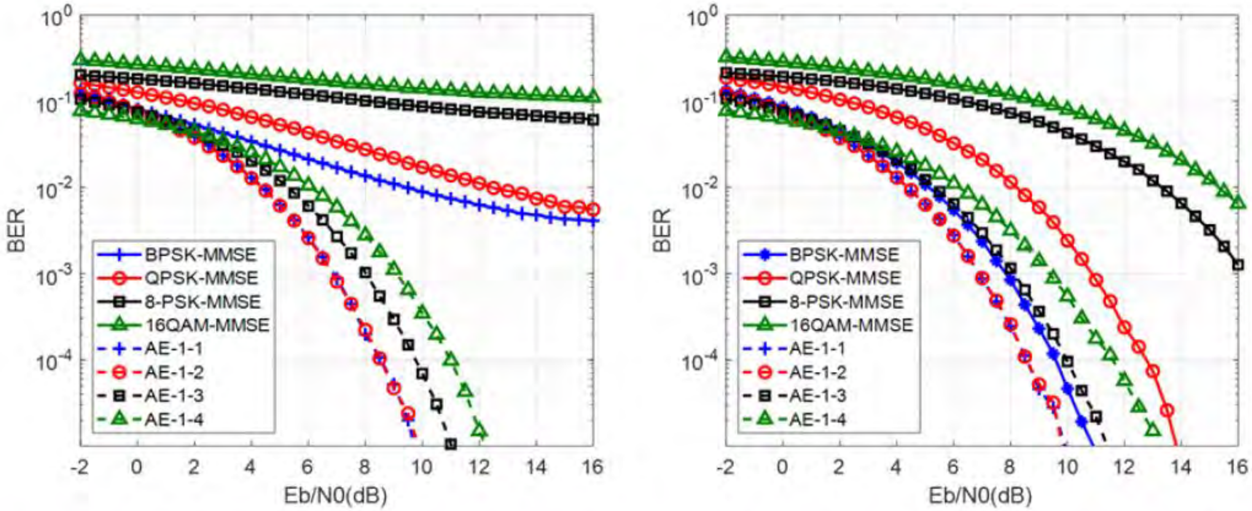


FIGURE7: Bit error rate vs SNR (E_b/N_0) of AE and several modulation schemes with MMSE equalizer for two-user symmetric and asymmetric interference channel.

Concurrent DL for distributed multi-user interference scenario

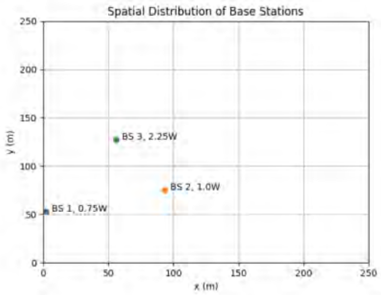


Fig. 2. Distribution of base stations in the 3 user simulation.

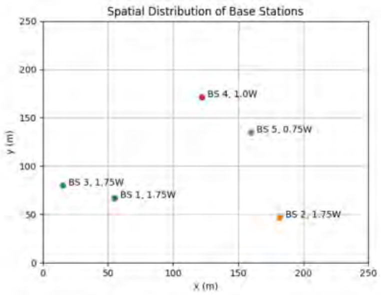
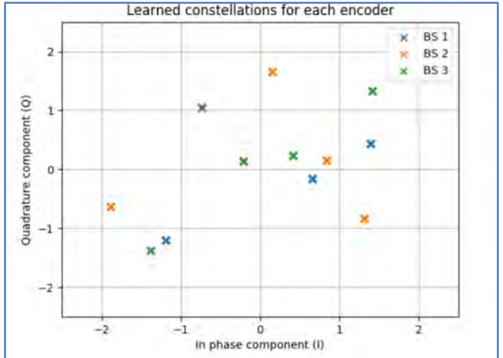


Fig. 3. Distribution of base stations in the 5 user simulation.



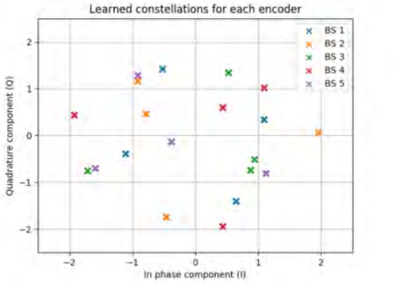


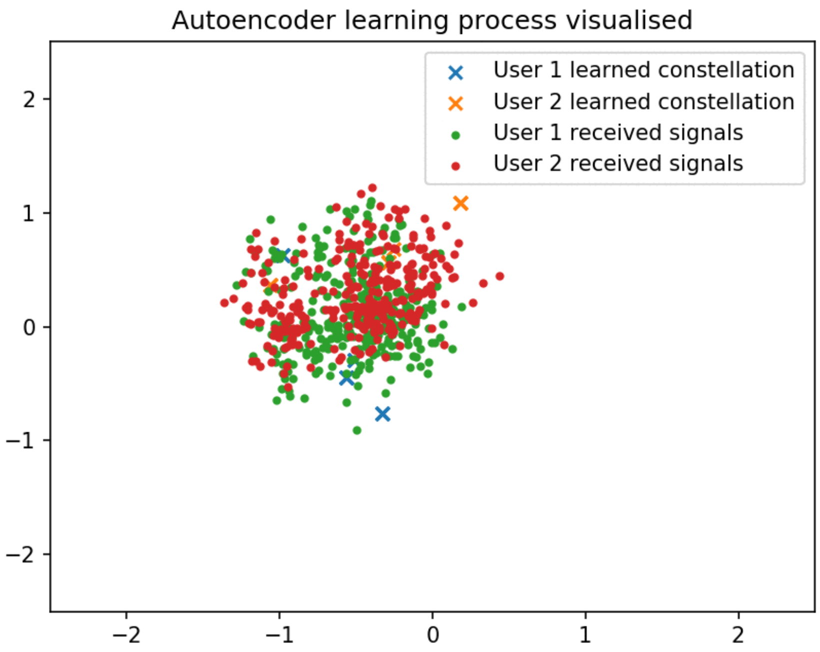
Fig. 7. Learned constellations for all of the autoencoders in the 5 BS system.

- 3 and 5 interfering BS randomly distributed in 200x200m

$$PL = 32.4 + 21 \log d + 20 \log(f_c) + \sigma_{SF}$$

Ref: L. Pellatt, D Wu, M Nekovee, “Deep Learning based Autoencoder for Concurrent Learning of the Interference channel”, IEEE Comm. Letters (Submitted)

Two-user DL based distributed auto encoder implementation

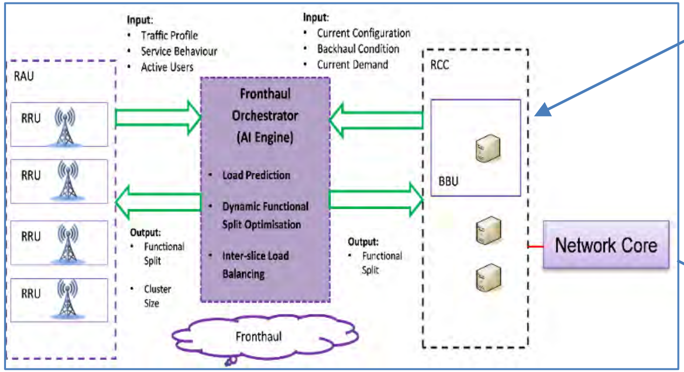


- An Deep Learning based auto encoder for the scenario of a two-user interference channel: the visualization demo of the constellation evolving as the network learns, alongside the received signals for each user.

AI for 5G/beyond-5G O-RAN/V-RAN

Radio front-end processing antenna

Baseband signal processing (virtualised)



Virtualised

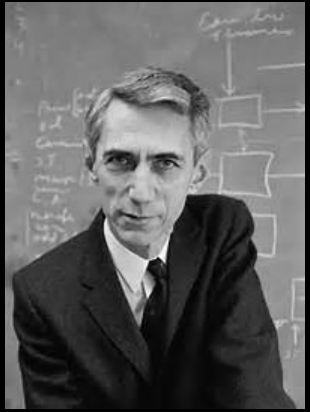
- Next generation fronthaul interface (NGFI) targets redefining flexibility and network function split between Raddio Remote Aggregation Units (RRU)s and Radio Cloud Centre (RCC).

- Orchesstrator Engine dynamically split the traffic on UL and DL per RAU across multiple fronthaul slice based on predicted levels of load, ensuring for each slice end-user requirements are met.
- The Orchestrator Engine balances the bandwidth reservation versus latency provision across different frothaul slices in an on-demand fashion by learning the load patterns and dynamic fumctional split per RAU-RCC

Ref: M. Nekovee, Wu, Wang, Shariat, "Artificial Intelligence and Data Analytics in 5G/beyond-5G Wireless Networks", in AI for Emerging Verticals, IET Publishing 2020

Towards terabit per second mobile connectivity

Shannon Capacity Formula



Claude Shannon
A Mathematical Theory
Of Communications
1948

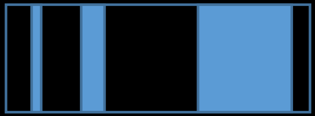
bandwidth of the channel

$$C = B \log_2 (1+S/N)$$

Channel capacity in bits/s

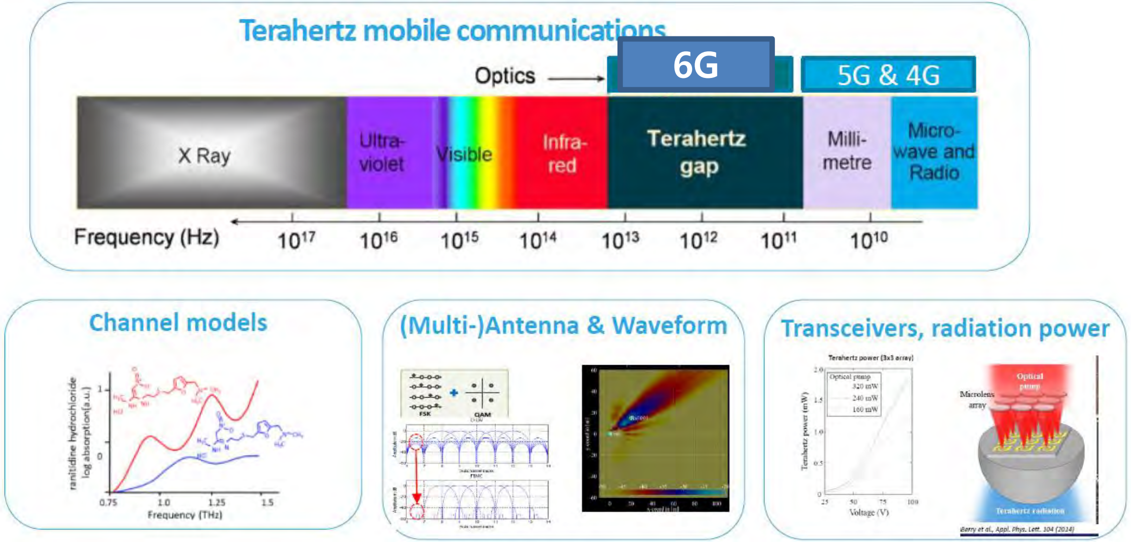
MIMO, OAM

signal-to-noise ratio



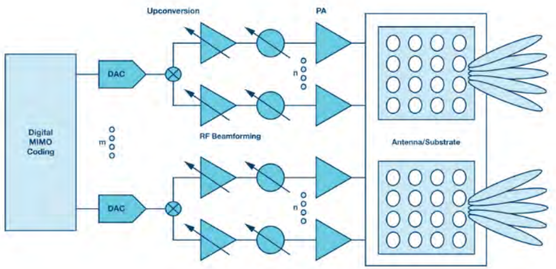
Where to find new spectrum for 6G?

- WRC19 agenda item 1.15 “Possible use of the band 275-455 GHz by land mobile and fixed services”
- 17 Mar 2019 - The **FCC** has unanimously voted to clear "terahertz wave" frequencies for experimentation that could one day represent **6G** connectivity.
- 17 Jan 2020 – **Ofcom** We are proposing to enable greater access to Extremely High Frequency (EHF) spectrum in the **100**-200 **GHz** frequency range...



Three fundamental RF challenges of THz communication for 6G

The 6G Antenna Technology Challenge



Hybrid beamforming/Digital beamforming

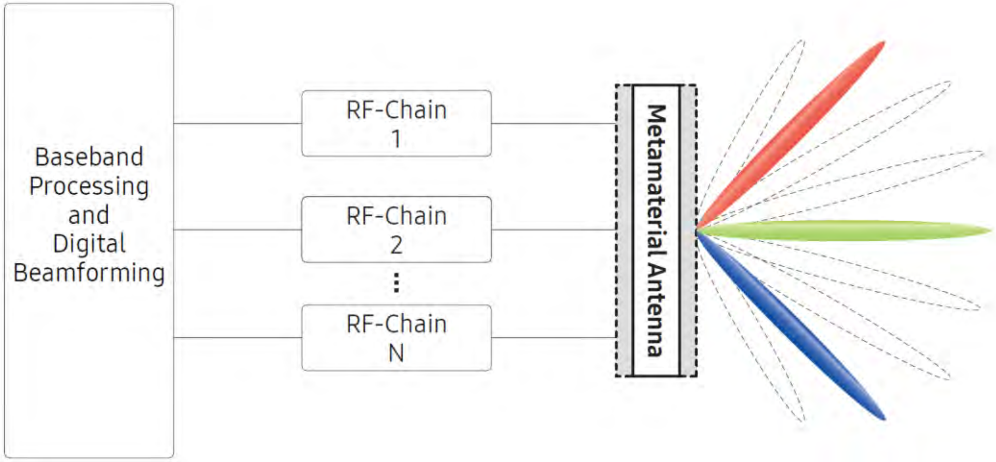
- **Scalability!**
- **Energy consumption**
- **Complexity**

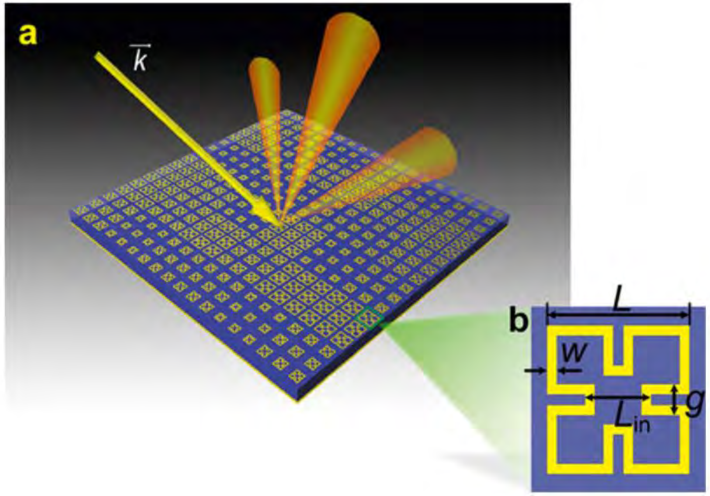
250m @28 GHZ

SAMSUNG

Frequency	Relative Pathloss	Antenna Gain (linear domain)	#Antenna Elements
2.8 GHz	1 (as reference)	1	~1
28 GHz	100	100	~1000
280 GHz	10000	10000	~100,000

Meta surfaces for THz antenna technology

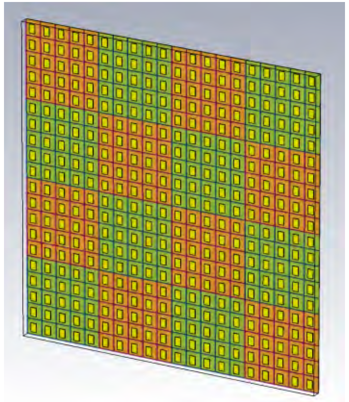




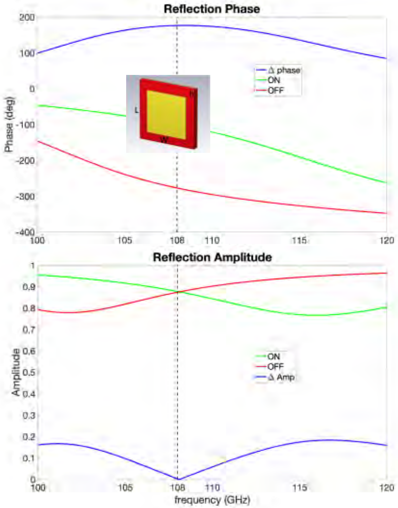
Hybrid Beam-forming with meta-surfaces

Reconfigurable meta-surface reflect array

▪ Liquid Crystal Based Reconfigurable Metasurface Antennas

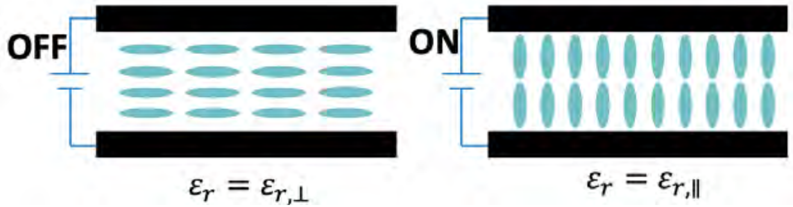


Full device: the simulated full device consists of 20x20 semi-passive patch antenna elements, each containing a LC substrate that is electronically controlled via biases.



Unit cell: the unit cell has 2 states: ON/OFF. The reflection phase/amplitudes are optimized for these 2 states at the operation frequency of 108GHz

Liquid Crystal



Liquid Crystal (LC): the liquid crystal substrate is controlled via voltage bias, aligning the molecular orientations of the LC, which in turn changes the effective permittivity of LC. This change in the substrate permittivity shifts the resonant frequency of the antenna, and given the that incident wave is kept at the same frequency of 108 GHz, the effect of change in permittivity is translated into change in phase, which is essential to shaping the wavefront.

- Amplitude optimized for maximal value and minimal difference between ON/OFF state
- Phase optimized for 180 degree difference between ON/OFF

Cross-platform routine

Algorithm 1: Matlab script to optimise unit cell dimensions

Input: S11p - S11 phase; S11a - S11 amplitude; hu, hl - LC height lower/upper bound; Wl, Wu - patch antenna width lower/upper bound; pl, pu - phase difference lower/upper bound; al, au, adm - amplitude lower/upper bound and amplitude difference margin

Output: h, W - Unit cell height and width optimised for close to 180 degrees phase difference, and maximal reflection amplitude (minimal difference) of both states

initialise pu, pl, au, al;
for h=$hl \rightarrow hu$ **do**
  for W=$Wl \rightarrow Wu$ **do**
    S11P{h,W}=S11p$_{on}${h,W}-S11p$_{off}${h,W};
    S11A{h,W}=S11a$_{on}${h,W}-S11a$_{off}${h,W};
  end
end
Result $\leftarrow$ Find (S11a $\geq$ al) and (S11a $\leq$ au) and (S11A $\leq$ adm) and (S11P $\geq$ pl) and (S11P $\leq$ pu);
Result = Sort Result;
h, W $\leftarrow$ Result

Algorithm 2: Matlab script for GA optimisation on beam-steering pattern synthesis

Input: LOC - index location of desired peak

Output: Matrix_f - final configuration/population

Initialise Matrix with random 1's and 0's;
while *(Counter $\leq$ max generation) or (cost $\leq$ max accepted)* **do**
  Compute E with Matrix;
  LOC_E $\leftarrow$ peak index of E;
  cost $\leftarrow$ |LOC - LOC_E|^2;

  Matrix_new $\leftarrow$ crossover, mutation, inversion on Matrix;

  compute E_new with Matrix_new;
  LOC_E_new $\leftarrow$ peak index of E_new;
  cost_new $\leftarrow$ |LOC - LOC_E_new|^2;

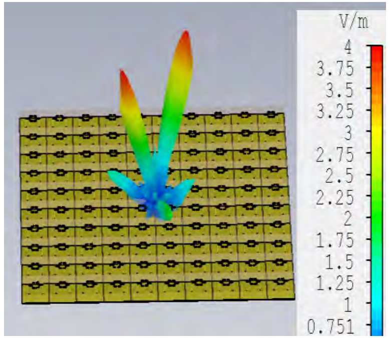
  if *cost_new < cost* **then**
    update Matrix with Matrix_new
  end
end

Algorithm 3: VBA script to initialise structure in CST according to configuration

Input: FILE - configuration of ON/OFF, 20 by 20 matrix

Output: Full device model updated according to ON/OFF configuration and ready for full wave simulation

Initialise 20 by 20 structure with permittivity ε undefined;
while *not end of line* **do**
  A $\leftarrow$ read current line;
  B $\leftarrow$ split(A) with delimiter;
  for *counter1, counter2* **do**
    Matrix(counter1,counter2)=B(counter1,counter2);
    update counters;
  end
end
for *i=1:20* **do**
  for *j=1:20* **do**
    if *Matrix(i,j)==1* **then**
      $\varepsilon_{i,j}$=2.46; $\tan\delta = 0.02$;
    else
      $\varepsilon_{i,j}$=3.28; $\tan\delta = 0.015$;
    end
  end
end



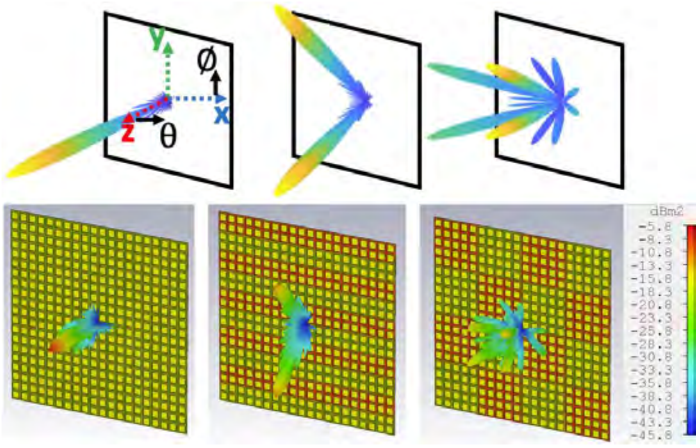
1) The unit cell structure is preliminarily designed and then simulated with periodic boundary conditions for optimal paramenters

2) GA algorithm is used to find the opmital configuration of ON/OFF states for specific beam-profile

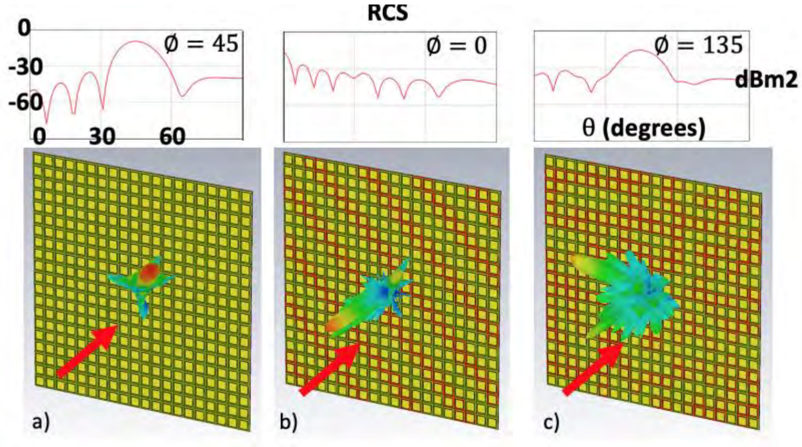
3) VBA script is use for automating the construction of the full device in CST environment given the configuration solutions.

4) Full wave simulation is performed in CST Studio Suite. The whole process is then repeated for other beam profiles.

Full device – plane wave, normal incidence



a) given a normally incident planewave, the theoretical farfield from the ON/OFF configurations shown in b). b) full-wave simulations of the farfields. ON: green, OFF: red



a) given a off-set incident plane wave and corresponding ON/OFF configurations, the radiation pattern at the plane of main lobe. b) the full wave simulation of the far-fields

- -5.8 dBsm gives linear RCS of 263,026 mm^2, which corresponds to approximately 28dB gain
- progressive phase can be implemented easily to achieve beam-steering, where GA has been tested utilised to find the optimal configurations

Internet evolution towards 6G

Standardization Activities on Internet evolution

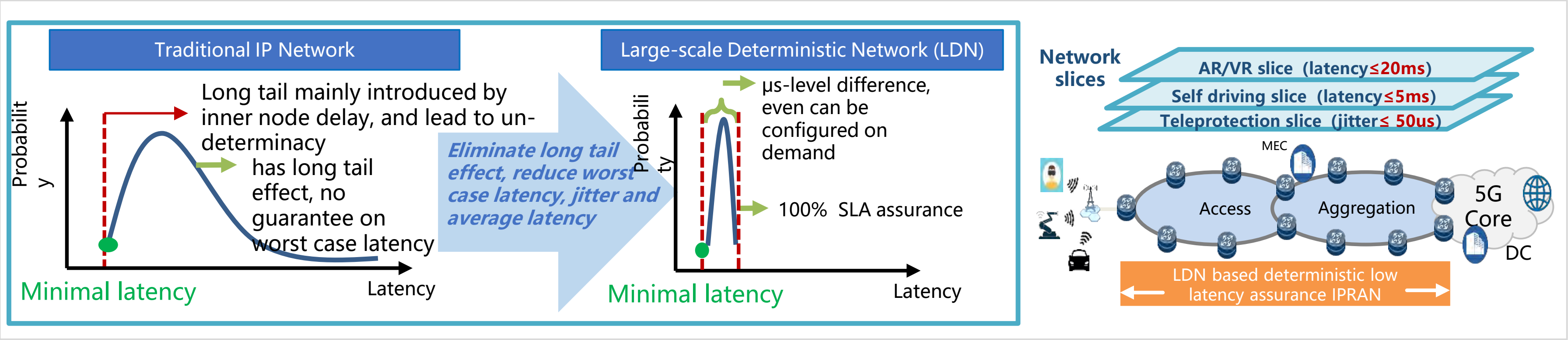
- IETF DetNet WG: main activity on IP-layer/DetIP solutions, e.g.,
  - https://datatracker.ietf.org/doc/rfc8655/ (RFC8655: DetNet Architecture)
  - https://datatracker.ietf.org/doc/rfc8578/ (RFC8578: DetNet use cases)
  - https://datatracker.ietf.org/doc/draft-ietf-detnet-bounded-latency/ (latency models)
  - https://datatracker.ietf.org/doc/draft-ietf-detnet-data-plane-framework/ (data plane framework)
  - https://datatracker.ietf.org/doc/draft-ietf-detnet-ip-over-tsn/ (DetNet IP over TSN)
  - https://datatracker.ietf.org/doc/draft-qiang-detnet-large-scale-detnet/ (large-scale DetNet forwarding, as described in previous slide)
- ITU-T SG13
  - *Proposal for High Precision & Deterministic IP Networking and Communication: Network requirements and functional architecture* as input into SG13 for new work items in 2021 and beyond
- ETSI
  - Non-IP Networking (NIN): Concentrates on candidate network protocol technologies that could be alternatives to TCP/IP

Vertical applications are not best effort, they need deterministic versus probabilistic services availability

Current mobile Internet fragmentation into islands of 5G private networks and networks slices -Need a revamp of Internet architecture towards 6G in order to support future applications including IoV.

Large-scale Deterministic Networking

The large-scale deterministic networking focuses on deterministic data paths that operate over Layer 2 bridged and Layer 3 routed segments, where such paths can provide bounds on latency, loss, and packet delay variation (jitter), and high reliability.



It supports massive nodes to achieve deterministic forwarding jitter at microsecond level. It is being standardized in IETF, and compatible with 5G seamlessly.

Outlook and collaboration opportunities

- Research on concepts, technologies and spectrum for 6G has already started, with standardisation likely to Kick-off c.a 2025 onwards, (e.g. 3GPP and ITU)
- Tbps connectivity, "new verticals", and AI are the likely key drives
- Many candidate technologies are being discussed. There is need for even closer collaboration between EEE and CS community
  - AI and machine-learning embedded in RAN and Core
  - Open RAN and vend-to-end virtualised architecture
  - Next Generation Internet > ITU 2030
  - Quantum Communication and Quantum Internet

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Thank You!

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