6G/B6G HAPS Networks

An Evolution with a Revolutionary Impact

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Acknowledgement: My research group + our collaborators

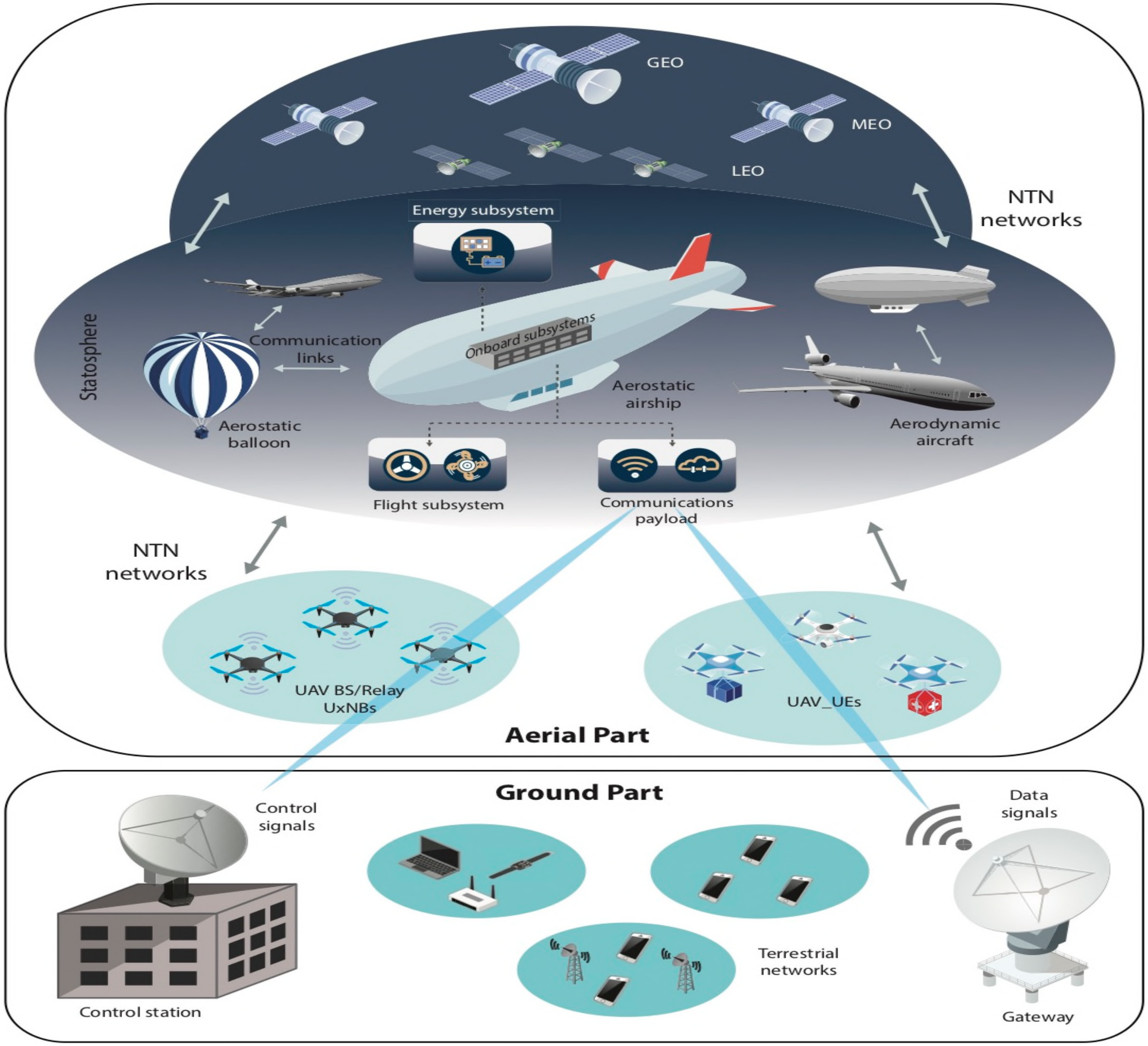
Carleton University

- Ottawa, Canada (est. 1946)
- 32,000 students
- BEng in Communications Engineering (unique in Canada)
- Global ranking in telecom engineering: #19 (GRAS 2021)

Agenda

- Concepts and Terminology
- High Throughput Satellites (HTS)
- High Altitude Platform Stations (HAPS) Systems
- VHetNet for Integrated Communications, Computing, Caching, Sensing, Navigation, Positioning, …
- 2040 Outlook

Integrated Terrestrial-Aerial-Satellite Network Architecture

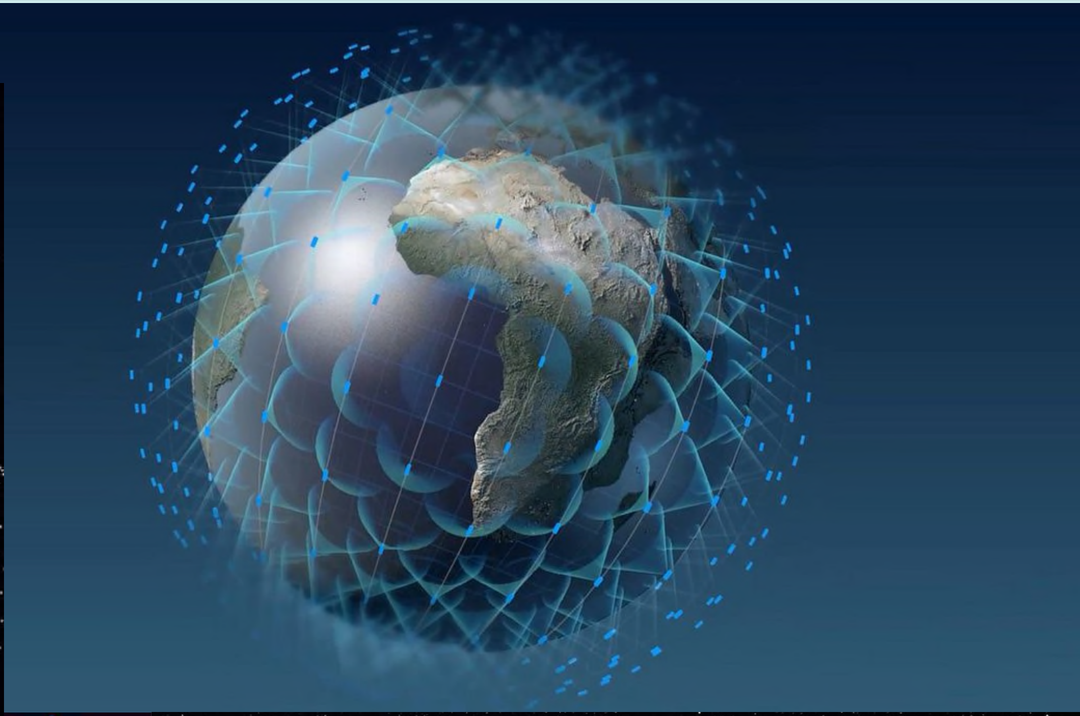


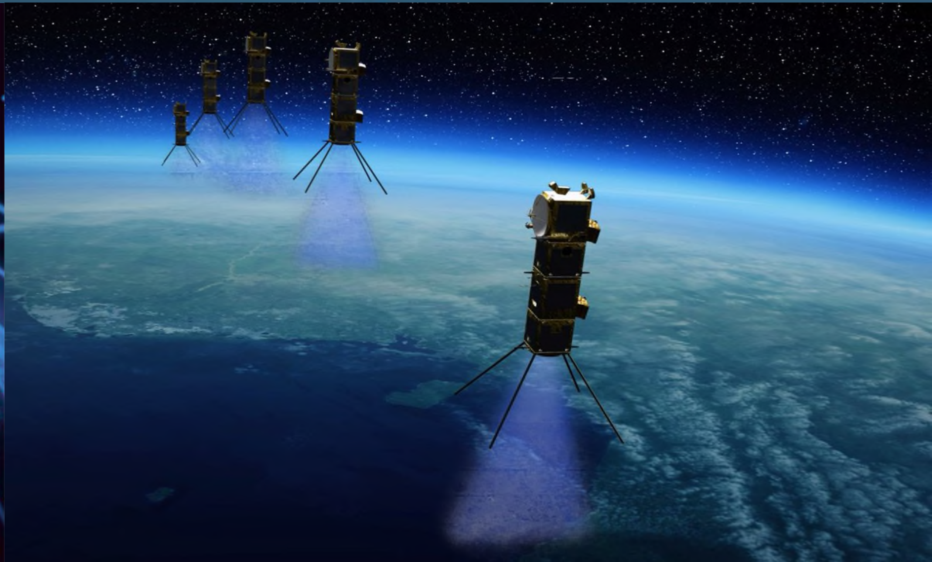
NTN:
Non-Terrestrial Networks (3GPP term):

- Satellite (+ Aerial)
- Integrated with terrestrial

Terrestrial Network

LEO Mega-Constellations





HAPS: High Altitude Platform Station (High Altitude Pseudo Satellite)

Article 1.66A of ITU's Radio Regulations: "A station on an object at an altitude of 20 to 50 km and at a specified, nominal, fixed point relative to the Earth". (1997)

Strong interest in ITU since 1990s for rural and remote coverage

HAPS dedicated spectrum allocations:
WRC 1997, …, WRC 2019

"The studies (see Report ITU–R F.2438-0 (11/2018)) indicate that there is a need for almost 3 GHz of additional spectrum for HAPS to meet the requirements of certain applications."

"This is much more than the 600 MHz that are currently identified worldwide for HAPS operating in the fixed service (additionally, to the fixed service identifications, some bands were identified for HAPS operating in the mobile service as IMT base stations)."

Integrated Terrestrial-Aerial-Satellite Networks Concept in ITU & 3GPP

ITU: WP5C Fixed Wireless Systems (satellites & HAPS) ||
WP5D IMT (Int'l Mobile Telecommunications) Systems (cellular)

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WP5D IMT Systems (cellular & HIBS)

HIBS:
HAPS as an IMT BS

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HIBS:
HAPS as an IMT BS

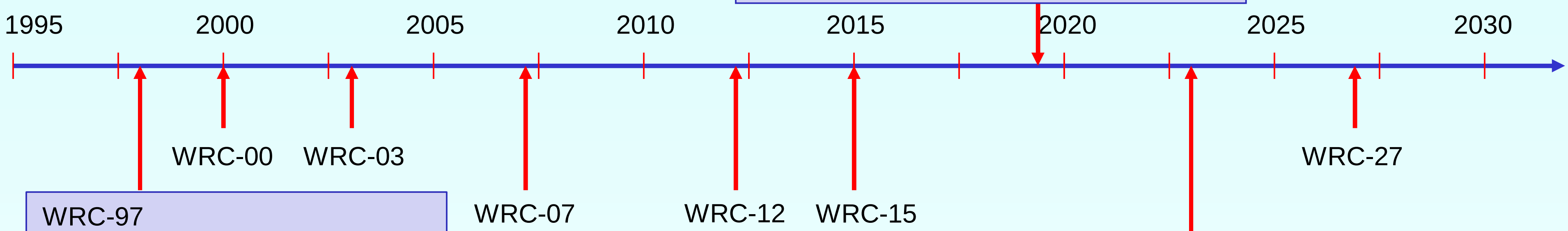
3GPP: Terrestrial-satellite integration discussions
since early 1990s: 2G, 3G, 4G, 5G

NTN (satellites & HAPS=HIBS) || UAS

NTN (satellites) || HAPS=HIBS || UAS

ITU and 3GPP timelines

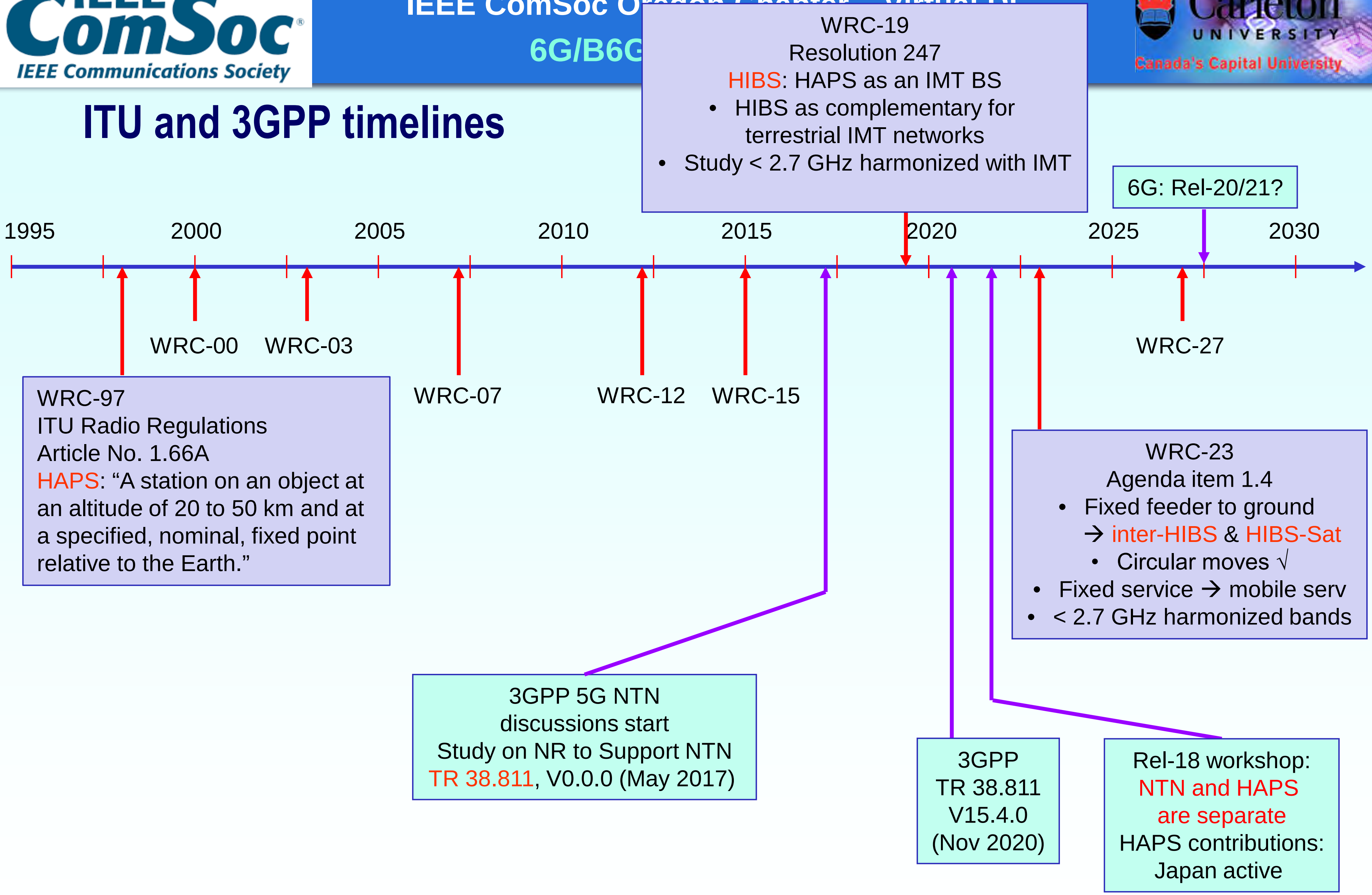
WRC-19
Resolution 247
HIBS: HAPS as an IMT BS
- HIBS as complementary for terrestrial IMT networks
- Study < 2.7 GHz harmonized with IMT



WRC-97
ITU Radio Regulations
Article No. 1.66A
HAPS: "A station on an object at an altitude of 20 to 50 km and at a specified, nominal, fixed point relative to the Earth."

WRC-23
Agenda item 1.4
- Fixed feeder to ground
  → inter-HIBS & HIBS-Sat
  - Circular moves √
- Fixed service → mobile serv
- < 2.7 GHz harmonized bands

ITU and 3GPP timelines



Integrated Terrestrial-Aerial-Satellite Networks Concept in ITU & 3GPP

- Integrated Terrestrial and Satellite √ (*light integration* of two networks)
- Integrated Terrestrial and Aerial X (can do better than *tight integration*)

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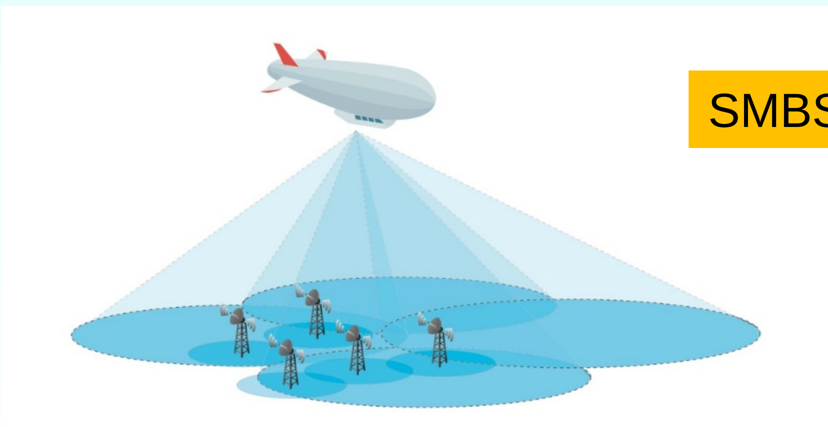
- Integrated Terrestrial and Satellite √ (*light integration* of two networks)
- Integrated Terrestrial and Aerial X (can do better than *tight integration*)

- Vertical HetNet = **VHetNet**
  - one single network with different types of access points
    Small BS + Macro BS + HAPS Super Macro BS (HIBS)
  - connectivity, computing, caching, sensing, navigation, positioning, …
  - urban: smart cities → smart societies
  - B5G technologies (AI/ML, RIS/RSS, …)

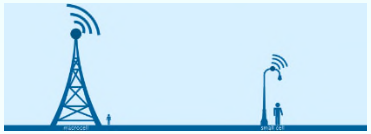
VHetNet: Integrated Terrestrial BSs & HAPS BSs in Urban Areas

- Owned/shared by the legacy operators, part of the 3GPP ecosystem
- Vertical HetNet (VHetNet): One single network with multiple tiers

super macro BS (SMBS)	←	macro BS	←	small BS
10-100 km	←	few km	←	100 m



SMBS: native



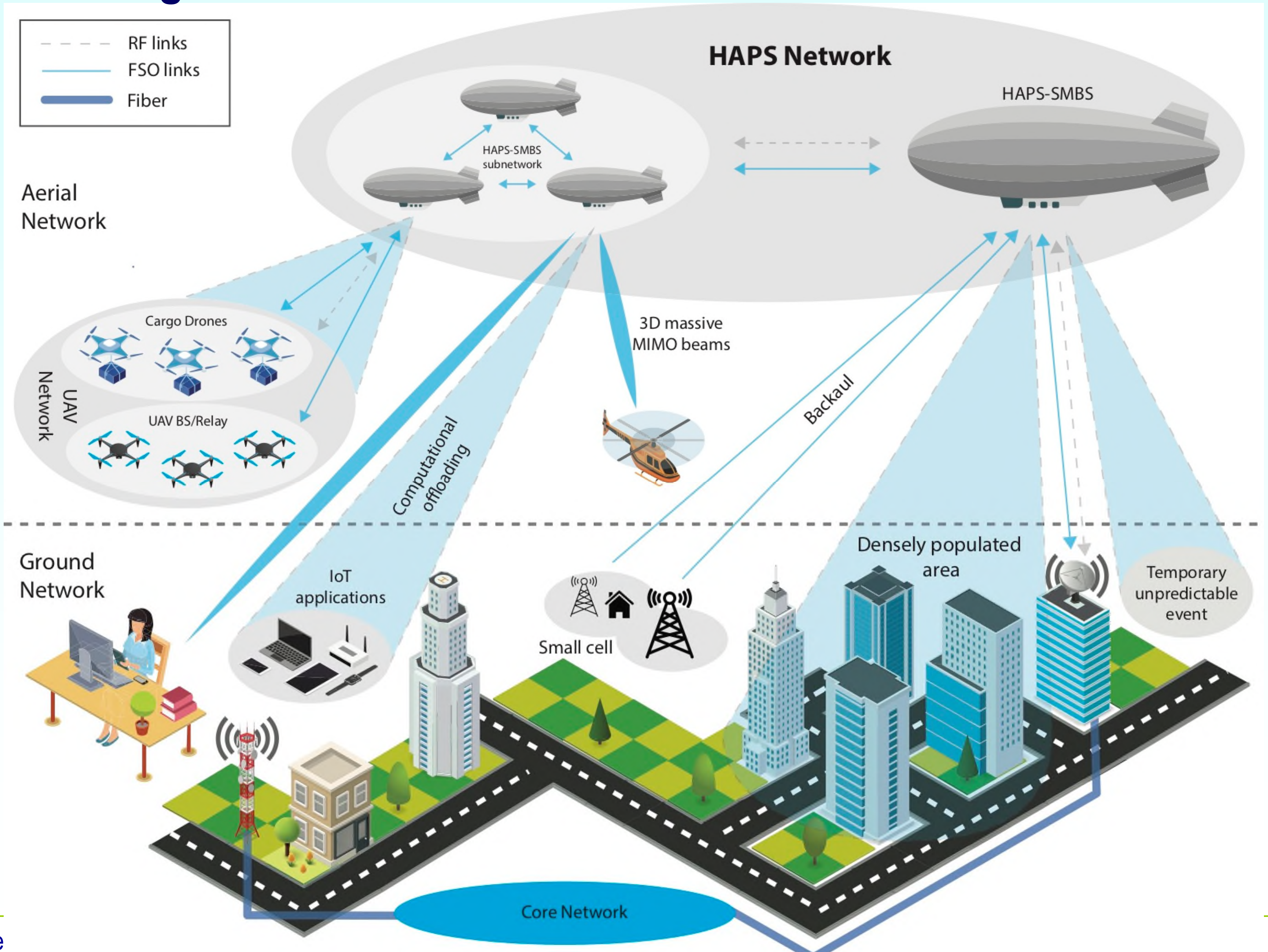
M. Alzenad, H. Yanikomeroglu, "Coverage and rate analysis for vertical heterogeneous networks (VHetNets)", *IEEE Transactions on Wireless Communications*, Dec 2019.

→ N. Cherif, M. Alzenad, H. Yanikomeroglu, A. Yongacoglu, "Downlink coverage and rate analysis of an aerial user in vertical heterogeneous networks (VHetNets)", *IEEE Transactions on Wireless Communications*, Mar 2021.

→ S. Alam, G. Karabulut Kurt, H. Yanikomeroglu, N.D. Dao, P. Zhu, "High altitude platform station based super macro base station (HAPS-SMBS) constellations", *IEEE Communications Magazine*, Jan 2021.

→ G. Kurt, M.G. Khoshkholgh, S. Alfattani, A. Ibrahim, T.S.J. Darwish, Md S. Alam, H. Yanikomeroglu, A. Yongacoglu, "A vision and framework for the high altitude platform station (HAPS) networks of the future", *IEEE Communications Surveys and Tutorials*, Q2 2021.

VHetNet: Integrated Terrestrial BSs & HAPS BSs in Urban Areas



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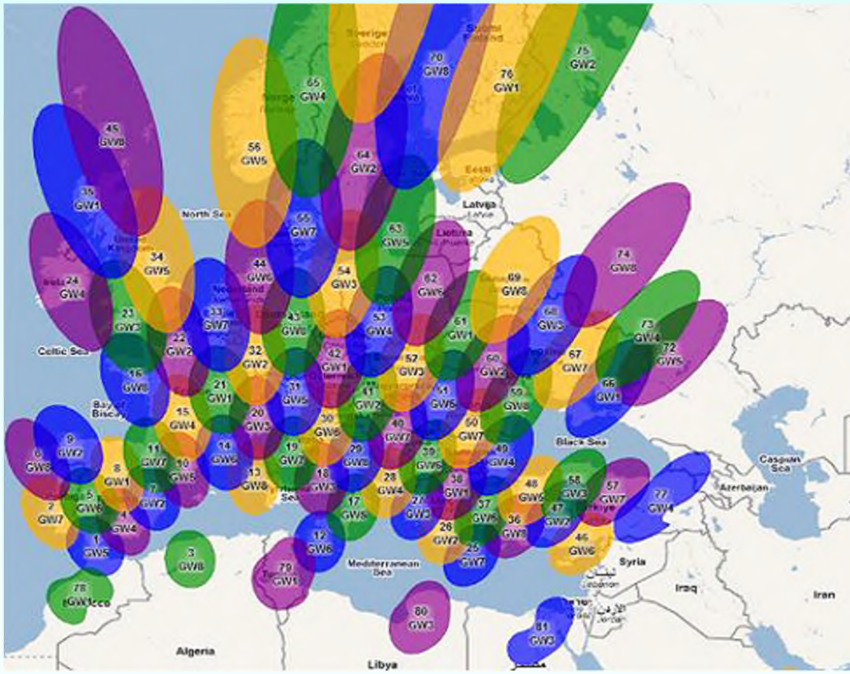
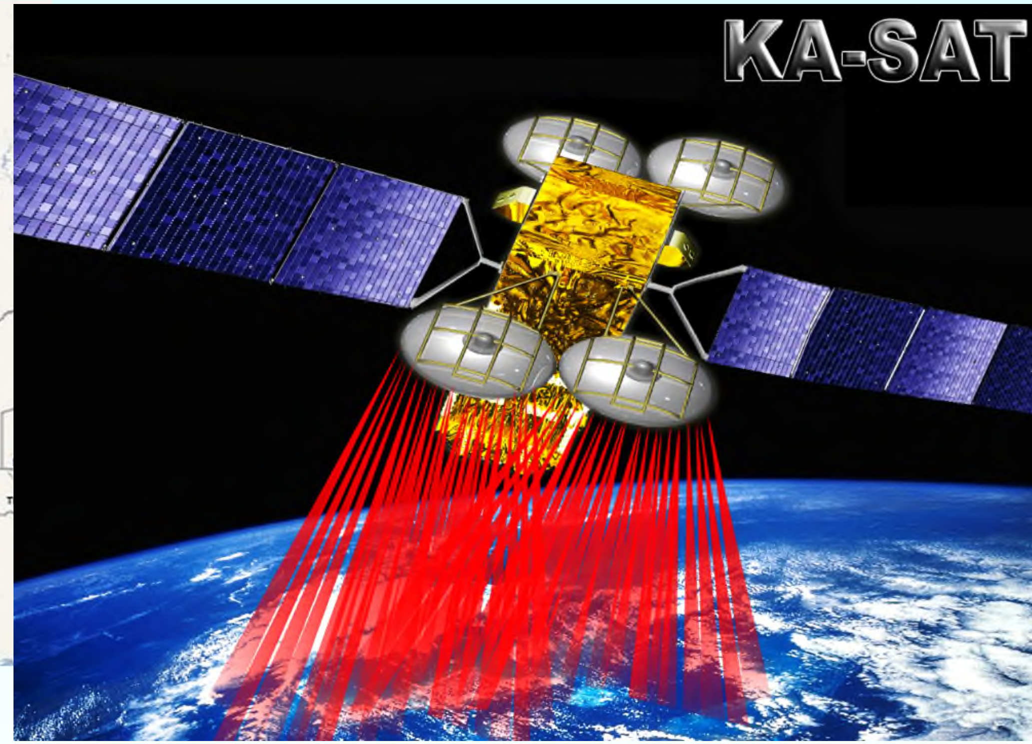
High Throughput Satellites (HTS, VHTS, UHTS) – KA-SAT



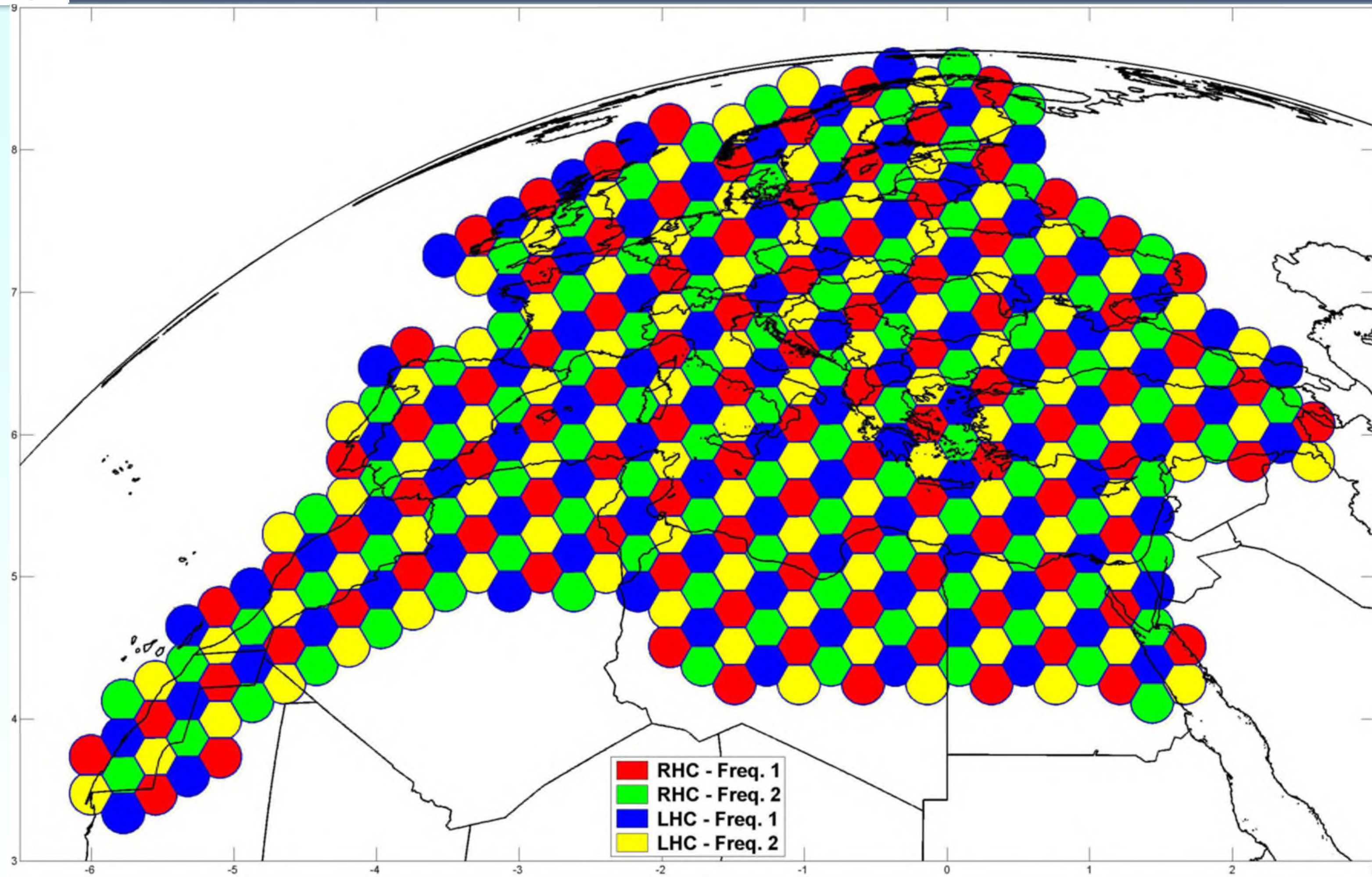


KA-SAT (May 2011) – GEO

82 beams; total satellite capacity: 90 Gbps
Fixed beams
Spacecraft power = 14 kW
Payload DC power = 11 kW
Payload mass = 1 ton
Launch mass = 6 tons
Lifetime = 16 years

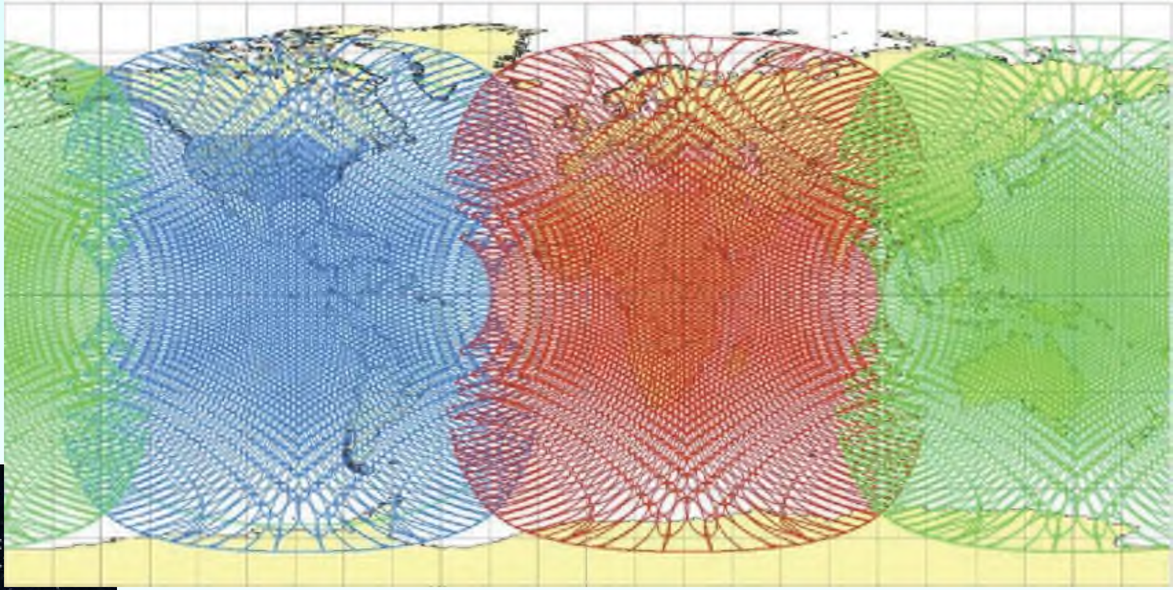
Broadcast → Broadband
Multi-beams

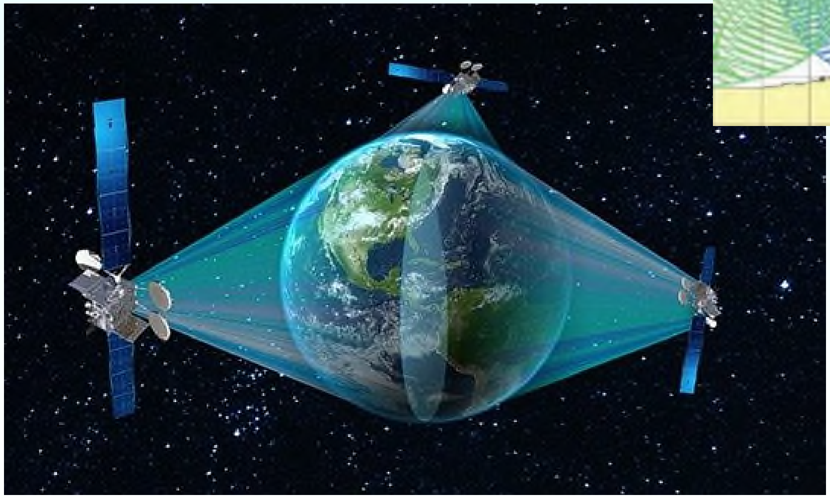
HTS GEO
403 beams
Diameter = 0.3°



M. Schneider, C. Hartwanger, M. Kilian, "Antenna Concepts and Technologies for Future 5G Satellites", *IEEE 5G World Forum 2019*.

High Throughput Satellites (HTS, VHTS, UHTS) – ViaSat-3 (2022+)



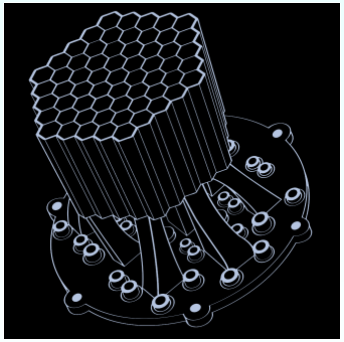


A.I. Perez-Neira, M.A. Vazquez, S. Maleki, M.R. Bhavani Shankar, S. Chatzinotas, "Signal Processing for High Throughput Satellites: Challenges in New Interference-Limited Scenarios", *IEEE Signal Processing Magazine*, Jul 2019.

ViaSat-3 (2022+) – GEO

~ 1,000 beams per satellite
Total capacity per satellite > 1 Tbps

High Throughput Satellites (HTS, VHTS, UHTS) – Telesat Lightspeed



Telesat Lightspeed Constellation (2023+) – LEO

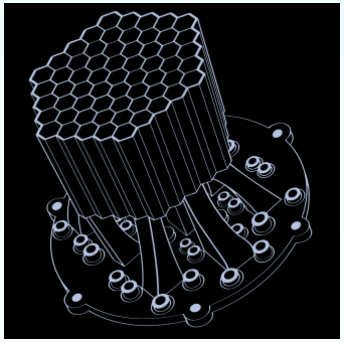
298 LEOs
Orbit altitude = 1,015 km | 1,325 km
Launch mass = 700 kg
4 kW
Laser inter-satellite links (LISLs)
10 years operational life

Total constellation capacity = 15 Tbps
→ Capacity per satellite = 50 Gbps
Up to 7.5 Gpbs to a single terminal
Up to 20 Gbps to a single hotspot (remote Communities, airport hubs, sea ports, …)

Phased arrays antennas + beam hopping
Total ~135,000 beams
Beams per satellite = ~675

Onboard signal processing:
Full digital modulation, demodulation, data routing

High Throughput Satellites (HTS, VHTS, UHTS) – Telesat Lightspeed



SpaceX Starlink Constellation – LEO
12,000 LEOs → 42,000 LEOs
(29+ years to launch at the current rate)
Orbit altitude = 340 km | 550 km | 1,150 km
Launch mass = 260 kg
Capacity per satellite = 20 Gbps

Telesat Lightspeed Constellation (2023+) – LEO

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Trends in HTS

5G SATELLITE USE CASES AND SERVICE REQUIREMENTS

- Communications on the move (COOM)
- Trunking and head-end feed (THEF)
- Backhauling and tower feed (BATF)
- Hybrid multiplay (HYMP)
- Wide area IoT (WAIoT)

In the medium term, integration of satellite-based technologies within 5G is expected to happen mainly at ground segment level, while in the long term even an higher level of integration might be foreseen.

Satellite beam size shall be drastically reduced (e.g., <0.2° degrees beamwidth) to implement aggressive frequency reuse and to increase RF performance.

GEO: Small beamwidths call for very large antennas (e.g., <0.2° beam widths) correspond to antenna apertures in the order of 5 m at Ka-band.

VLEO: A 40-cm-diameter antenna in Ku-band (12-18 GHz), or a 20-cm in Ka band (26.5-40 GHz) at an orbit altitude of 200 km would generate beams with a radius smaller than 10 km.

R. De Gaudenzi, P. Angeletti, D. Petrolati, E. Re, "Future technologies for very high throughput satellite systems", *Wiley International Journal of Satellite Communications and Networking*, Mar/Apr 2020.

Trends in HTS

Payload shall provide a very high number of beams (e.g., >1000 beams for GSO global) with the possibility of dynamically activate, reshape, and/or steer the beams to adapt the active beams to the traffic demand and user density. This calls for the adoption of active reconfigurable antenna/payload.

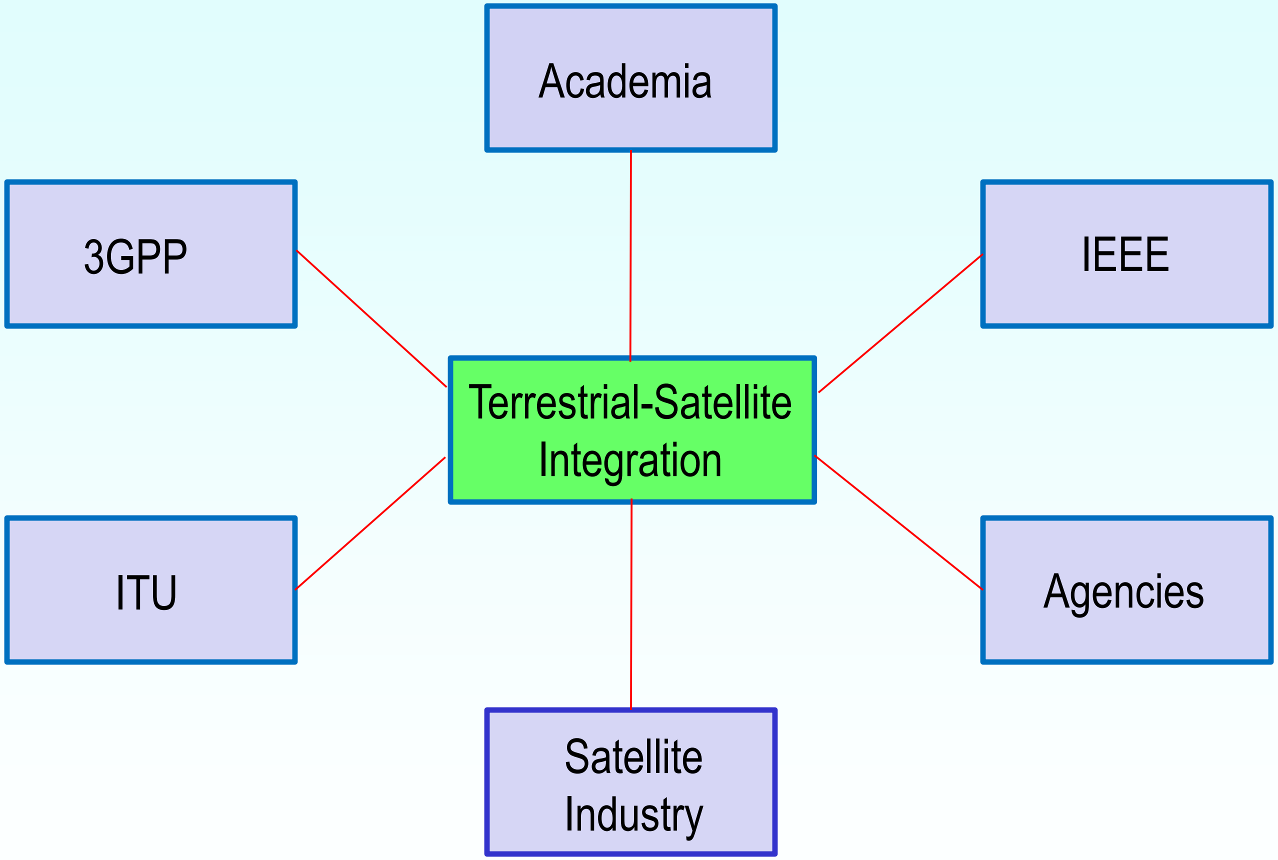
As the trend is to deploy systems with very high flexibility in terms of assigning capacity to beams as well as to reconfigure the beam pattern, there is a need of developing efficient RRM algorithms to optimize the use of resources (frequency, power, and coverage).

The adoption of active antennas with large number of feeds and digital beam-forming makes possible the exploitation of massive multiple input multiple output (M-MIMO) techniques in telecommunication satellites. While M-MIMO technologies is finding its way in terrestrial 5G networks, its application to satellite is still at its infancy. Low-complexity M-MIMO solutions, combined with smart radio resource management techniques, will allow implementing full frequency reuse and achieving substantial throughput gain combined with modest payload complexity increase.

Intersatellite links (ISLs) for LEO satellites may be an effective solution to reduce the total number of gateways. Should ISLs be implemented, the payload architecture shall provide connectivity from/to ISLs via dedicated antennas (or telescopes, in case of optical ISLs).

R. De Gaudenzi, P. Angeletti, D. Petrolati, E. Re, “Future technologies for very high throughput satellite systems”, *Wiley International Journal of Satellite Communications and Networking*, Mar/Apr 2020.

Terrestrial – Satellite Integration Dynamics



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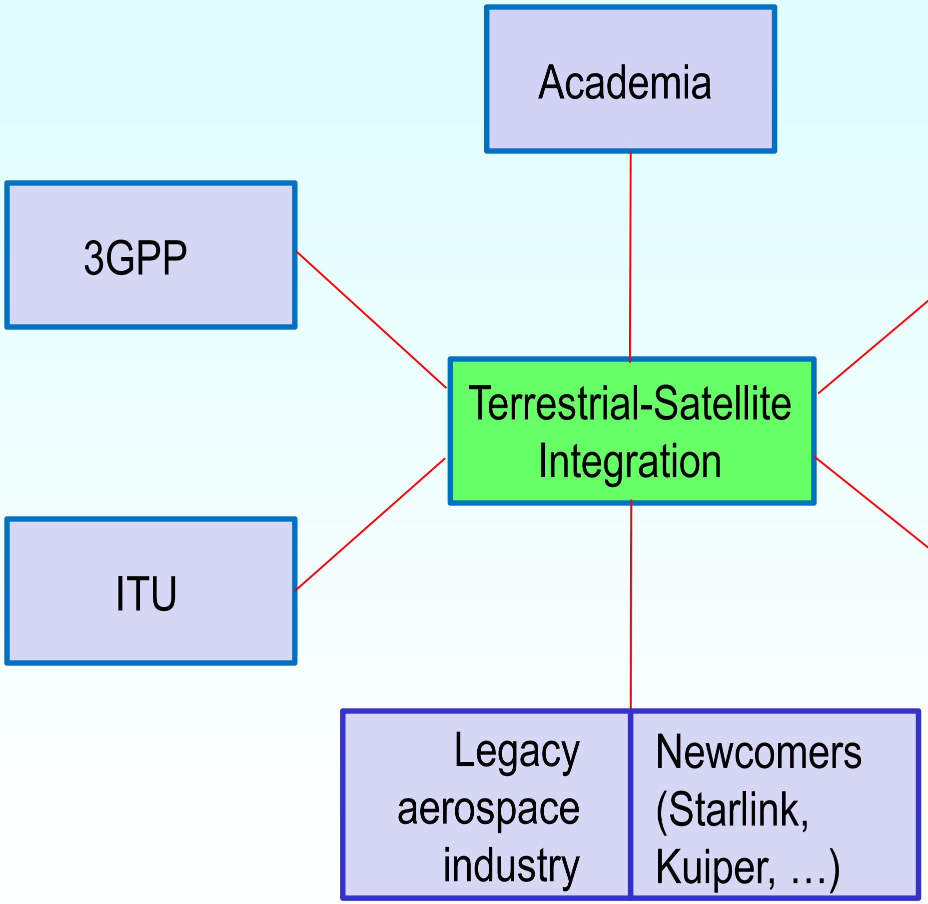

Terrestrial – Satellite Integration Dynamics

- LEO constellations are being built as we speak
  Updating air-interface will be difficult / not possible
- Many use-cases (WAIoT, COOM) do not need integration

- In some cases some integration is necessary (dual connectivity in ITS)
- Integration mainly for proper end-to-end operation
- Prediction: *Light integration* in 2020s | 5G era (ex: backhauling)

- Satellites reaching UE with IMT air-interface: Strong integration
- Prediction: *Tight integration* in 2030s | 6G/B6G era

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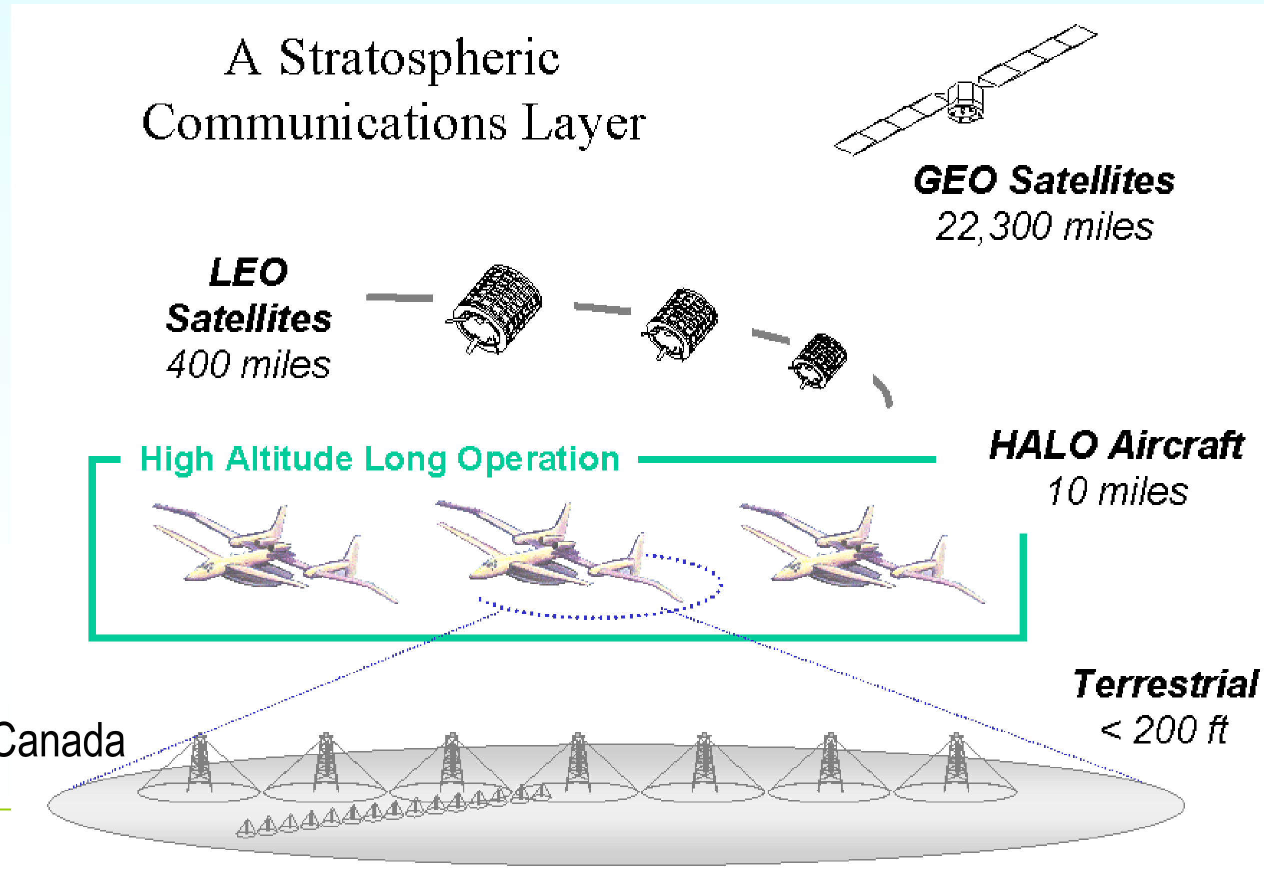
HAPS: 1960 – 2010 (Deep Past)

Experimental, no commercial deployment

1960s: Project Echo and PAGEOS

2000s: HALO
High-Altitude Long-Endurance

1980s: Project SHARP
Communications Research Centre Canada



HAPS: 2010s (Google Loon | 4G Era)

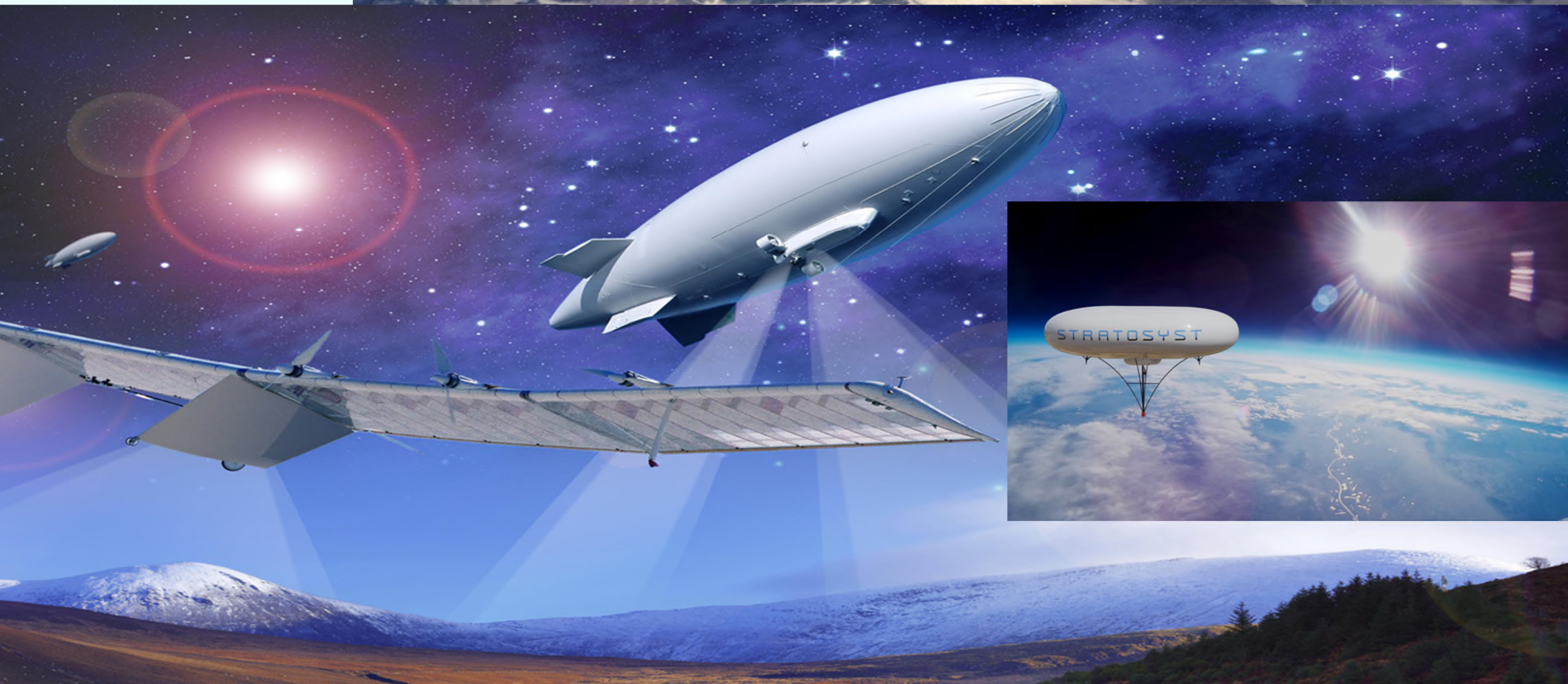
– Limited commercial deployments in rural & remote regions

– Balloon-type aircrafts

IEEE ComSoc
IEEE Communications Society

HAPS: Late 2020s (5G Era)

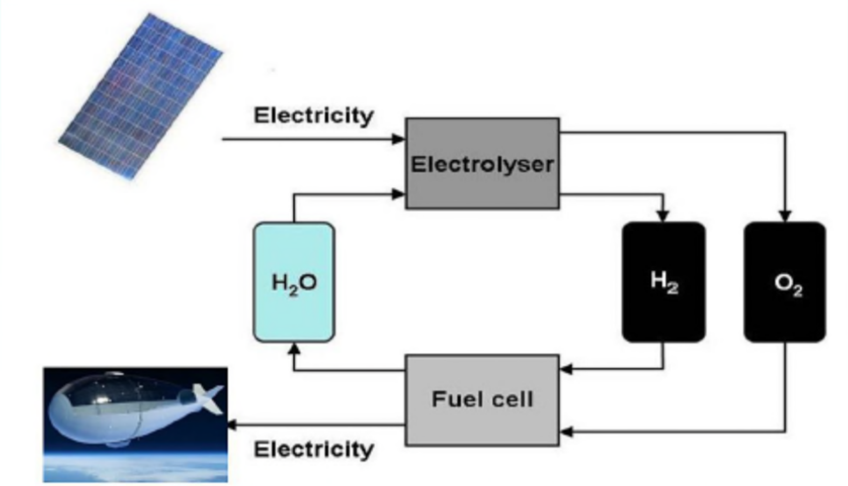
– Widespread deployments in rural & remote regions
– Fixed-wing aircrafts and airships



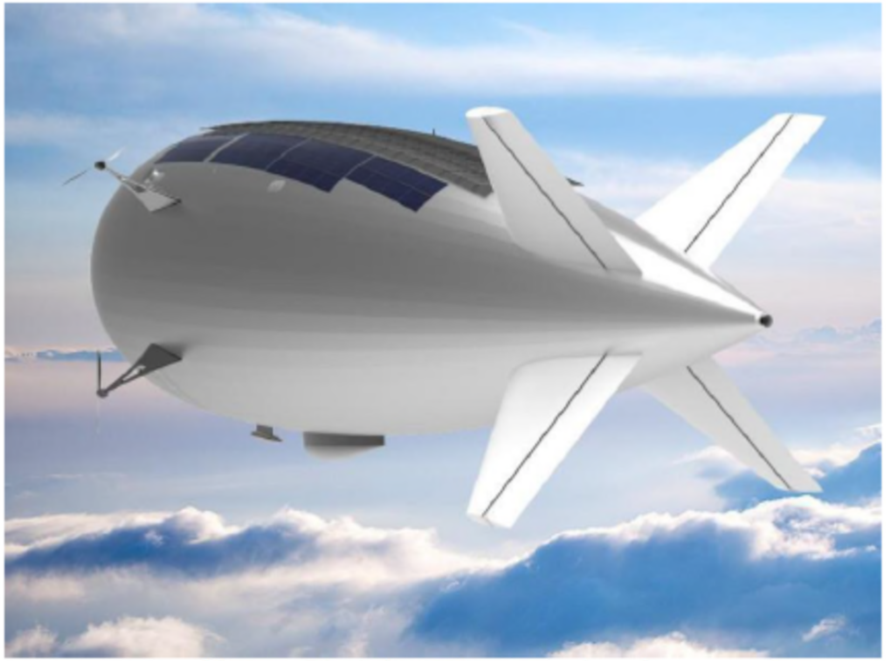
Stratobus by Thales Alenia Space

Started in 2010
Length = 140 m;   diameter = 33 m
Flight duration = one year

Payload = 450 kg
8 kW
Flight demonstration = 2023+



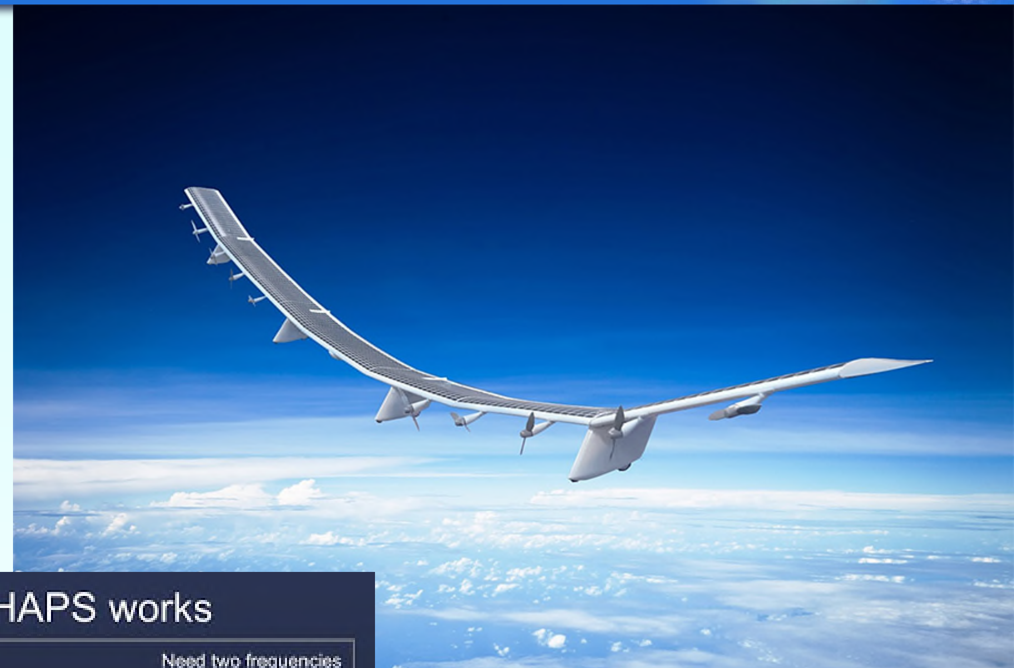
RFC system process diagram. Source: Protech

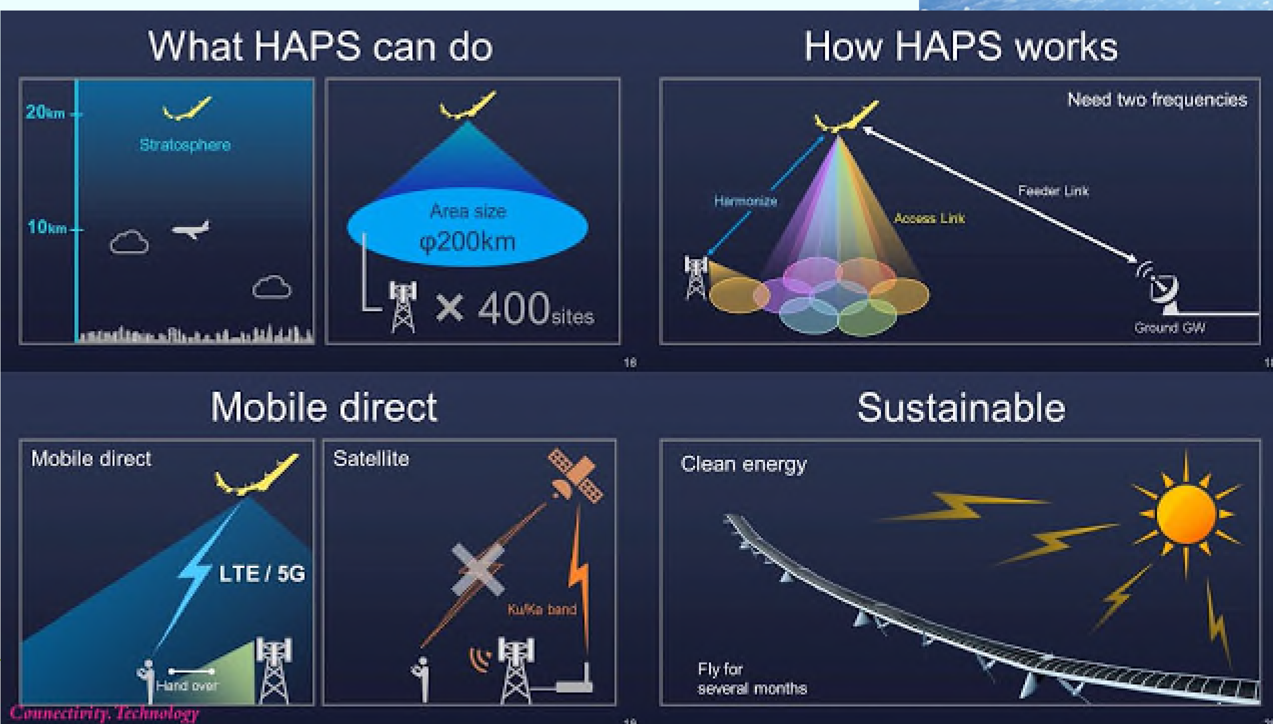


Above: Stratobus stern quarter view.
Below: Airship-to-airship laser data links.
Source, both graphics: Thales Alenia Space, circa 2018

Sunglider by HAPSMobile (Softbank)

Started in 2017
Wingspan = 78 m
Flight duration = several months
Battery = High energy density Li-ion
Deployment = 2023+





State of the Art: Cambridge Consultants + SPL (Deutsche Telekom)

Started in late 2010s
Antenna: 3 m², 120 kg
480 individually steerable beams

Total capacity > 100 Gbps

Target: 2024

HAPS: 2030s and beyond (6G | B6G Era)
– Deployments in metro (dense urban & suburban) regions
– ISS-size aircrafts and airships

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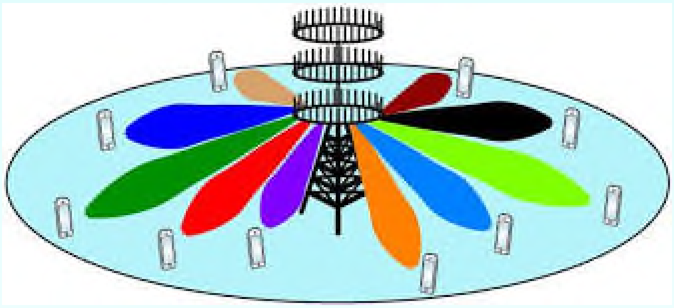
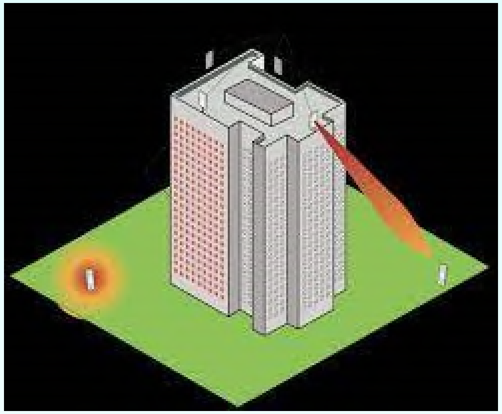
Ultra Massive MIMO (umMIMO)

- 1024+ umMIMO





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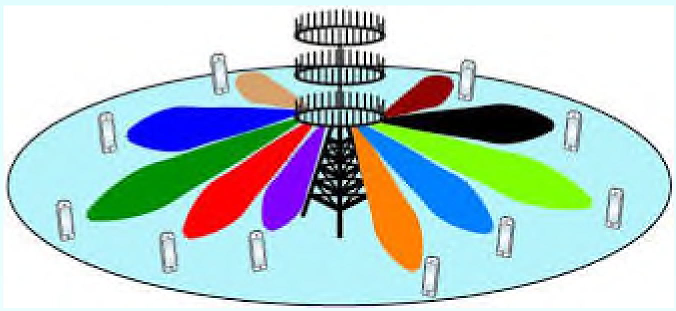
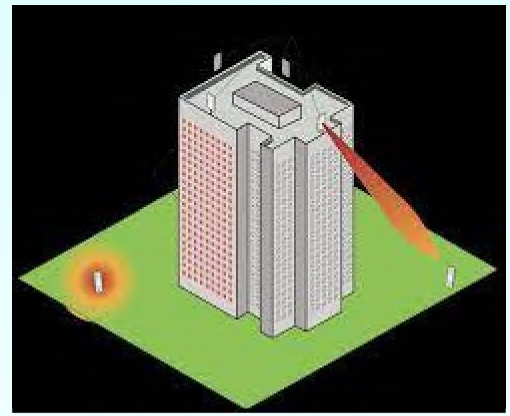
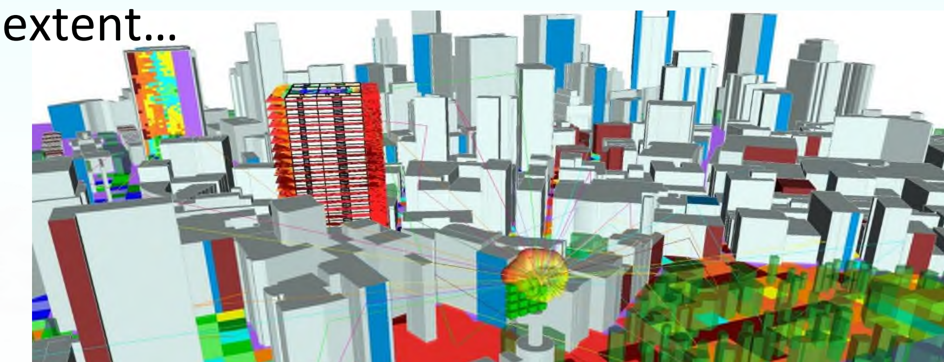




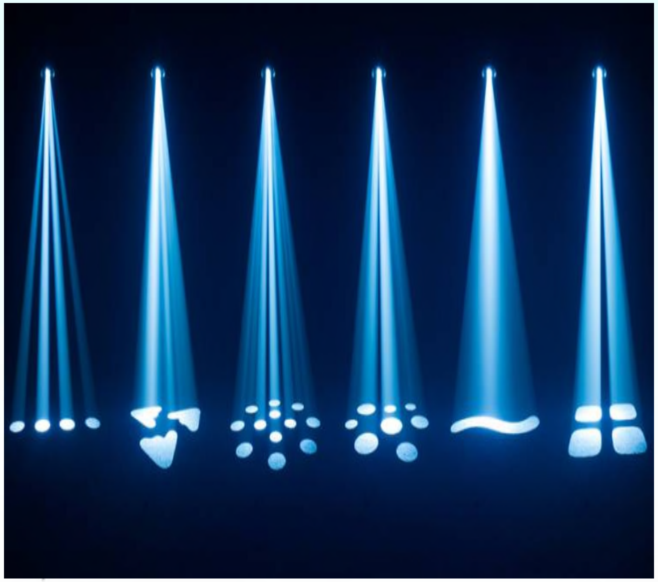
- How will the umMIMO capacity be utilized within an urban clutter?

  umMIMO advantage is lost to some extent…



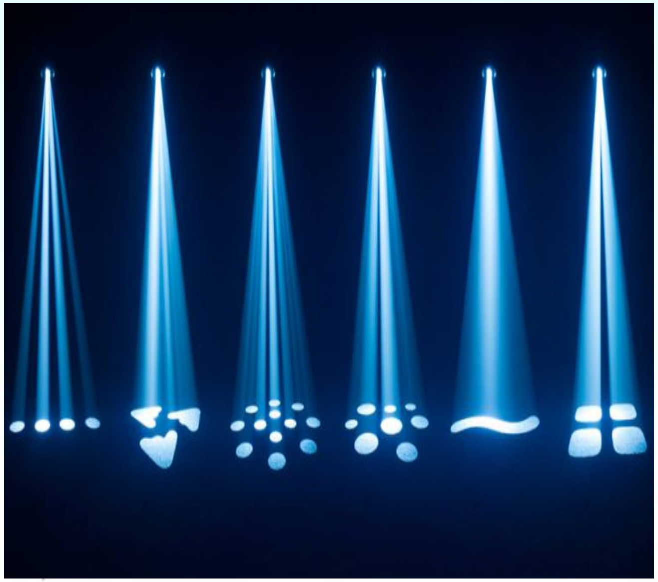
HAPS: Perfect fit for ultra massive MIMO (umMIMO)

- Dynamic beamforming with dense reuse
- Centralized and maneuverable massive capacity → ultra-agile RAN



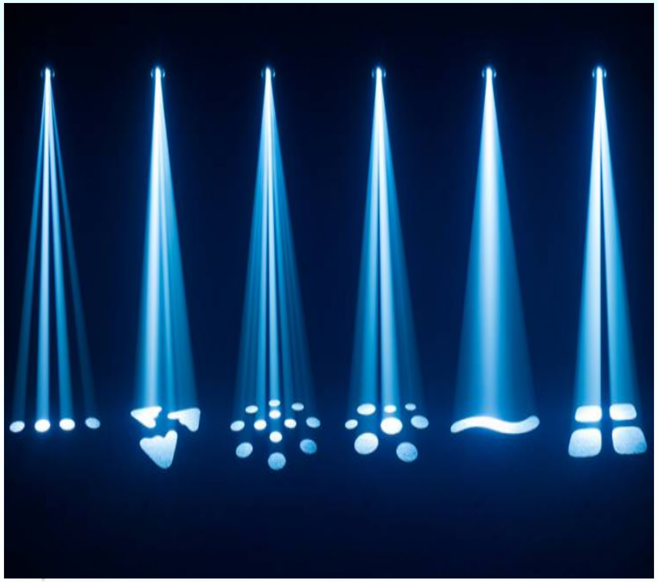
HAPS: Perfect fit for ultra massive MIMO (umMIMO)

- Dynamic beamforming with dense reuse
- Centralized and maneuverable massive capacity → ultra-agile RAN
- 10 GHz x 4 b/s/Hz x 250 reuse (1000 beams) = 10 Tbps



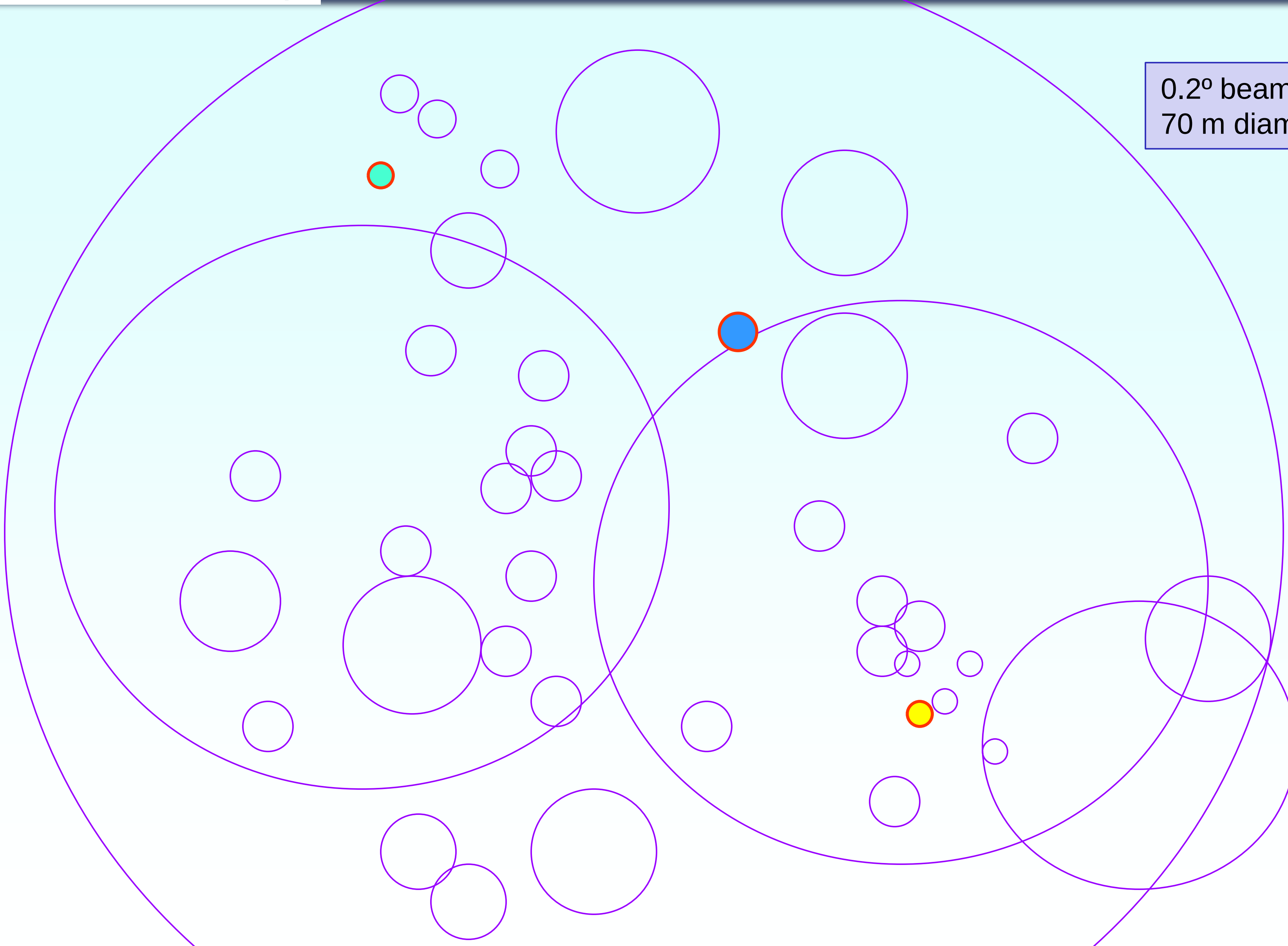
HAPS: Perfect fit for ultra massive MIMO (umMIMO)

- Dynamic beamforming with dense reuse
- Centralized and maneuverable massive capacity → ultra-agile RAN
- 10 GHz x 4 b/s/Hz x 250 reuse (1000 beams) = 10 Tbps
- 10 GHz x 4 b/s/Hz x 2500 reuse (10,000 beams) = **100 Tbps**



6G/B6G HAPS Networks

0.2º beamwidth →
70 m diameter hotspot



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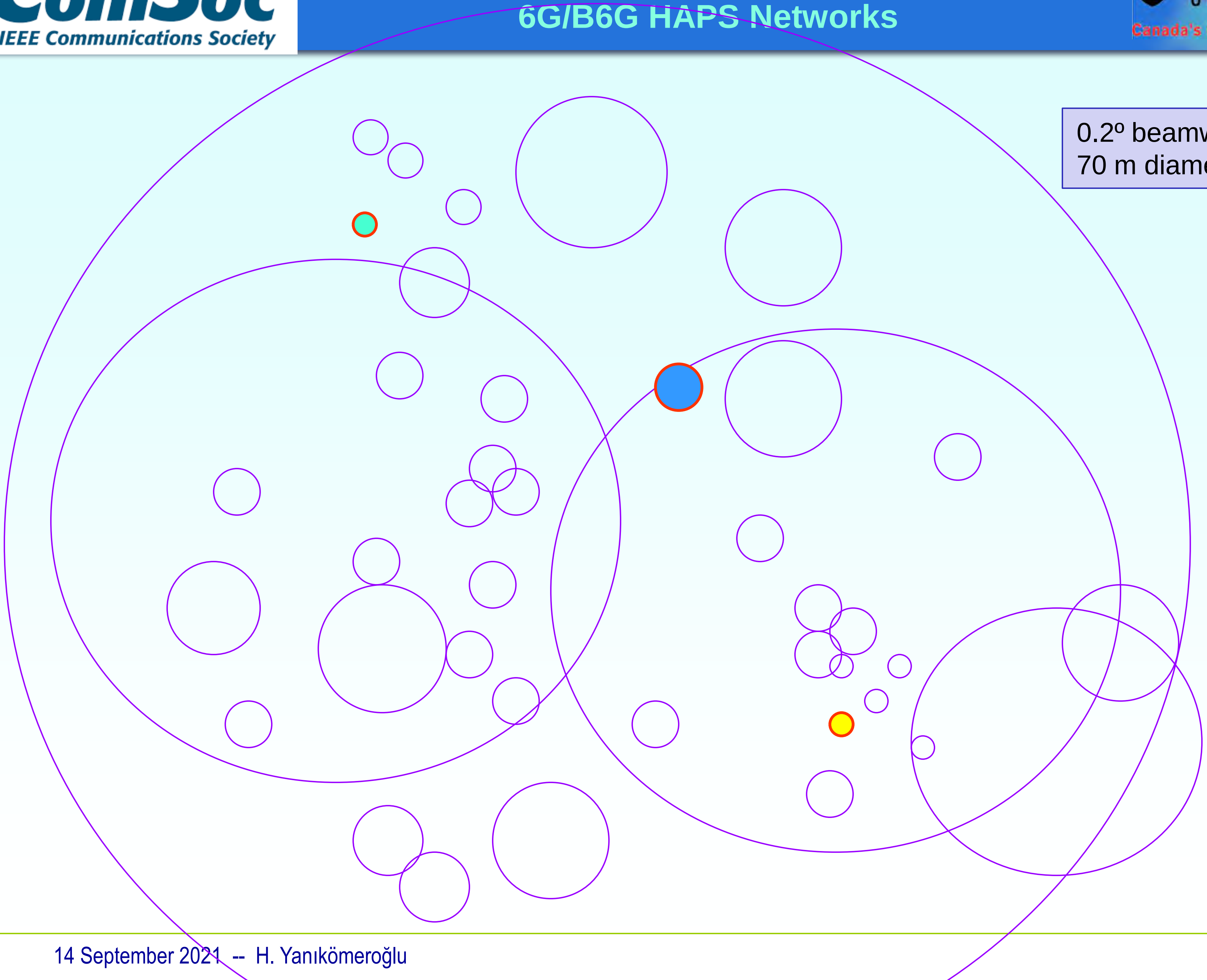

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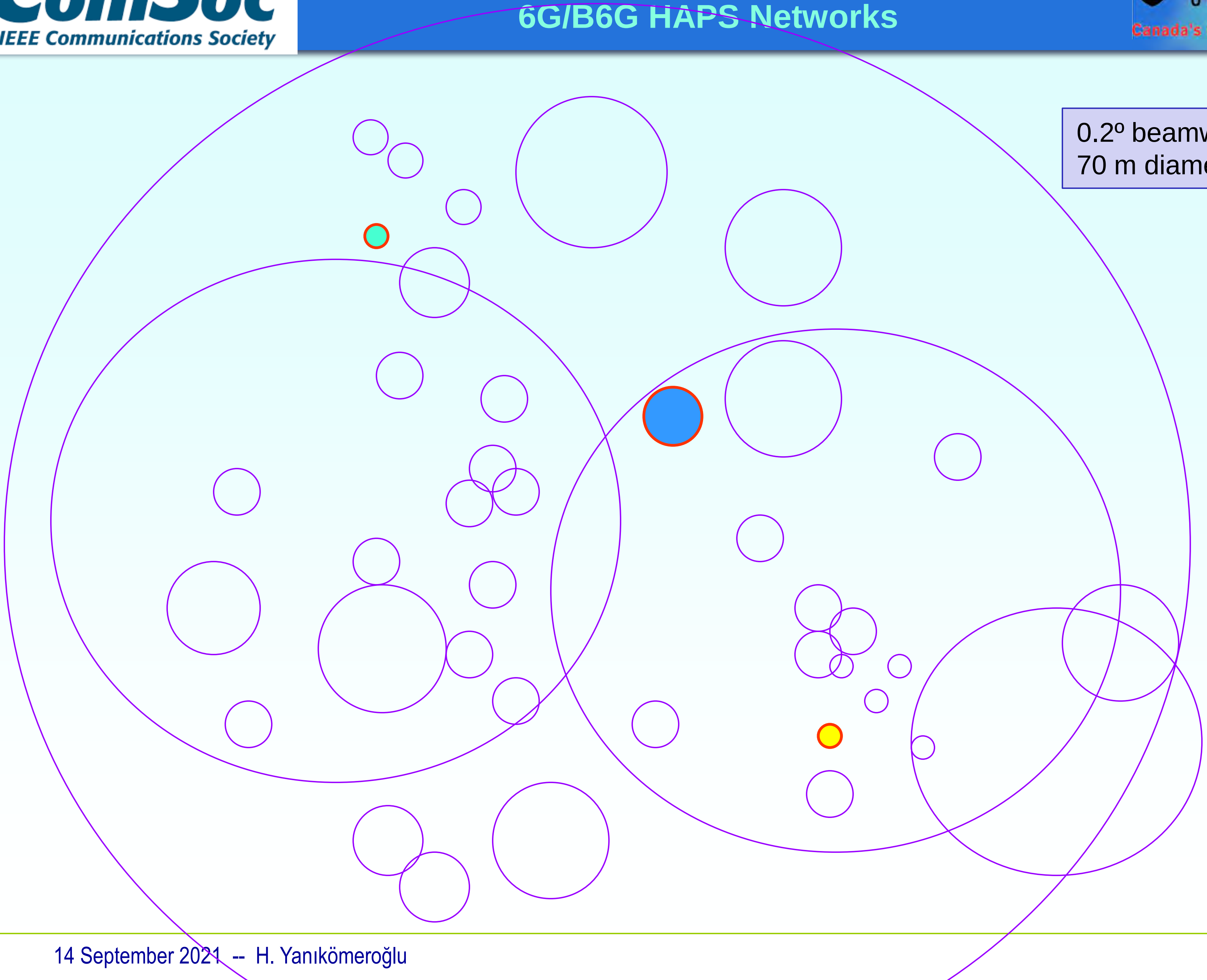

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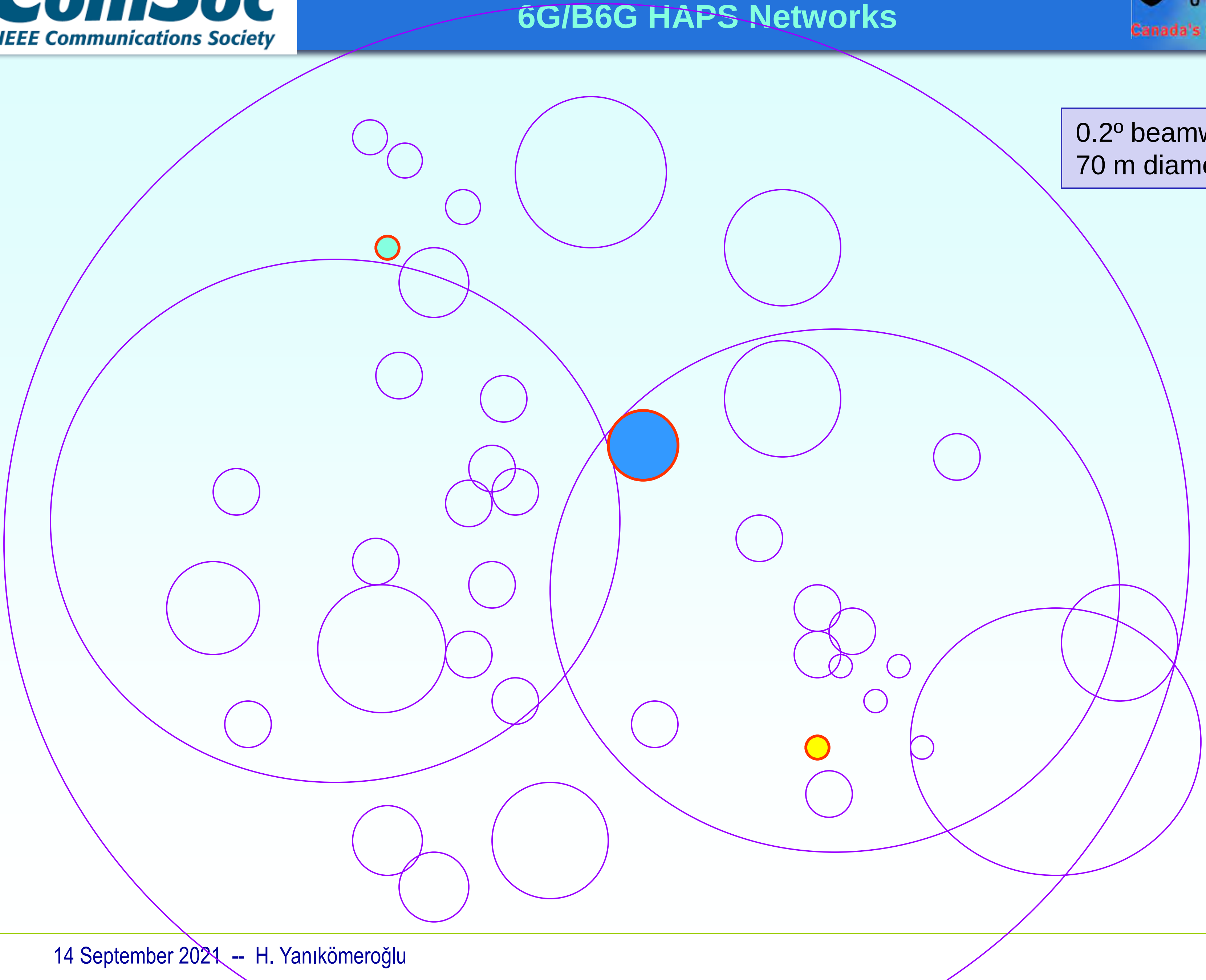


0.2º beamwidth → 70 m diameter hotspot

HAPS-SMBS Characteristics

- How big should the footprint be? → Capacity or coverage?

  Coverage: h = 50 km, r = 500 km → A = 800,000 km2

  Capacity: h = 20 km, r = 8 km → A = 200 km2

- Indoors: Sub 6 GHz; Outdoors: Up to 170 GHz (D band)
- Access: Ultra massive MIMO

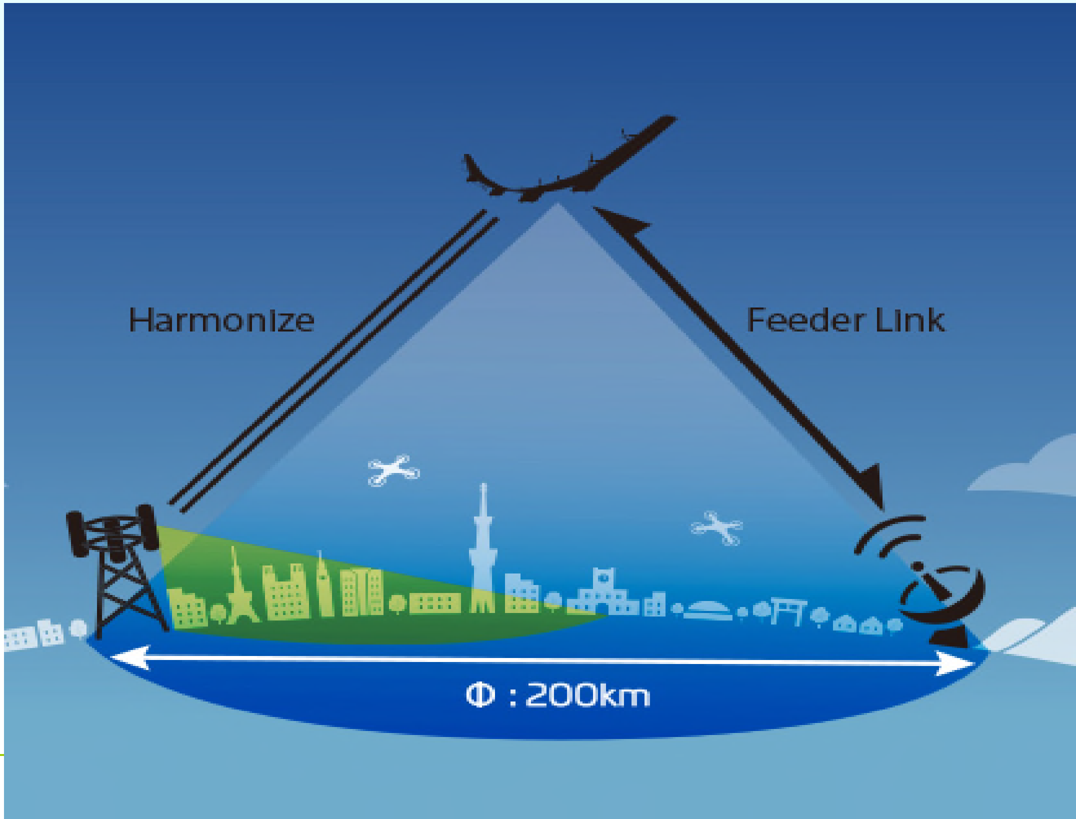
  Hundreds of beams
- SMBS rate: > Tbps
- Backhaul: FSO (?)

- Centralized massive capacity

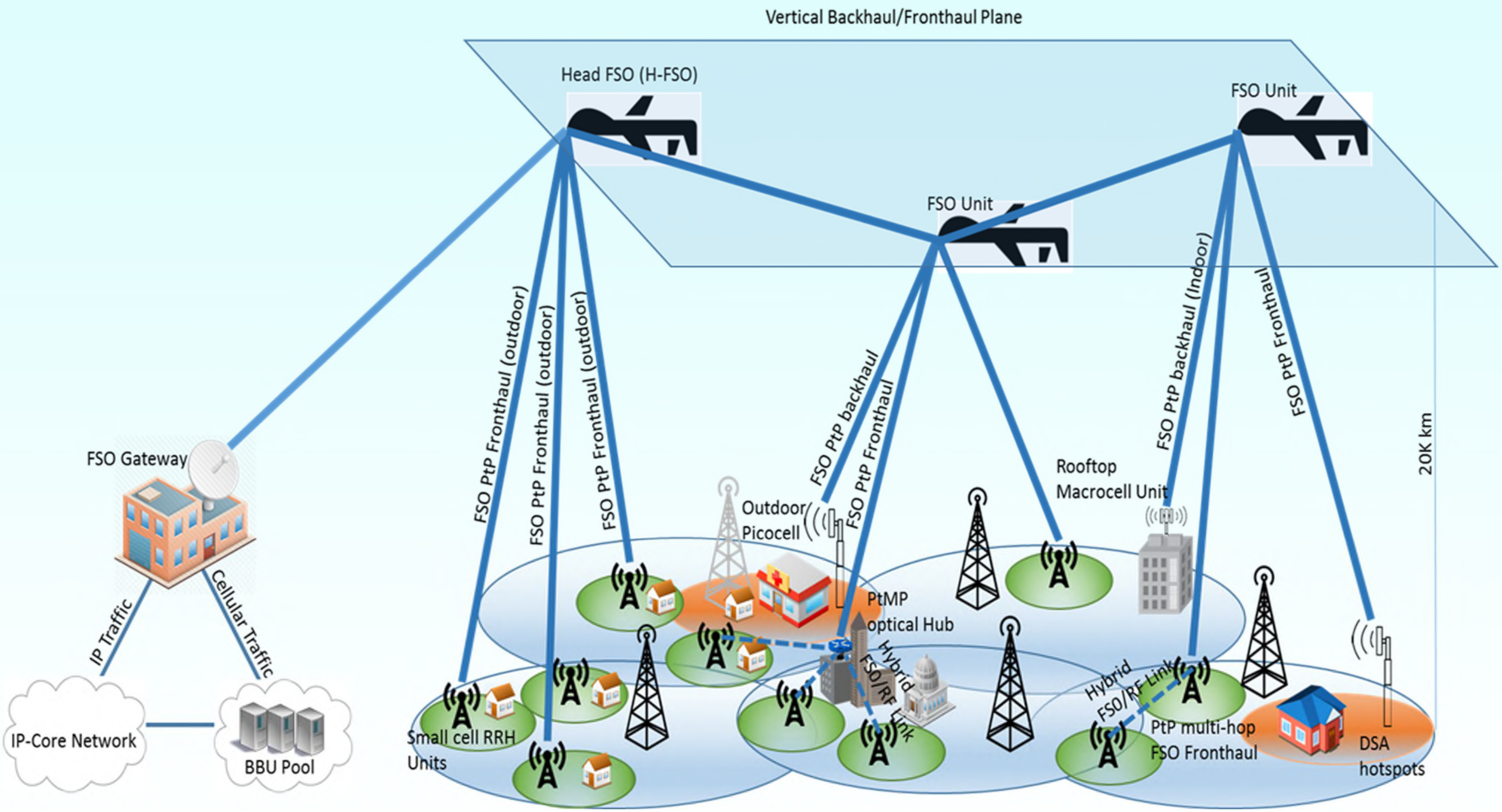
  White spot filler

  Temporary hot-spots

  Coverage holes
- Very many other use-cases

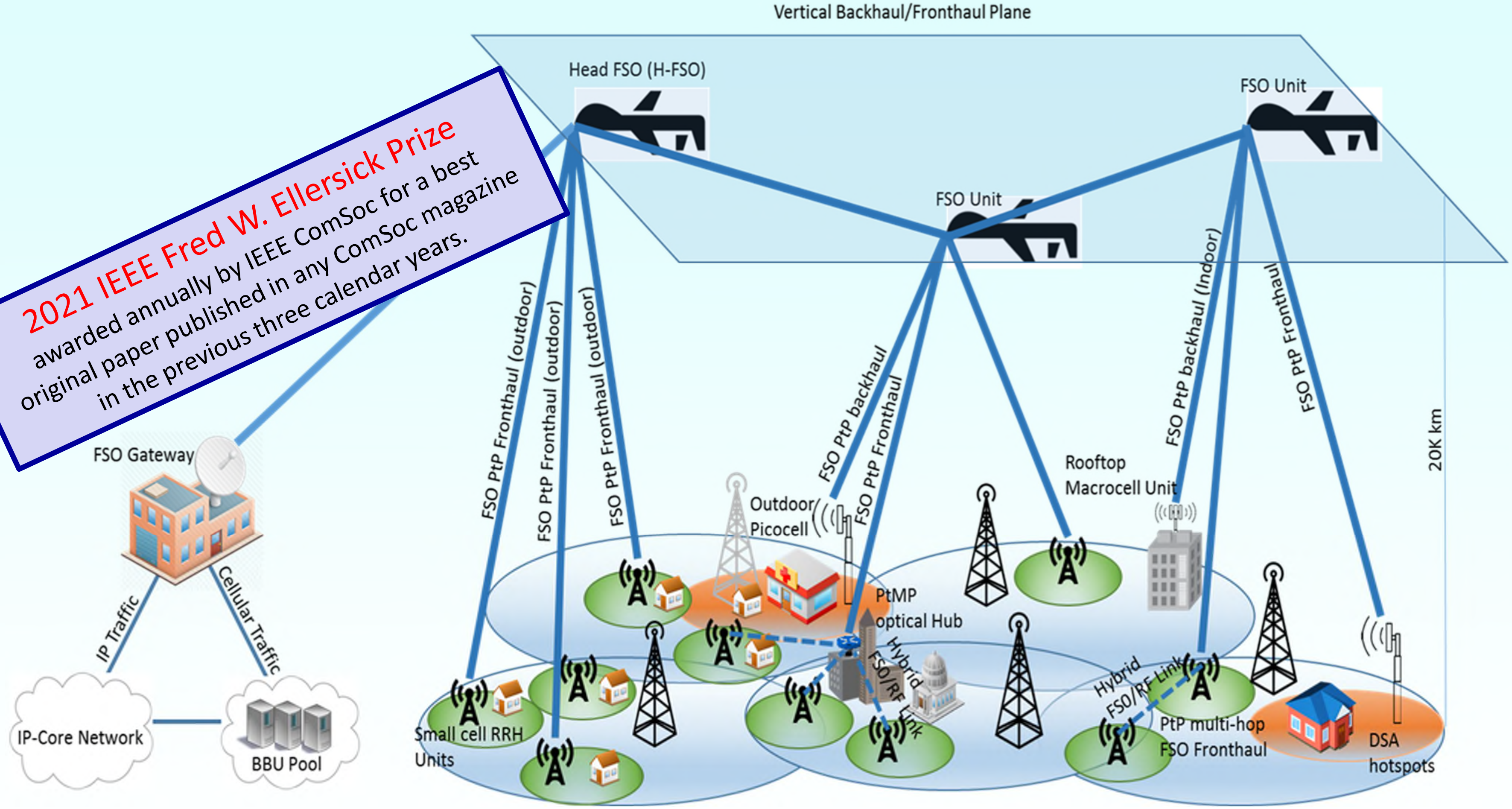


Backhauling Small Cells



M. Alzenad, M.Z. Shakir, H. Yanikomeroglu, M.-S. Alouini, "FSO-based vertical backhaul/fronthaul framework for 5G+ wireless networks", *IEEE Communications Magazine,* Jan 2018. [ieeexplore.ieee.org/document/8255764]

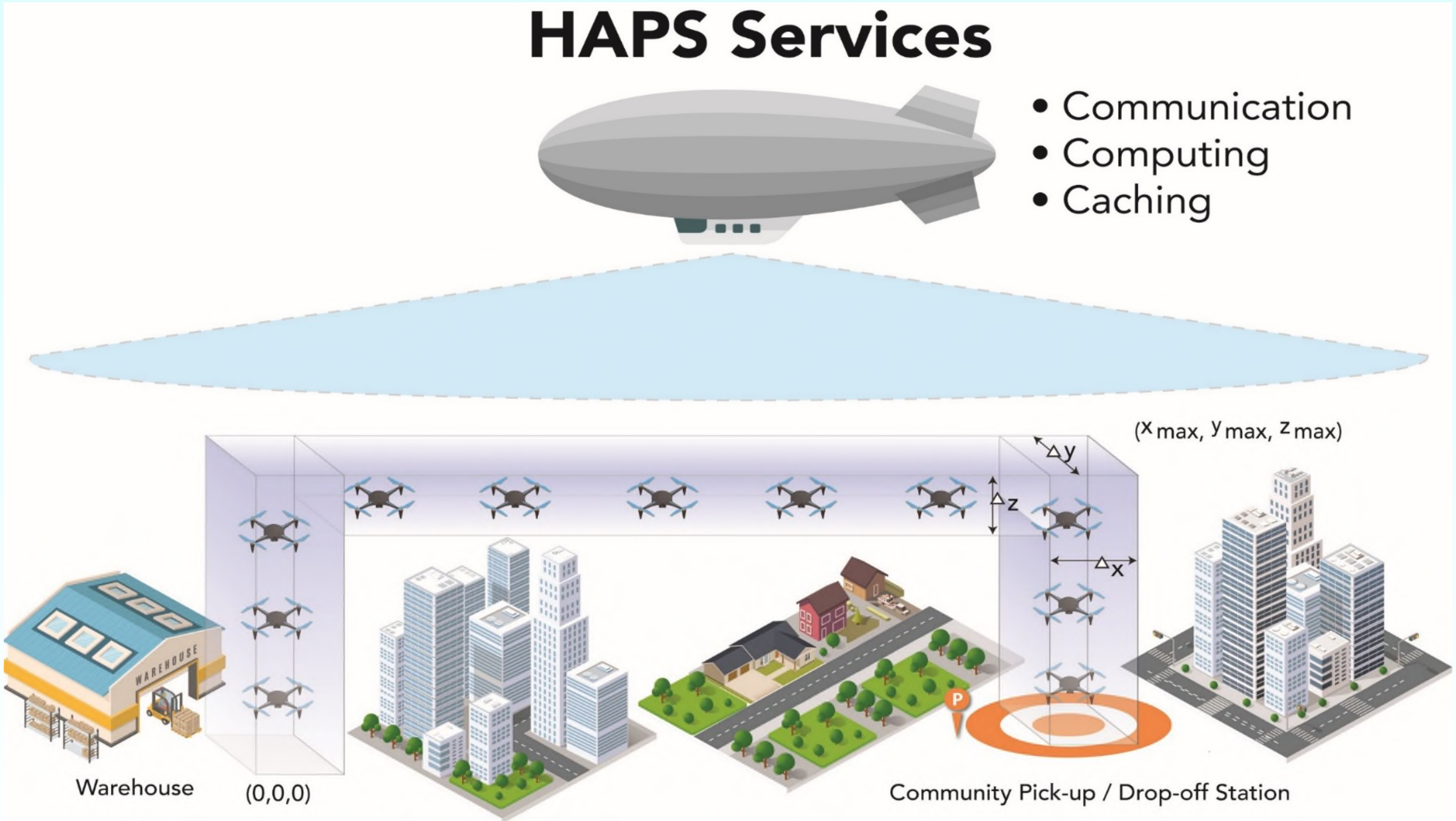
Backhauling Small Cells



2021 IEEE Fred W. Ellersick Prize
awarded annually by IEEE ComSoc for a best original paper published in any ComSoc magazine in the previous three calendar years.

M. Alzenad, M.Z. Shakir, H. Yanikomeroglu, M.-S. Alouini, "FSO-based vertical backhaul/fronthaul framework for 5G+ wireless networks", *IEEE Communications Magazine,* Jan 2018. [ieeexplore.ieee.org/document/8255764]

HAPS-SMBS for 3D Aerial Highways

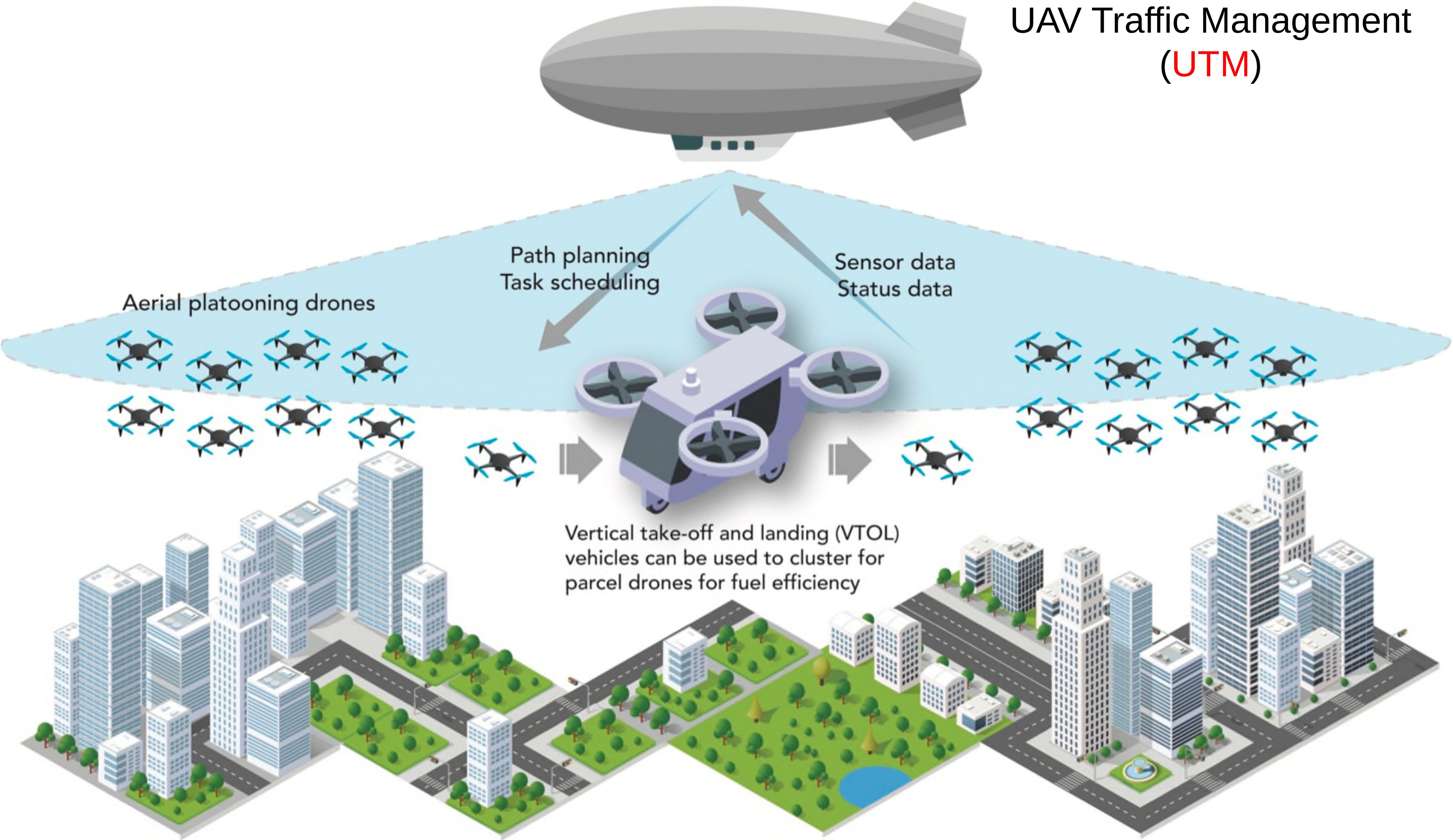


N. Cherif, W. Jaafar, H. Yanikomeroglu, A. Yongacoglu, "3D Aerial highways: The key enabler of the retail industry transformation", *IEEE Communications Magazine*, Sep 2021. [arxiv.org/abs/2009.09477]

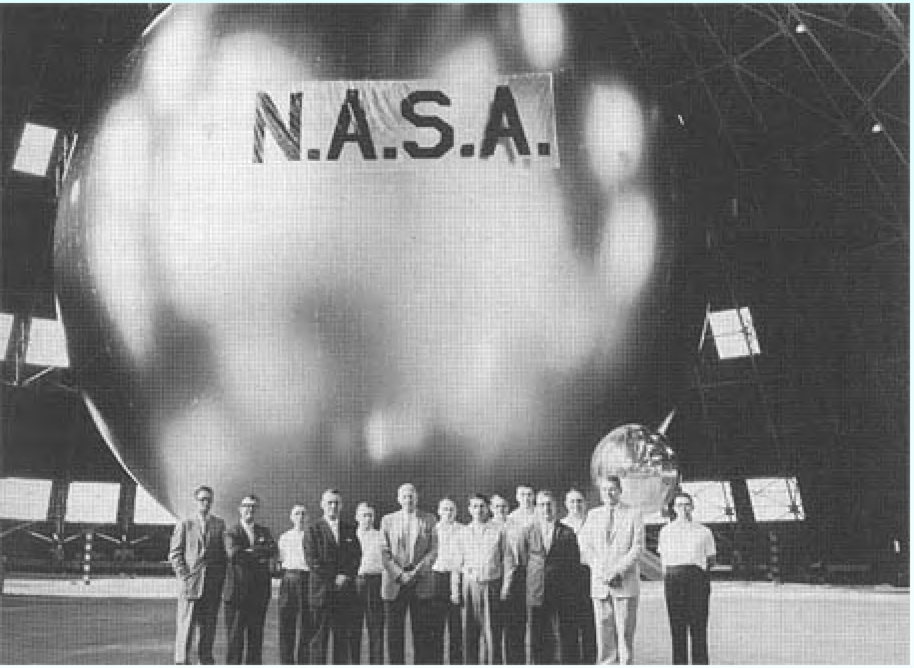
G. Karabulut Kurt, H. Yanikomeroglu, "Communication, computing, caching, and sensing for next generation aerial delivery networks: Using a high-altitude platform station as an enabling technology ", *IEEE Vehicular Technology Magazine*, Sep 2021. [ieeexplore.ieee.org/document/9462712]

Multi-Industry Artificial Intelligence Engine

UAV Traffic Management (UTM)



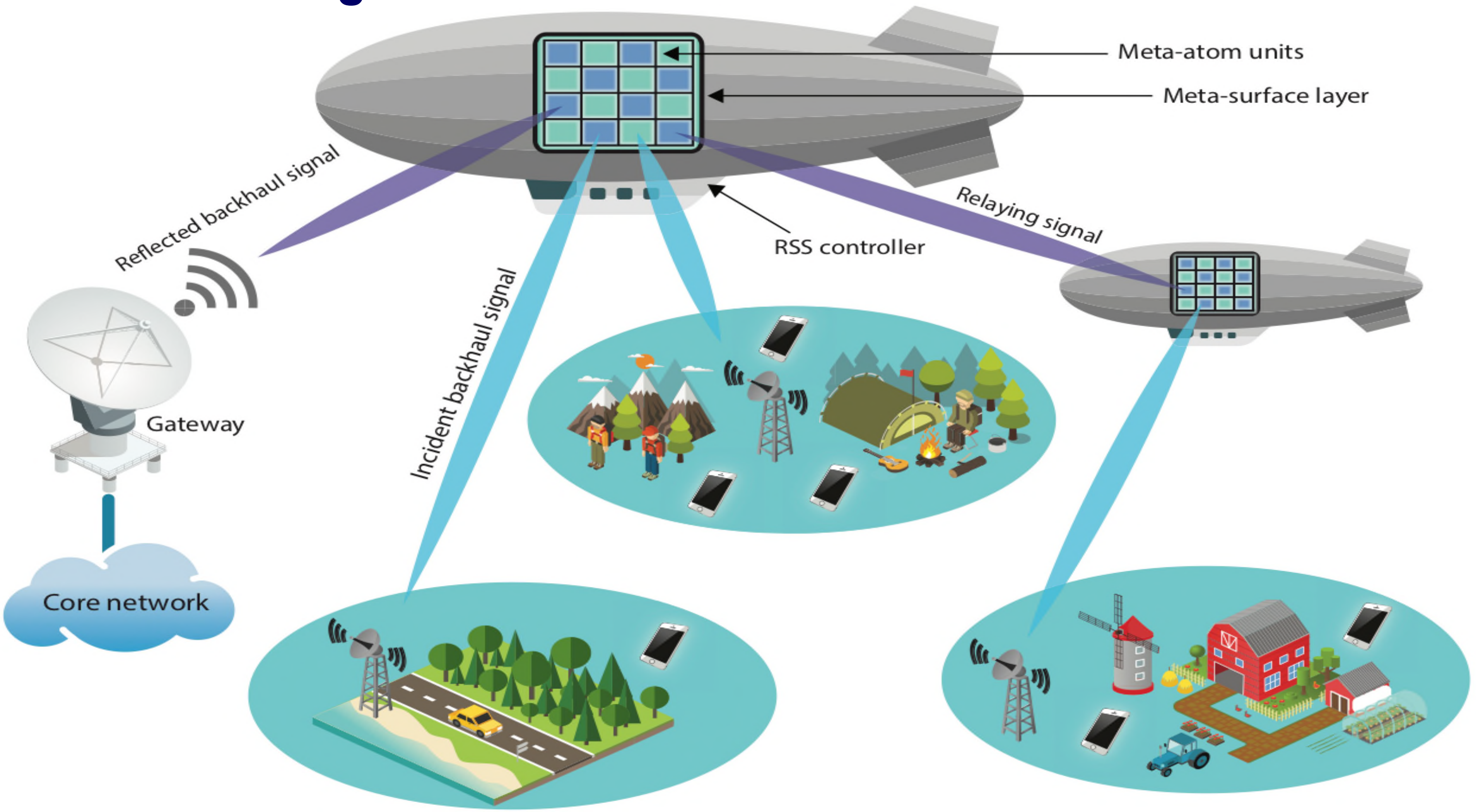
Project Echo and PAGEOS



Project Echo was the first passive communications satellite experiment. Each of the two American spacecraft, launched in 1960 and 1964, were metalized balloon satellites acting as passive reflectors of microwave signals. Communication signals were transmitted from one location on Earth and bounced off the surface of the satellite to another Earth location. The first transmissions using Echo were sent from Goldstone, California, to Holmdel, New Jersey on 12 August 1960. [Wikipedia]
100 ft = 30.48 m diameter; 1,600 km altitude

PAGEOS (PAssive Geodetic Earth Orbiting Satellite)
A balloon satellite launched by NASA in June 1966
100 ft = 30.48 m diameter; 4,000 km altitude; constellation of 46

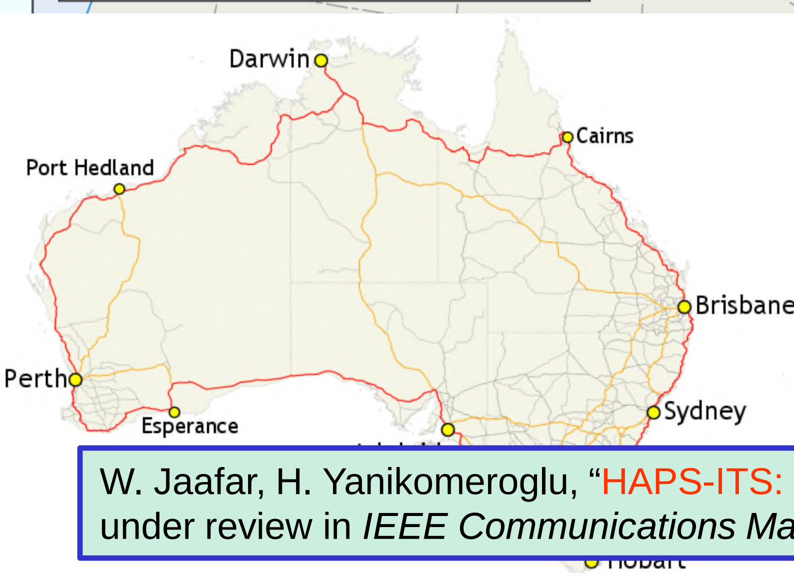
HAPS + Reconfigurable Smart Surfaces

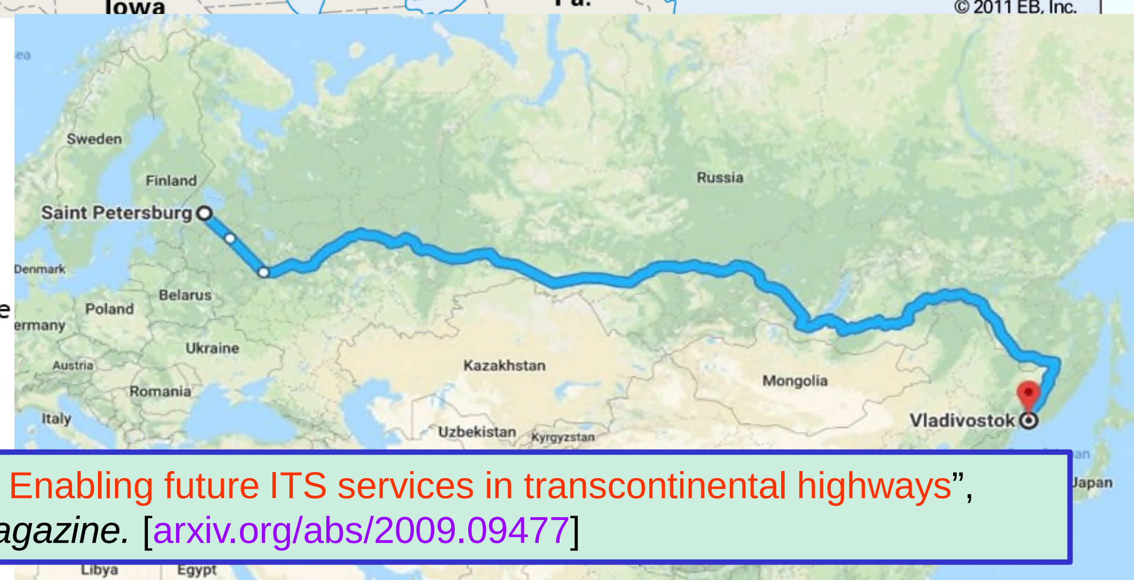


S. Alfattani, W. Jaafar, Y. Hmamouche, H. Yanikomeroglu, A. Yongacoglu, N.D. Dao, P. Zhu, "Aerial platforms with reconfigurable smart surfaces for 5G and beyond", *IEEE Communications Magazine*, Jan 2021. [ieeexplore.ieee.org/document/9356531]

S. Alfattani, W. Jaafar, Y. Hmamouche, H. Yanikomeroglu, A. Yongacoglu, "Link budget analysis for reconfigurable smart surfaces in aerial platforms", *IEEE Open Journal of Communications Society*, vol. 2, 2021. [ieeexplore.ieee.org/document/9518388]

HAPS-SMBS Constellation for Intelligent Transportation Systems





W. Jaafar, H. Yanikomeroglu, "HAPS-ITS: Enabling future ITS services in transcontinental highways", under review in *IEEE Communications Magazine.* [arxiv.org/abs/2009.09477]

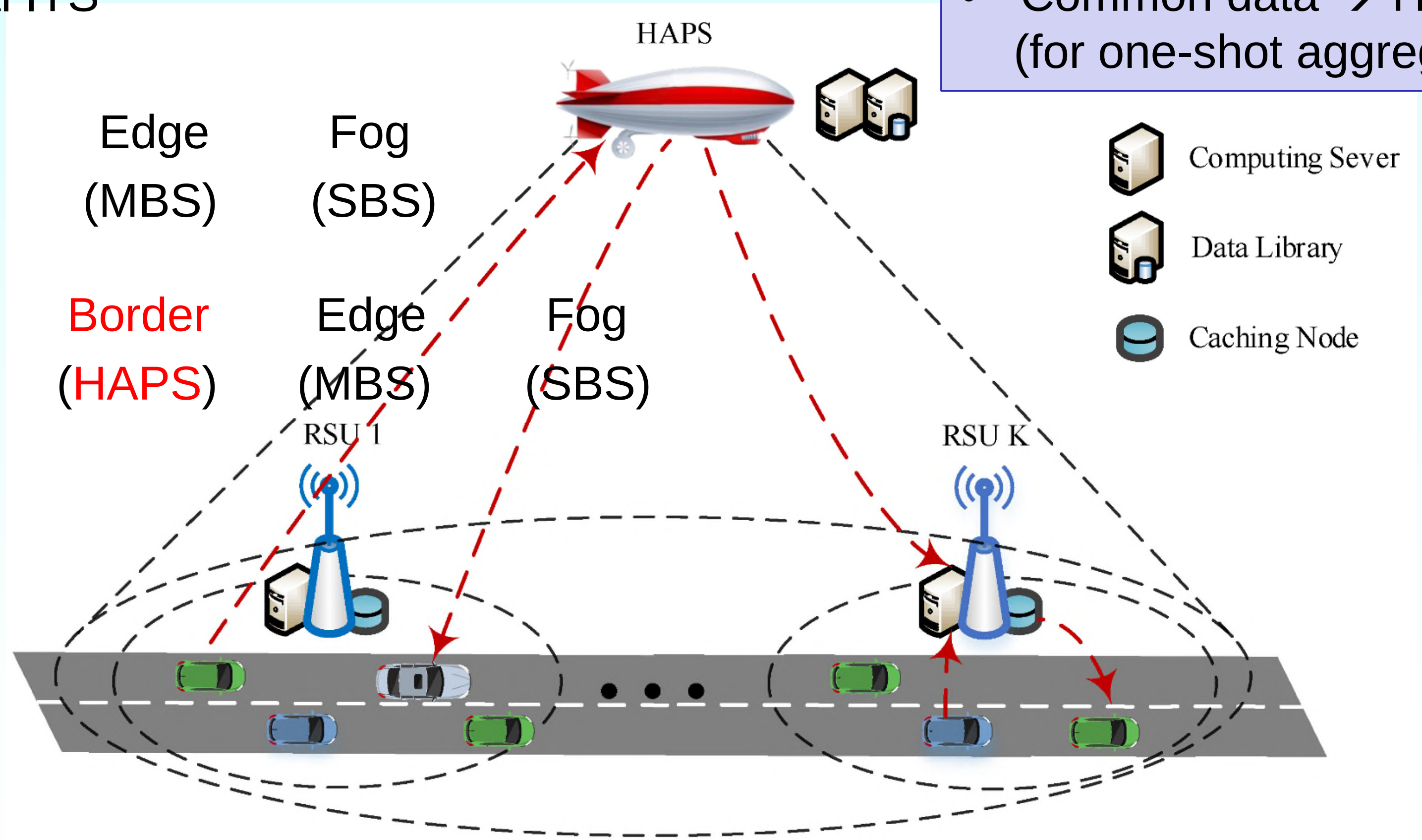
Edge Computing @ HAPS

- Terrestrial ITS
- Aerial ITS

Control plane → HAPS
User plane
- User-specific data → RSU
- Common data → HAPS (for one-shot aggregation)

- Core | Edge (MBS) | Fog (SBS)

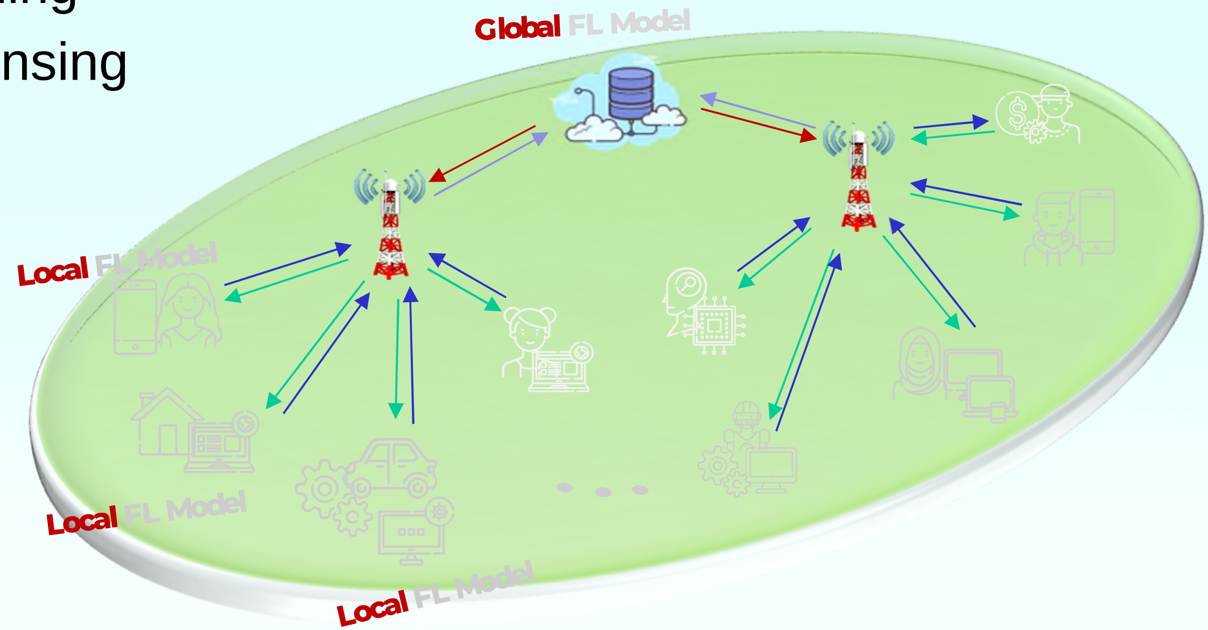
Core | Border (HAPS) | Edge (MBS) | Fog (SBS)



Q. Ren, O. Abbasi, G. Karabulut Kurt, H. Yanikomeroglu, J. Chen, "Caching and computation offloading in high altitude platform station (HAPS) assisted intelligent transportation systems", under review in *IEEE Transactions on Wireless Communications*. [arxiv.org/abs/2009.02771]

One-Shot Aggregation

Ex: Federated learning
Compressed sensing
Digital twin



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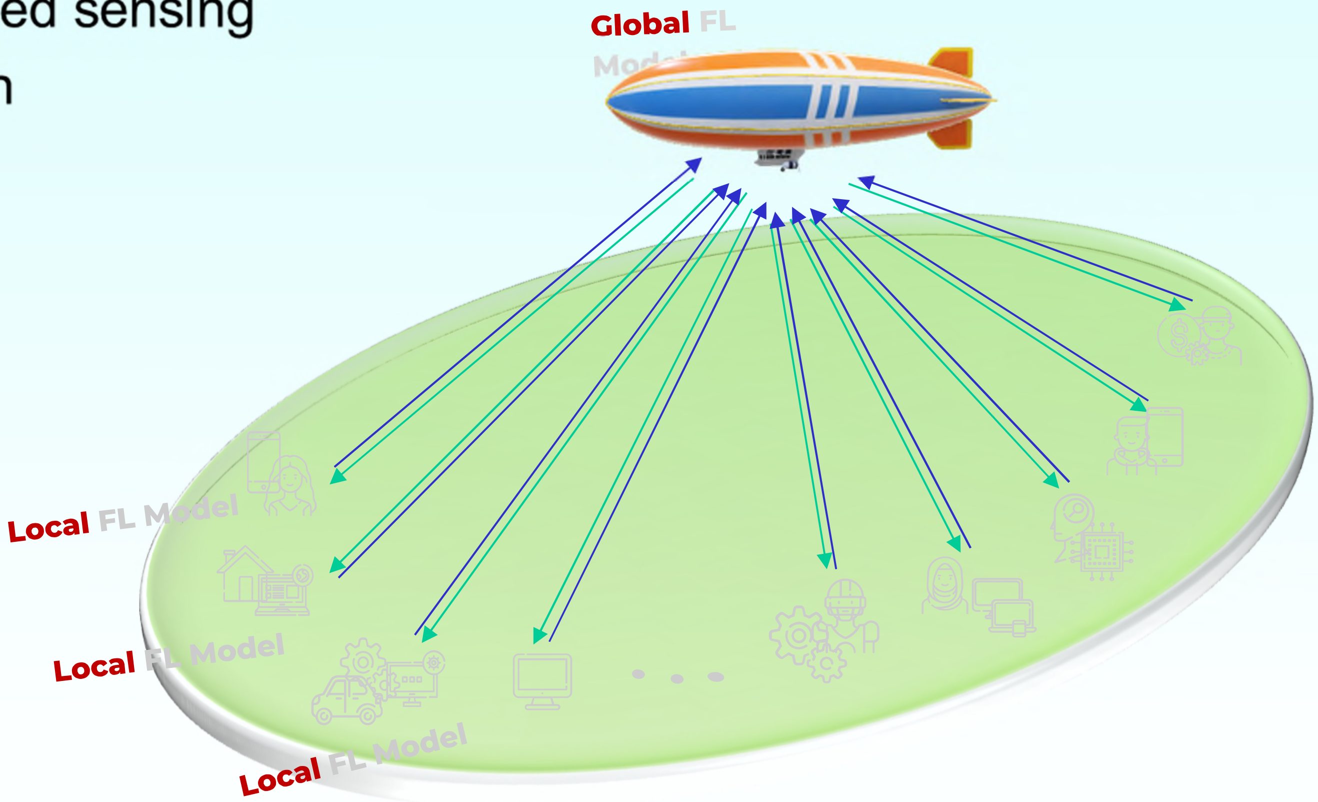
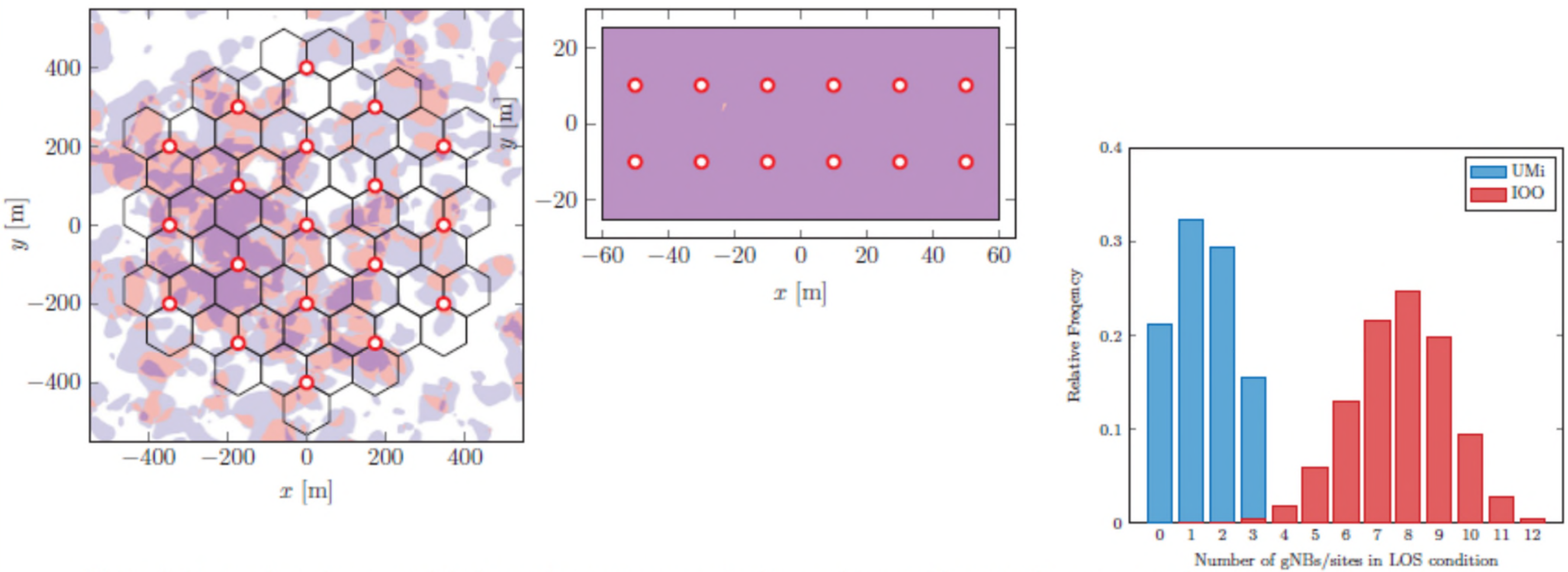


Localization

3GPP scenarios for 5G localization

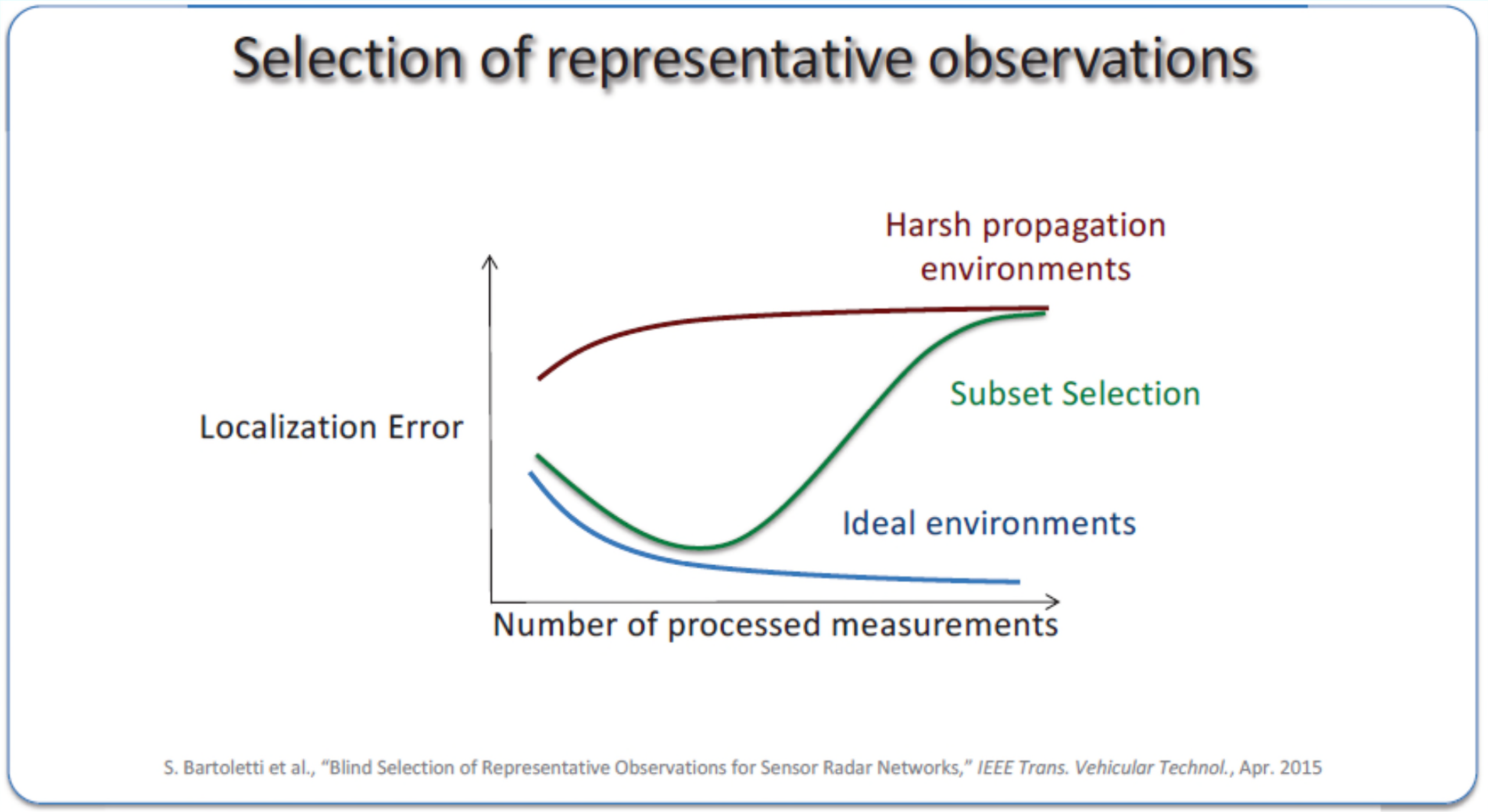
- **Examples:** urban micro (UMi) and indoor open office (IOO) [3GPP TR 38.855]



White, light purple, salmon, and dark purple areas correspond to positions with no anchors, one anchor, two anchors, and at least three anchors in LOS, respectively.

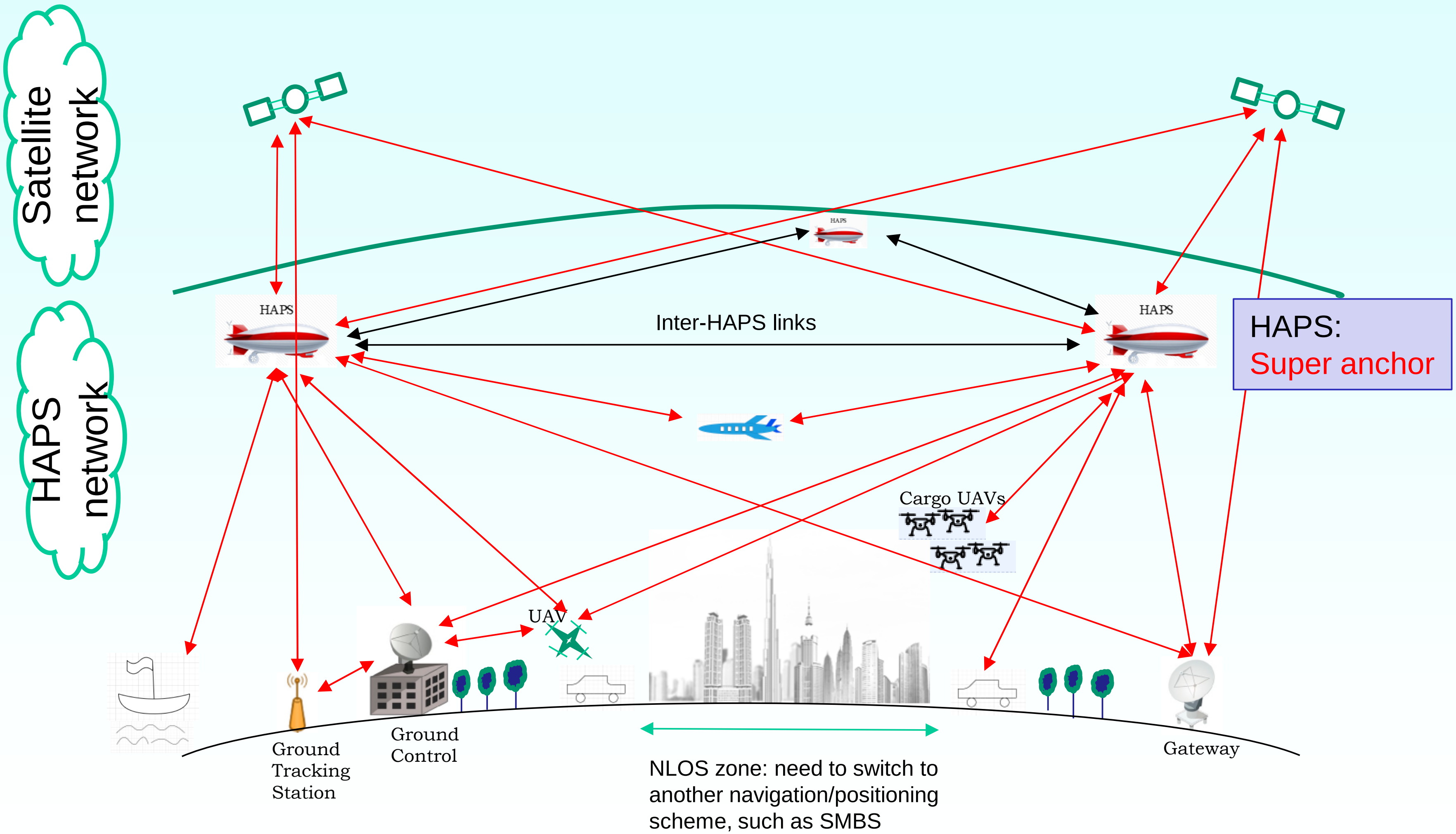
M.Z. Win, A. Conti, "Localization-of-Things: From Foundation to 5G Ecosystem", Tutorial, *IEEE ICC 2021*.

Localization

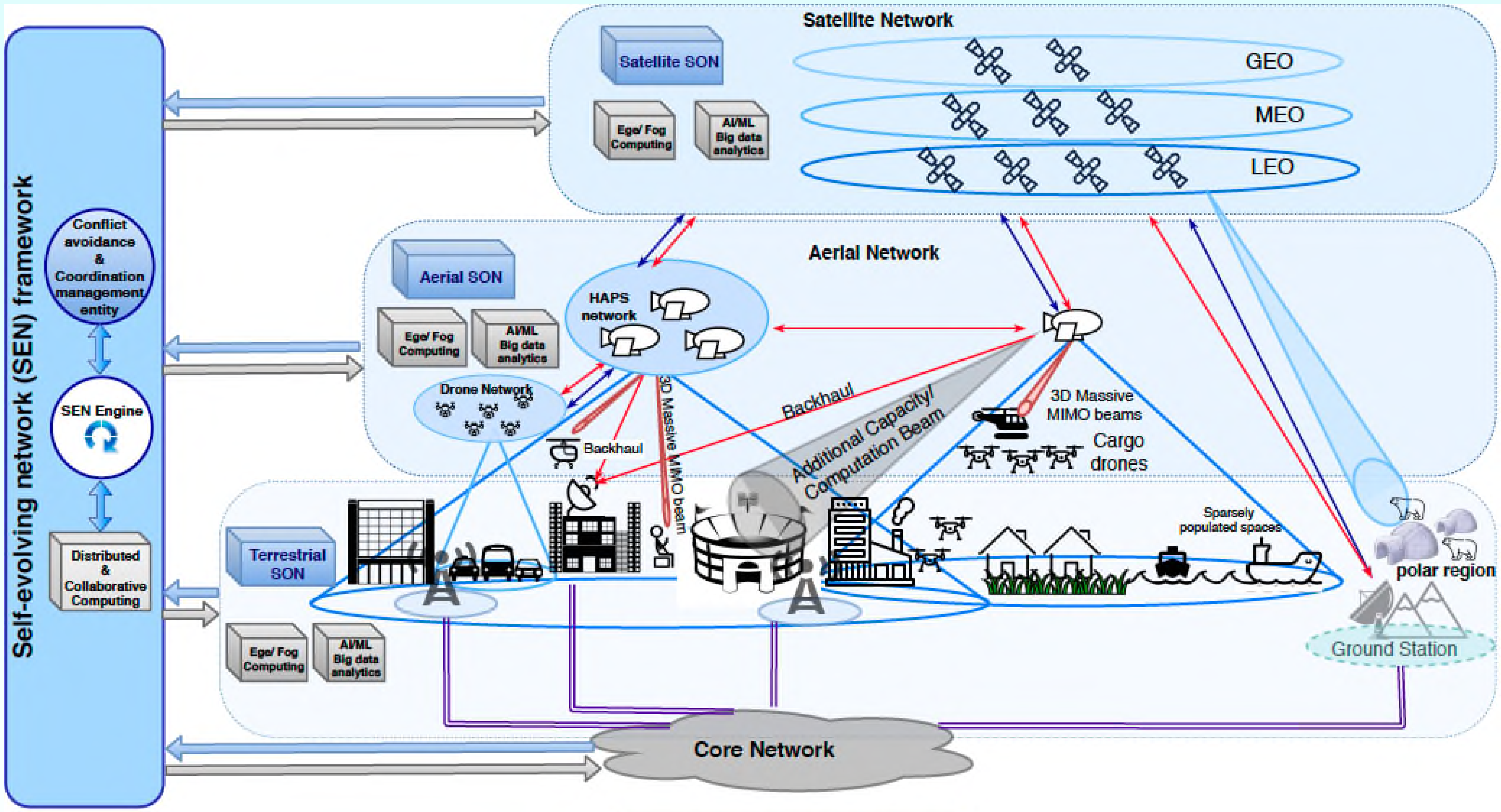


S. Bartoletti, A. Giorgetti, M.Z. Win, A. Conti, "Blind Selection of Representative Observations for Sensor Radar Networks", *IEEE Transactions on Vehicular Technology*, Apr 2015.

VHetNet for Localization / Navigation / Positioning



AI/ML for Control & Management



End-to-end SDN, NFV, slicing, inter-domain in a network of networks

T. Darwish, G. Karabulut Kurt, H. Yanikomeroglu, G. Senarath, P. Zhu, "A vision of self-evolving network management for future intelligent vertical HetNet", *IEEE Wireless Communications Magazine*, Aug 2021. [ieeexplore.ieee.org/document/9535454]

HAPS Features

- **Scalable**; no big upfront investment; can start with 1 HAPS, no need for 1000s of LEOs
- Easy to launch (just an open field)
- Deploy wherever necessary

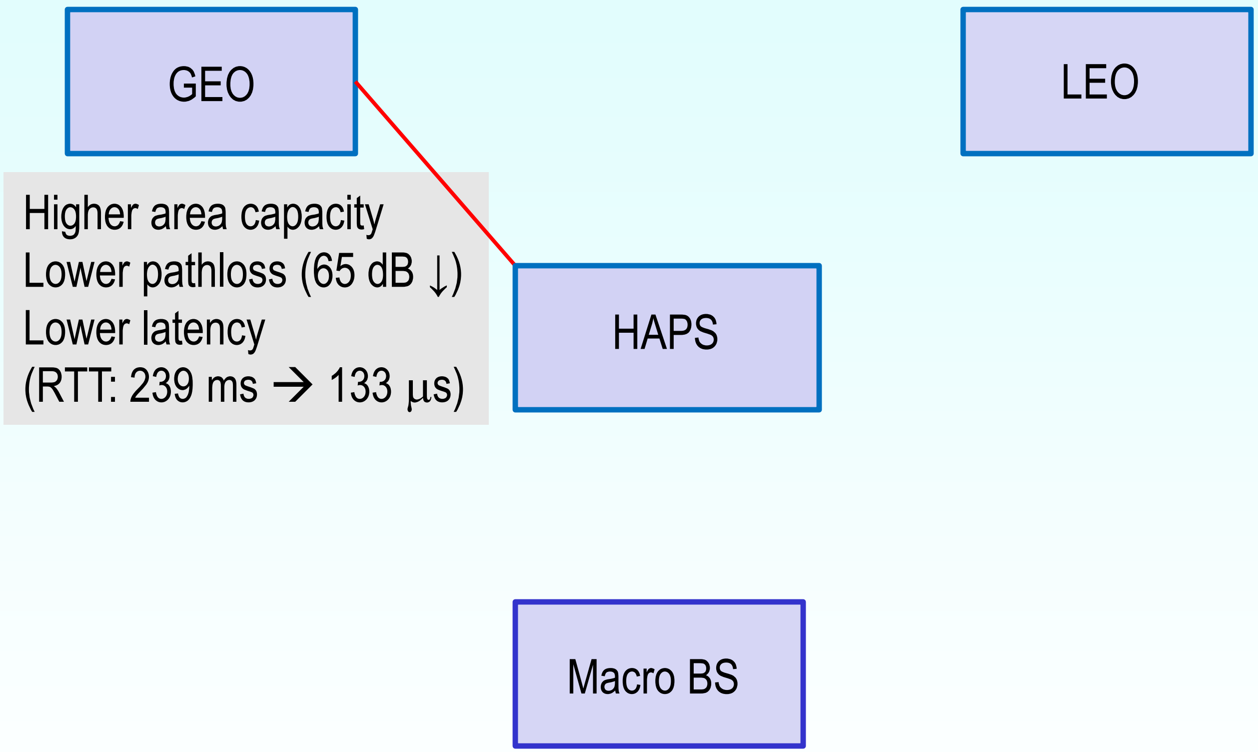
- **Evolutionary**; logical next level in multi-tier (V)HetNets, easy integration
- Owned by MNO, same/similar eco-system
- xG cellular air-interface (no need for dedicated air-interface)

- **Geostationary**
- No tracking on the ground
- No networking concerns (handoff, routing, addressing difficulties)

- **Closer to earth**
- Low latency
- Low pathloss: Direct link to UE
- Outdoors and indoors
- mmWave up to 100 GHz (high rates)

- **Legislation-friendly**; no data privacy concerns
- No international agreements, regularity barriers, spectrum rights

Is HAPS like a GEO or LEO or Macro BS?



Is HAPS like a GEO or LEO or Macro BS?

GEO

LEO

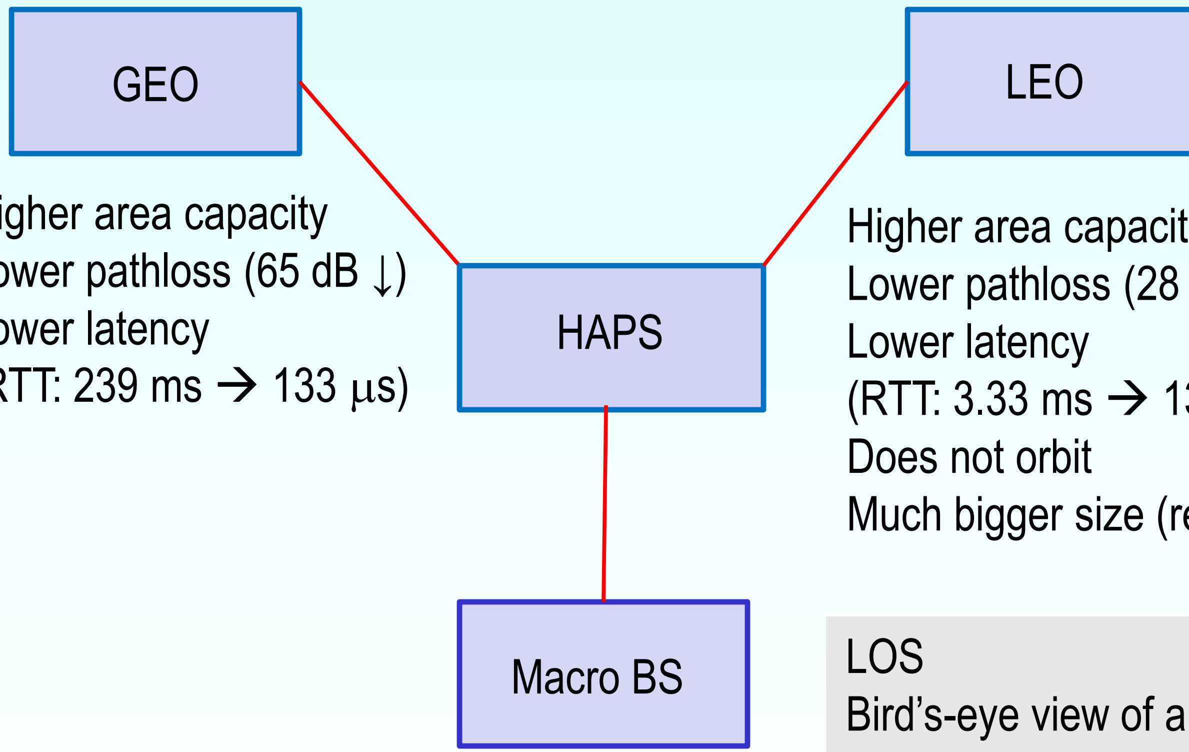
Higher area capacity
Lower pathloss (65 dB ↓)
Lower latency
(RTT: 239 ms → 133 μs)

HAPS

Higher area capacity
Lower pathloss (28 dB ↓)
Lower latency
(RTT: 3.33 ms → 133 μs)
Does not orbit
Much bigger size (real estate)

Macro BS

Is HAPS like a GEO or LEO or Macro BS?



GEO:
Higher area capacity
Lower pathloss (65 dB ↓)
Lower latency
(RTT: 239 ms → 133 μs)

LEO:
Higher area capacity
Lower pathloss (28 dB ↓)
Lower latency
(RTT: 3.33 ms → 133 μs)
Does not orbit
Much bigger size (real estate)

Macro BS:
LOS
Bird's-eye view of a large area
One-shot
Pathloss *may be* lower
Ex: $(20,000)^2/(1000)^3 = 0.4$
Ex: $(20,000)^2/(100)^4 = 4$

Is HAPS like a GEO or LEO or Macro BS?

GEO

Higher area capacity
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HAPS

Macro BS

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Bird's-eye view of a large area
One-shot
Pathloss *may be* lower
Ex: $(20,000)^2/(1000)^3 = 0.4$
Ex: $(20,000)^2/(100)^4 = 4$

Most things that GEO/LEO can do can be achieved by HAPS (even better)

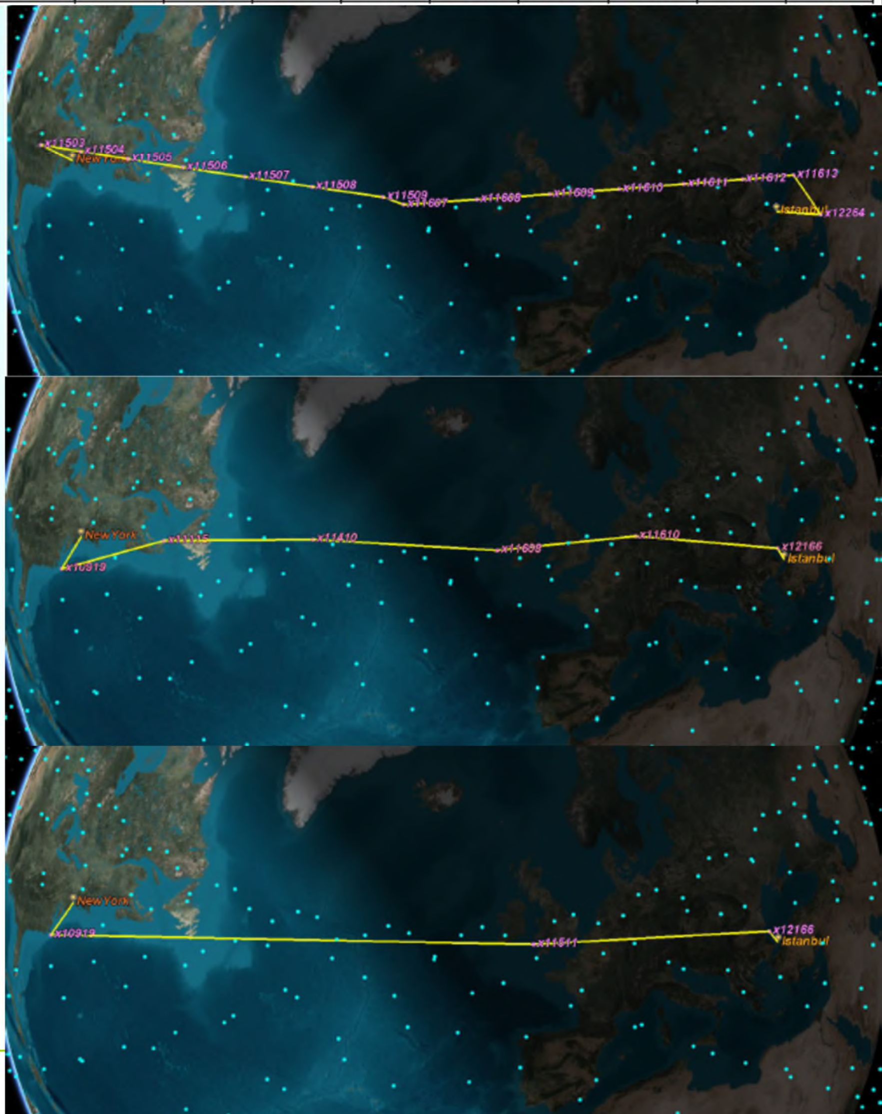
Most things that Macro BS can do can be achieved by HAPS (even better)

Certain things that neither GEO/LEO nor Macro BS can do, can be achieved by HAPS

LEO Constellation Advantage
RTT in Long-Haul Links

LISL Range (km)	Average Number of Hops and Average Network Latency											
	New York–London				New York–Istanbul				New York–Sydney			
	n_{hop}	d_{prop} (ms)	d_{node} (ms)	d_{total} (ms)	n_{hop}	d_{prop} (ms)	d_{node} (ms)	d_{total} (ms)	n_{hop}	d_{prop} (ms)	d_{node} (ms)	d_{total} (ms)
659.5	10.35	23.49	10.35	33.84	14.91	33.19	14.91	48.10	28.83	63.46	28.83	92.29
1,319	5.00	21.65	5.00	26.65	7.00	30.99	7.00	37.99	14.13	60.57	14.13	74.70
1,500	4.99	21.63	4.99	26.63	7.00	30.89	7.00	37.89	13.71	60.03	13.71	73.75
1,700	4.17	21.68	4.17	25.86	6.00	30.93	6.00	36.93	12.97	59.98	12.97	72.95
2,500	3.03	21.58	3.03	24.61	4.83	30.76	4.83	35.59	8.48	59.85	8.48	68.32
5,016	2.00	21.33	2.00	23.33	3.00	30.45	3.00	33.45	5.00	58.55	5.00	63.55

- Laser links: More efficient than RF links
- Acquisition, tracking, pointing (ATP)
- Number and range of LISLs
- Latency analysis (round trip time)
- Substantial reduction in long-haul round trip time (ex: New York – Istanbul)



A.U. Chaudhry, H. Yanikomeroglu, "Laser inter-satellite links in a Starlink constellation: A classification and analysis", *IEEE Vehicular Technology Magazine*, Jun 2021.

A.U. Chaudhry, H. Yanikomeroglu, "Optical wireless satellite networks versus optical fiber terrestrial networks: The latency perspective", *Invited Paper, Biennial Symposium on Communications (BSC)*, Jun 2021.

A.U. Chaudhry, H. Yanikomeroglu, "Free space optics for next-generation satellite networks", to appear in *IEEE Consumer Electronics Magazine.*

A.U. Chaudhry, G. Lamontagne, H. Yanikomeroglu, "Laser inter-satellite link range in free-space optical satellite networks: Impact on latency", under review in *IEEE Network Magazine*.

A.U. Chaudhry, H. Yanikomeroglu, "When to crossover from Earth to space for lower latency data communications?", under review in *IEEE Trans. Aerospace and Electronic Systems.*

AI-enabled Satellite Communication Networks

- Distributed Handover Management in Satellite Networks
- Data Packets Routing in Satellite Networks
- Laser Inter-Satellite Links (LISLs) in Satellite Networks

Dr. Halim Yanikomeroglu
Professor

Dr. Gunes Karabulut Kurt
Professor

Dr. Tasneem Darwish (PDF)
Dr. Mohammed Abdelsadek (PDF)
Dr. Aizaz Chaudhry (Senior Research Associate)
Dr. Jean-Daniel Medjo Me Biomo (PDF)
Dhiraj Bhattacharjee (PhD student)
Mohamed Hozayen (MASc student)
Jintao Liang (MASc student)

Agenda

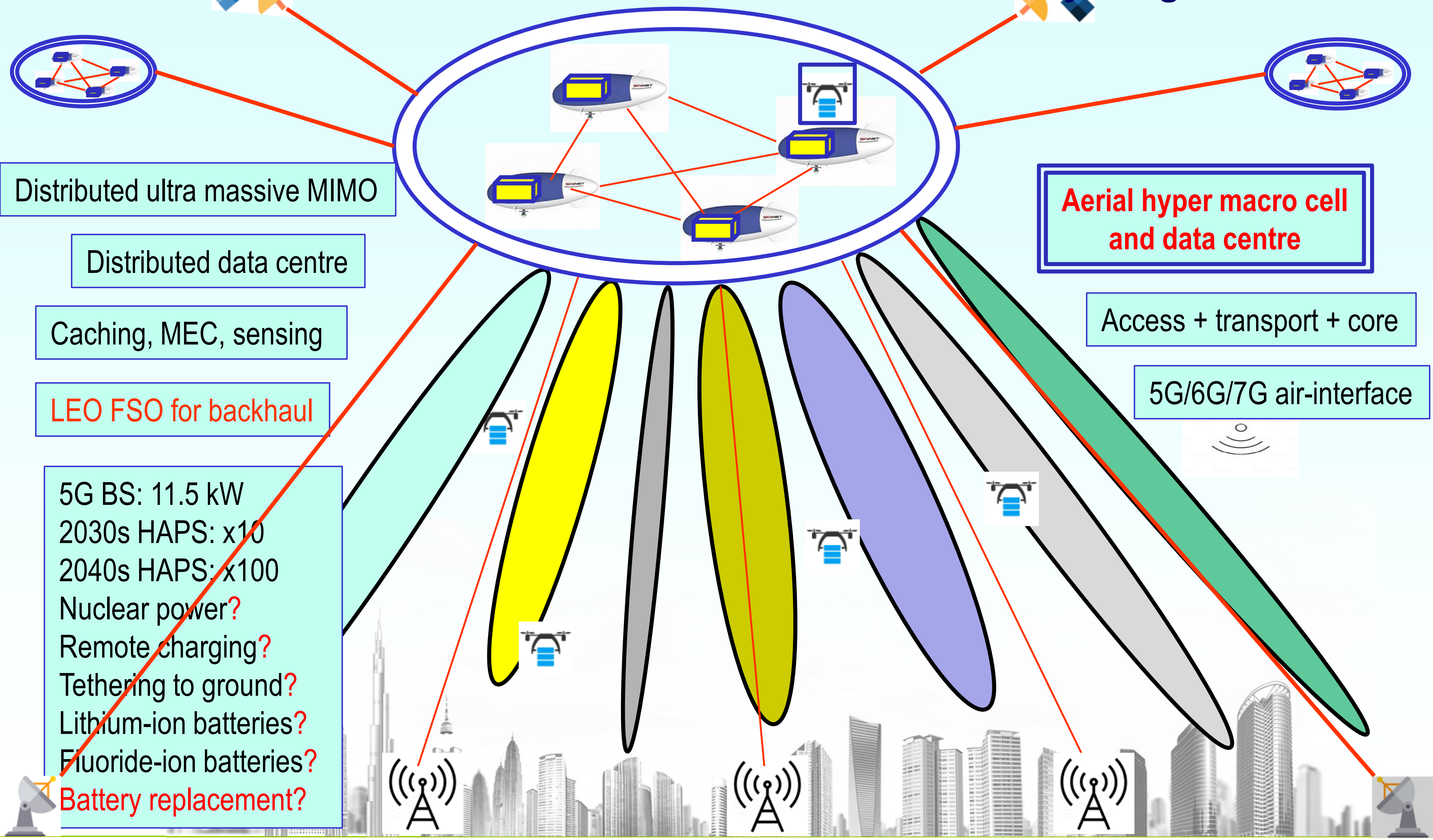
- Concepts and Terminology
- High Throughput Satellites (HTS)
- High Altitude Platform Stations (HAPS) Systems
- VHetNet for Integrated Communications, Computing, Caching, Sensing, Navigation, Positioning, …
- 2040 Outlook

Towards HAPS Networks: Major Challenges

- Endurance
- Energy
- ICT

T. Tozer, D. Grace, "High-altitude platforms for wireless communications", *Electronics & Communication Engineering Journal*, Jun 2001.

HAPS Constellations of the Future – Platform for Everything



HAPS Networks Research @ Carleton: Concept and Vision Papers 2021

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G. Kurt, M.G. Khoshkholgh, S. Alfattani, A. Ibrahim, T.S.J. Darwish, Md S. Alam, H. Yanikomeroglu, A. Yongacoglu, "A vision and framework for the high altitude platform station (HAPS) networks of the future", *IEEE Communications Surveys and Tutorials*, Q2 2021. [ieeexplore.ieee.org/document/9380673]

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W. Jaafar, H. Yanikomeroglu, "HAPS-ITS: Enabling future ITS services in trans-continental highways", under review in *IEEE Communications Magazine*. [arxiv.org/abs/2105.04756]

LOOKING FORWARD TO DISCUSSION & COLLABORATION

halim@sce.carleton.ca

https://www.youtube.com/channel/UCE7CGxWVxDbRFJUO-inSDOA

https://www.sce.carleton.ca/faculty/yanikomeroglu.html