HAPS Networks in Urban Regions

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Carleton U's global ranking in telecom engineering: #28



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Alouette 1 Satellite Programme National Historic Event

Ottawa, Ontario

Drs. Nelms & Chapman toasting Alouette 1
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Address : 3701 Carling Avenue, Ottawa, Ontario

Recognition Statute: Historic Sites and Monuments Act (R.S.C., 1985, c. H-4)
Designation Date: 2007-06-08

Other Name(s): Alouette 1 Satellite Programme (Designation Name)
Research Report Number: 2006-024, 2008-SCD/CED-020, 2008-043
Importance: Enabled Canada to be the third country in the world to design and build a successful satellite

Plaque(s)

Existing plaque: 3701 Carling Avenue, Ottawa, Ontario
Alouette 1 was launched on September 29, 1962, making Canada the third country in the world to design and build a satellite. The data gathered during its ten-year lifespan greatly extended our knowledge of the ionosphere and the Earth's upper atmosphere, and validated the innovative design and stringent testing used in its development. Conceived by a team of engineers and scientists at the Defence Research Telecommunications Establishment, Alouette 1 was a scientific success and an engineering feat that enabled the space programme to prosper and contributed to the emergence of a Canadian space industry.

Project SHARP (Stationary High Altitude Relay Platform) by CRC

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Summary report on SHARP (Stationary High Altitude Relay Platform). Part A, Technical feasibility of microwave-powered airplanes / by G.W. Jull.

"The SHARP (Stationary High Altitude Relay Platform) system concept envisages use of high altitude microwave-powered airplanes as platforms to relay telecommunications signals. The concept takes advantage of microwave power transmission developments associated with the Solar Power Satellite and High Altitude Powered Platform concepts and adapts these to Canadian needs. Microwave power would be transmitted from a large ground antenna system to an unmanned airplane circling at about 21 km. This power would be converted to dc power using rectennas on lower surfaces of the airplane. The dc power would drive lightweight electric motors. Over the period 1981 to 1984, the Radar and Communications Technology Branch of DOC carried out a series of background research activities on technologies associated with SHARP. ... This report summarizes principal results and conclusions of the research and assessment studies as related to microwave powering of high altitude unmanned airplanes. Other studies defined telecommunications missions and assessed their commercial viability"--Abstract, page 1.

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MARC XML format MARC HTML format

Publication information

Department/Agency	Communications Research Centre (Canada), issuing body.
Title	Summary report on SHARP (Stationary High Altitude Relay Platform). Part A, Technical feasibility of microwave-p by G.W. Jull.
Series title	CRC report ; no. 1393
Publication type	Series - View Master Record
Language	[English]

NTN for Accelerating Canada's Ubiquitous Connectivity and Digital Future (NTN-CAN)

Infrastructure Fund (applied): $13,500,000

Universities | Government | Industry | Non-profits

Carleton University

POLYTECHNIQUE MONTRÉAL
UNIVERSITÉ D'INGÉNIERIE

uOttawa

CRC

NRC·CNRC Canada

The Canadian Academy of Engineering
L'Académie canadienne du génie

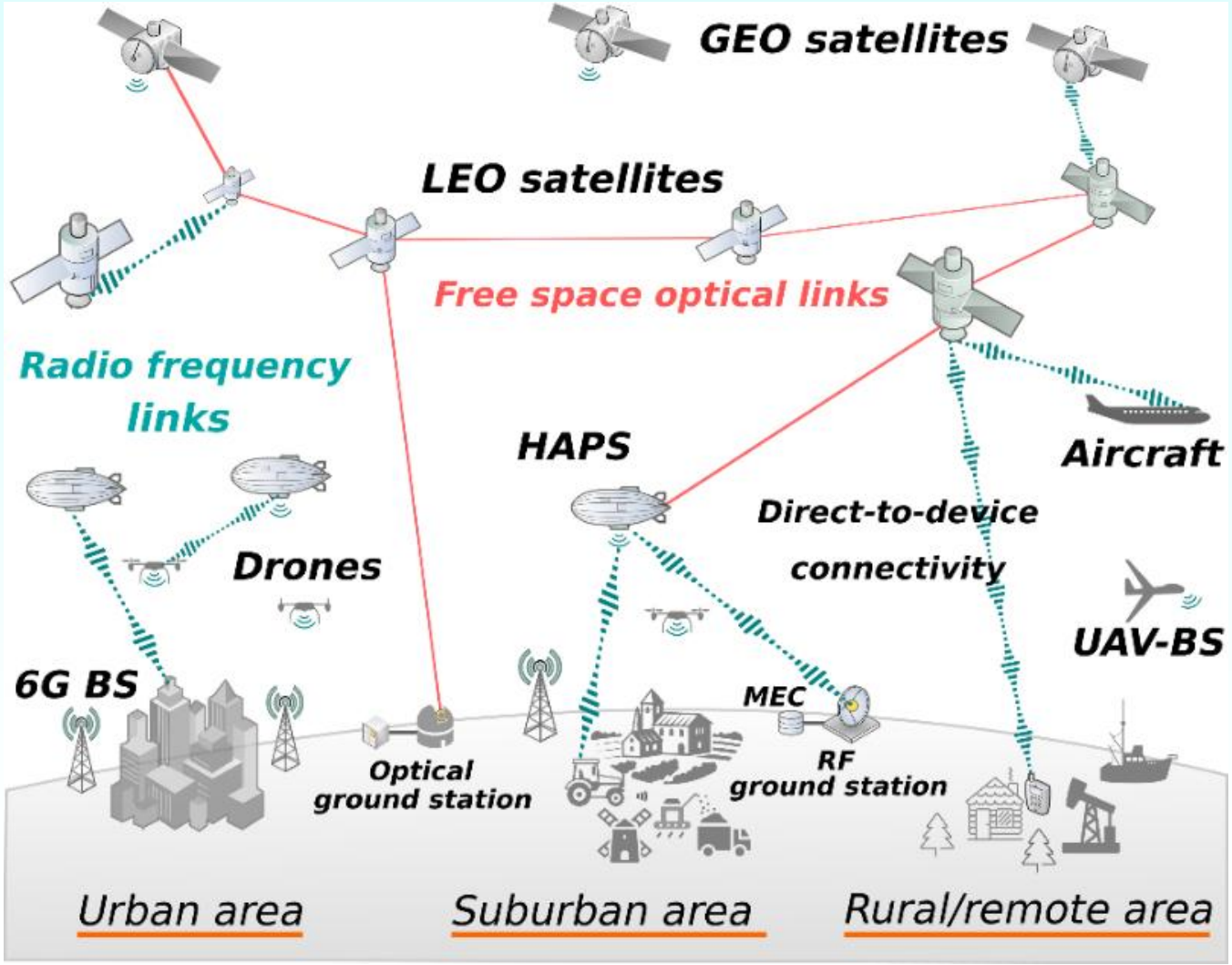
MDA SPACE

TELESAT

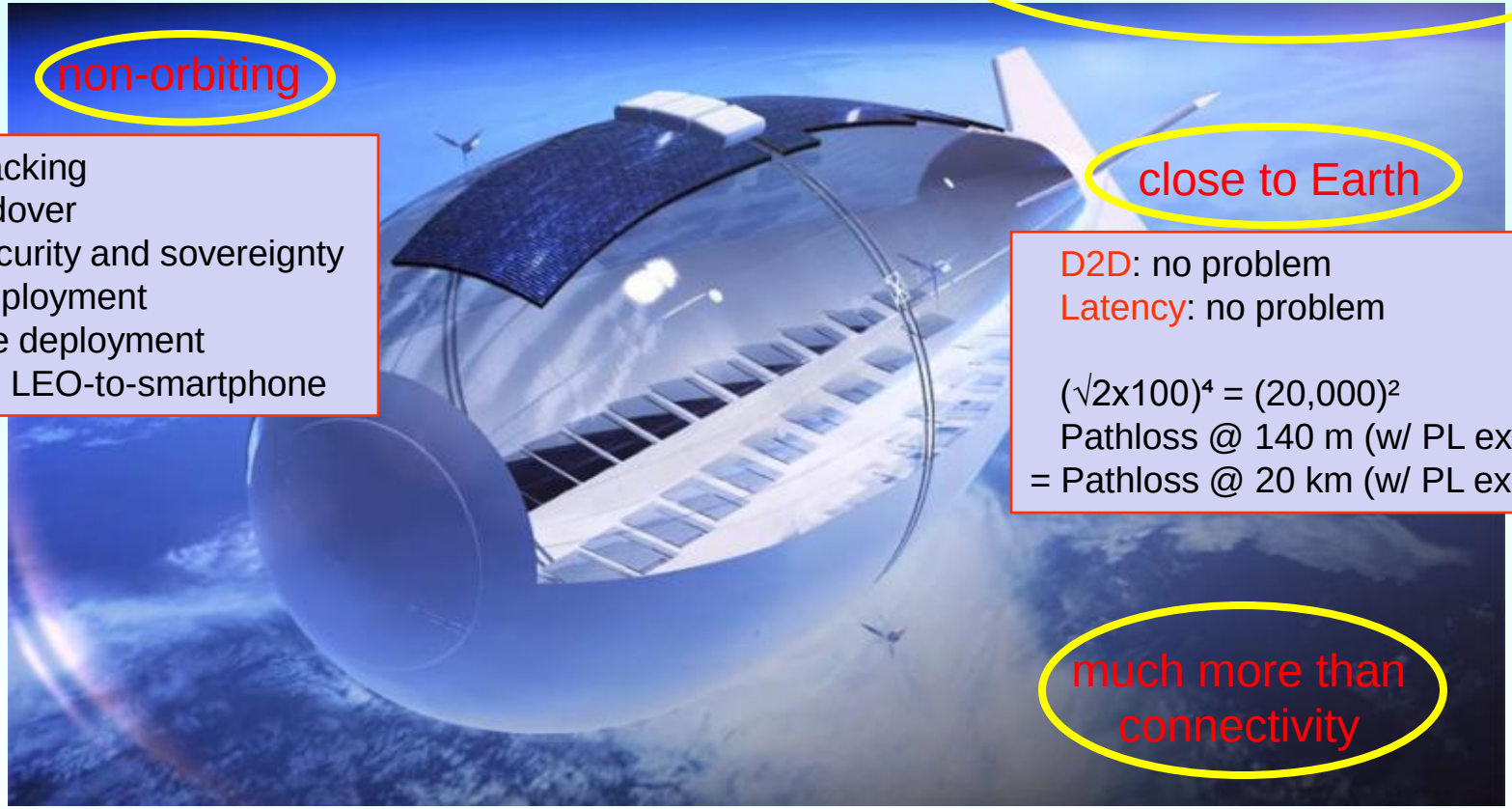
Honeywell AEROSPACE

ERICSSON

NTN-CAN Reference Architecture



HAPS: High Altitude Platform Station -- Urban/Suburban Regions



- Easy tracking
- No handover
- Data security and sovereignty
- Easy deployment
- Scalable deployment
- Relay in LEO-to-smartphone

D2D: no problem
Latency: no problem

$(\sqrt{2}\times100)^4 = (20{,}000)^2$
Pathloss @ 140 m (w/ PL exp = 4)
= Pathloss @ 20 km (w/ PL exp = 2)

HAPS: Super Macro Base Station in Stratosphere (20 km)

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.

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.

Imaging for Intelligence, Surveillance, and Reconnaissance (ISR)

Launch Complex 39A (with Polaris Dawn)

A very high resolution satellite image of SpaceX's Launch Complex 39A with the Polaris Dawn Falcon 9 standing vertical on the launch pad.

Date: September 6, 2024

Satellite Provider: Airbus

Satellite: Pleiades NEO-4

620 km

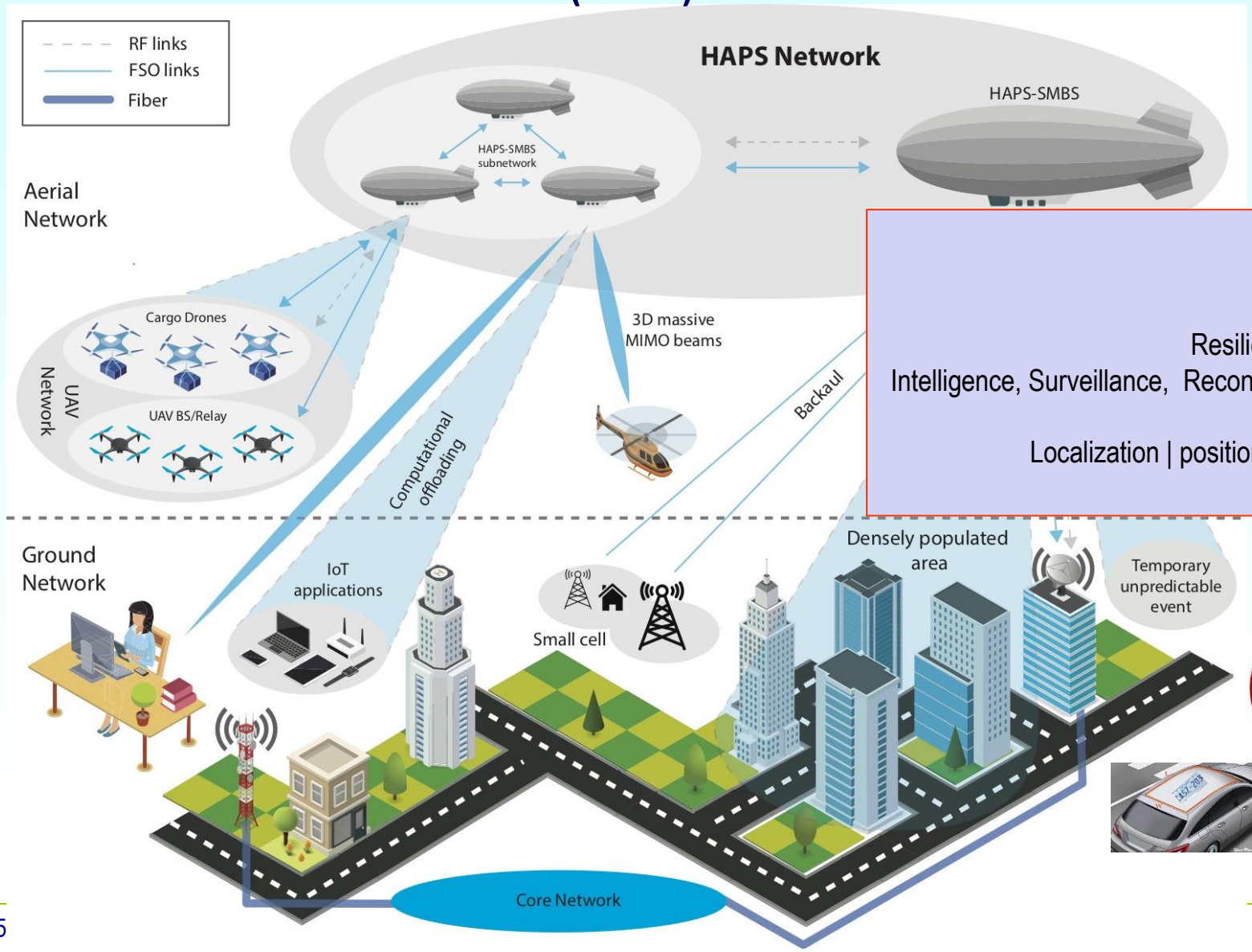
Resolution: 30cm/pixel

- 2025 – Pleiades NEO @ 620 km: 30 cm/pixel (GSD)
- 2025 – Spy satellites @ 160-250 km: 5-10 cm/pixel (GSD)
- 2030s & 2040s – HAPS with bigger, AI-aided, ultra-cameras @ 20 km: few mm/pixel? (GSD)

UND SOaRS 2025 | St. Paul, Minnesota

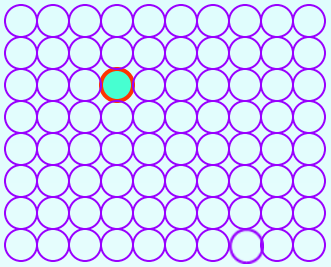
HAPS Networks in Urban Regions

Terrestrial BSs + HAPS BSs (HIBS) in Urban/Suburban Areas

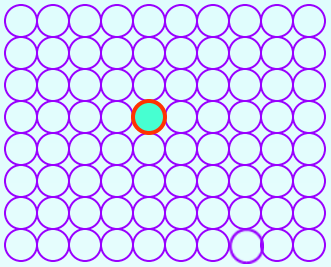


Connectivity
Edge
Data centre
Resilient | sustainable
Intelligence, Surveillance, Reconnaissance (ISR)
Sensing
Localization | positioning | navigation
-- and more

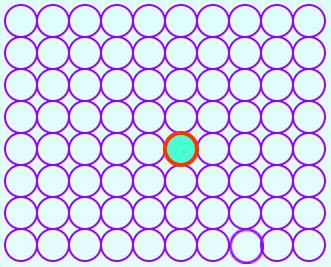
Brute-Force Solution: Blind Densification (Worst-Case Solution)



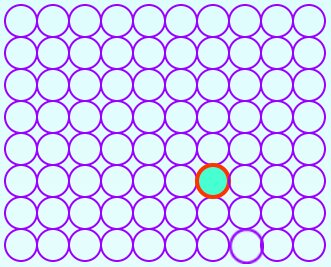
Brute-Force Solution: Blind Densification (Worst-Case Solution)



Brute-Force Solution: Blind Densification (Worst-Case Solution)



Brute-Force Solution: Blind Densification (Worst-Case Solution)



Current design: for the worst case

→ Over-engineering, over-provisioning
→ High CAPEX and/or high OPEX
→ High user fees, high carbon footprint
→ Not green, not sustainable, not aligned with UN SDGs





Current design: for the worst case

→ Over-engineering, over-provisioning
→ High CAPEX and/or high OPEX
→ High user fees, high carbon footprint
→ Not green, not sustainable, not aligned with UN SDGs


Efficient ways of distributing and collecting radio (wireless) signals?

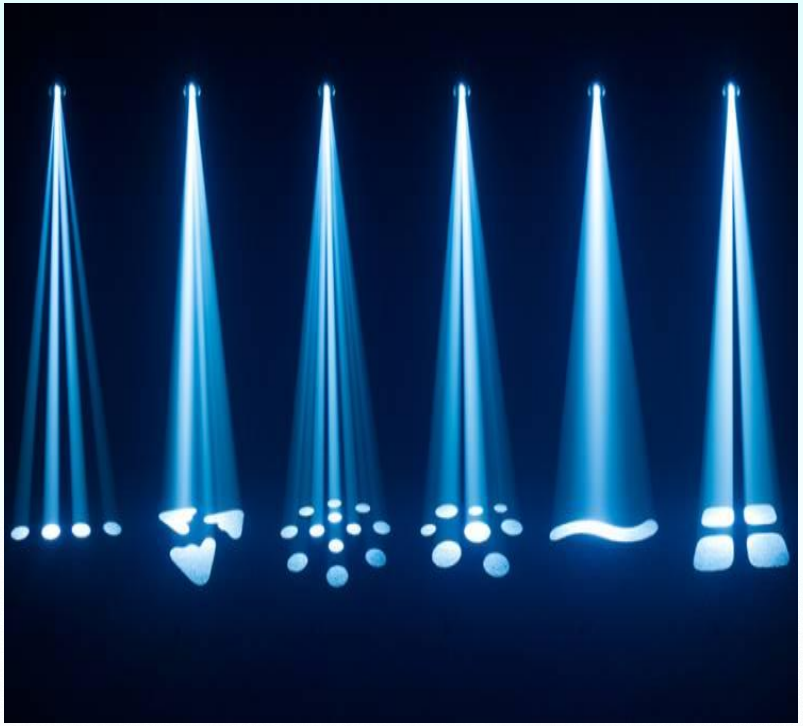
A highly dynamic, agile, green & sustainable architecture | infrastructure



Ubiquitous & Instantaneous Hotspot – Anytime, Anywhere, Affordable

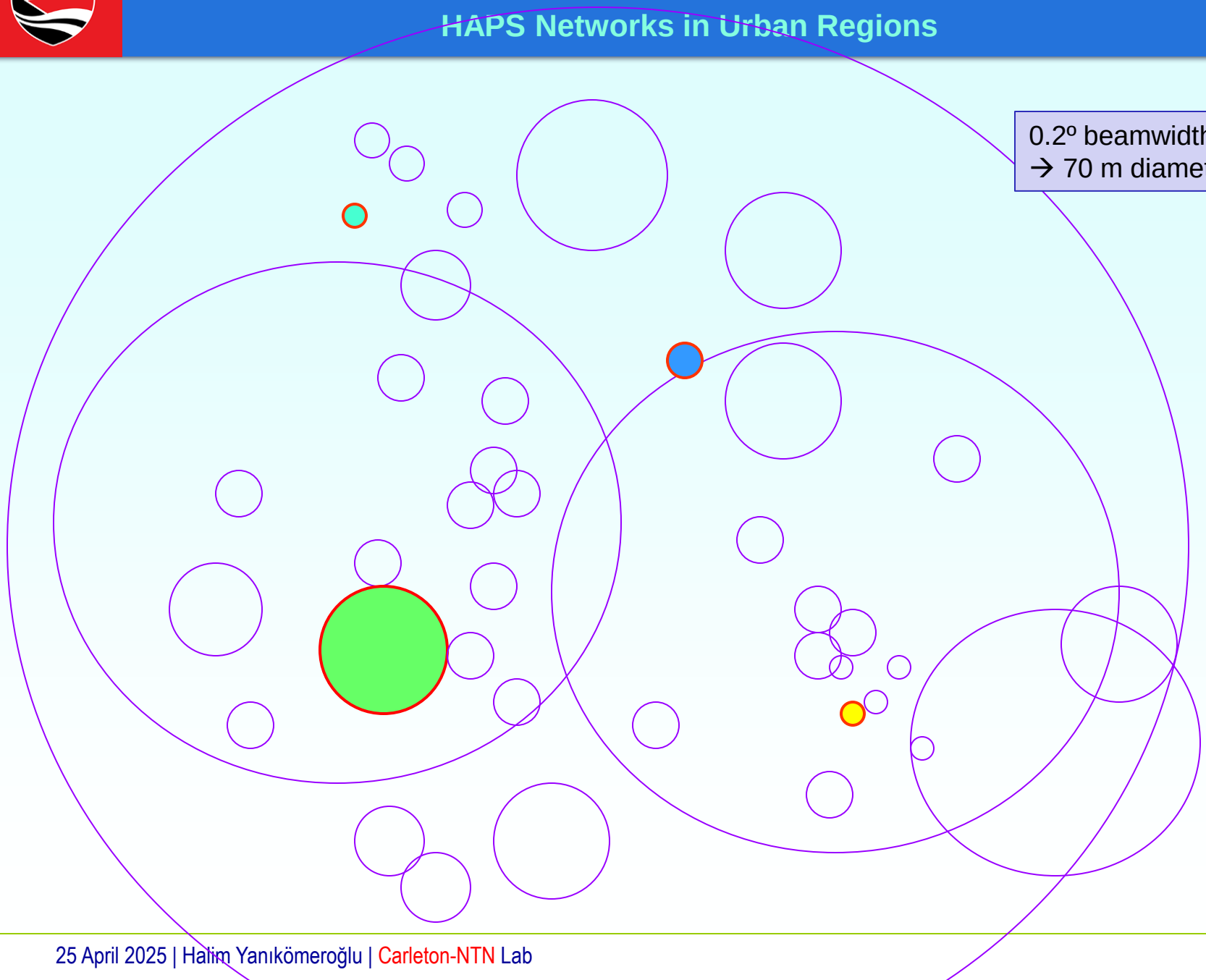
20 km

HAPS: High Altitude Platform Station



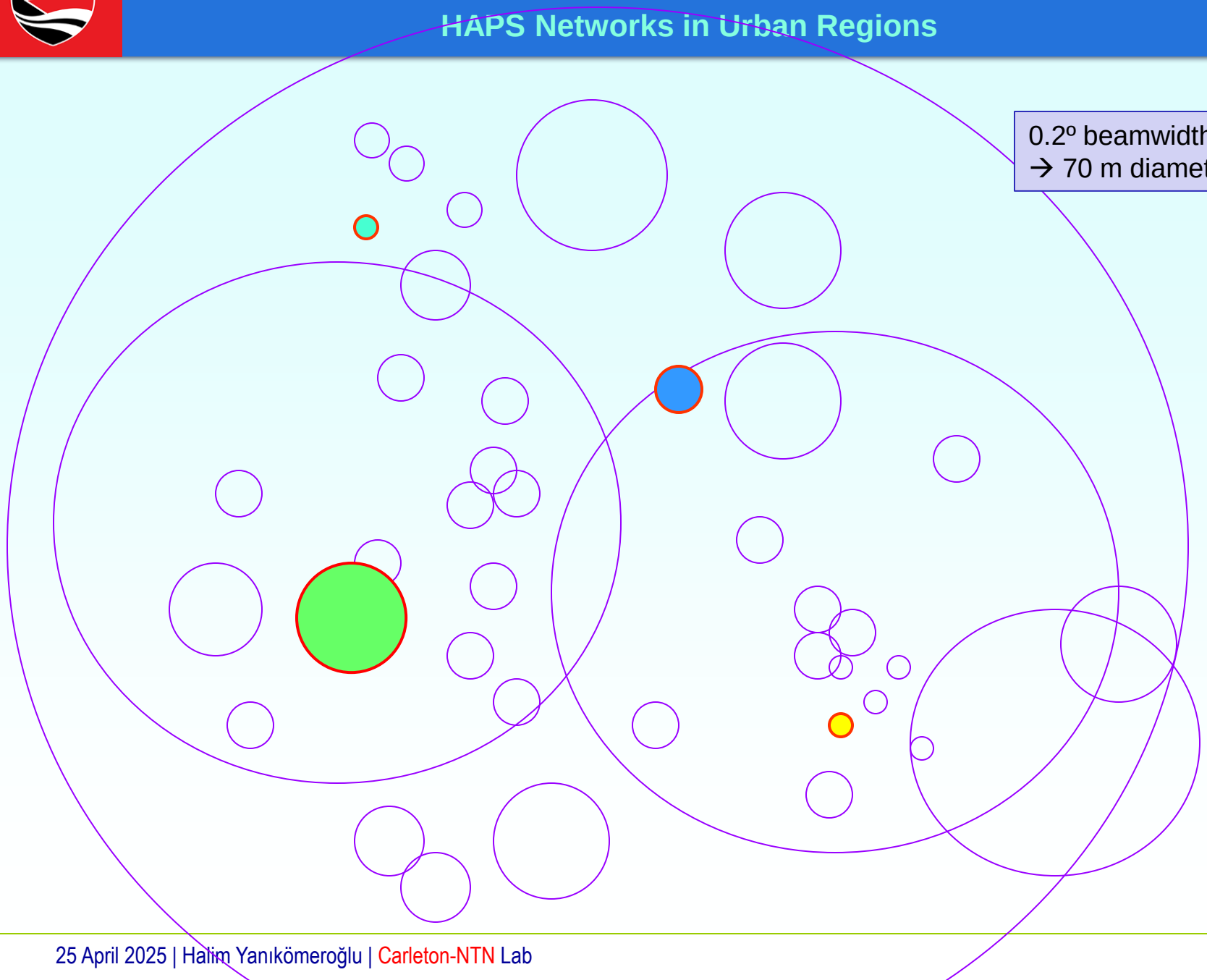
centralized massive access capacity provided through dynamic beams wherever necessary, whenever necessary

HAPS Networks in Urban Regions



0.2º beamwidth @ 20 km
→ 70 m diameter hotspot

HAPS Networks in Urban Regions



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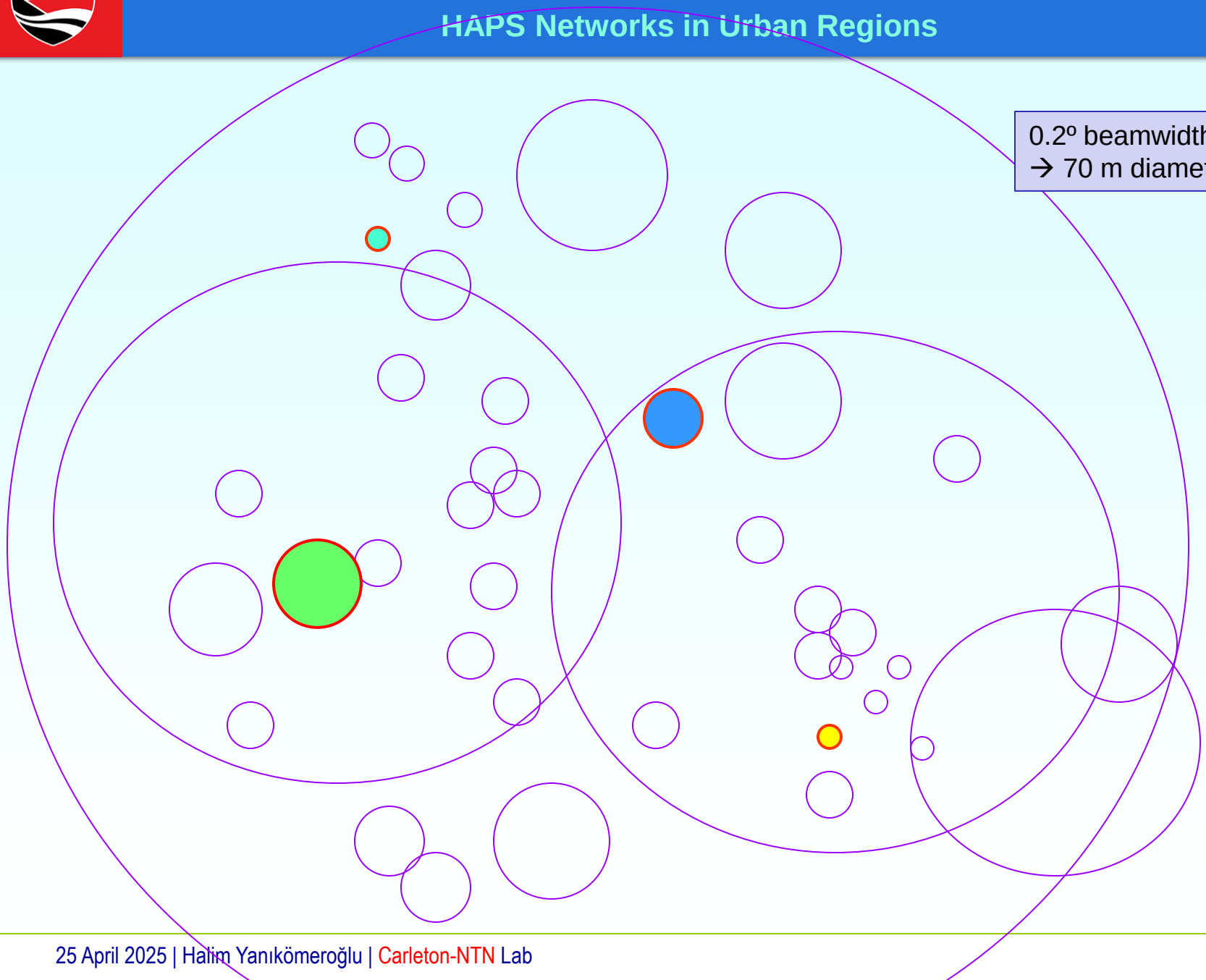
HAPS Networks in Urban Regions



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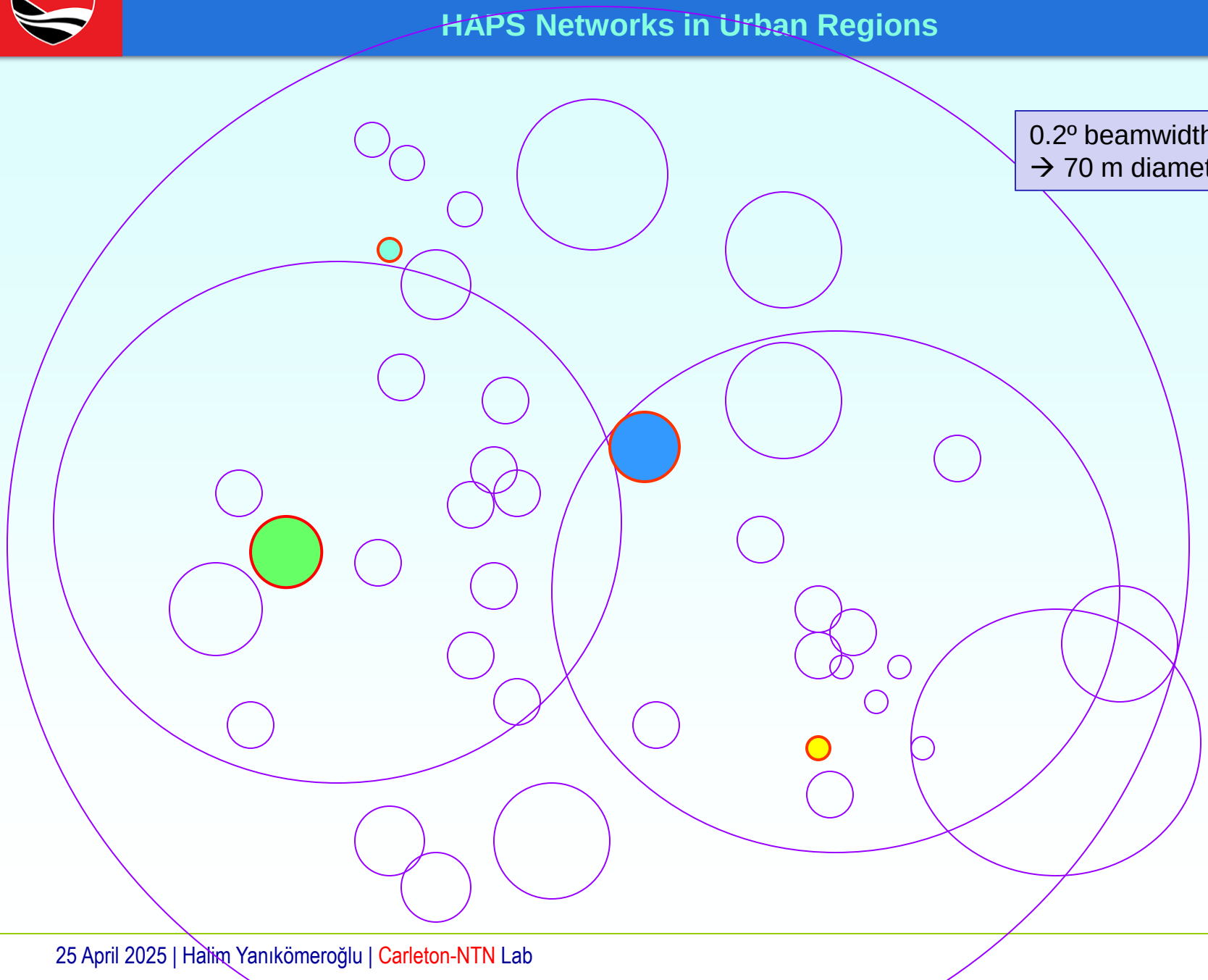
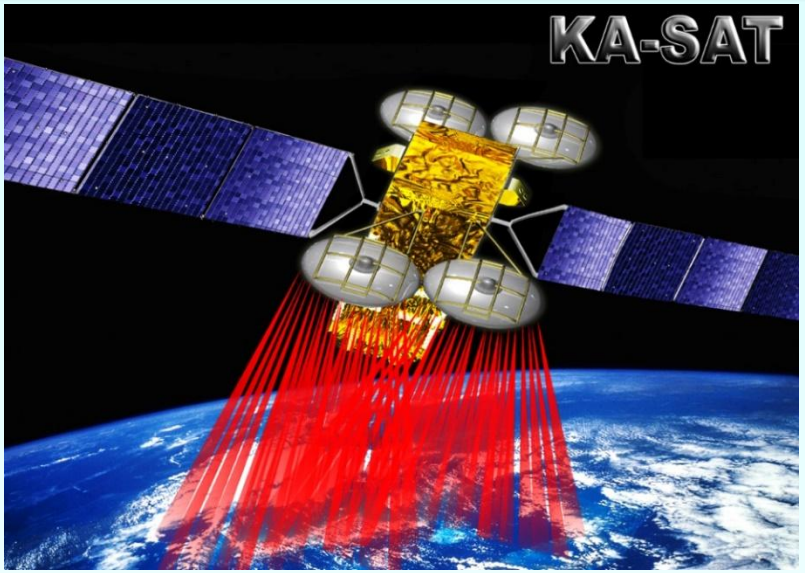
HAPS Networks in Urban Regions



0.2º beamwidth @ 20 km
→ 70 m diameter hotspot

HAPS Super Macro BS: 100 Tb/s



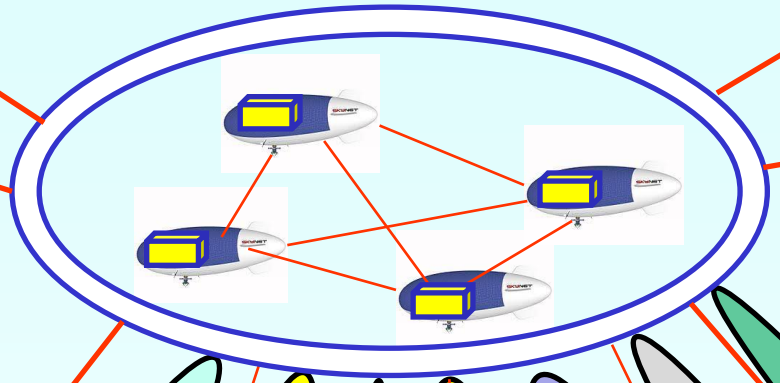
2000–2010: 3G 1 M
2010–2020: 4G 100 M
2020–2030: 5G 10 G
2030–2040: 6G 1 T
2040–2050: 7G 100 T

100x per G

GEO HTS 2025: 1,000+ beams → >1 Tb/s @ 35,786 km
HAPS 2040-2050: 10,000 beams → 100 Tb/s @ 20 km

Best practices from SatNets and terrestrial networks → HAPS networks

HAPS-enabled Wireless Infrastructure towards 2050



Integrated terrestrial – HAPS – LEO network: VHetNet

Access + backhaul + edge + transport + core + spectrum + optical → infrastructure

Integrated communications, computing, sensing, navigation, positioning, …

10,000 – 100,000+ HAPS

Transformative

Distributed massive antenna architecture

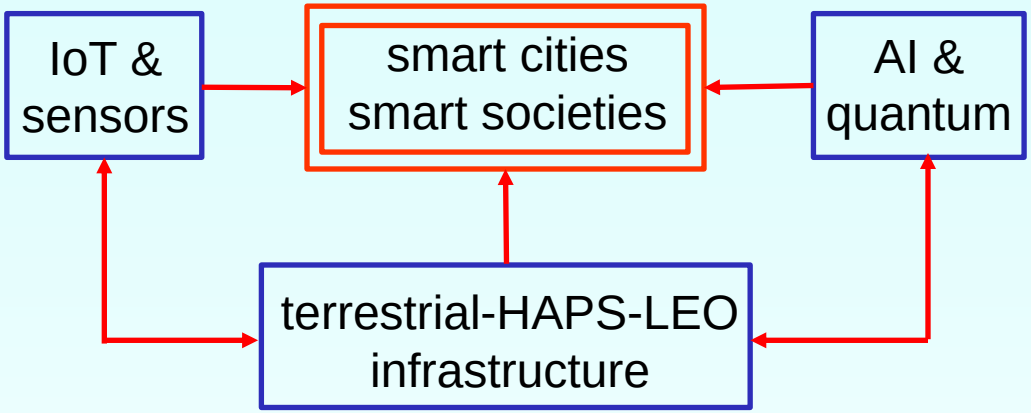
Distributed edge and data centre

5G/6G/7G air-interface

RF/FSO for backhaul

- IoT: 100 km diameter
- Hotspot: 70 m diameter (0.2º beamwidth)

Wireless Infrastructure for Green and Sustainable Smart Cities & Societies



0% outage
0 sec setup
0 touch



HAPS Networks Research @ Carleton (ICT)

1) Access
2) Backhaul | Transport
3) Integration | Interference management
4) Antenna architectures
5) Edge intelligence
6) Spectrum | Propagation
7) Sensing
8) Navigation | Localization | Positioning
9) Control | Management
10) Cybersecurity
11) Sustainability | Network Energy Savings
12) Advanced PHY
13) Emerging technologies (RIS, digital twins, quantum key distribution, …)

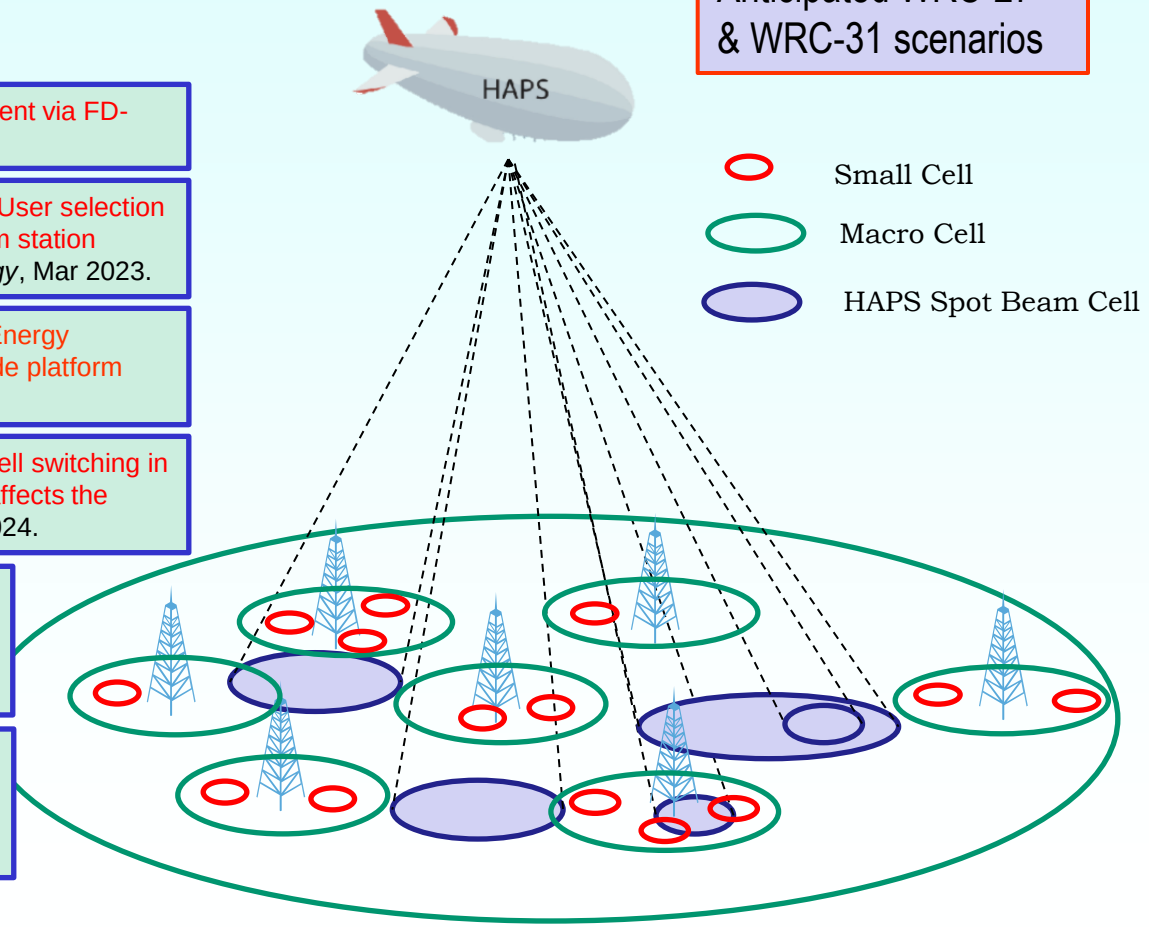
non-ICT

1) Aircraft endurance
2) Loitering time
3) Energy
4) Material science
5) Policy/Regulations
6) Single point of failure

Interference Management

Fully Integrated HAPS-Terrestrial Macro Base Stations and Small Cells
HAPS in urban/suburban areas (2030s onward)

Anticipated WRC-27 & WRC-31 scenarios



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I. Cumali, B. Ozbek, G. Karabulut Kurt, H. Yanikomeroglu, "User selection and codebook design for NOMA-based high altitude platform station (HAPS) communications", *IEEE Trans. Vehicular Technology*, Mar 2023.

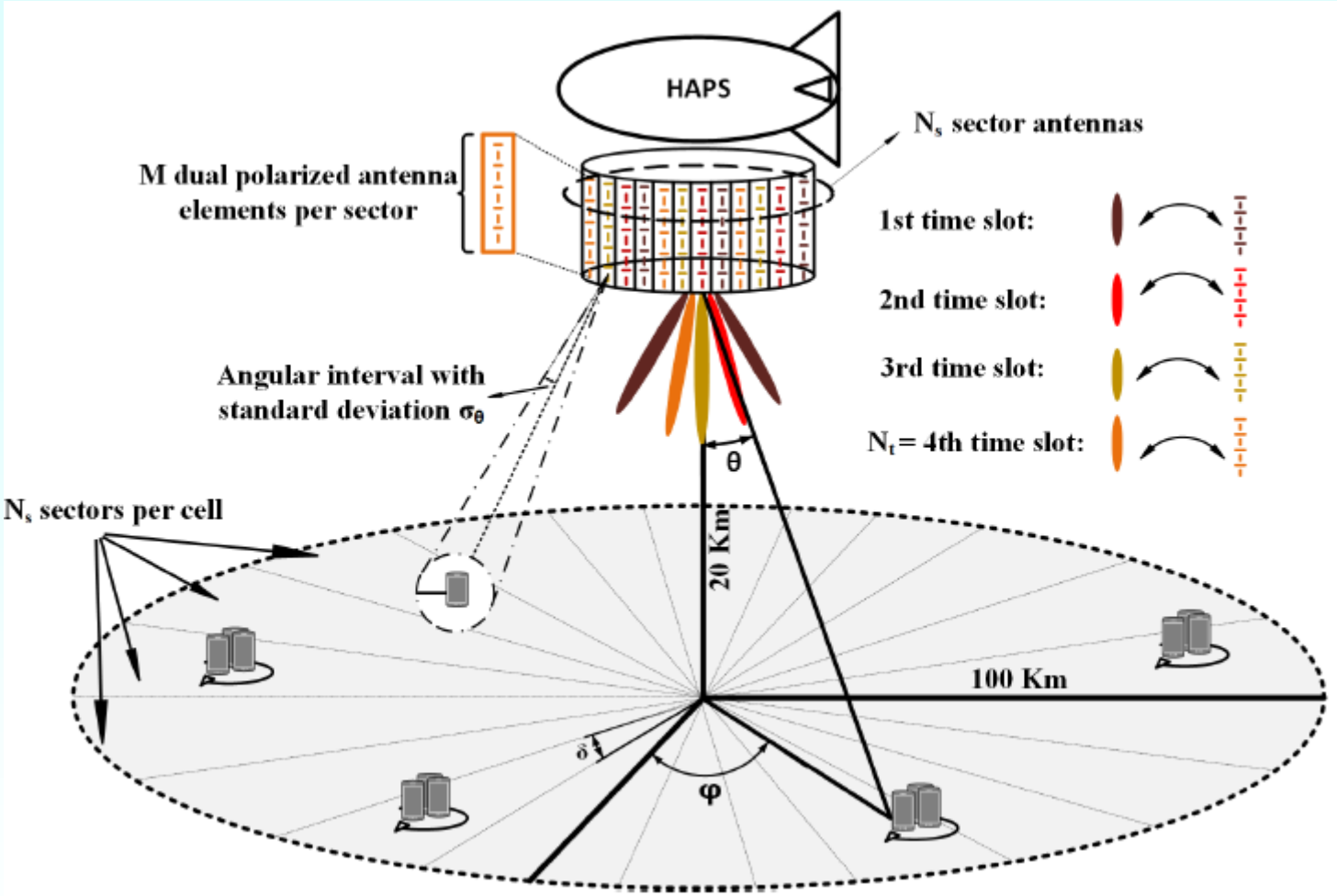
M. Salamatmoghadasi, A. Mehrabian, H. Yanikomeroglu, "Energy sustainability in dense radio access networks via high altitude platform stations", *IEEE Wireless Networking Letters*, Mar 2024.

B. Ciloglu, G. Berkay Koc, M. Ozturk, H. Yanikomeroglu, "Cell switching in HAPS-aided networking: How the obscurity of traffic loads affects the decision", *IEEE Transactions on Vehicular Technol.*, Nov 2024.

A. Alidadi Shamsabadi, A. Yadav, O. Abbasi, H. Yanikomeroglu, "Handling interference in integrated HAPS-terrestrial networks through radio resource management", *IEEE Wireless Communications Letters*, Dec 2022.

A.Alidadi Shamsabadi, A. Yadav, H. Yanikomeroglu, "Enhancing next-generation urban connectivity: Is integrated HAPS-terrestrial network a solution?", *IEEE Commun Letters*, May 2024.

HAPS Networks in Urban Regions



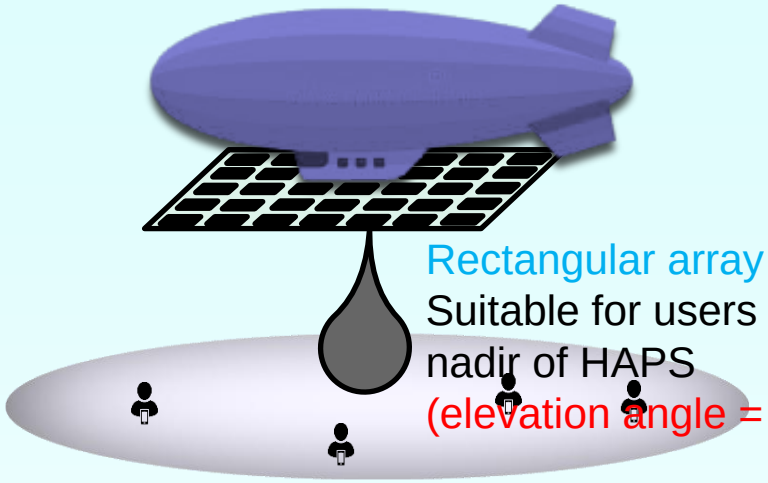
R. Shafie, M.J. Omidi, O. Abbasi, H. Yanikomeroglu, "MIMO-NOMA enabled sectorized cylindrical massive antenna array for HAPS with spatially correlated channels", *IEEE Trans. Wireless Communications*, Oct. 2024.

R. Shafie, M.J. Omidi, O. Abbasi, H. Yanikomeroglu, "A novel 3D massive MIMO architecture with strategic resource allocation for near-space HAPS systems with spatially correlated channels", *IEEE ICC 2025*.

Background

- The problem with the traditional rectangular antenna array for HAPS is that its antenna elements are always facing downward, and hence these elements have a very low gain for the far users.

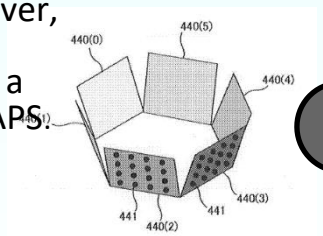
B. El-Jabu and R. Steele, "Cellular communications using aerial platforms", *IEEE Transactions on Vehicular Technology*, vol. 50, no. 3, pp. 686-700, May 2001, doi: 10.1109/25.933305.

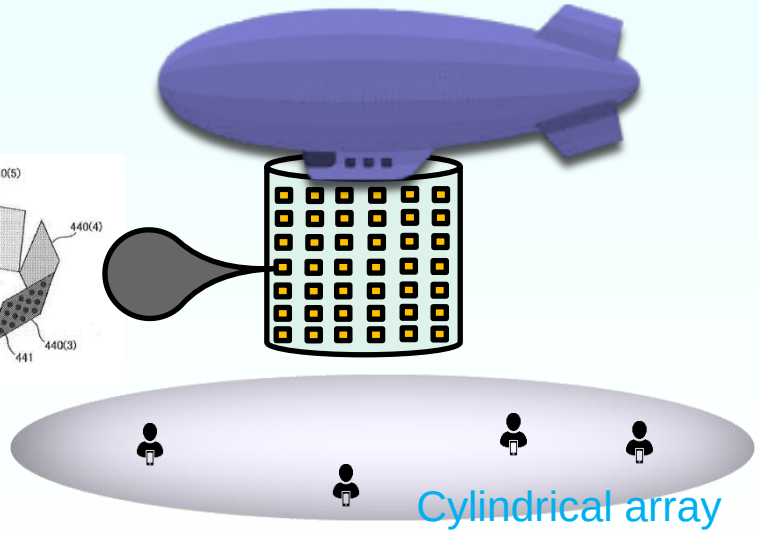


Rectangular array
Suitable for users in nadir of HAPS
(elevation angle = 0)

- Recently, a cylindrical antenna array has been proposed for HAPS to solve this problem. However, the antenna elements of cylindrical arrays are always facing the horizon, and hence they have a very low gain for the near users beneath the HAPS.

Hoshino, Kenji, Shoichi Sudo, and Yoshichika Ota. Service link antenna configuration and beam forming control in HAPS.
U.S. Patent No. 11,177,874, 16 Nov. 2021.



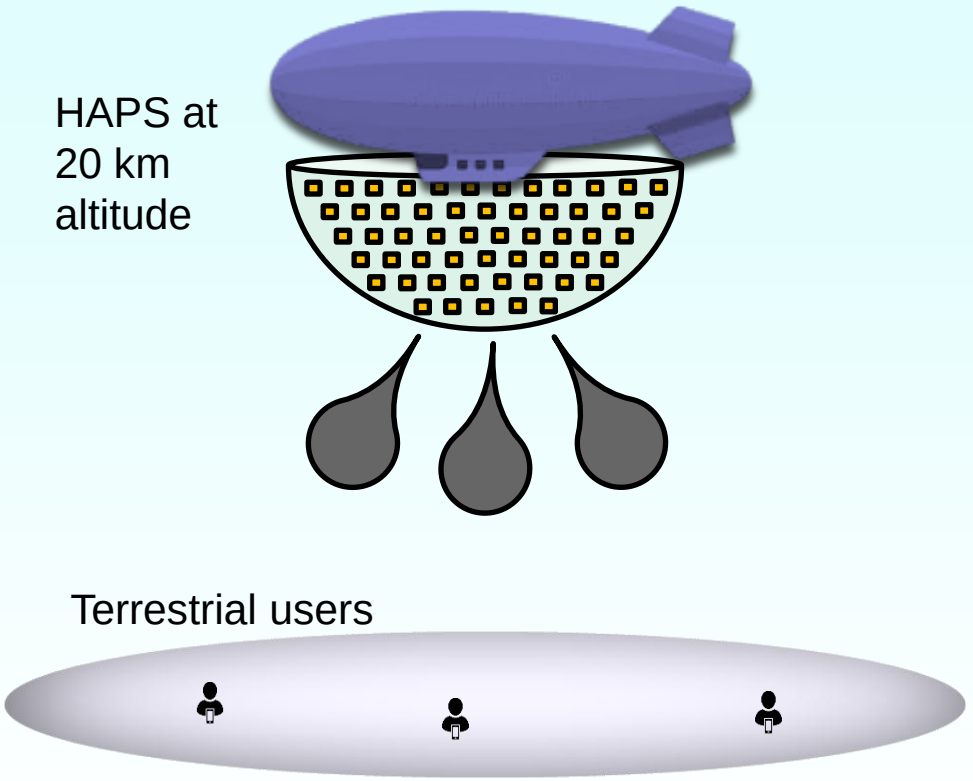


Cylindrical array
Suitable for far users
(elevation angle = 90)

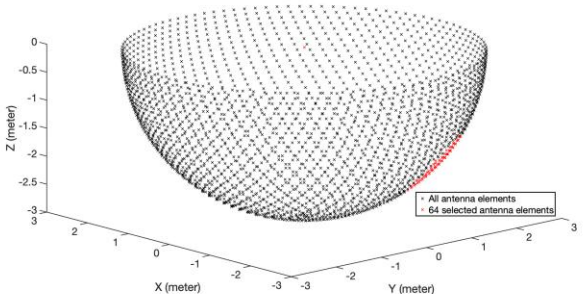
Hemispherical Antenna Array

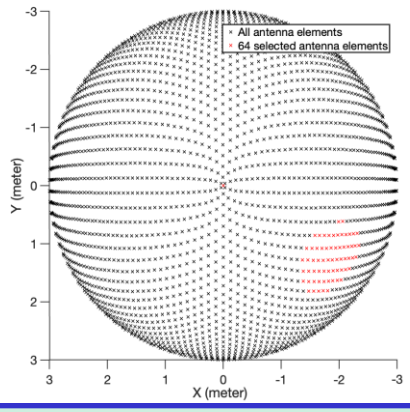
Hemi-spherical array
Suitable for **all** users
(0 < elevation angle < 90)

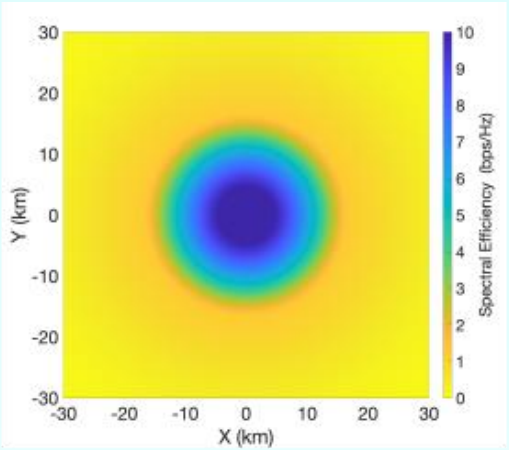
- In order to have a trade-off between rectangular and cylindrical arrays, we propose a hemispherical antenna array for HAPS in which antenna elements are facing the users.



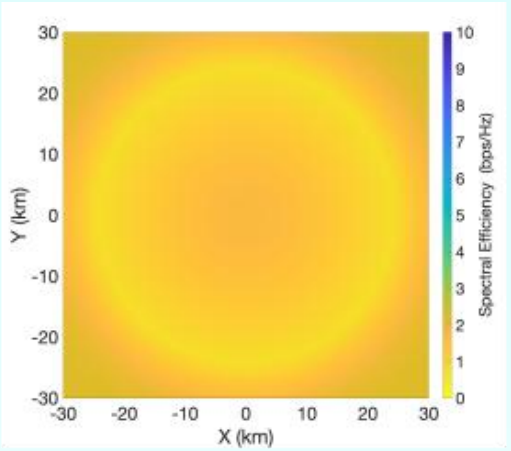
Hemispherical Antenna Array



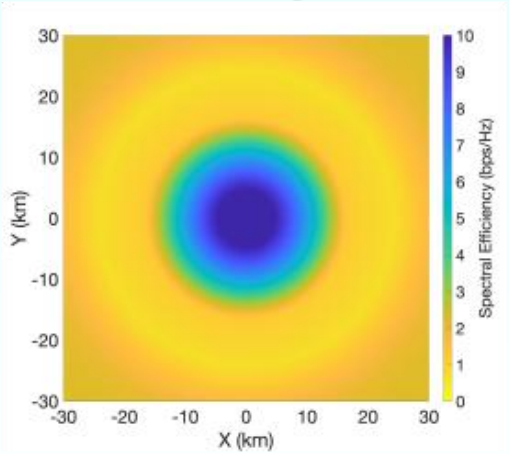




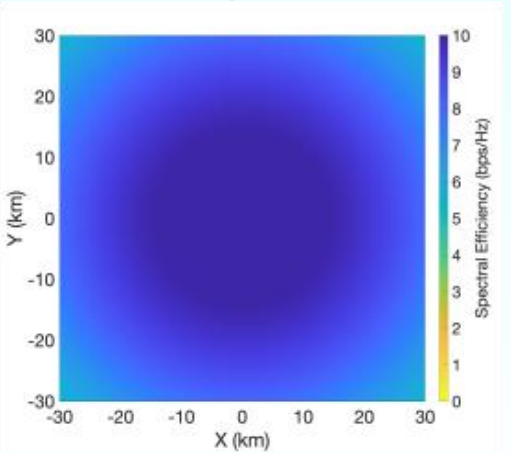
(a) Rectangular



(b) Cylindrical



(c) Hybrid rectangular and cylindrical



(d) Proposed hemispherical

Fig. 4: Heatmap of the spectral efficiency for rectangular, cylindrical, hybrid, and hemispherical antenna arrays. For this figure, we assumed a user, with a fixed power allocation of 1 Watt, is uniformly distributed across 10,000 different locations in a square urban area with dimensions of 60 km × 60 km.

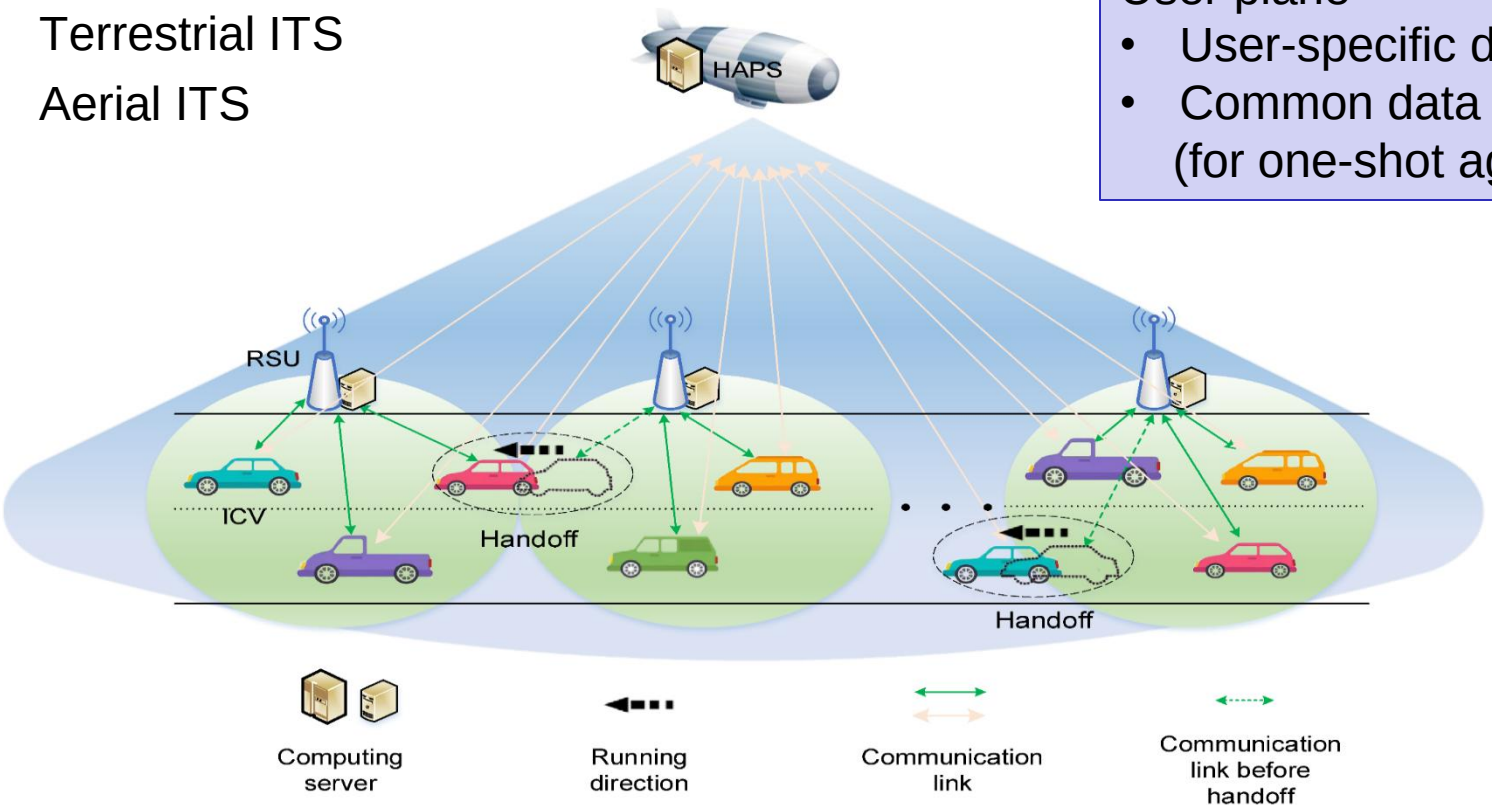
O. Abbasi, G. Kaddoum, H. Yanikomeroglu, "An ML-assisted OFDM-based hemispherical array antenna with hybrid beamforming for HAPS", u/r *IEEE Trans. Wireless Commun,*, Sep 2024, revised Mar 2025.

O. Abbasi, H. Yanikomeroglu, G. Kaddoum, "Hemispherical antenna array architecture for high-altitude platform stations (HAPS) for uniform capacity provision", *IEEE Trans. Wireless Commun.*, Dec 2024.

Edge Computing @ HAPS

- Terrestrial ITS
- Aerial ITS

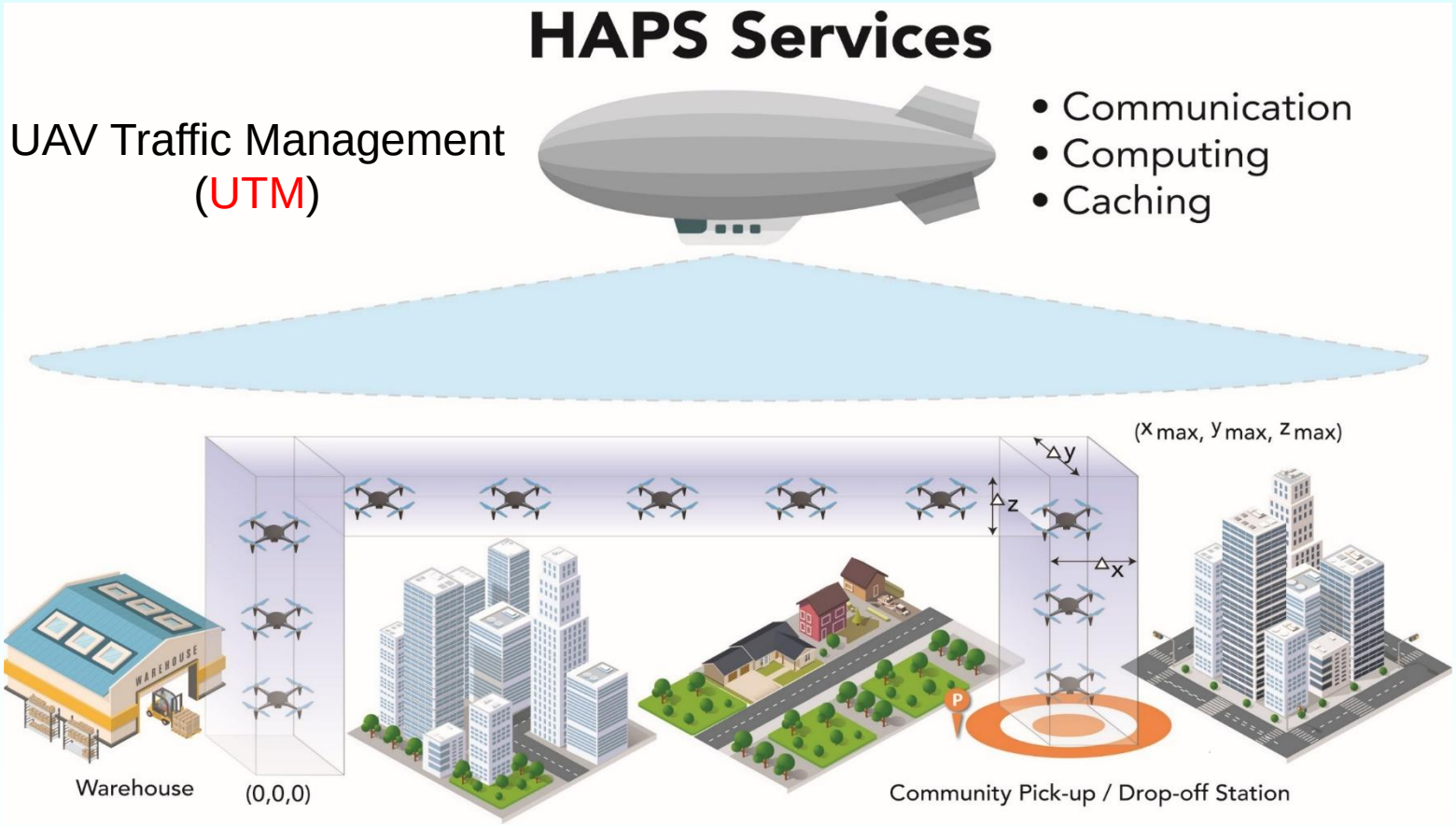
Control plane → HAPS
User plane
- User-specific data → RSU
- Common data → HAPS (for one-shot aggregation)



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", *IEEE Transactions on Wireless Communications*, Nov. 2022.

Q. Ren, O. Abbasi, G. Karabulut Kurt, H. Yanikomeroglu, J. Chen, "Handoff-aware distributed computing in high altitude platform station (HAPS)-assisted vehicular networks", *IEEE Transactions on Wireless Communications*, Dec. 2023.

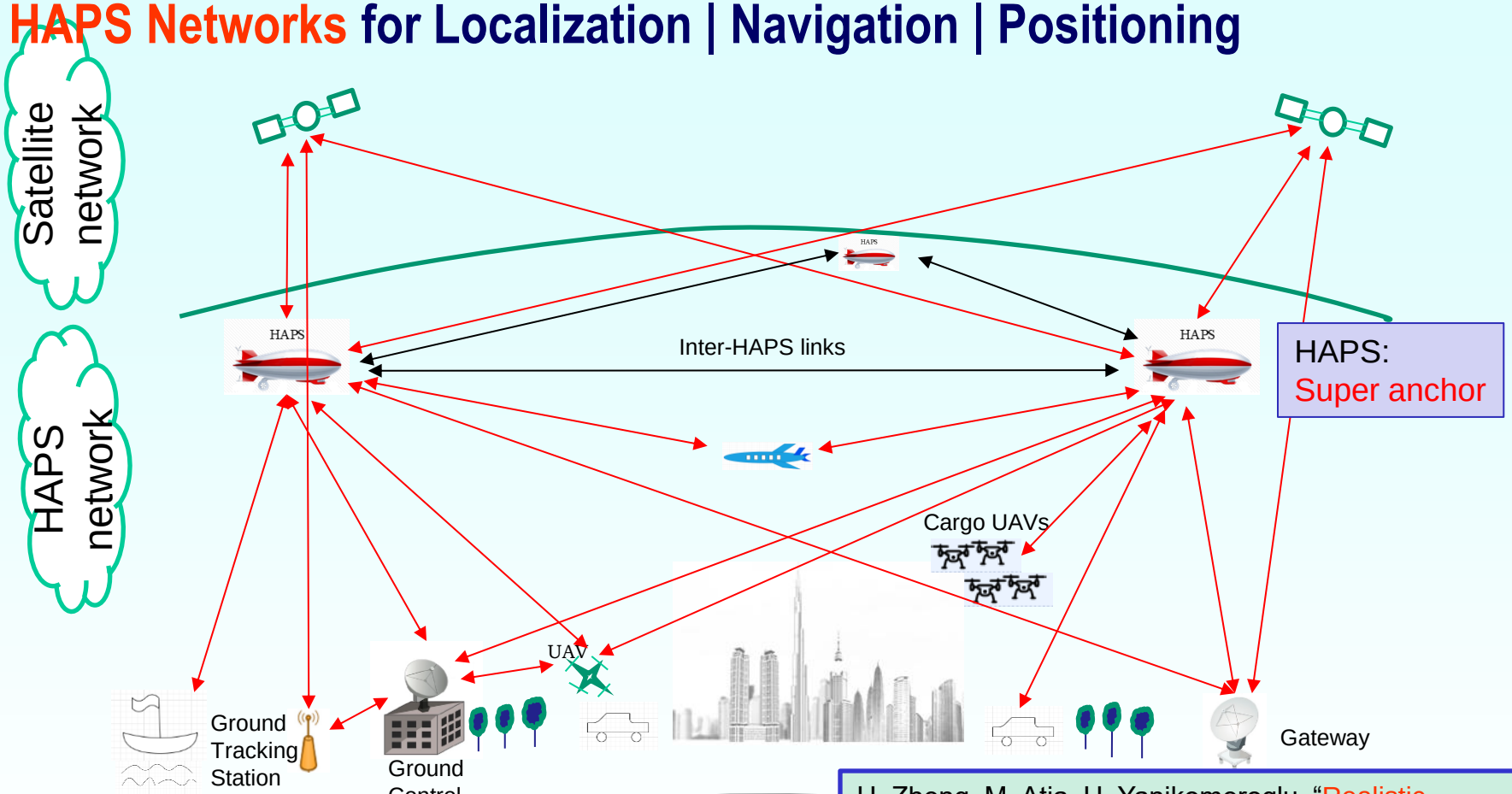
HAPS for 3D Aerial Highways



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

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.

HAPS Networks for Localization | Navigation | Positioning



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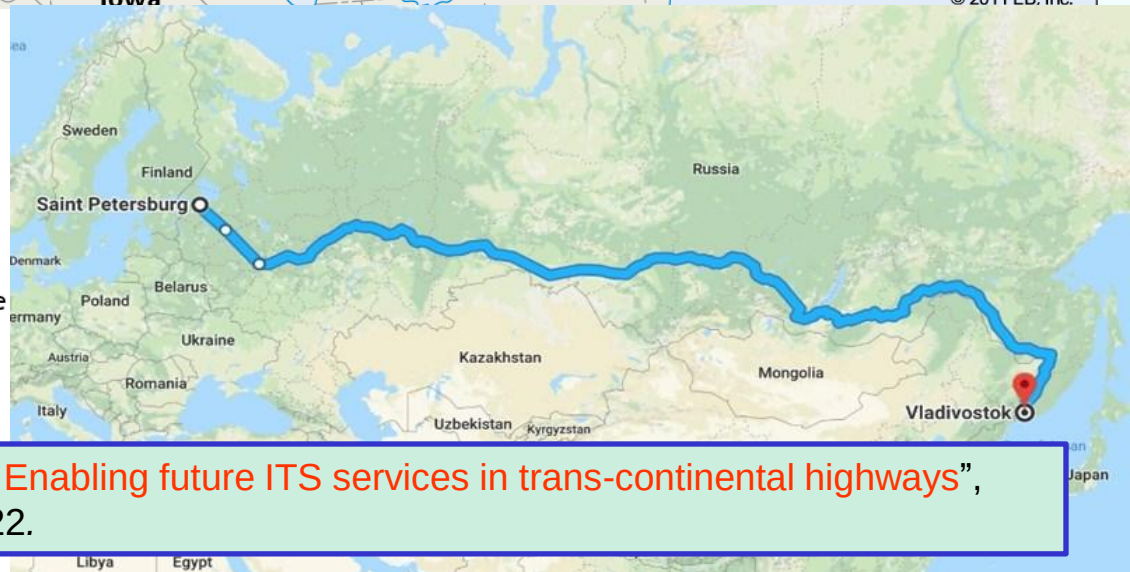
H. Zheng, M. Atia, H. Yanikomeroglu, P. Diniz, "Synthetic waveform generation for satellite, HAPS, and 5G base station signals using QuaDRiGa", *IEEE ICC 2024*.

HAPS Constellation for Intelligent Transportation Systems

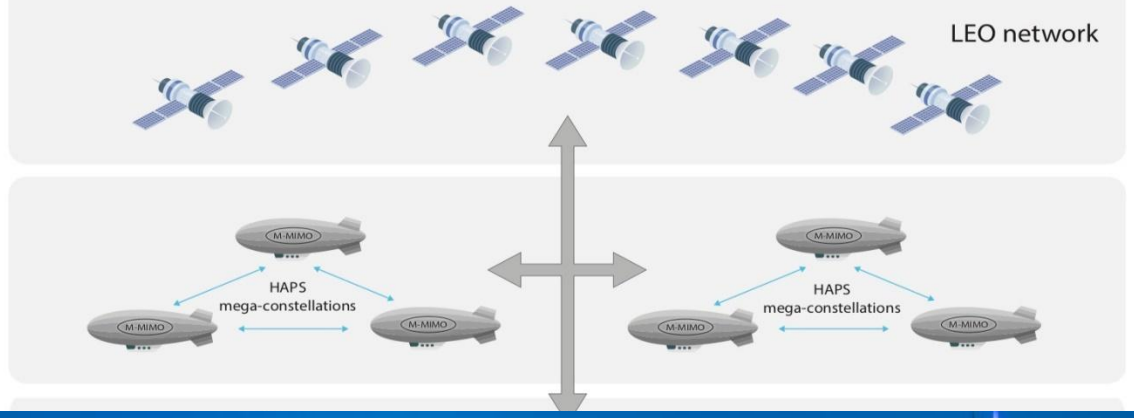


W. Jaafar, H. Yanikomeroglu, "HAPS-ITS: Enabling future ITS services in trans-continental highways", *IEEE Communications Magazine*, Oct 2022.

A Proposal to Starlink and Kuiper for 2030s

- No of cities with population 1M+ (2030): ~700
- Complement 10,000 LEOs with 1,000 HAPS
- Reach out to 2B people in metro areas ($$$)
- Mature technology → will also help rural & remote

Business case



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Concluding Remarks

- NTN is more than satellite constellations.
- A new network in stratosphere/near-space with HAPS constellations (between terrestrial and space layers).
- Complementary to & synergistic with (rather than alternative to) terrestrial and space networks.
- More than connecting the unconnected.
- Opportunities are very many: Connectivity, edge, computing, sensing, ISR, navigation, localization, positioning, and more.
- Will unfold progressively in the next 2-3 decades.
- Can be truly transformative in urban regions.

HAPS Networks in Urban Regions