# Non-Terrestrial Networks (NTN)

## Towards 2030s and Beyond

Halim Yanikomeroglu
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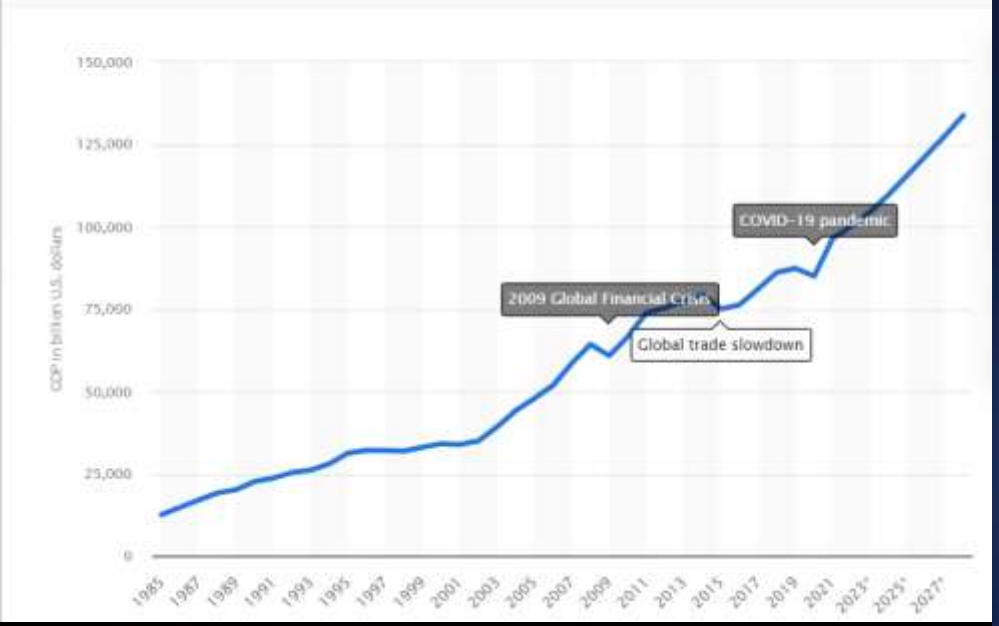
Director, Carleton-NTN Lab
Systems and Computer Engineering
Carleton University

Global gross domestic product (GDP) at current prices fr

*(in billion U.S. dollars)*



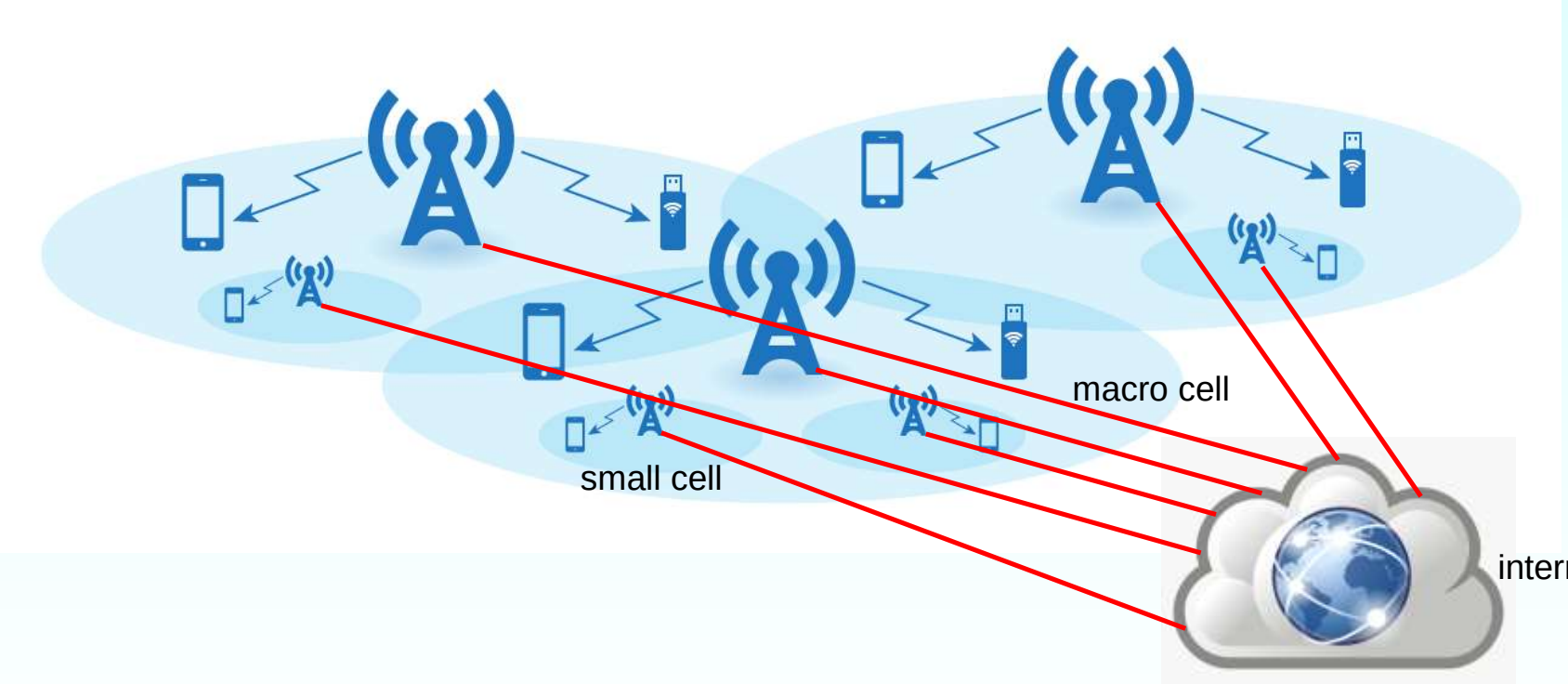

# Layers of Non-Terrestrial Networks (NTN)

- Space networks (LEO satellite mega-constellations, MEO, GEO)
- Stratospheric networks (HAPS: high altitude platform stations)
- Aerial networks (UAV as a user | UAV as a BS)
- Integration of one or more of the above with terrestrial networks

# Agenda

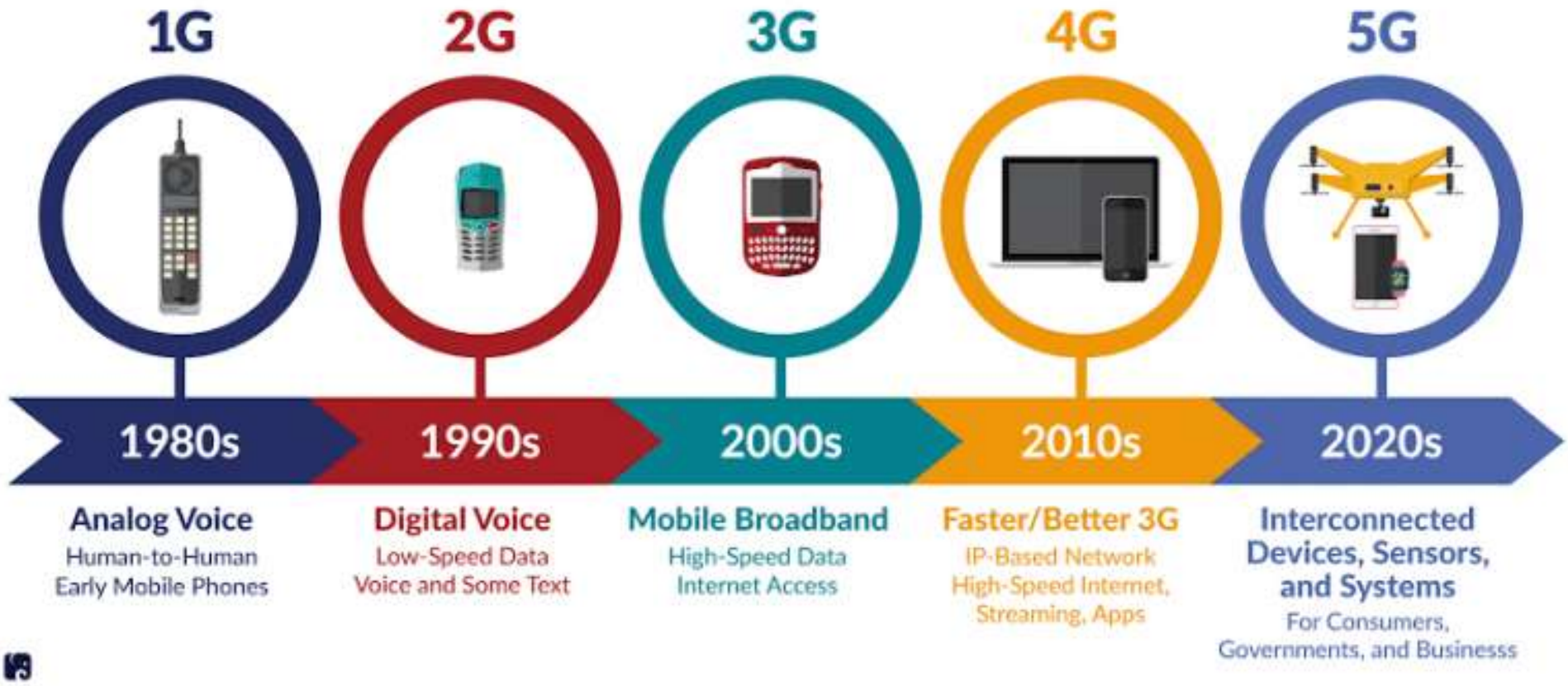
- Generations of Mobile | Cellular | Wireless Networks
- Satellite Networks
- HAPS (High Altitude Platform Station) Networks
- Concluding Remarks

# Terrestrial Mobile | Cellular | Wireless Networks




- Handoff → Seamless roaming
- Network-wide frequency (channel) reuse planning → Quality-of-Service (QoS) guarant

# Generations of Mobile | Cellular | Wireless Networks

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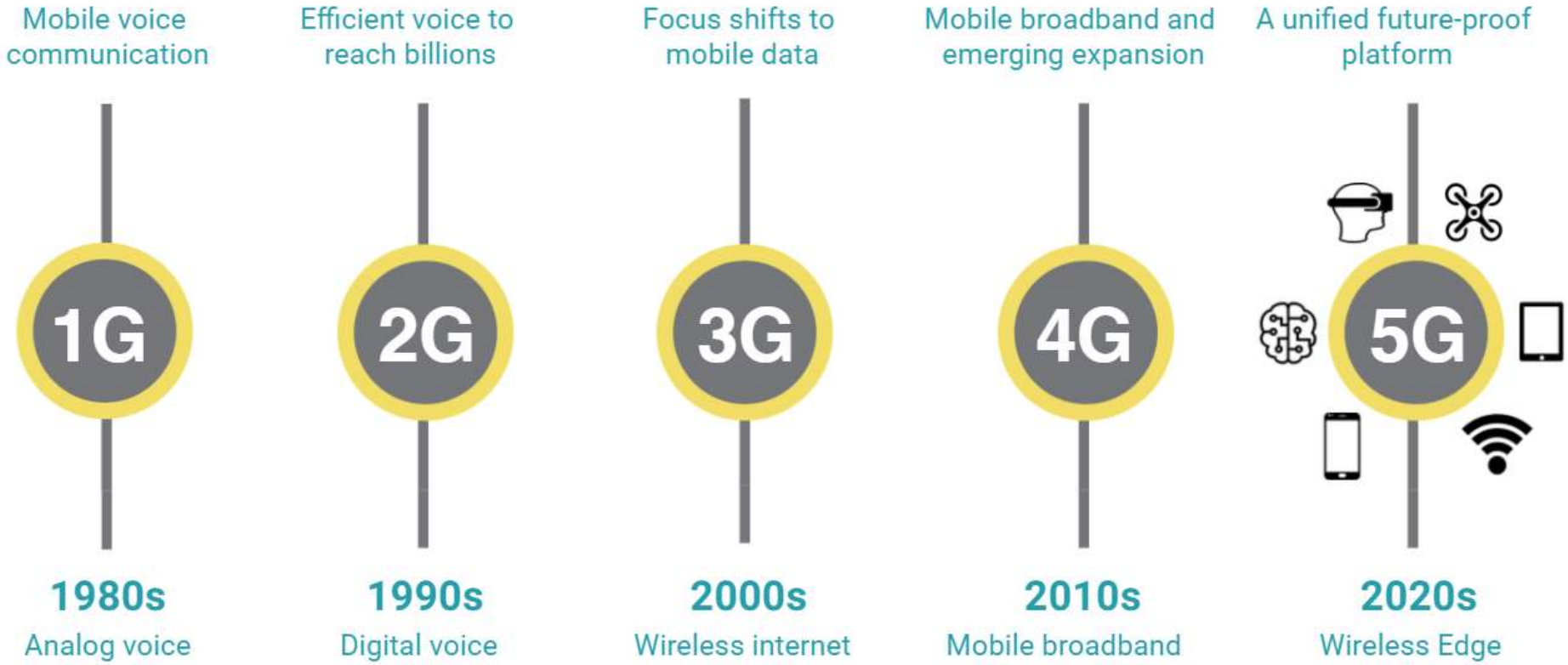
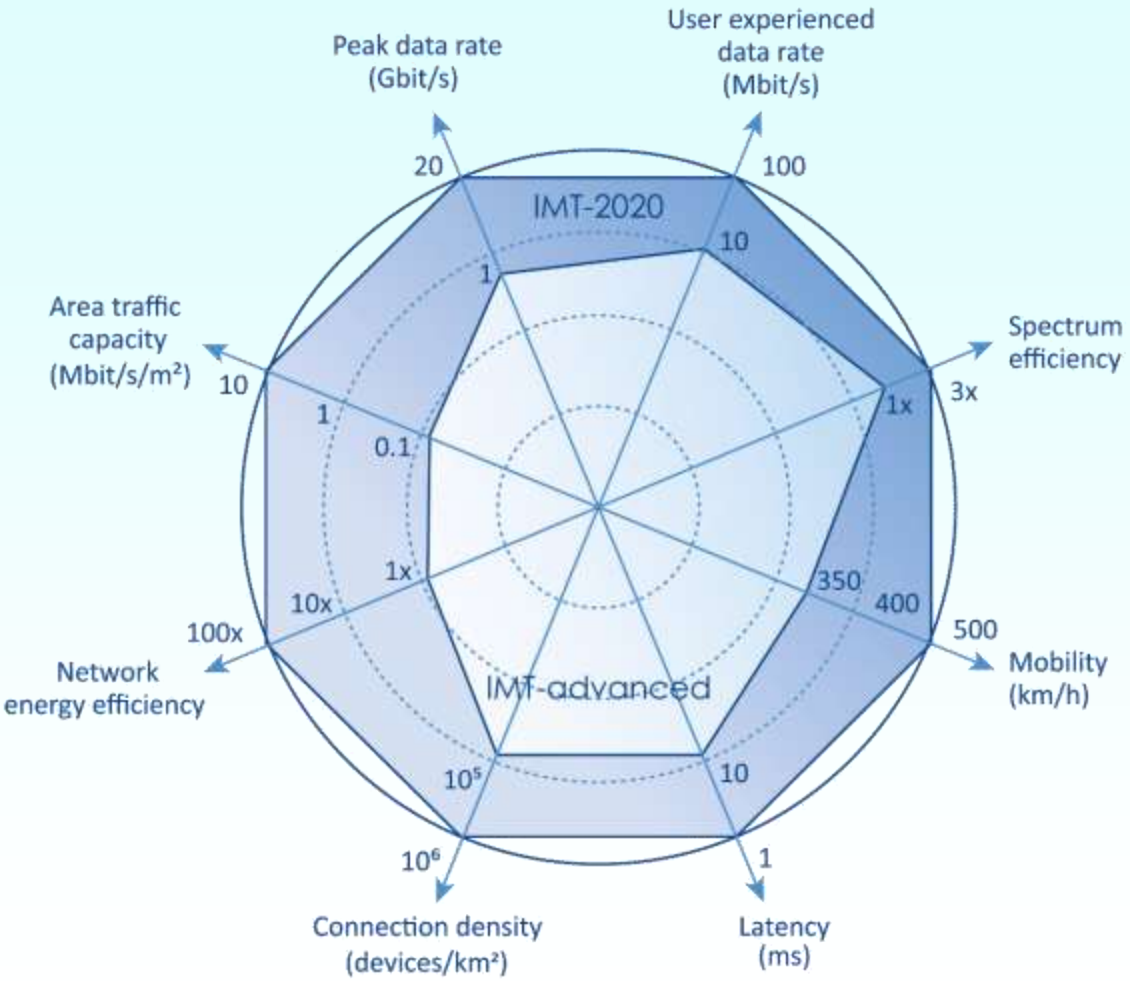
# Generations of Mobile | Cellular | Wireless Networks



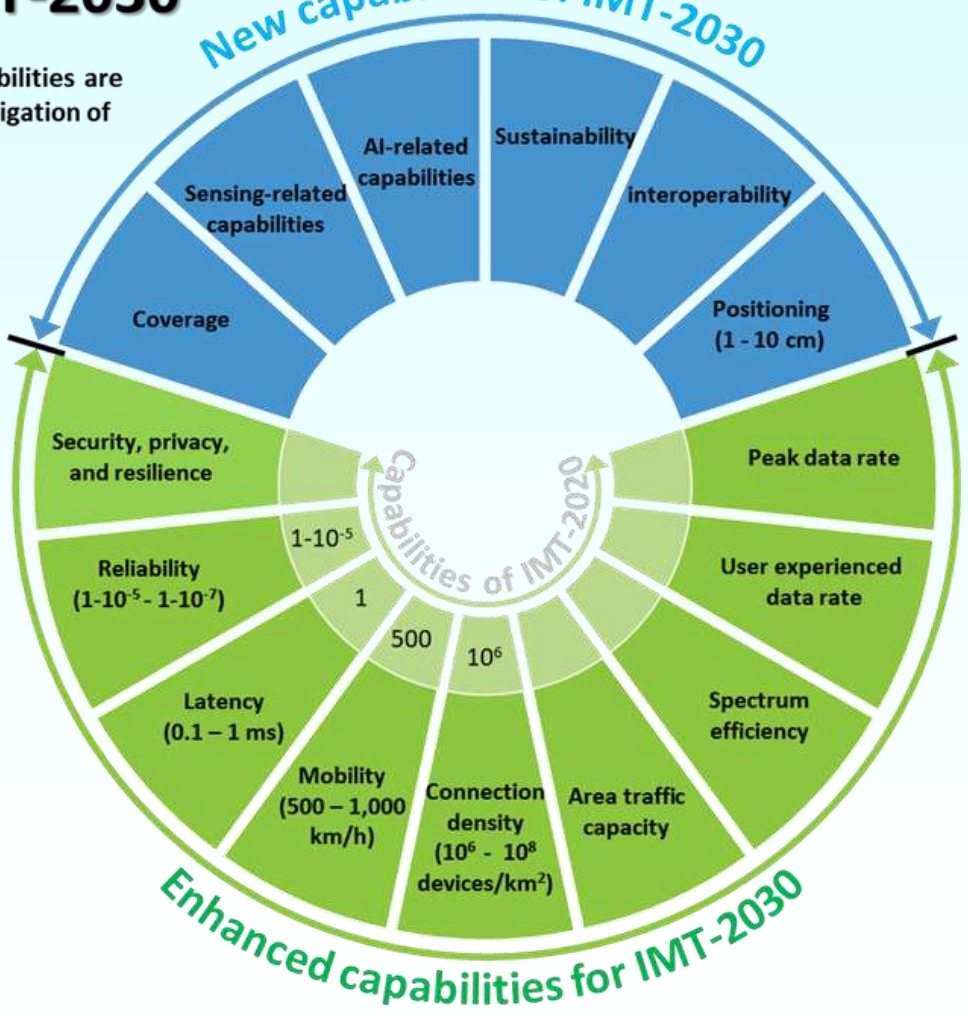
# 4G LTE and 5G Key Performance Indicators (KPIs)



# What is New in 6G Discussions?

## Capabilities of IMT-2030

NOTE: The range of values given for capabilities are estimated targets for research and investigation of IMT-2030.



# What is New in 6G Discussions?

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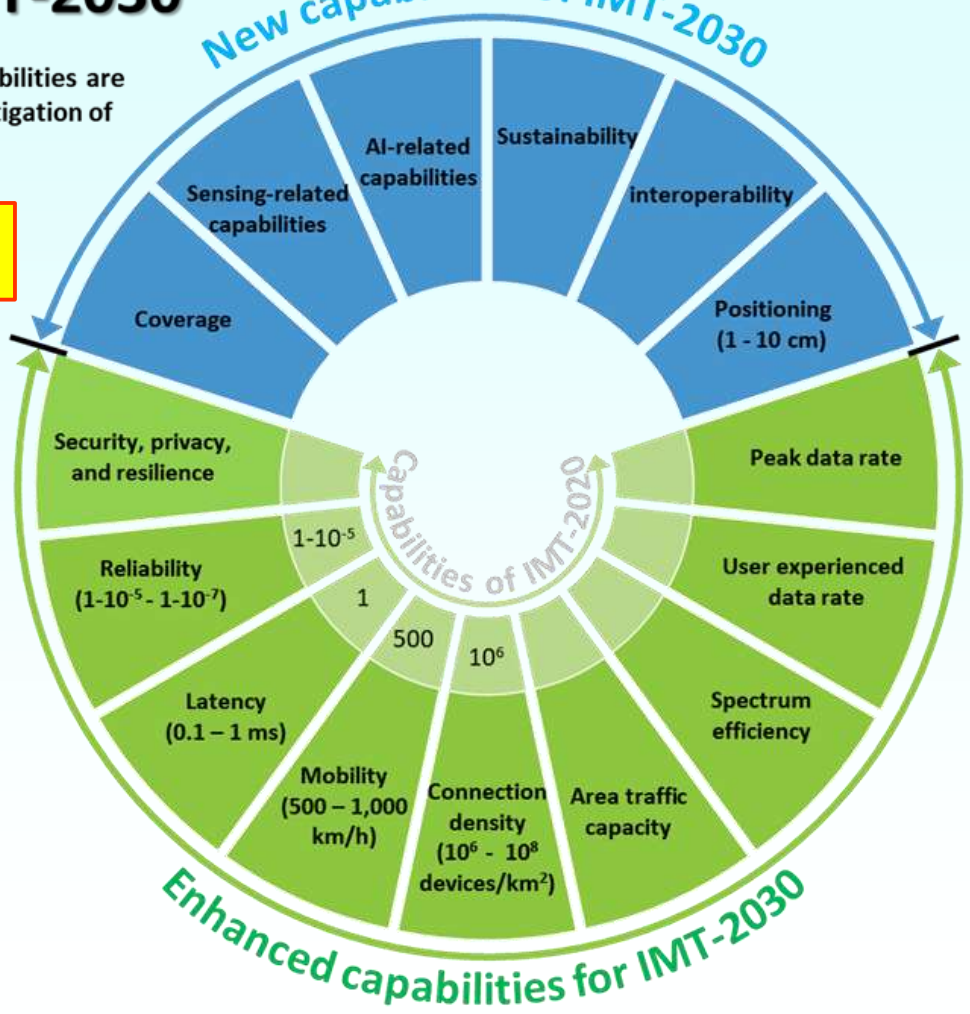
direct-to-device (D2D)
dual-mode → triple-mode

**NTN**
Non-Terrestrial Networks

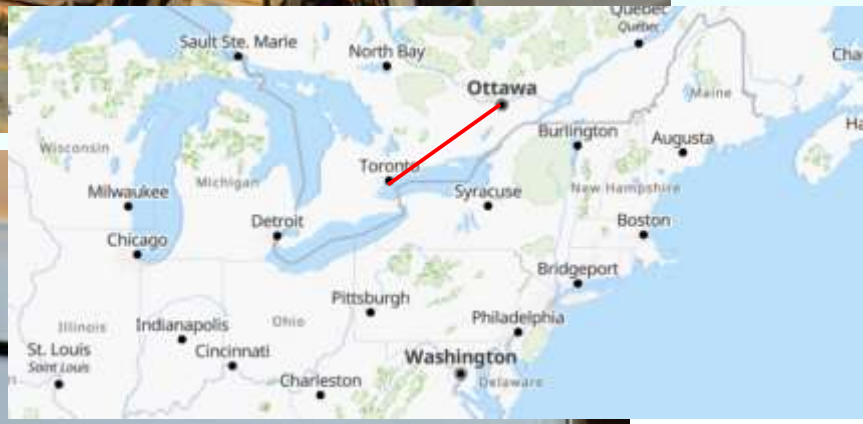


# The Wireless Revolution

1G, 2G, 3G, 4G, 5G

mobile | connectivity


REALITY:
September 8, 2023
Toronto → Ottawa




## Non-Terrestrial Networks | Towards 2030s and Beyond


# The 2nd Wireless Revolution: D2D = Triple-Mode

| | | |
|---|---|---|
| 1R | 1G, 2G, 3G, 4G, 5G | mobile \| connectivity |
| 2R | 6G, 7G, … | ubiquitous \| hyper-connectivity |

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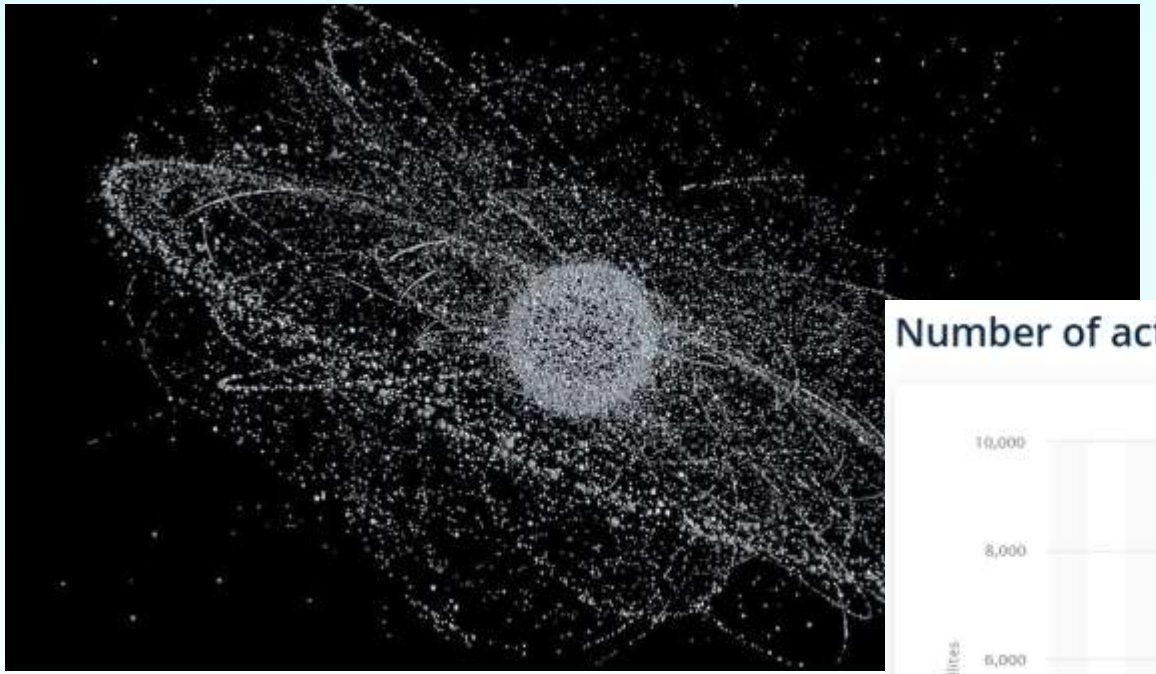
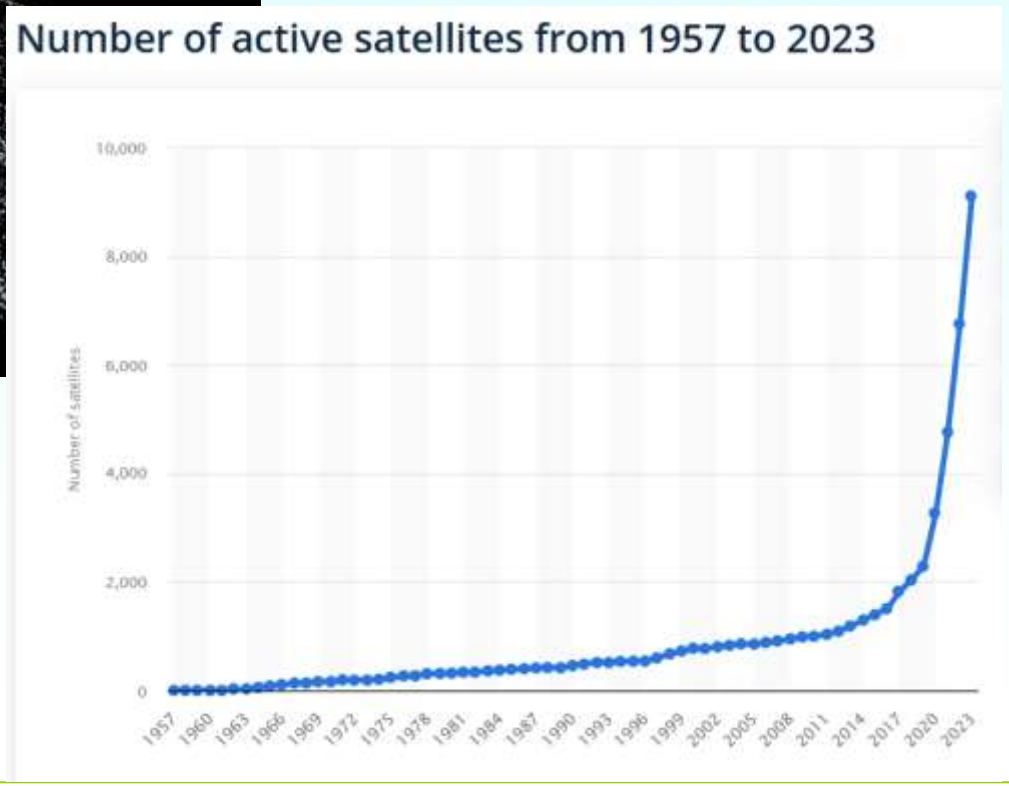
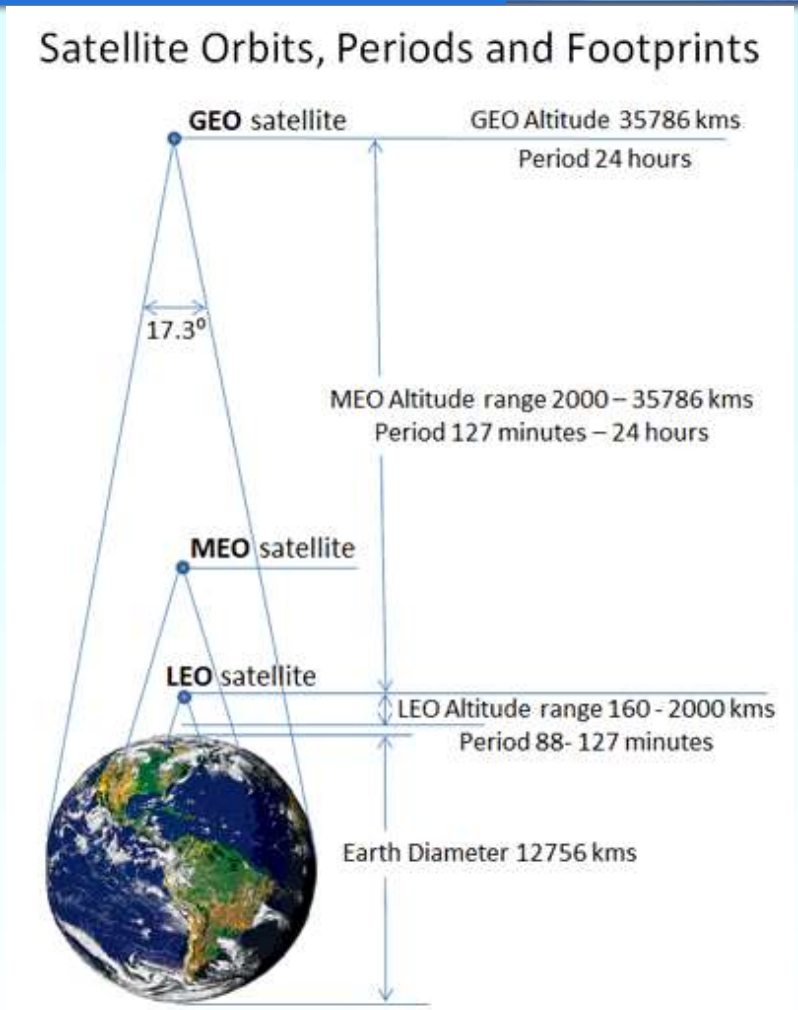
# It is Getting Crowded Out There






1957: 1 active satellite
04 May 2024: 9,900 active satellites
2030: 100,000+ active satellites

# New?: LEOs (Low Earth-Orbit Satellites)




GEO: 35,786 km
MEO: 2,000 km – 35,000 km
LEO: 160 km – 2,000 km

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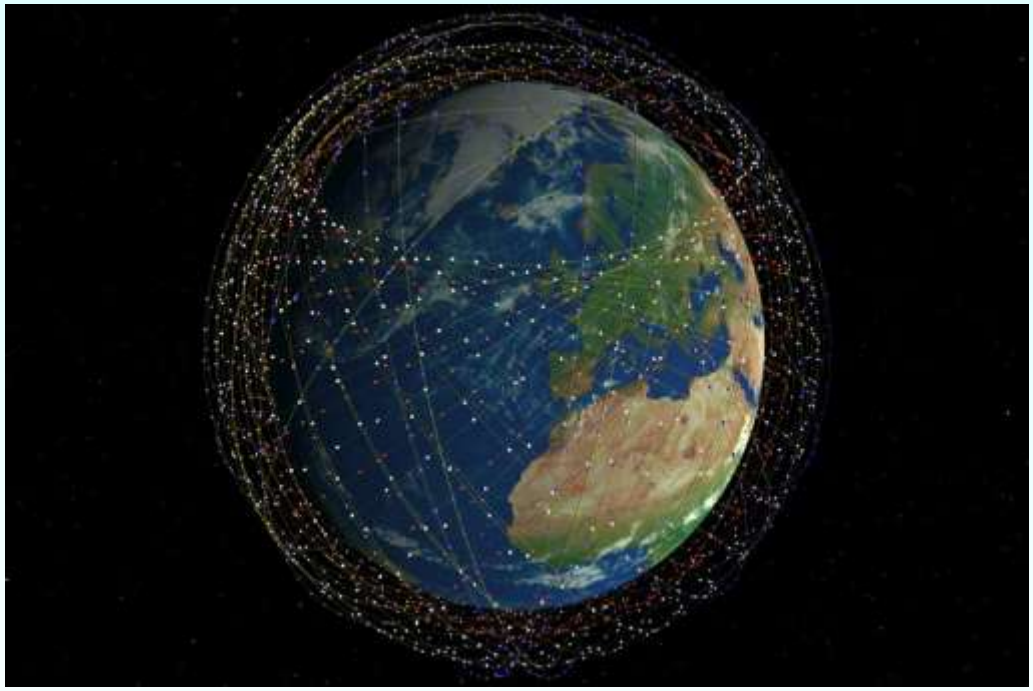
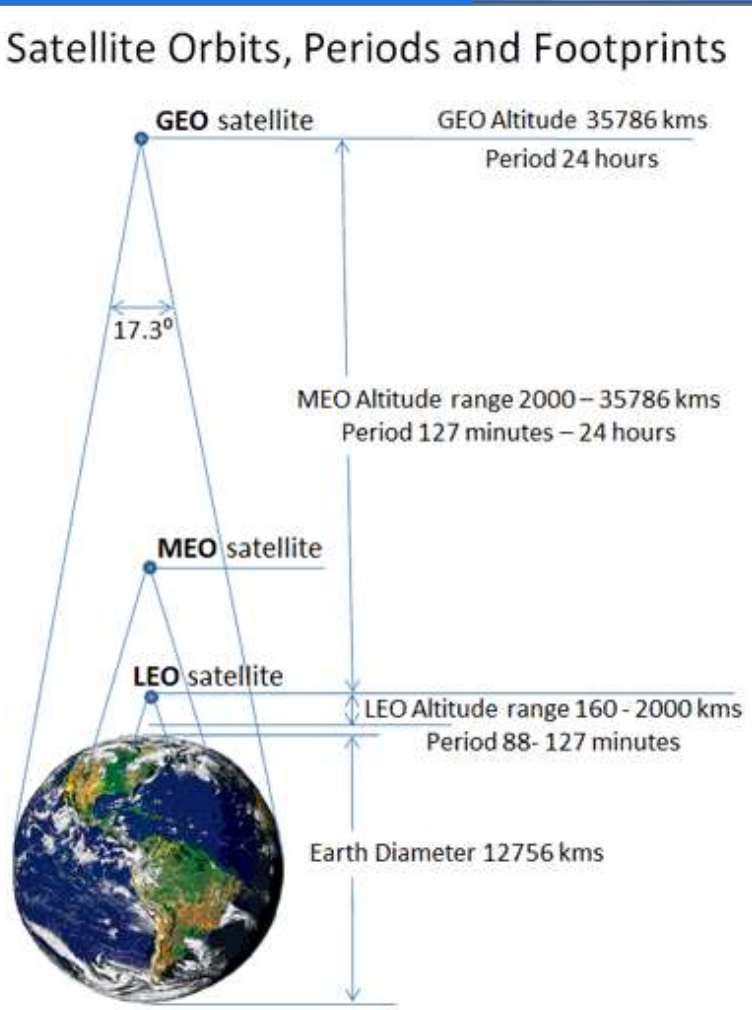


- Small footprint → High throughput
- Close to earth → Low latency
- Easy to launch → Low-cost
- Inter-satellite links → Constellation

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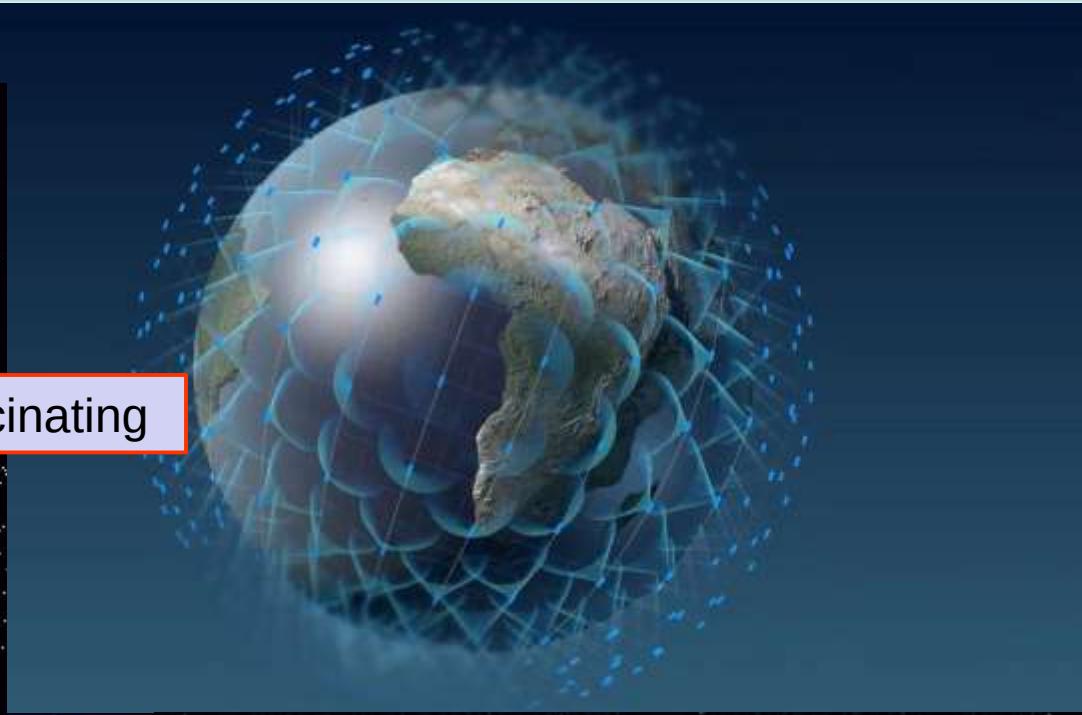
# LEO Mega-Constellations

Fascinating



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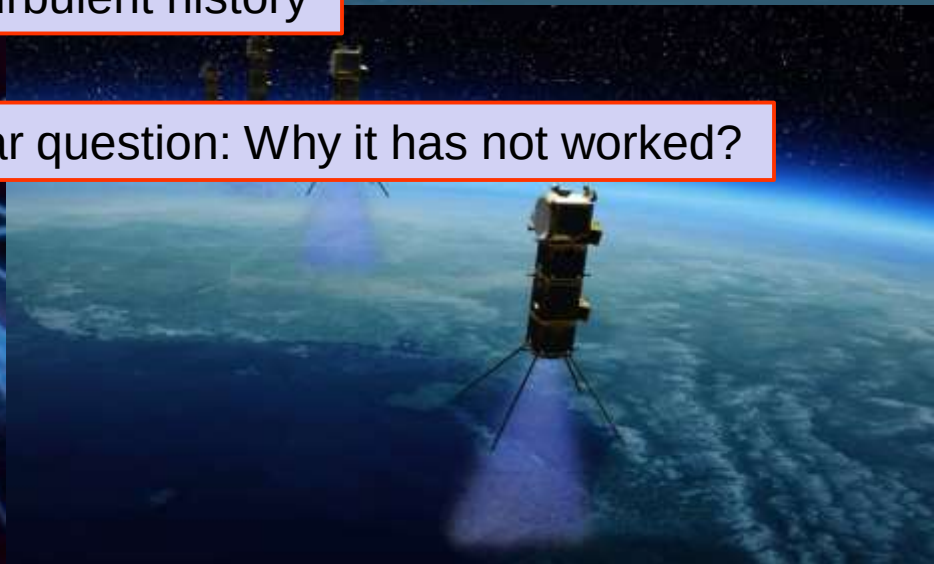

# LEO Mega-Constellations

- Fascinating
- SatCom: Not new
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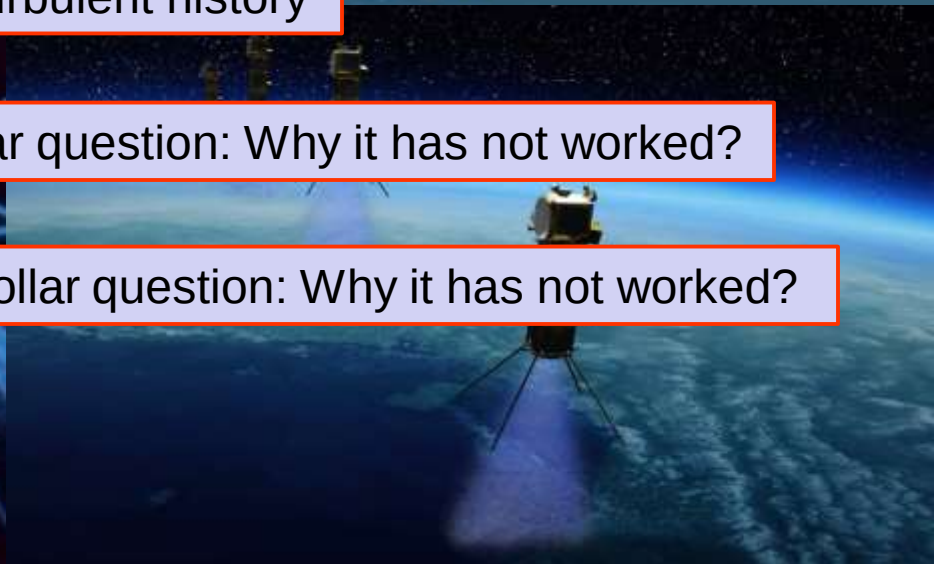
- Million-dollar question: Why it has not worked?
- 50-billion-dollar question: Why it has not worked?



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**constellation → mega-constellation**

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**RF → optical**

**LEO-LEO (LISL)**
**LEO-GS**
**dense GS network with site diversity**

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**dense GS network with site diversity**

**bent pipe → mesh**

**on–board processing**
**regenerative payload**

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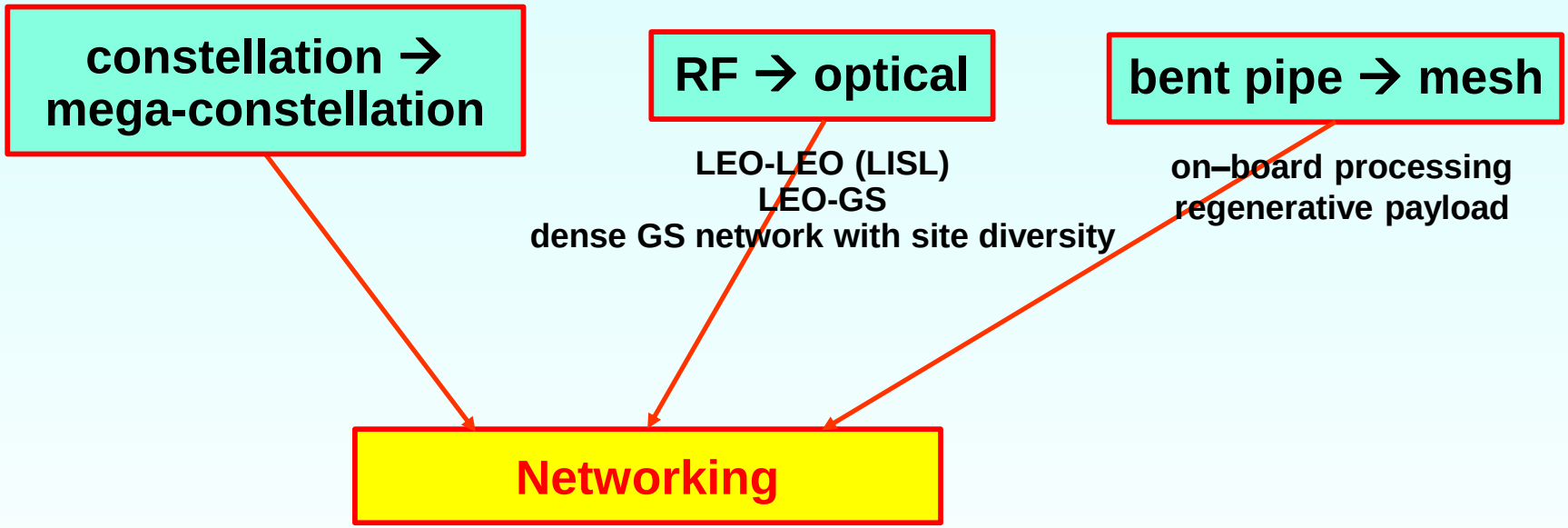

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dense GS network with site diversity

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**Networking**

highly dynamic and complex
different than terrestrial network
routing, load-balancing, …

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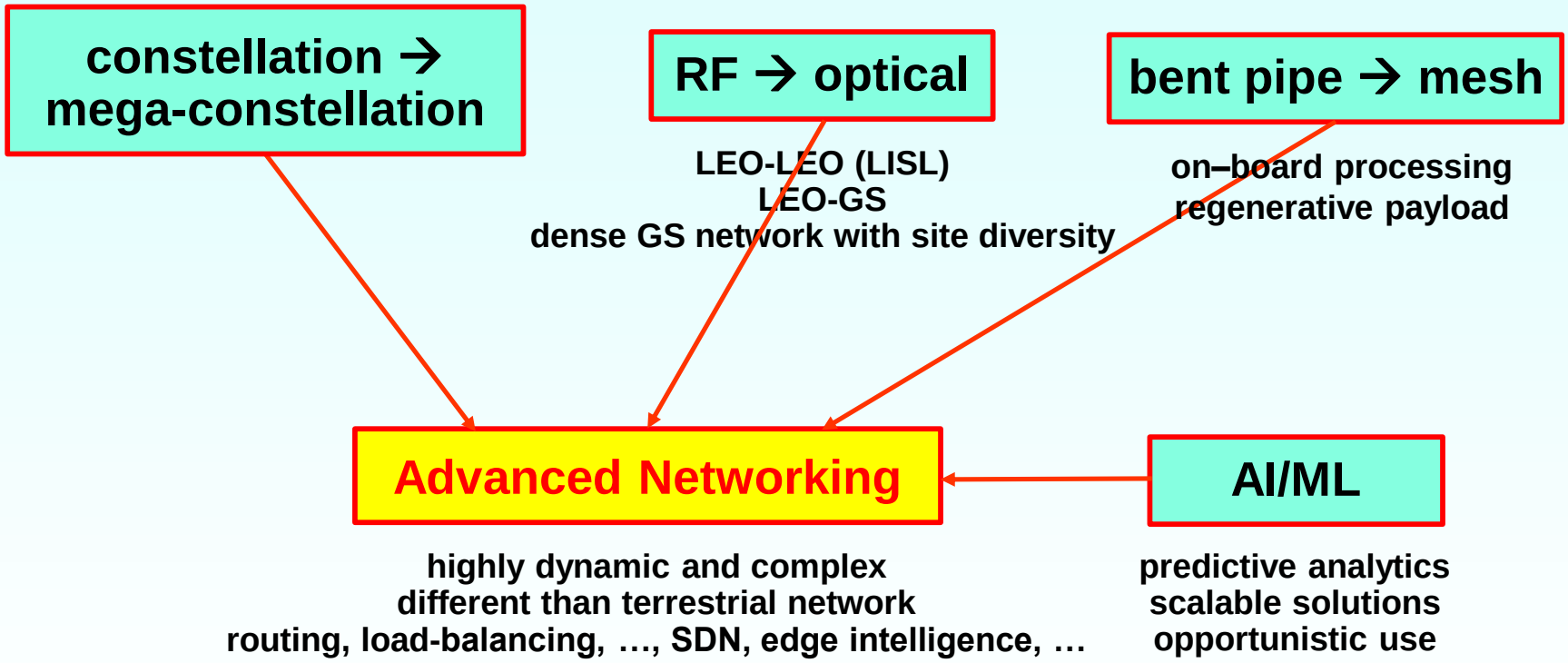
**AI/ML**

predictive analytics
scalable solutions
opportunistic use

# NG SatComNets



Customer pool (who can afford): **M**illions

50-billion-dollar question: Business Case

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Customer pool: **B**illions → **T**rillions


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The holy grail of LEO research:
Direct connectivity to smartphones

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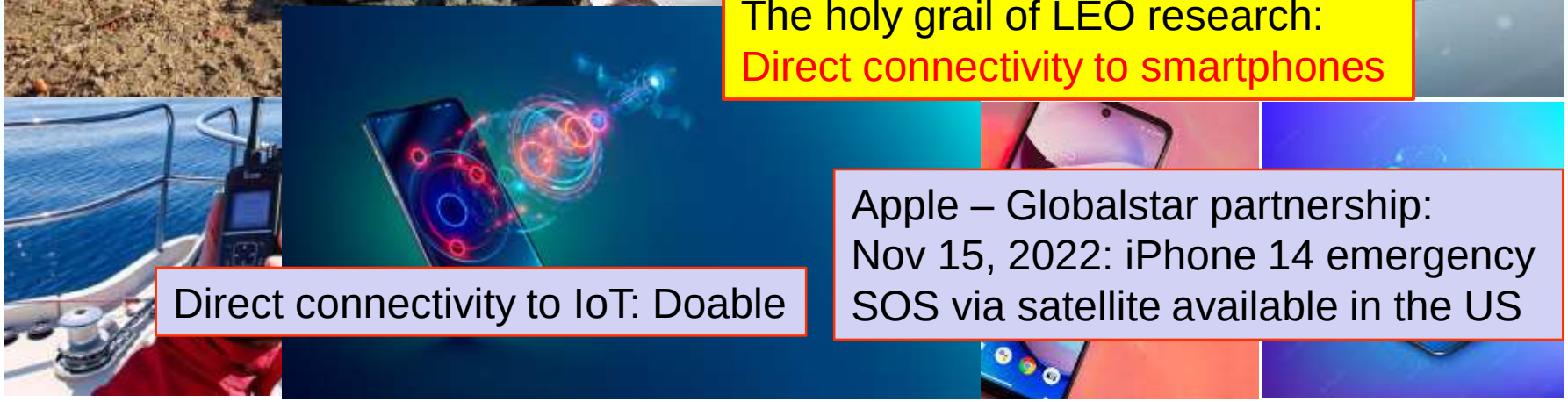


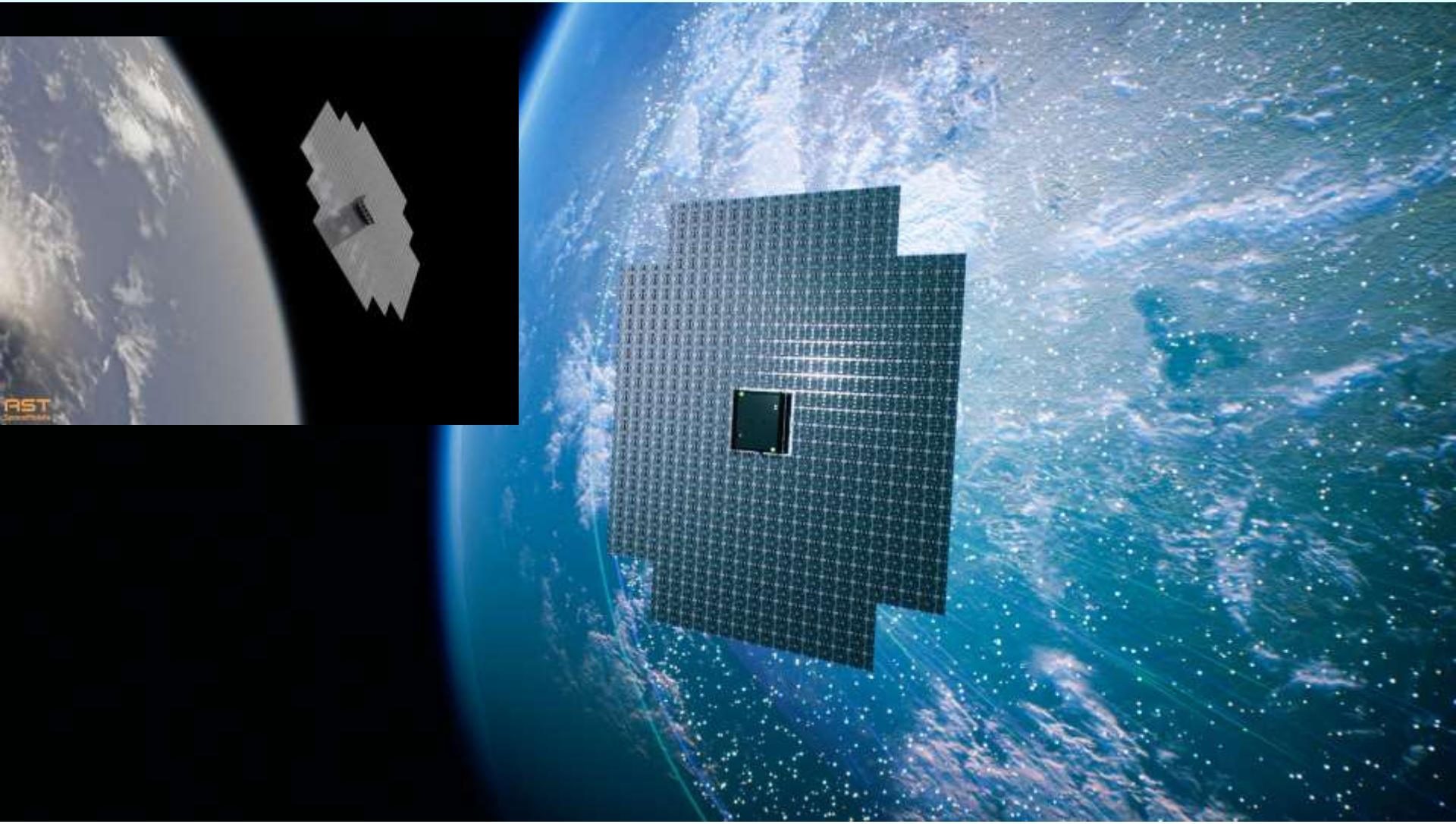
Direct connectivity to IoT: Doable

Apple – Globalstar partnership:
Nov 15, 2022: iPhone 14 emergency SOS via satellite available in the US

# Gigantic Antenna Arrays @ LEO (→ Larger LEOs)

AST SpaceMobile: Gigantic antenna arrays in LEO orbit
8 m x 8 m = 64 m² (deployed in Nov 2022) → 30 m x 30 m = 900 m²

Starlink Gen2: Surface area 10x bigger than Gen1



NRC · CNRC

Carleton University
Non-Terrestrial Network (NTN) Lab

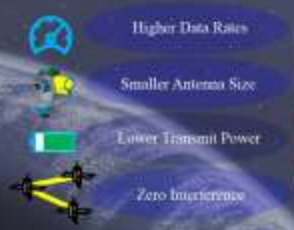
MDA

# Laser Inter Satellite Links in Next-Generation Satellite Megaconstellations

Dhiraj Bhattacharjee, Jintao Liang, Aizaz Chaudhry, Pablo Madoery, Halim Yanikomeroglu, Gunes Karabulut Kurt, Peng Hu, Stephane Martel, Khaled Ahmed

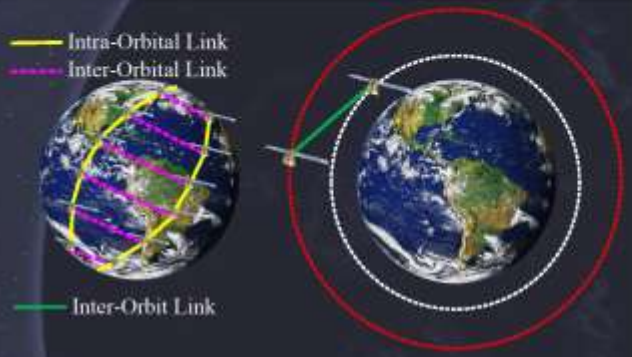
## Emerging Applications


## Why LISLs

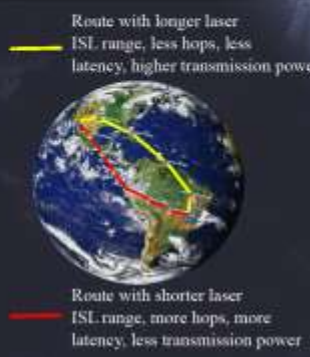



## Ongoing Projects

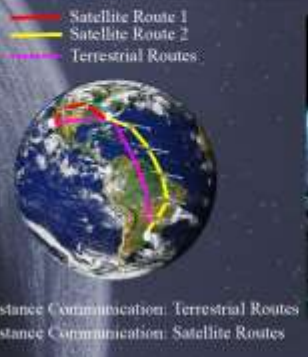

## Classification of Inter-Satellite Links




## Power-Delay Trade off

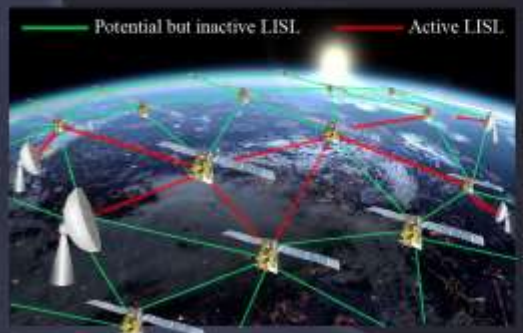


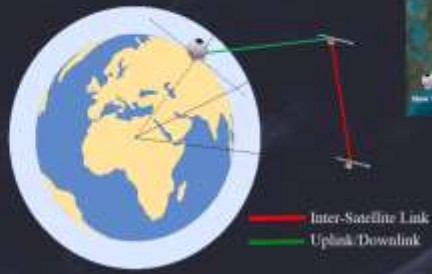

## Crossover Function




## On Demand Dynamic Routing


## LISL Setup Delay Removal by Route Prediction




## Latency Minimization for Multi-Pair End-to-End Connections

Binary Linear Program

Objective Function

$$min \sum_{i,j} \sum_{k} l_{ij} x_{ij}^{k} + T_{node} \sum_{i} \sum_{k} y_{i}^{k}$$

Constraints

Flow conservation constraints
Node-degree constraints
Line-disjoint constraints
Satellite optical link transmission power constraints

# Agenda

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# 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".

# ECOR 1055 – Introduction to Engineering Principles

## Non-Terrestrial Networks | Towards 2030s and Beyond

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## Non-Terrestrial Networks | Towards 2030s and Beyond


# VHetNet: 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

urban/suburban (metro) areas

Integrated with terrestrial network in harmonized spectrum

→ One air-interface

→ One device

→ One network

# HAPS: High Altitude Platform Station

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

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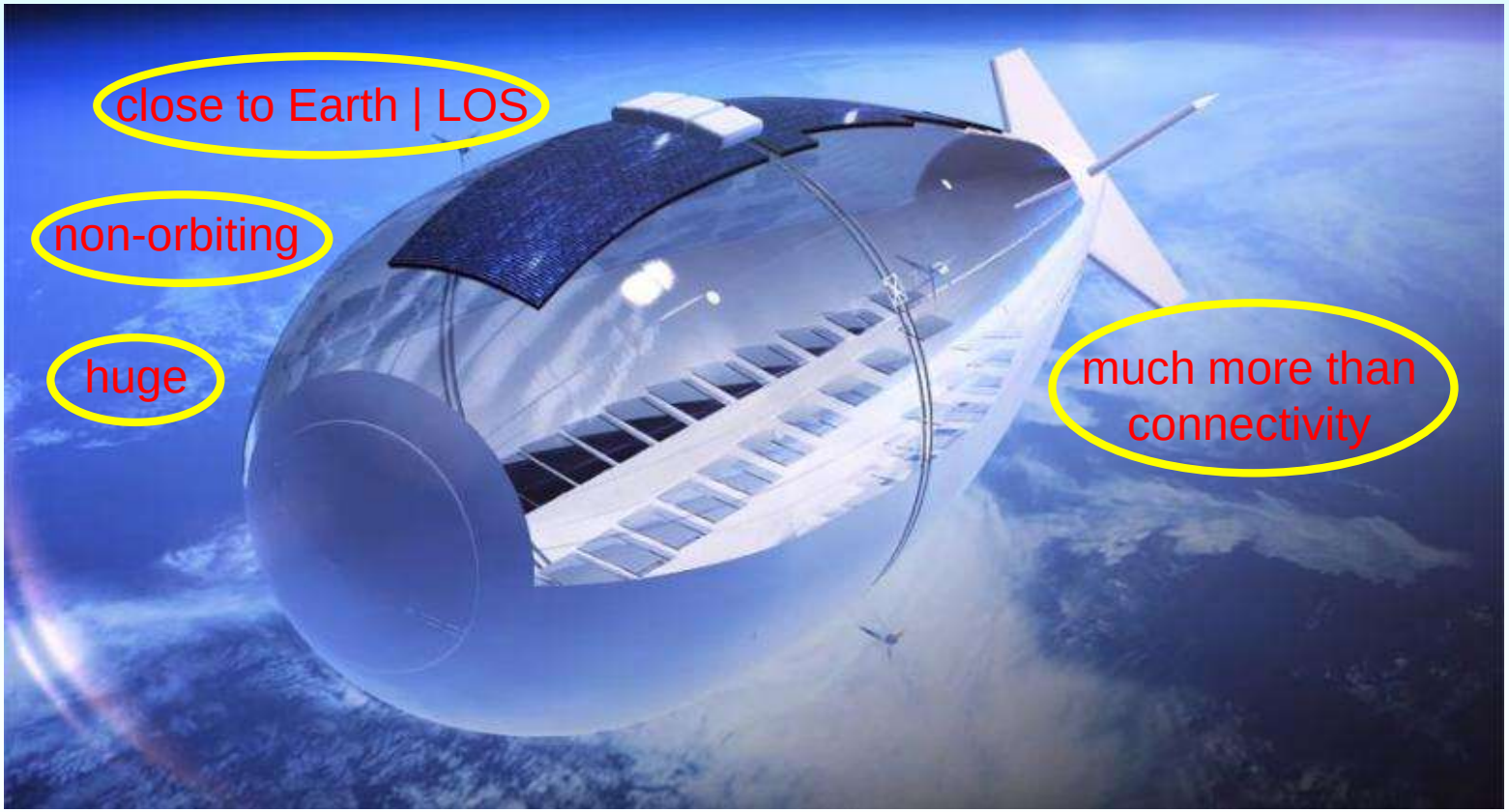
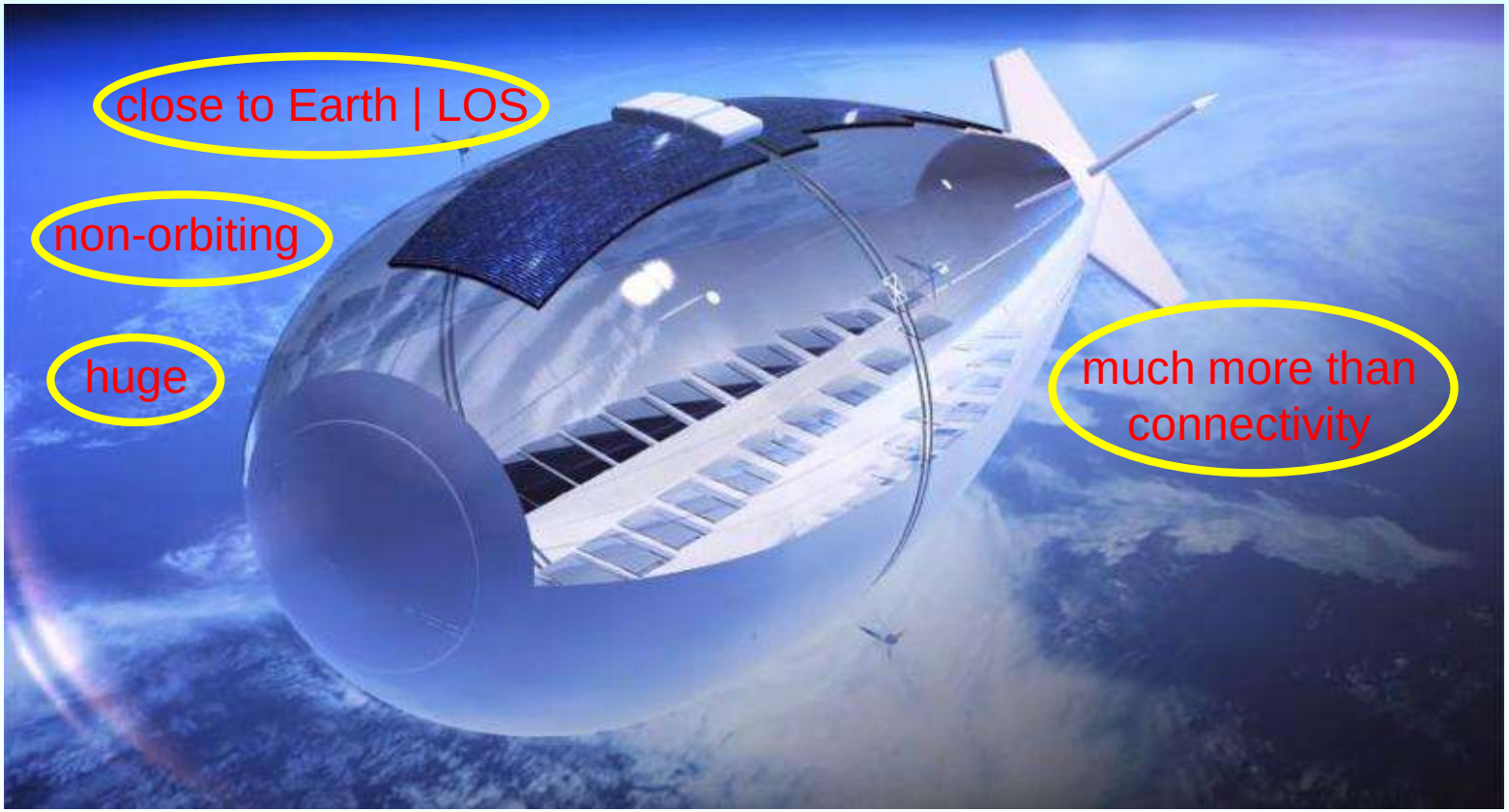



HAPS: Super Macro Base Station in Stratosphere (20 km)

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

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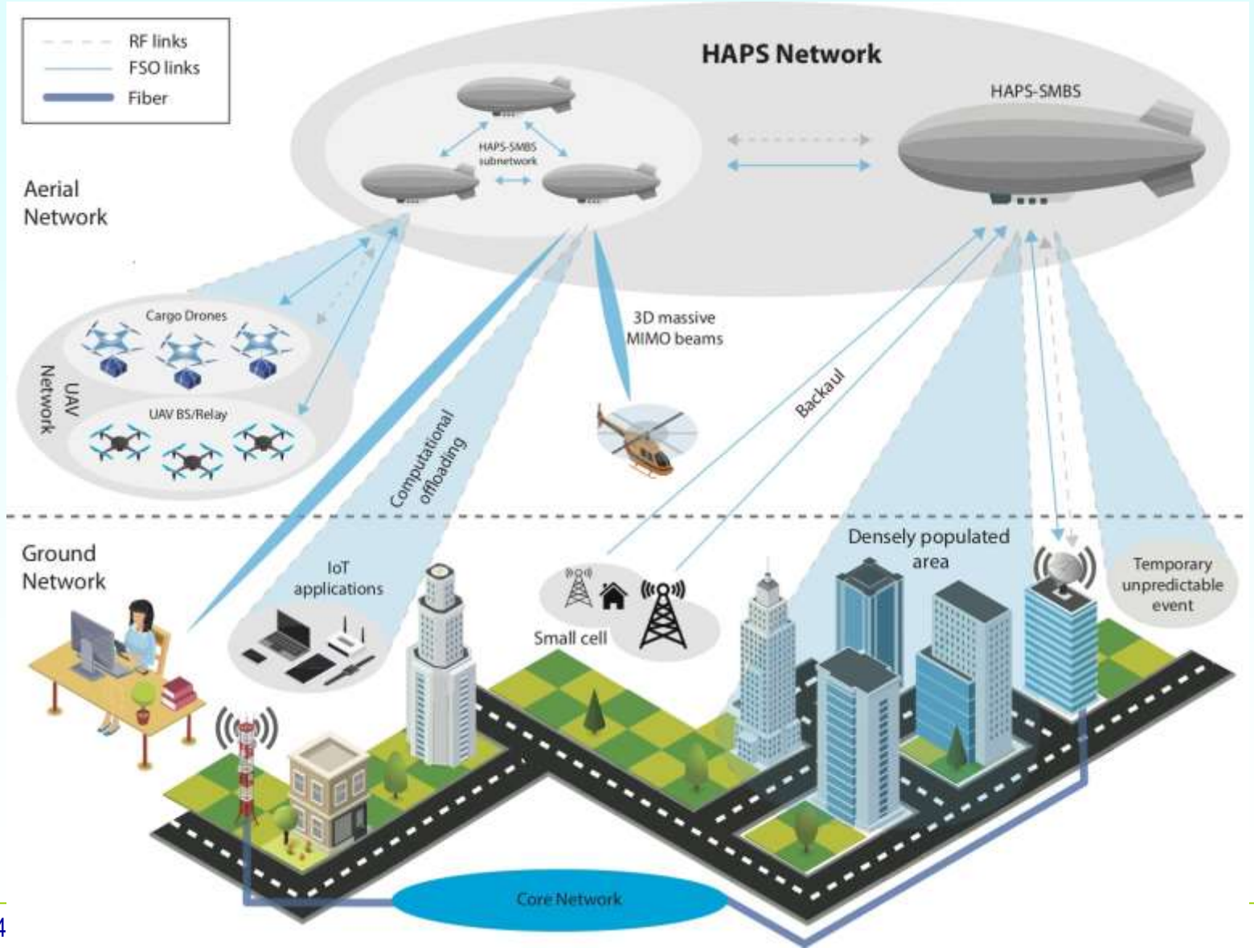
# VHetNet: Terrestrial BSs + HAPS BSs in Urban/Suburban Areas



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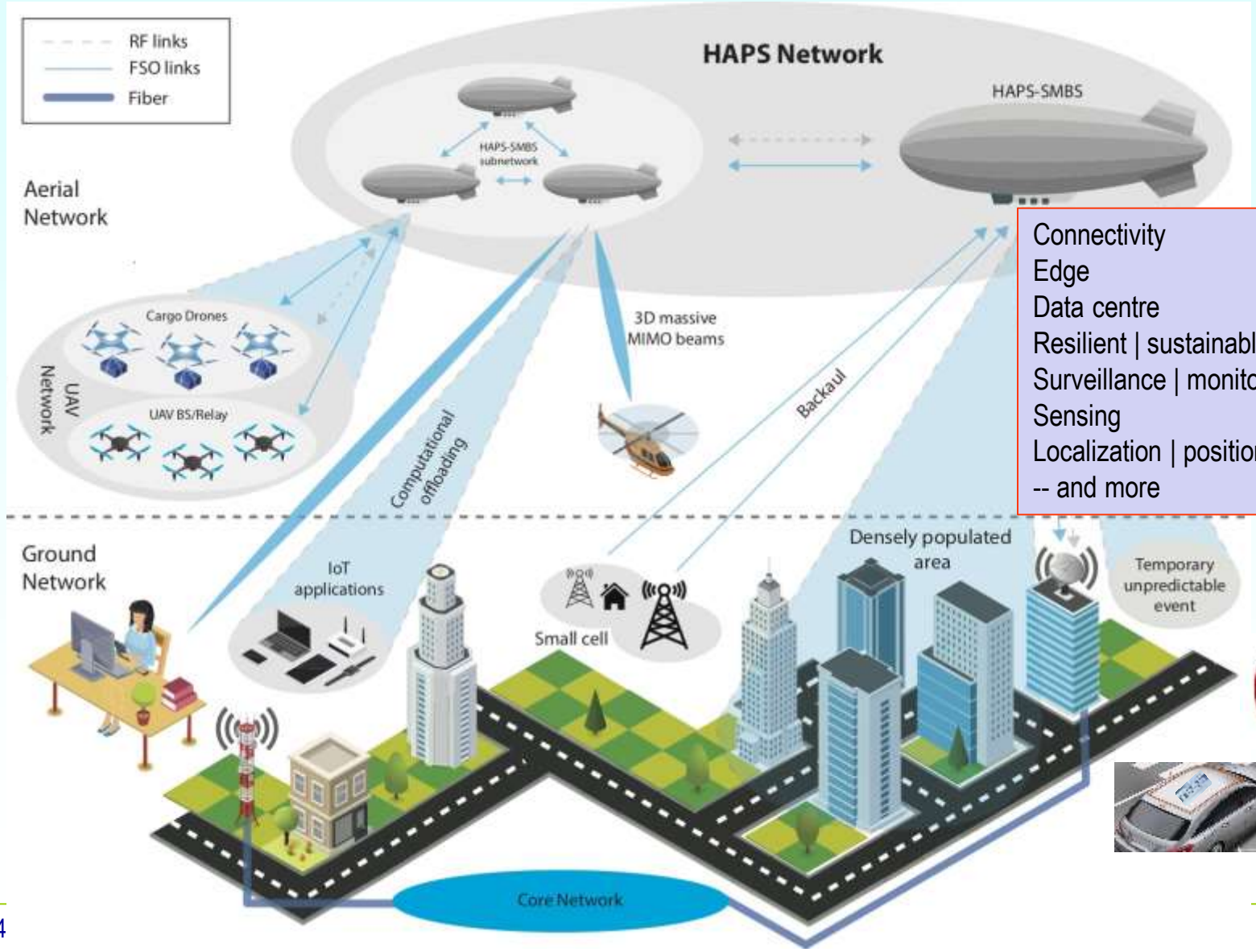


Connectivity
Edge
Data centre
Resilient | sustainable
Surveillance | monitoring
Sensing
Localization | positioning | navigation
-- and more

# Ubiquitous & Instantaneous Hotspot – Anytime, Anywhere, Affordable

20 km

HAPS: High Altitude Platform Station

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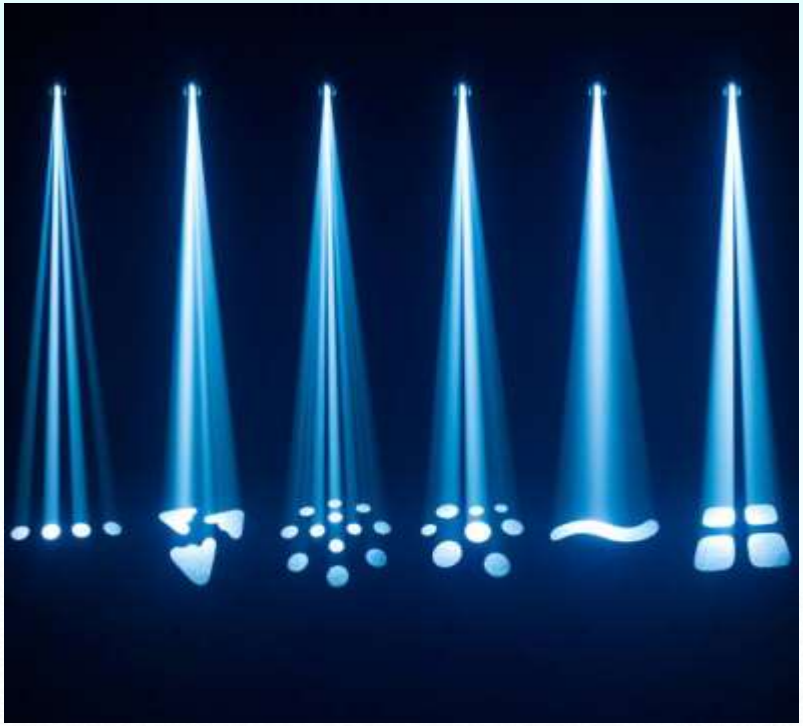
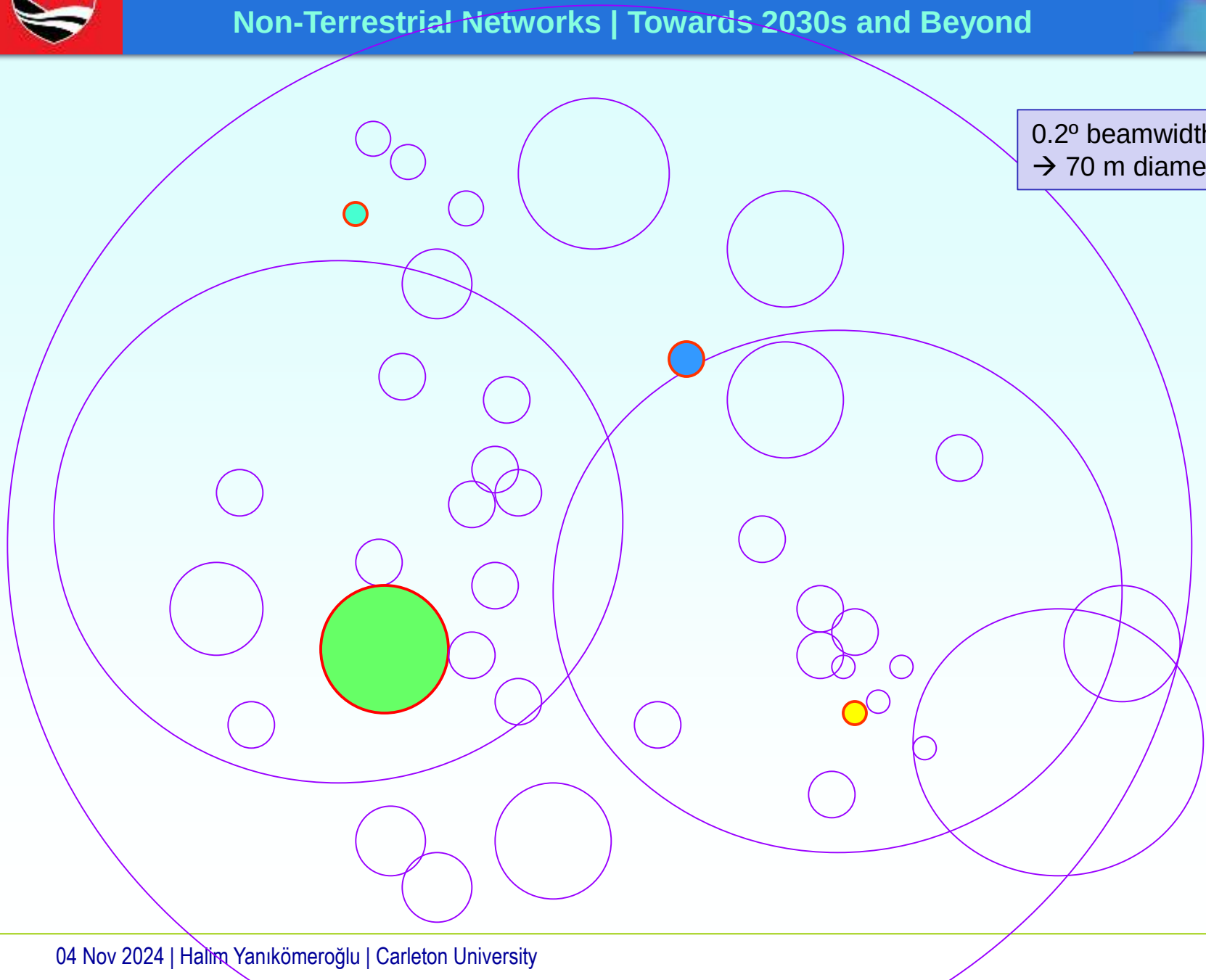
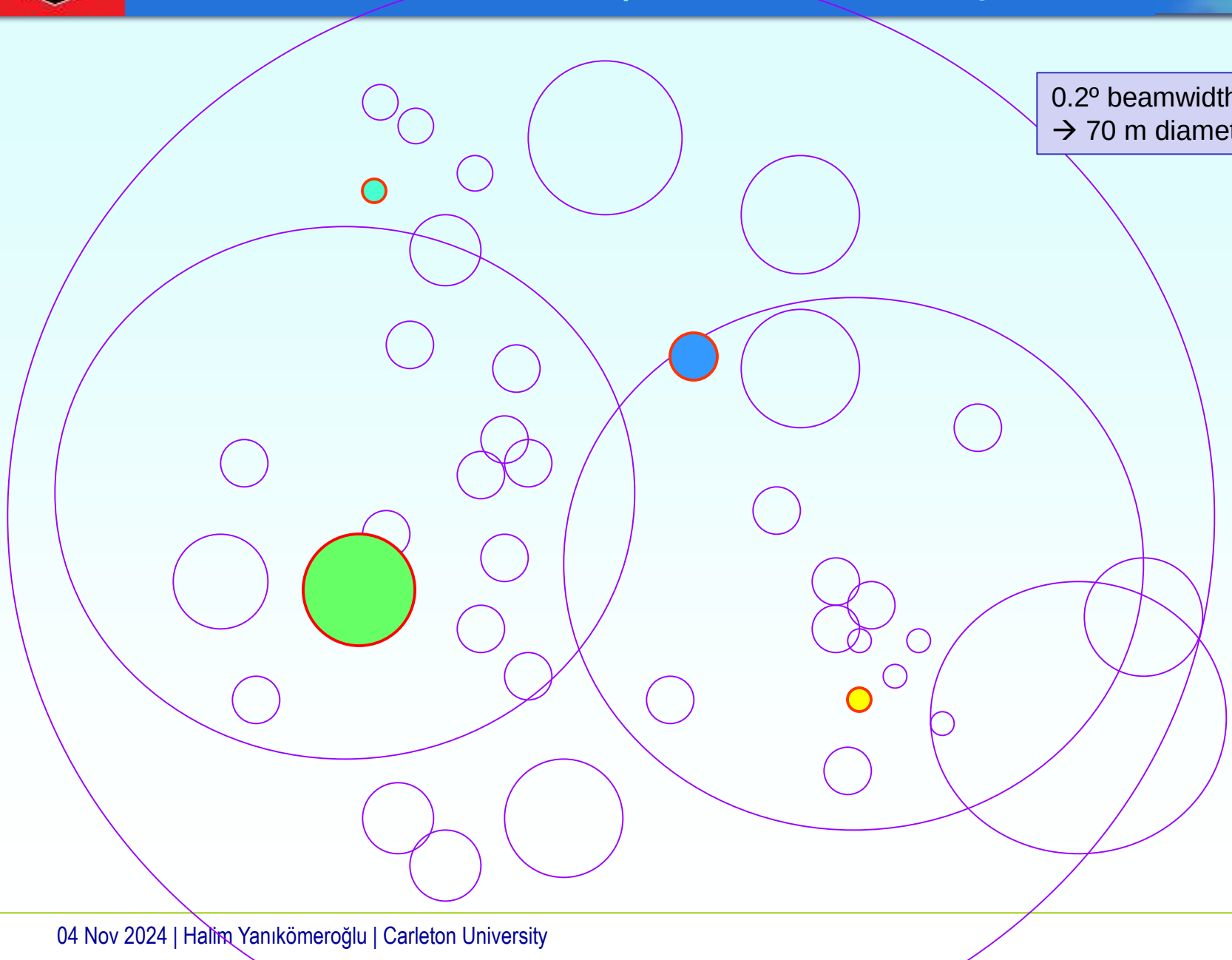


centralized massive access capacity provided through dynamic beams wherever necessary, whenever necessary


0.2º beamwidth @ 20 km
→ 70 m diameter hotspot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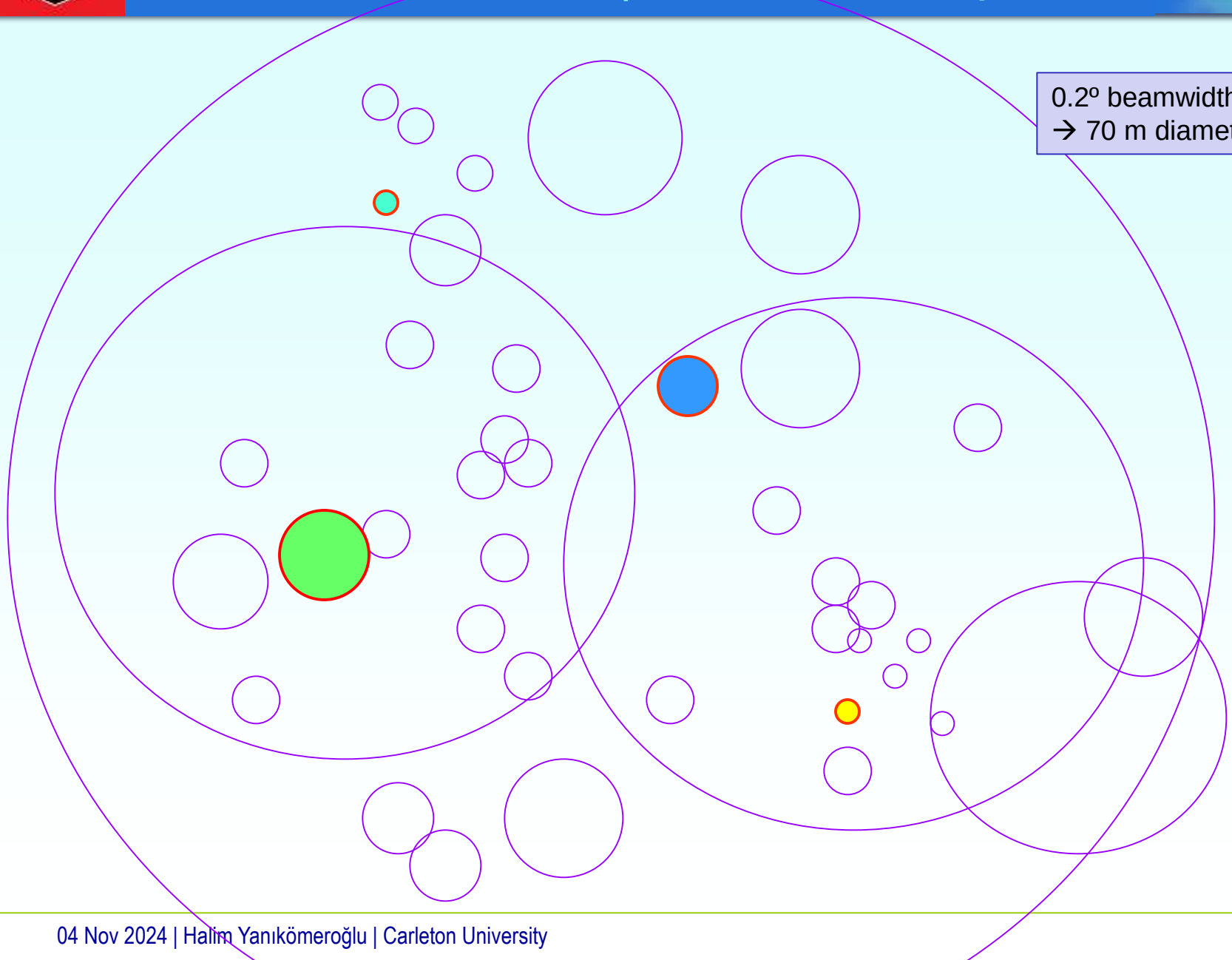
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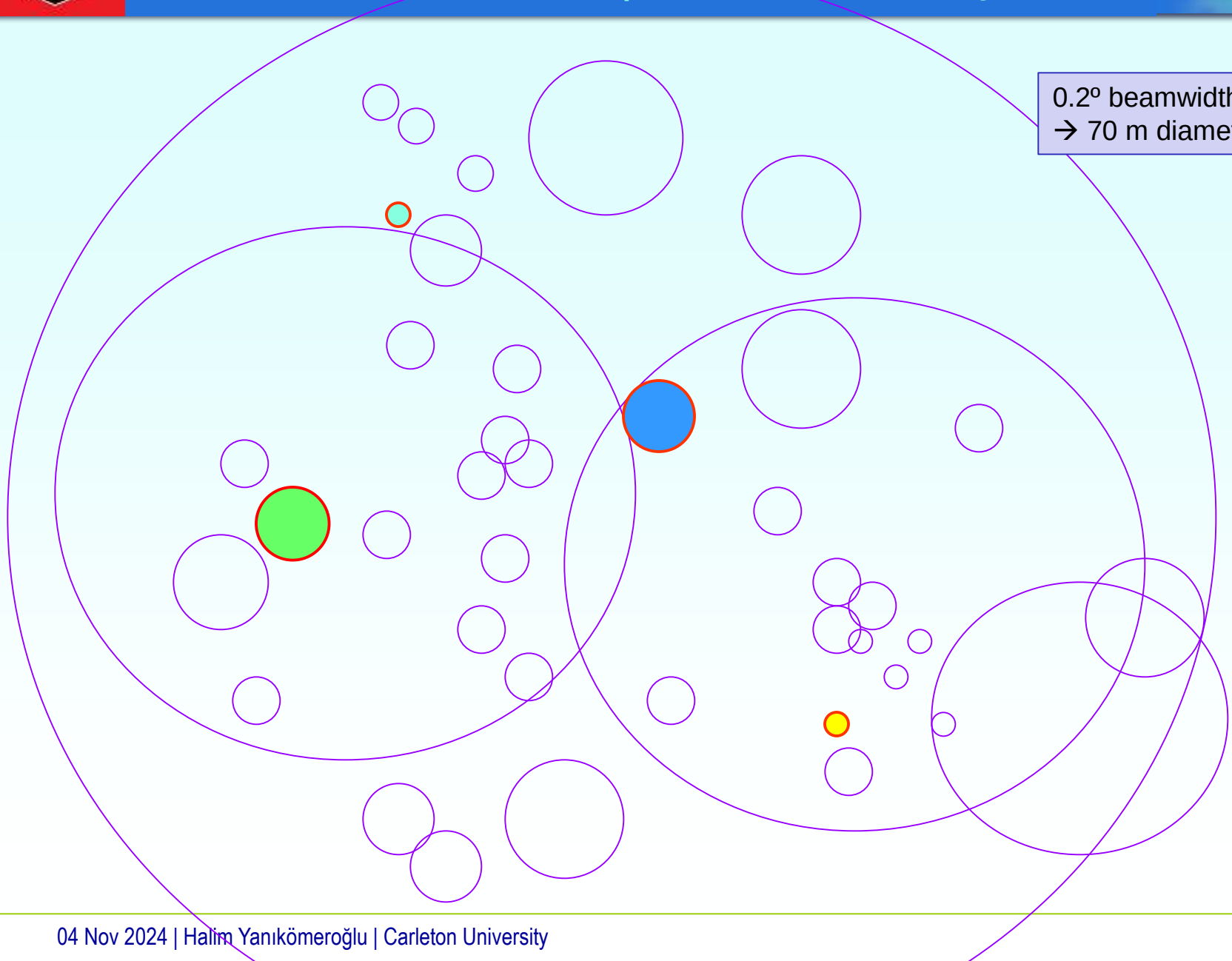
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# HAPS Super Macro BS: 100 Tb/s

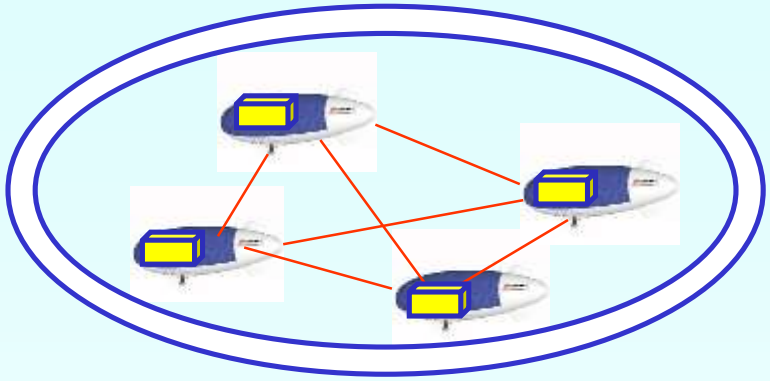

2000s: 3G 1 M
2010s: 4G 100 M
2020s: 5G 10 G
2030s: 6G 1 T
2040s: 7G 100 T

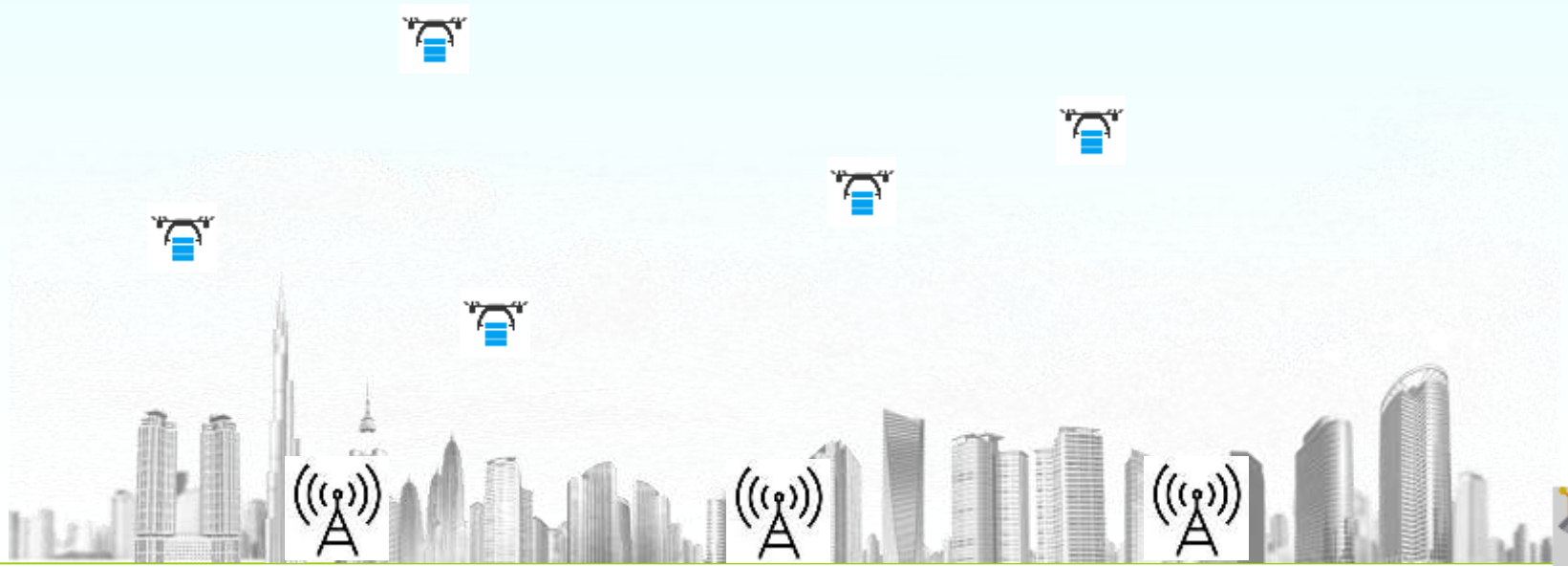
100x per G

| | | | | |
|---|---|---|---|---|
| GEO HTS | 2023: | 1,000 beams → | 1 Tb/s | @ 35,786 km |
| HAPS | 2040s: | 10,000 beams → | 100 Tb/s | @ 20 km |

Best practices from SatNets and terrestrial networks → HAPS networks

# HAPS-enabled Wireless Infrastructure towards 2050





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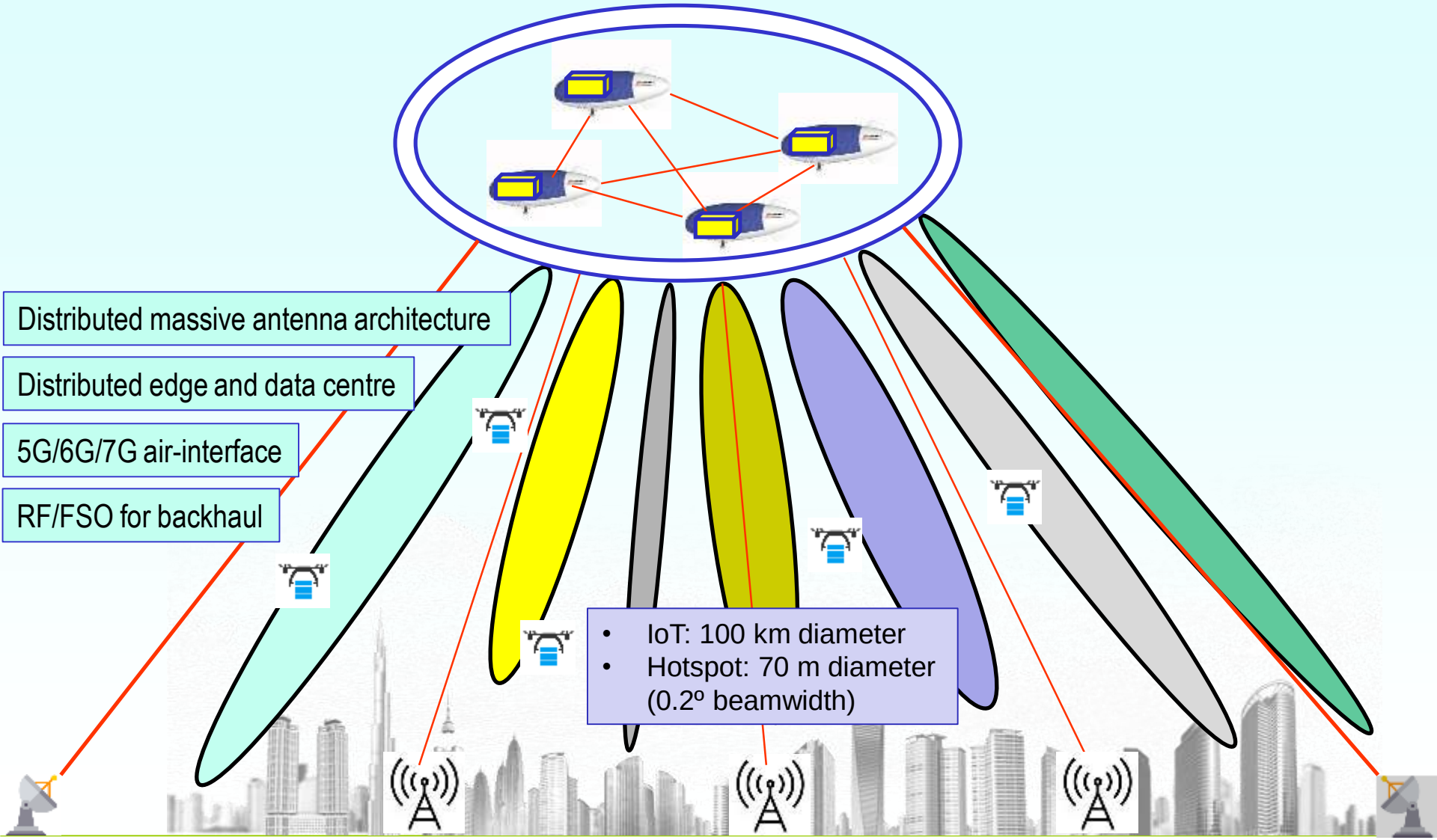

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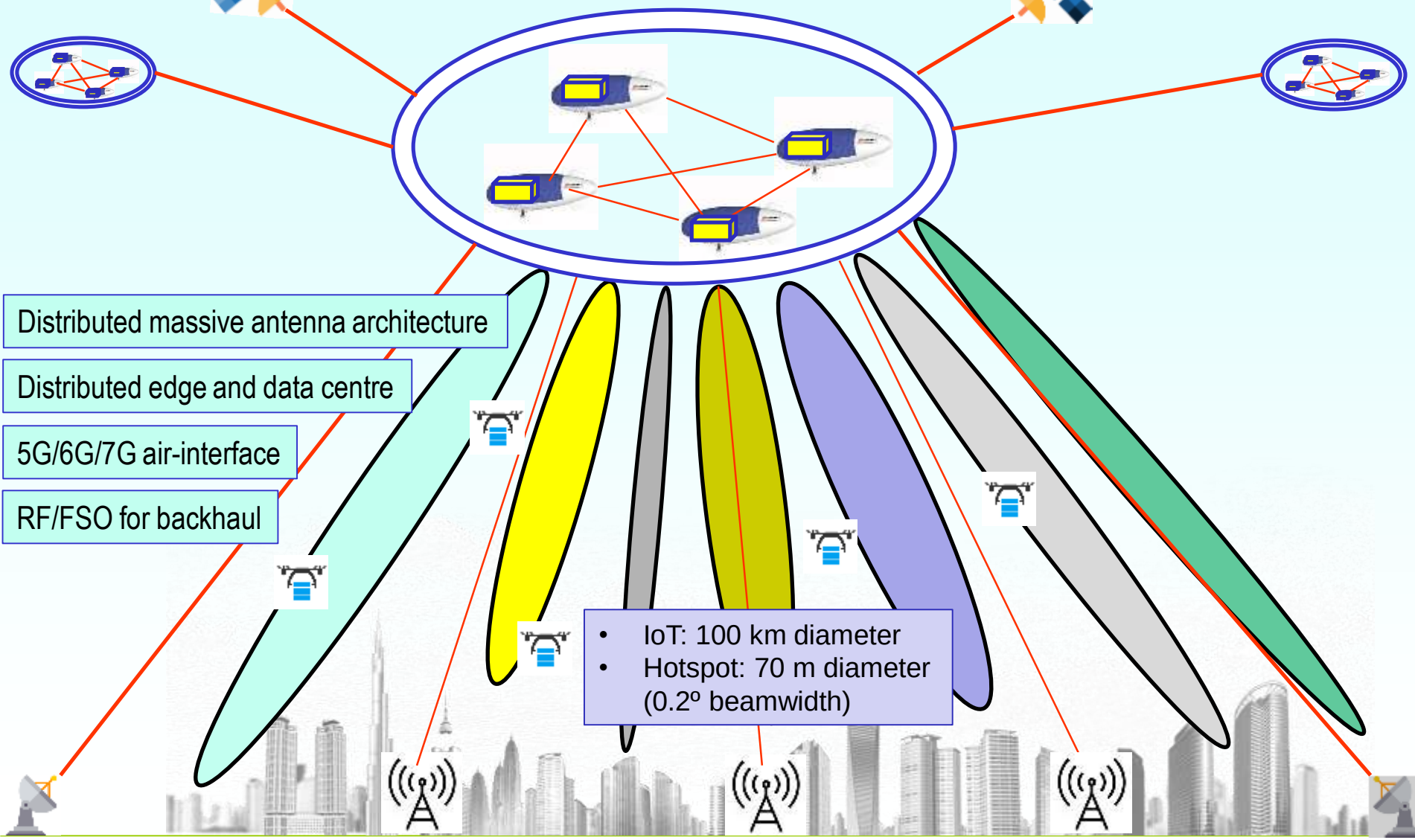

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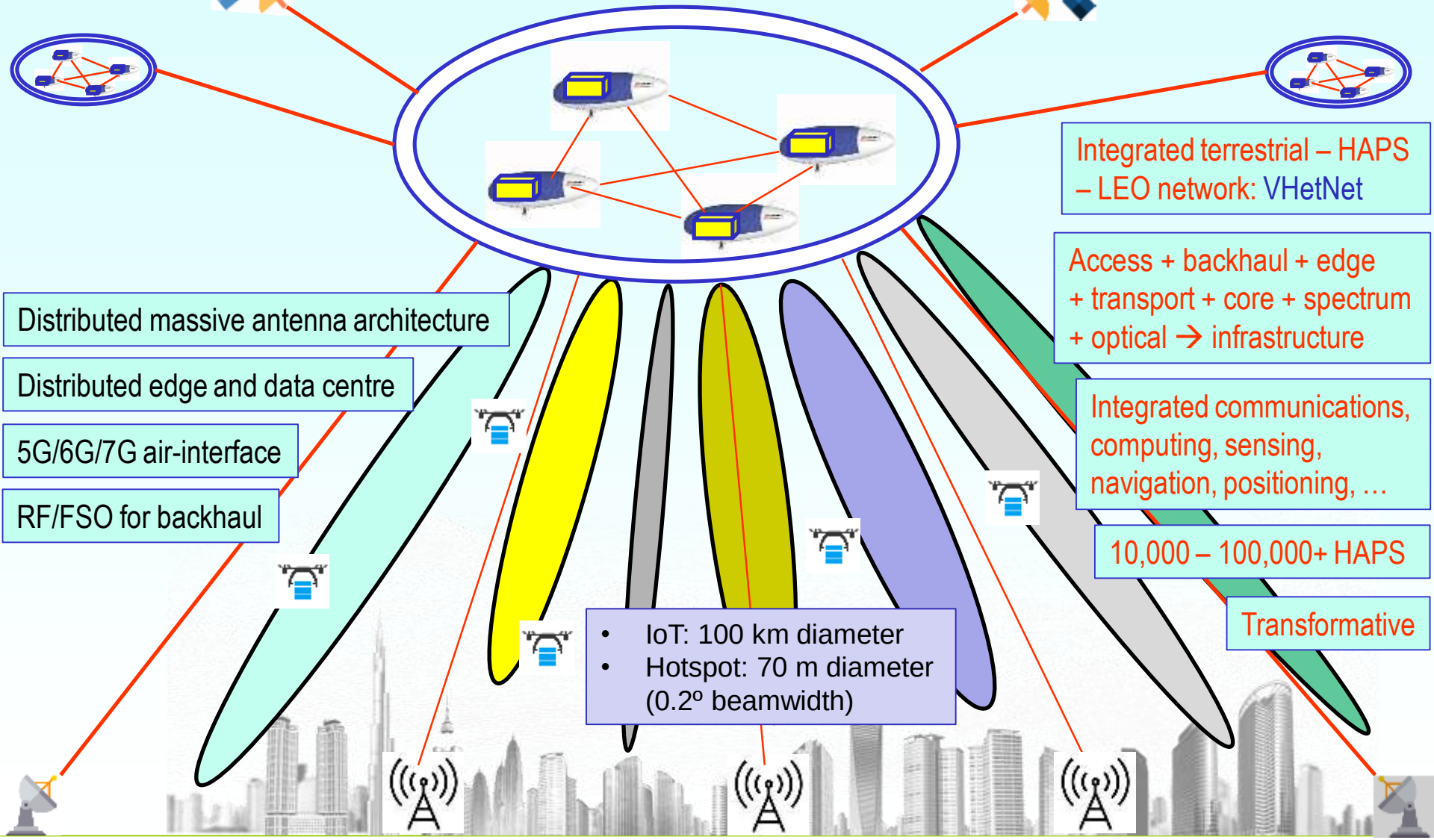
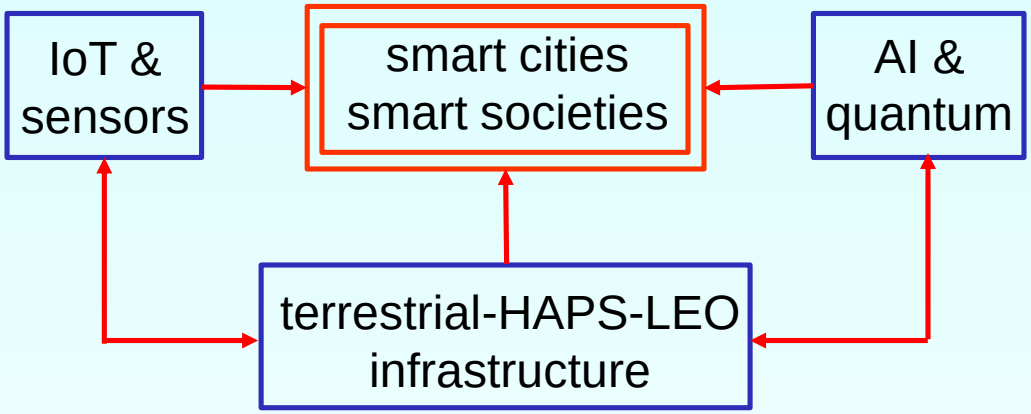


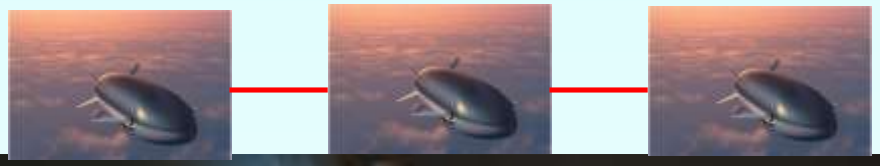
# Wireless Infrastructure for Green and Sustainable Smart Cities & Societies




0% outage
0s setup
0 touch

100s or 1000s of dynamic spot beams from stratosphere (20 km):
10 – 100 Tbps of capacity whenever needed, wherever needed (no waste)

HAPS Constellations



# Linear HAPS Constellation for Neom City

# HAPS Energy Source

5G BS in 2020s: 11.5 kW

HAPS SMBS in 2040s: x10

- Nuclear power?
- Remote charging?
- Tethering to ground?
- Lithium-ion batteries?
- Lithium-metal batteries? (HAPS Mobile, Mar 2023)
- Fluoride-ion batteries?
- Hydrogen fuel?
- Battery replacement?

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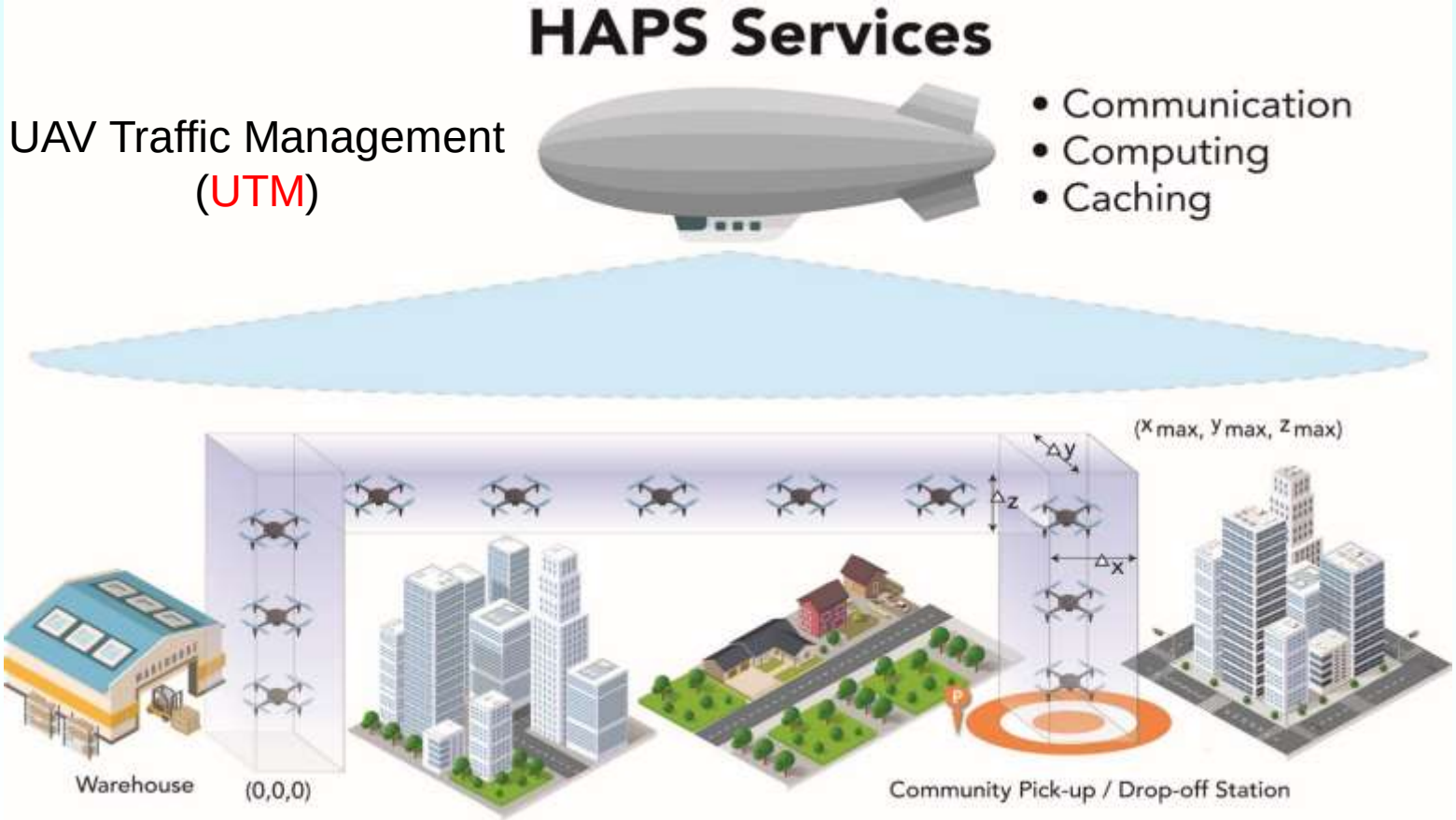
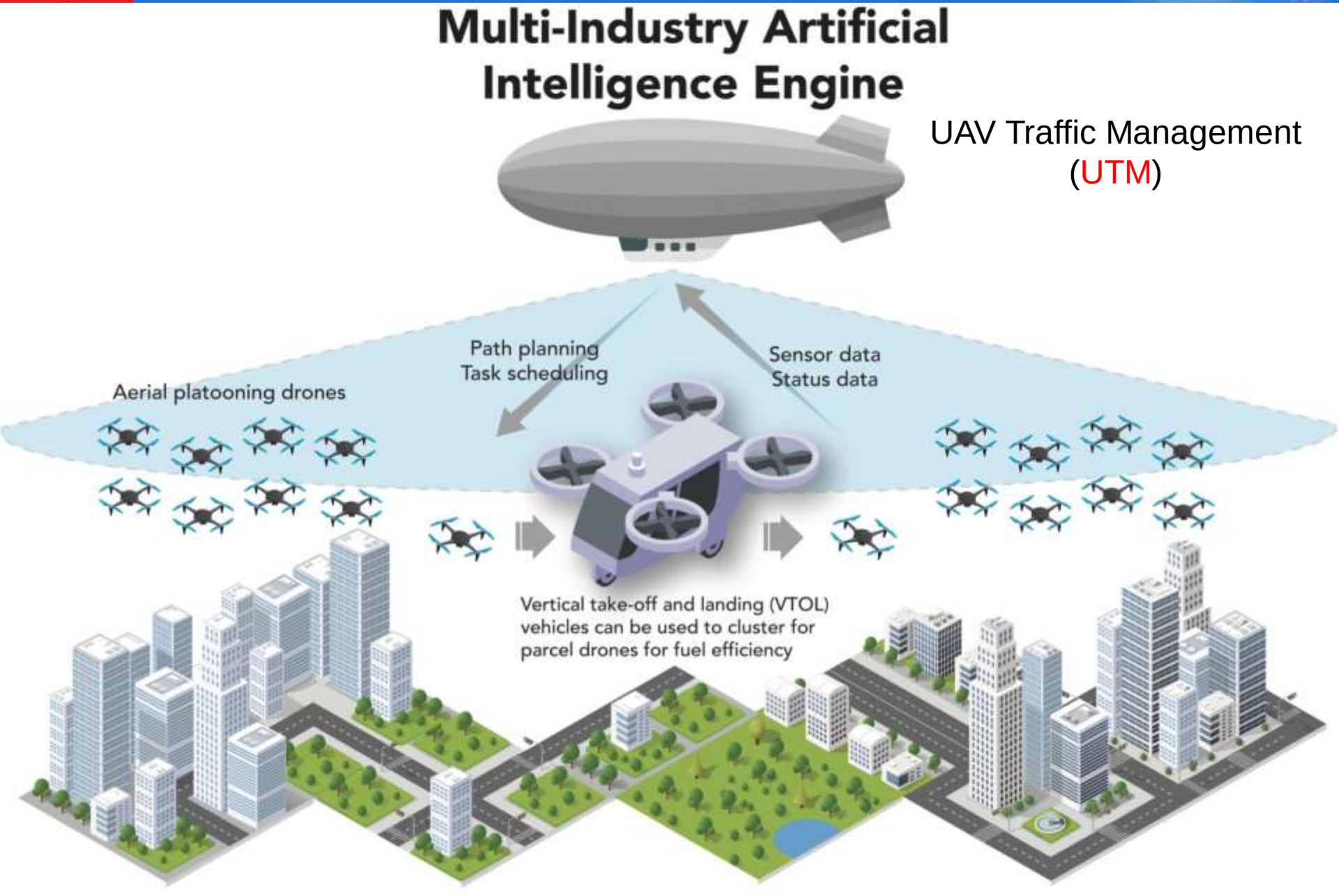
Aerial refueling (In-Flight Refueling – IFR)
KC-135 Stratotanker refuels an F-16 Fighting Falcon

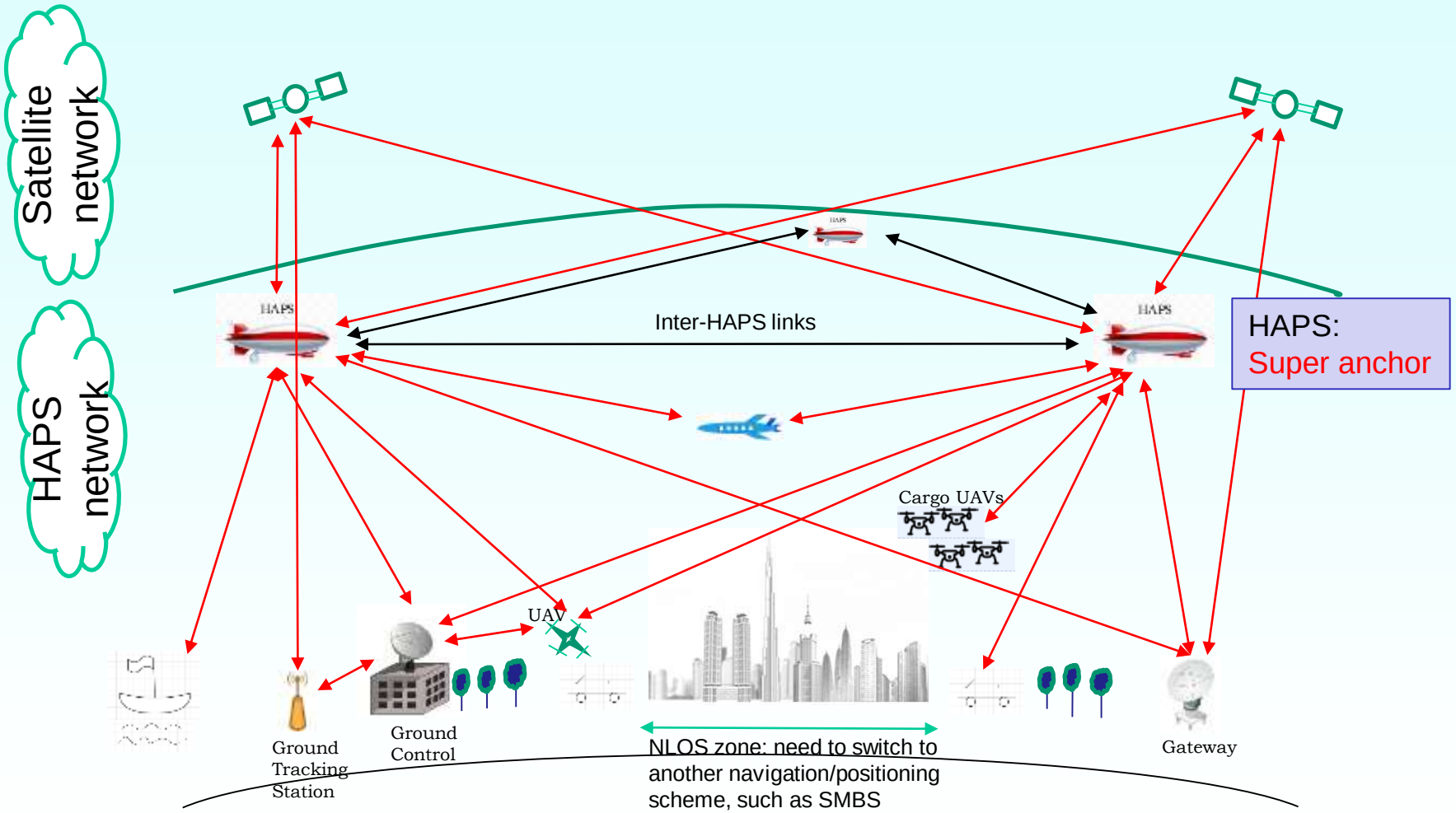
# HAPS for 3D Aerial Highways



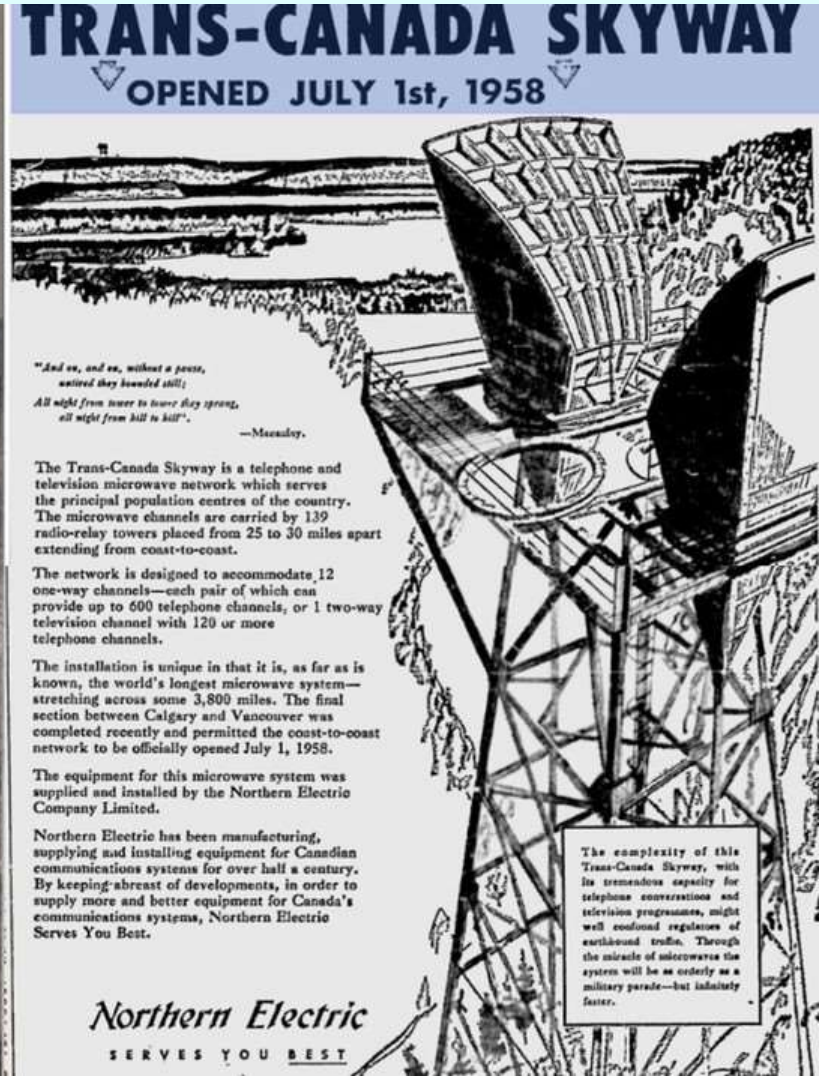


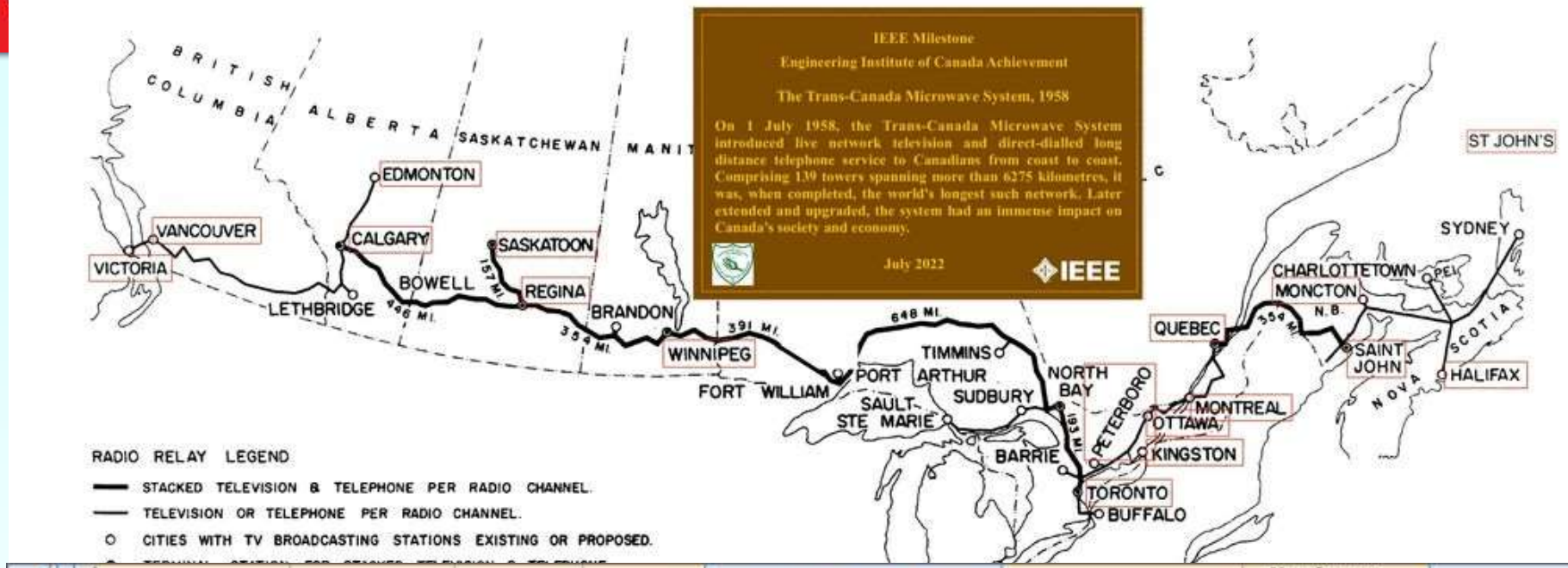

UAV Traffic Management (UTM)

# HAPS Networks for Localization | Navigation | Positioning




TELEPHONE
NEWS
To give you a better understanding of our business and the services we provide.
BELL CANADA
FOR TELEPHONE AND TELEPHONE
New Radio-Relay Skyway Opens
Canadian communications history was made on May 14 with the opening of our modern Microwave Radio-Relay system for network television service and long distance telephone calling.
The new "skyway" — built and operated by telephone people — links the Canadian Broadcasting Corporation's television stations in Toronto, Ottawa and Montreal. It also connects those stations with United States networks via Buffalo, N.Y.
Telephone calls can travel over the Radio-Relay system at the same time as TV programs. Thus it provides many important new long distance voiceways between Toronto, Ottawa and Montreal.
Building the 400-mile Radio-Relay system was a big telephone job. It required 15 stations, some with towers as tall as the 225-foot steel structure pictured at the left, and tons of intricate telephone equipment.
Telephone people, experienced in all branches of communications, completed the job on schedule. They are ready to extend the new skyway to other centres as requirements develop.
May 1953. No. 2


TRANS-CANADA SKYWAY
OPENED JULY 1st, 1958
"And on, and on, without a pause,
untired they bounded still;
All night from tower to tower they sprang,
all night from hill to hill".
—Macaulay.
The Trans-Canada Skyway is a telephone and television microwave network which serves the principal population centres of the country. The microwave channels are carried by 139 radio-relay towers placed from 25 to 30 miles apart extending from coast-to-coast.
The network is designed to accommodate 12 one-way channels—each pair of which can provide up to 600 telephone channels, or 1 two-way television channel with 120 or more telephone channels.
The installation is unique in that it is, as far as is known, the world's longest microwave system—stretching across some 3,800 miles. The final section between Calgary and Vancouver was completed recently and permitted the coast-to-coast network to be officially opened July 1, 1958.
The equipment for this microwave system was supplied and installed by the Northern Electric Company Limited.
Northern Electric has been manufacturing, supplying and installing equipment for Canadian communications systems for over half a century. By keeping abreast of developments, in order to supply more and better equipment for Canada's communications systems, Northern Electric Serves You Best.
The complexity of this Trans-Canada Skyway, with its tremendous capacity for telephone conversations and television programmes, might well confound regulators of earthbound traffic. Through the miracle of microwaves the system will be as orderly as a military parade—but infinitely faster.
Northern Electric
SERVES YOU BEST


IEEE Milestone
Engineering Institute of Canada Achievement
The Trans-Canada Microwave System, 1958
On 1 July 1958, the Trans-Canada Microwave System introduced live network television and direct-dialled long distance telephone service to Canadians from coast to coast. Comprising 139 towers spanning more than 6275 kilometres, it was, when completed, the world's longest such network. Later extended and upgraded, the system had an immense impact on Canada's society and economy.
July 2022
IEEE
BRITISH COLUMBIA
ALBERTA
SASKATCHEWAN
MANIT
EDMONTON
VANCOUVER
CALGARY
SASKATOON
VICTORIA
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FORT WILLIAM
PORT ARTHUR
TIMMINS
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NORTH BAY
SAULT STE MARIE
PETERBORO
BARRIE
TORONTO
BUFFALO
OTTAWA
MONTREAL
KINGSTON
QUEBEC
CHARLOTTETOWN
MONCTON
N.B.
P.E.I.
SAINT JOHN
HALIFAX
SYDNEY
ST JOHN'S
NOVA SCOTIA
RADIO RELAY LEGEND
STACKED TELEVISION & TELEPHONE PER RADIO CHANNEL.
TELEVISION OR TELEPHONE PER RADIO CHANNEL.
CITIES WITH TV BROADCASTING STATIONS EXISTING OR PROPOSED.


Hudson Bay
British Columbia
Alberta
Saskatch-ewan
Manitoba
Ontario
Quebec
Newfoundland and Labrador
St. John's
Jasper Nat'l Park
Glacier Nat'l Park
Banff Nat'l Park
Kamloops
Banff
Vancouver
Calgary
Yoho & Kootenay Nat'l Parks
Moose Jaw
Regina
Riding Mountain Nat'l Park
Winnipeg
Victoria
Medicine Hat
Brandon
Kenora
Nipigon
Marathon
Thunder Bay
Sault Ste. Marie
Sudbury
OTTAWA
Montreal
Edmundston
N.B.
Charlottetown
P.E.I.
Channel-Port aux Basques
N. Sydney
Fredericton
Nova Scotia
Maine
PACIFIC OCEAN
Wash.
Waterton-Glacier Int'l Peace Park
Mont.
N.D.
Minn.
Mich.
Wis.
S.D.
Idaho
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Mass.
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ATLANTIC OCEAN
Ferry
The Trans-Canada Highway
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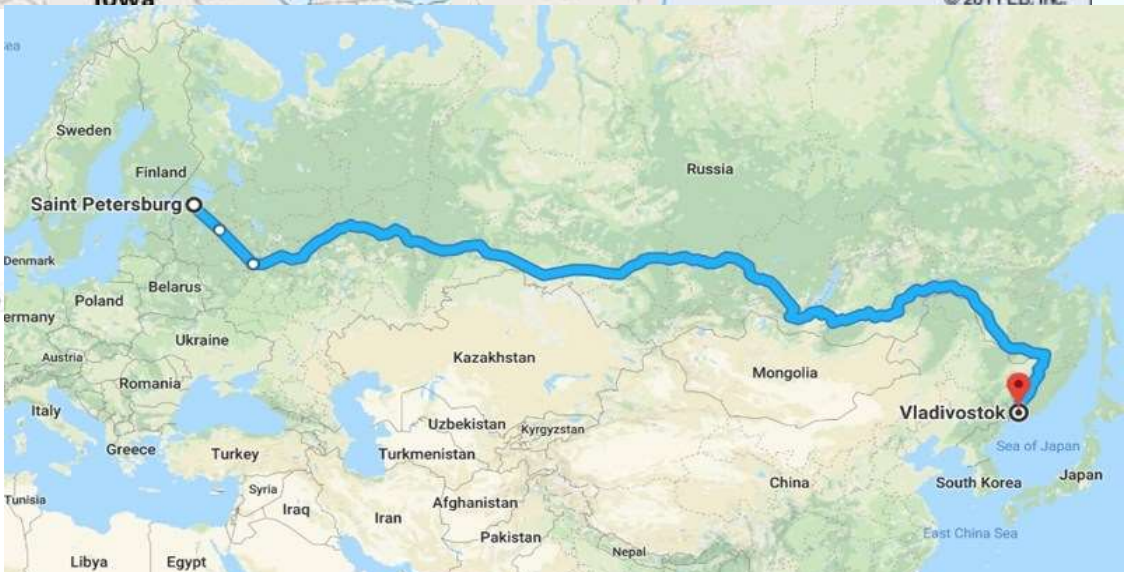
# HAPS Constellation for Intelligent Transportation Systems





# Agenda

- Generations of Mobile | Cellular | Wireless Networks
- Satellite Networks
- HAPS (High Altitude Platform Station) Networks
- Concluding Remarks

# Concluding Remarks

**NTN**:

Non a single technology,

a colossal infrastructure paradigm with unprecedented opportunities

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A new network infrastructure layer in stratosphere

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Why not?

# Major Opportunities lie in the Air & Space, rather than on the Ground


Musk + Bezos: $0.5 T