CCL Seminar

High Altitude Platform Station (HAPS)-aided Communication Systems

Linh T. Hoang

UoA, May 12th, 2021

Contents

6G Vertical Heterogeneous Network (VHetNet)

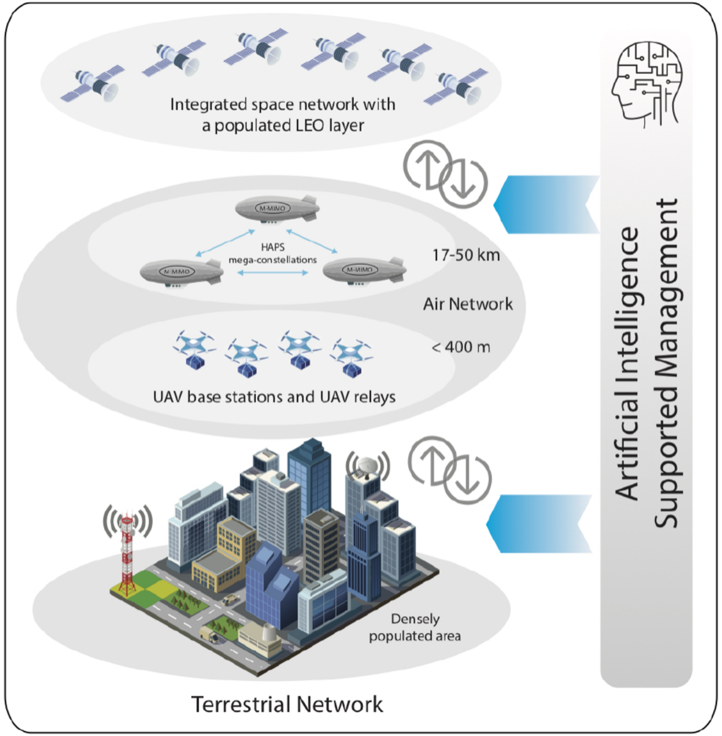
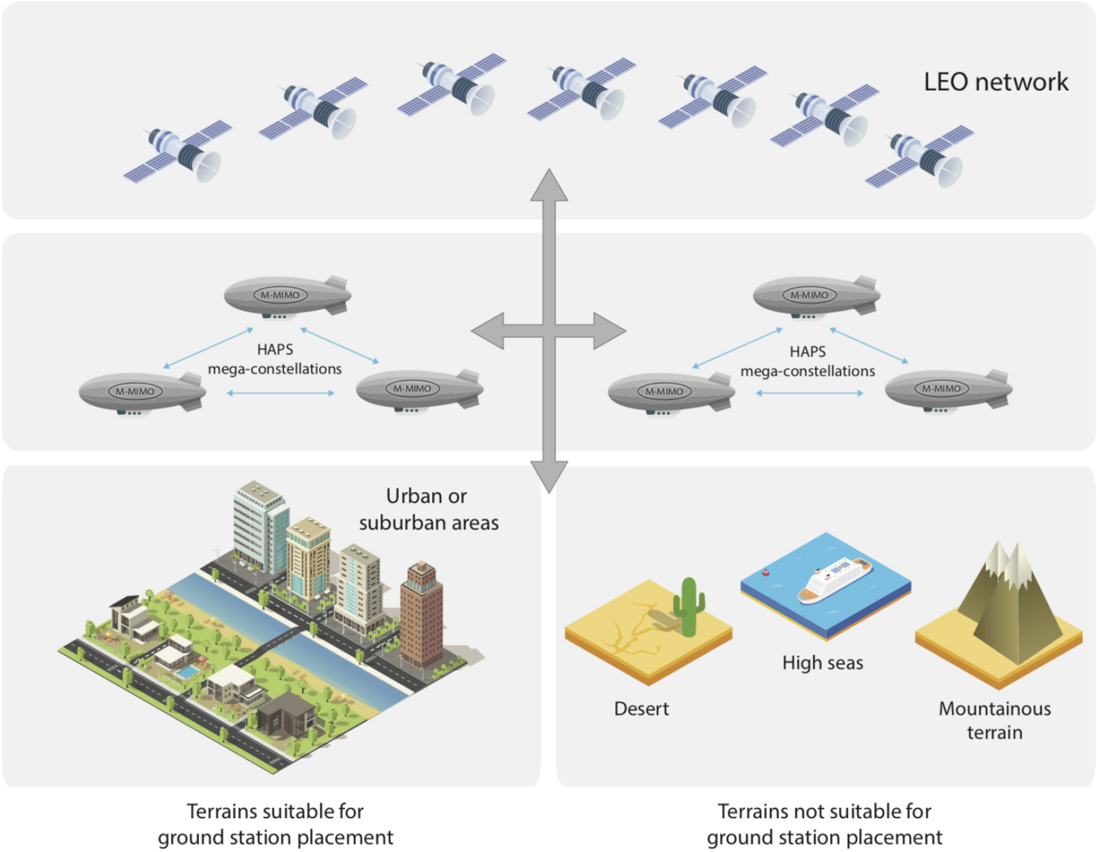


Figure: Vision of 6G VHetNets [1]

- VHetNet : under discussion for 6G network architecture [1] [2]
  - 3 layers : satellites (space), aerial, and terrestrial
- **HAPS** : an integral component of the aerial network
  - Before: research activities since 1990s, focus on rural areas and disaster applications
  - In 6G: envisioned to support mobile services for densely-populated areas (with ultra-wide coverage and high capacity)

[1] G. K. Kurt *et al.*, “A Vision and Framework for the High Altitude Platform Station (HAPS) Networks of the Future,” *IEEE Commun. Surv. Tutorials*, pp. 1–1, 2021.
[2] 3GPP, “Study on New Radio (NR) to support non-terrestrial networks V15.4.0 (Rel. 15),” Tech. Rep., 2020.

Vision of HAPS in 6G VHetNet



- Bridge the space and terrestrial networks over densely populated urban areas
- Provide connectivity and computation over terrains that are not suitable for ground network architectures

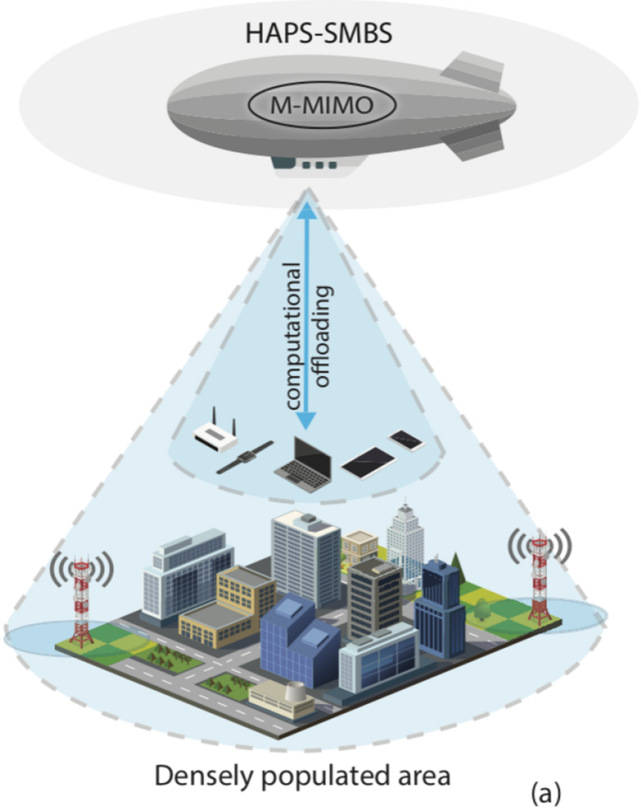
HAPS-mounted Super Macro Base Station (HAPS-SMBS)

Approaches for improving the coverage and capacity of terrestrial networks:

- Increase the network densification through small cell deployments
  - Not up to the task of matching the future demand [1]
- UAV-mounted BSs
  - Constraints in size, weight, and power (SWAP)
  - Limited lifetime, coverage, and computational power
- HAPS-SMBS systems:
  - Quasi-stationary & larger footprint
  - More computational power
  - Better LOS communications link
  - Not an alternative, but a complementary solution

[1] J. G. Andrews, X. Zhang, G. D. Durgin, and A. K. Gupta, “Are we approaching the fundamental limits of wireless network densification?” IEEE Communications Magazine, vol. 54, no. 10, pp. 184–190, Oct. 2016.

Use cases of HAPS-SMBS (1)

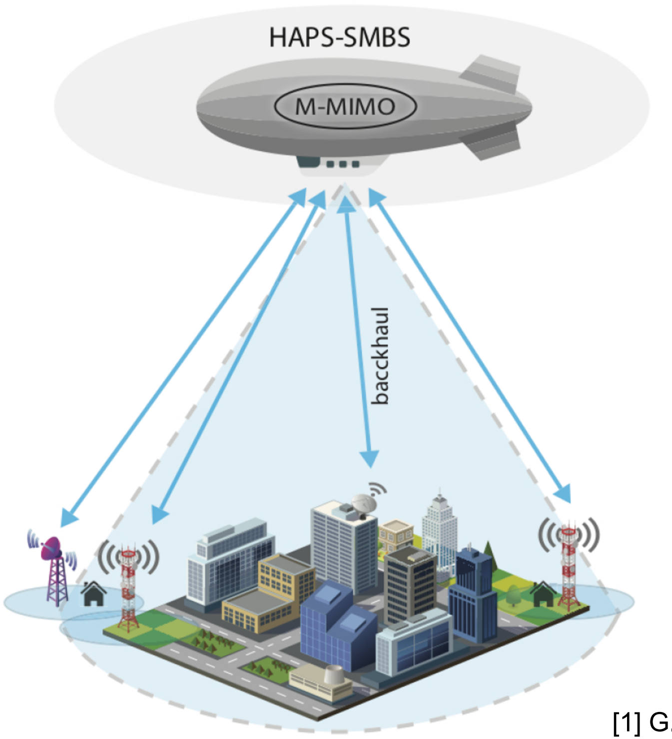


(a) Delivering IoT services

IoT devices with **low data transmission rate** are capable of communicating directly with a HAPS using **low transmission power** [1]

[1] G. K. Kurt *et al.*, “A Vision and Framework for the High Altitude Platform Station (HAPS) Networks of the Future,” *IEEE Commun. Surv. Tutorials*, pp. 1–1, 2021.

Use cases of HAPS-SMBS (2)



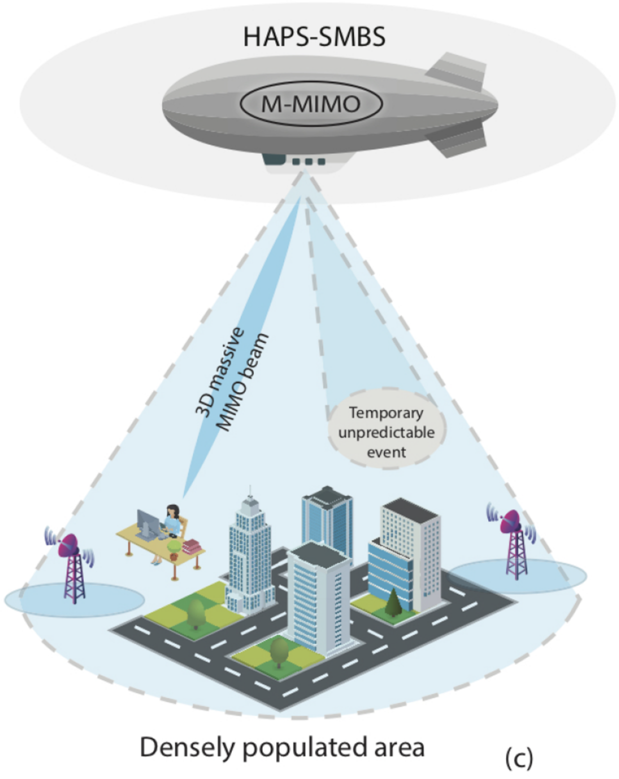
(b)

(b) Backhauling small-cell BSs

- Fiber optic communications for backhaul connectivity is cost-demanding for small cell BSs
- Using wireless microwave links or mmWave bands: well-accepted approaches
- **A small-BS (200 km away from the HAPS) could gather almost the same average power gain that it would receive from a macro-BS (1 km away)** [1]
  - Almost LOS
  - Moderate shadowing/fading fluctuations due to lack of scattering

[1] G. K. Kurt *et al.*, “A Vision and Framework for the High Altitude Platform Station (HAPS) Networks of the Future,” *IEEE Commun. Surv. Tutorials*, pp. 1–1, 2021.

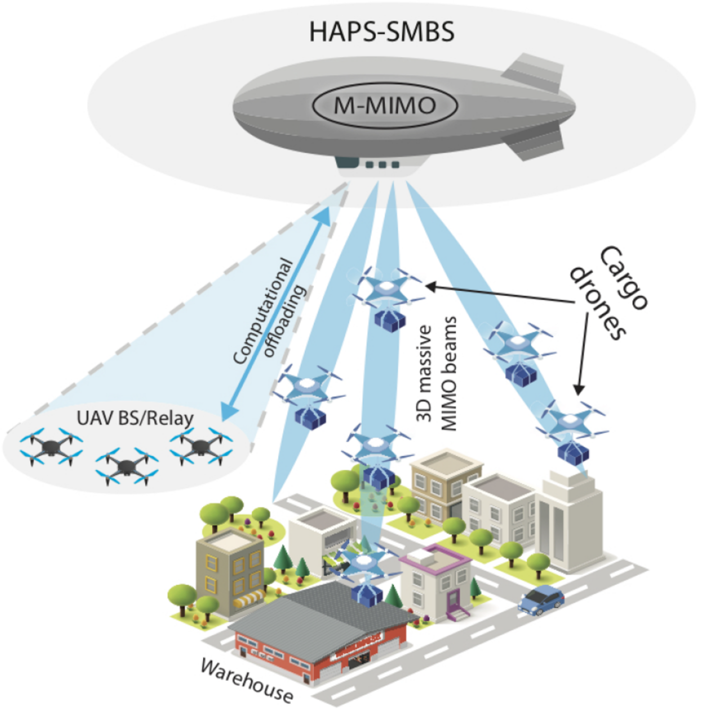
Use cases of HAPS-SMBS (3)



(c) Covering unplanned events and filling coverage gaps

- Unexpected and temporary events such as flash crowds
- UAV-mounted aerial BSs and HAPS-SMBS: feasible solutions
- Required the HAPS-SMBS to steer a beam in a targeted direction

Use cases of HAPS-SMBS (4)

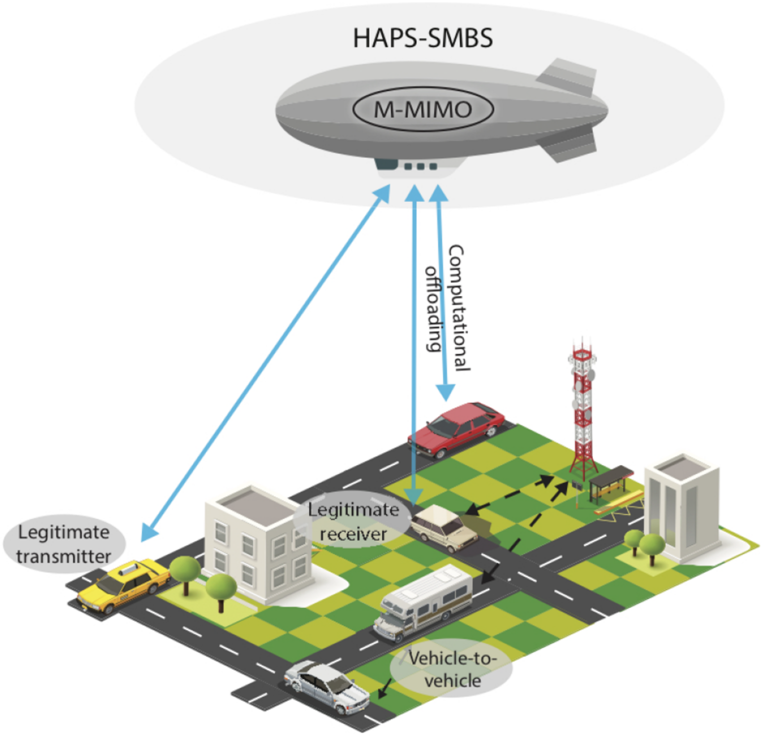


(d)

(d) Supporting and managing aerial networks

- Control and manage the UAV network
- Collect data and support computational offloading from UAVs
- Requires seamless connectivity between UAV nodes and the HAPS-SMBS

Use cases of HAPS-SMBS (5)

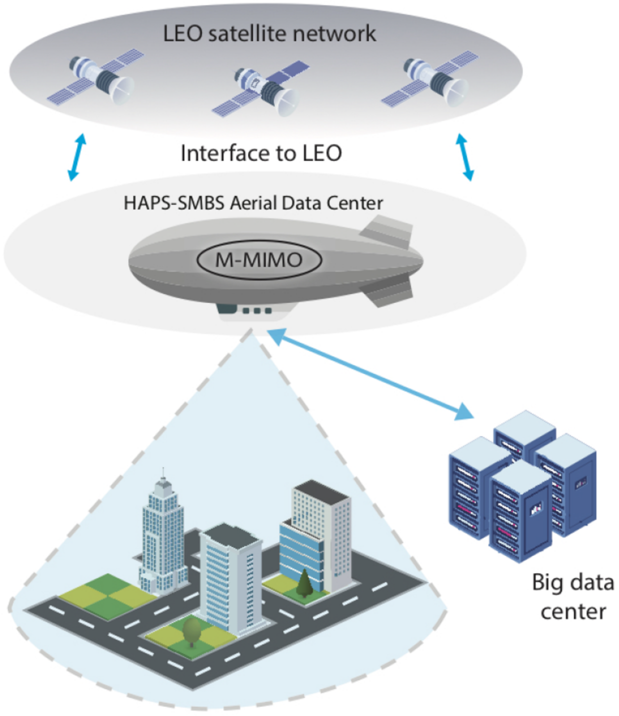


(e)

(e) Supporting intelligent transportation systems

Transport systems include urban area, remote area (highways, trains, flights, ships, …) and future cargo drones.

Use cases of HAPS-SMBS (6)



(f)

(f) Serving as an interface with LEO satellites and as an aerial data center

- Ground to HAPS
- HAPS to LEO satellites
- Possible links: RF, FSO

Classification

- Based on the physical principle of lifting force:
  - **Aerodynamic** (*khí động học*): heavier than air

    HAWK30 (HAPSMobile, Japan, 2017-Now)
  - **Aerostatic** (*khí tĩnh học*): lighter than air

    - Balloons, Google Loon (2011-2021)

    - Airships, Stratobus (France, 2014-Now)
- Aerodynamic HAPS: more preferable for unplanned events or emergency situations
- Aerostatic HAPS: more appropriate for longer-term use cases (supporting cargo drones, autonomous vehicles, computational offloading, …)

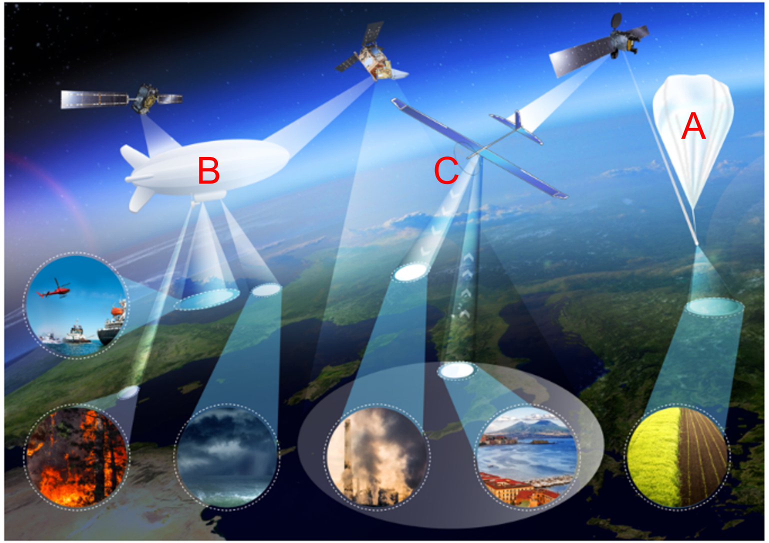


Figure: Balloons (A), airships (B), and aerodynamic HAPS (C).
Credit: https://www.space4water.org/

Specifications

Table: HAPS vs UAV, VLEO and LEO satellites [1]

Parameters	UAV	HAPS	VLEO	LEO
Operational altitude	100–400 m	20–50 km	250–500 km	500–2000 km
Cost	Low	Medium	Medium	High
Round-trip propagation delay	0.66-2.66 μs	0.13–0.33 ms	1.66–3.33 ms	3.33–13.33 ms
Communication endurance	Short	Long	Long	Long
Resource limitation	High	Low (empowered by solar battery charging)	High	High
Mobility	Varying speeds	Quasi-stationary	Fast	Fast
Coverage area	Small	Wider	Wider	Wider
Free space path loss (dB)	101–113	147–155	169–175	175–187

HAPS:
- coverage diameter up to hundreds of km (e.g.: Stratobus, 500 km)
- stay airborne up to years (e.g.: Stratobus, 5 years with annual maintenance)

[1] M. S. Alam, G. K. Kurt, H. Yanikomeroglu, P. Zhu, and N. D. Dao, "High Altitude Platform Station Based Super Macro Base Station Constellations," *IEEE Commun. Mag.*, vol. 59, no. 1, pp. 103–109, Jan. 2021.

Specifications

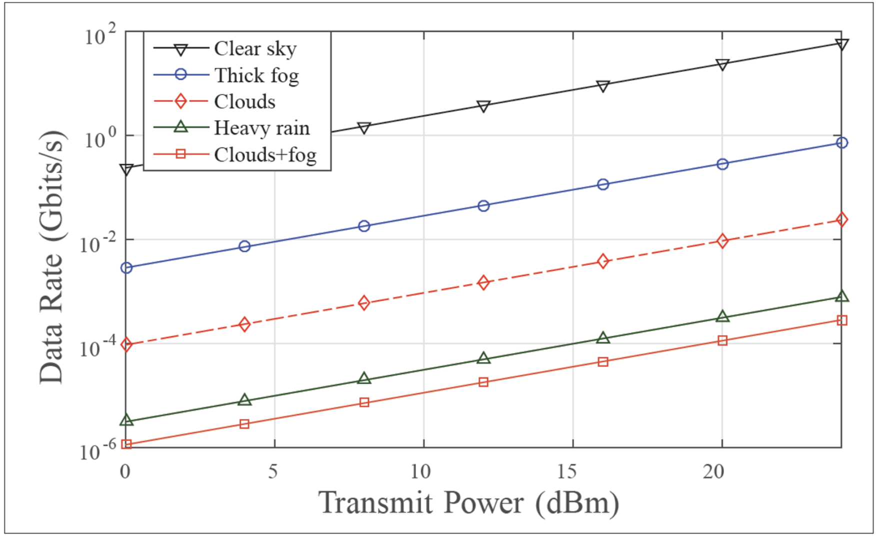


FIGURE 3. Data rate vs transmit power of a vertical FSO link for different weather conditions. It is assumed that a HAPS-SMBS is placed at a distance of 18 km.

Example of achievable data rate versus transmit power of the FSO link between terrestrial small-cell BSs and HAPS-SMBS [1]

- Mostly affected by clouds and the rain
- Possible approach: use FSO for clear skies or foggy conditions, switch to RF during rainy conditions

[1] M. S. Alam, G. K. Kurt, H. Yanikomeroglu, P. Zhu, and N. D. Dao, "High Altitude Platform Station Based Super Macro Base Station Constellations," *IEEE Commun. Mag.*, vol. 59, no. 1, pp. 103–109, Jan. 2021.

Specifications

- Quasi-stationary position (*):
  - Avoid Doppler shift
  - No need for location tracking (compared to LEO satellites)
  - Mobility management (e.g., handoff) for other components
- Located in the stratosphere
  - Almost free from weather disturbance (lightning, thunderstorms, …)
  - Almost absent of cloud (solar energy harvesting)

(*) Position of a HAPS should be maintained in a cylinder with a radius of 400 m and height of ± 700m [1]

[1] ITU-R Rec. F.1500, "Preferred Characteristics of Systems in the Fixed Service Using High Altitude Platforms Operating in the Bands 47.2-47.5 GHz and 47.9-48.2 GHz," Geneva, Switzerland, Jan. 2000.

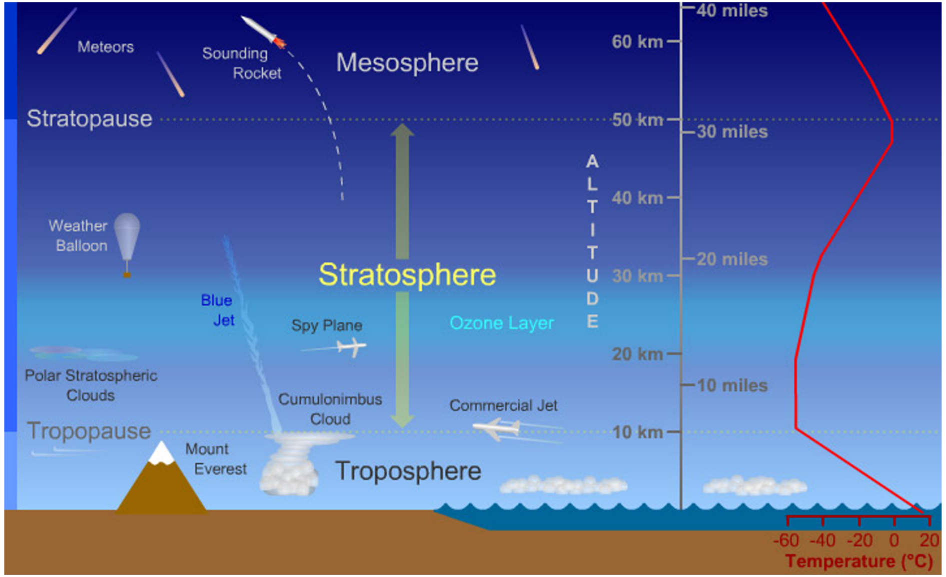


Figure: The stratosphere, Credit: Randy Russell, UCAR

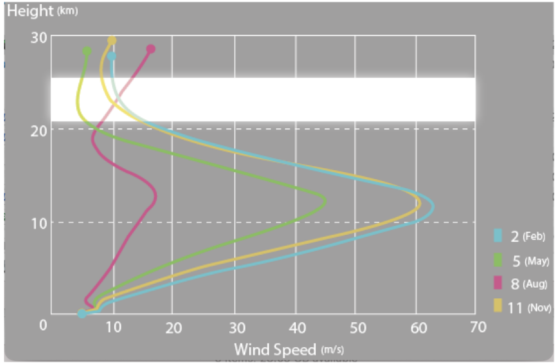


Figure: Wind Speed
Credit: HAPSMobile

Open Challenges (selected)

- Network Management/Control
  - Joint communications, control, computing, and caching in a HAPS-SMBS
  - Make the network more autonomous, self-organizing, self-configuring, and self-sustaining
  - For example: dynamic spectrum slicing to avoid under/over-utilization
- HAPS Constellations and Inter-HAPS Networking
  - Design of a HAPS mega-constellation and its interaction with satellite mega-constellation and the terrestrial network
  - Optimization of a HAPS constellation to maximize the QoS
  - Coordination among HAPS nodes to avoid interference, wasting resources, or overlapping footprints

Conclusions

- Potential opportunities and target use cases of HAPS-SMBS-aided VHetNet were discussed.
- While research on HAPS goes back to 1990s, the concept HAPS-SMBS has attracted new attention in recent years, especially for application in densely-populated areas.
- Specifications of HAPS networks in the new scenario are different from those of the past, and different from those of UAV networks/satellite constellation.

=> Further investigation is needed to realize the potentials of HAPS in the next-generation communication systems.

Thank you for your listening

HAPS projects

Loon [74]	Aerostatic- (Balloon)	Subsidiary of: (Alphabet Inc.) Previously: (Google X)	United States	2011-2021	○ Its mission was to connect people everywhere using a network of HAPS. ○ It was the most mature project whose fleet constituted a meshed network managed by Loon SDN, which provided service to over 300,000 users. ○ Last design was able to fly up to 312 days at an altitude around 18-23 km, with a 40 km coverage radius. ○ In 2019, Loon's balloons accomplished over one million flight hours, flying for a total of around 40 million km.
Stratobus [82]	Aerostatic- (Airship)	Thales Alenia Space	France	2014-Now	○ One of its goals is to provide 5G telecommunications. ○ Its length and width are about (115 m x 34 m), and it can carry up to 450 kg payload for a 5-year mission with annual maintenance. ○ It is positioned at an altitude of 20 km and can cover up to 500 km in diameter. ○ It is expected to be on the market in 2021.
HAWK30 [83]	Aerodynamic	HAPSMobile	Japan	2017-Now	○ Its objective is to connect mobiles, UAVs, and IoT nodes around the world. ○ It has a wingspan of 78 m, deployed at an altitude of 20 km, and can provide a 100 km coverage radius for several months.
PHASA-35 [84], [85]	Aerodynamic	BAE Systems and Prismatic	United Kingdom	2018-Now	○ It is designed for a variety of services including 5G communications. ○ It has a payload capacity of 15 kg and can remain airborne continuously for up to one year.. ○ It can maintain an altitude of 17-21 km with a payload power capacity of 300-1,000 w, and it can cover a radius of up to 200 km.

- PHASA 35 Payload trials 2020

  https://youtu.be/0C25oOIPRc8
- Stratobus: halfway between a drone and a satellite! Official video

  https://youtu.be/nvmkendJI2Y

Spectrum bands for HAPS [1]

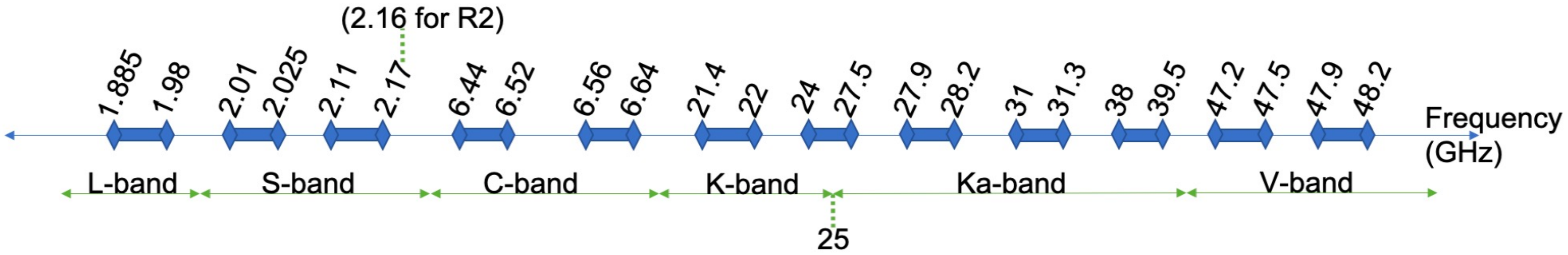


Fig. 4: An overview of the spectrum bands dedicated for HAPS.

[1] G. K. Kurt *et al.*, "A Vision and Framework for the High Altitude Platform Station (HAPS) Networks of the Future," *IEEE Commun. Surv. Tutorials*, pp. 1–1, 2021.