Ubiquitous Global Coverage, Ample Throughput, Low Power, Low Latency & Zero Error...

Would It Ever Work?

Presented by
Lajos Hanzo
with
Jiankang Zhang, Taihai Chen, Shida Zhong, Jingjing Wang, Wenbo Zhang, Xin Zuo & Robert G. Maunder
School of Electronics and Computer Science,
University of Southampton, SO17 1BJ, UK.

http://www-mobile.ecs.soton.ac.uk

Acknowledgements

- Sincere thanks for the cordial invitation
- The team back at 'base' in Southampton, especially Jiankang Zhang, Taihai Chen, Shida Zhong and Robert G. Maunder
- The Sponsors: Cobham, Thales, the TSB, EPSRC and the ERC Advanced Fellow Grant

Sincere thanks for the invitation - I am honored!

特别感谢组织者的盛情邀请，
并向我的中国朋友和同行们致
以热烈的欢迎！

你们的莱哲思·汉叟

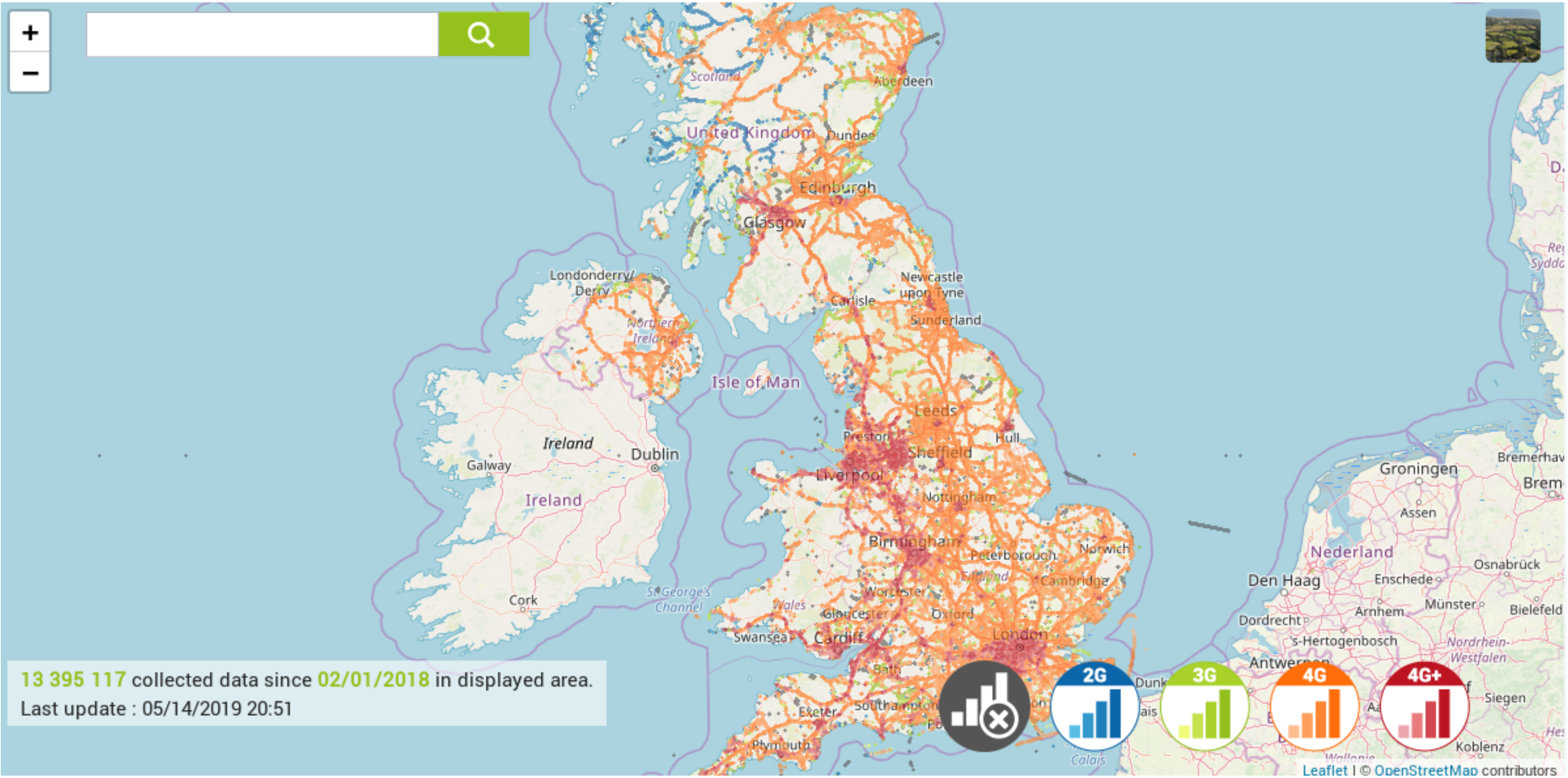

Electronics and
Computer Science
UNIVERSITY OF
Southampton
Southampton Wireless
Research Group

Outline

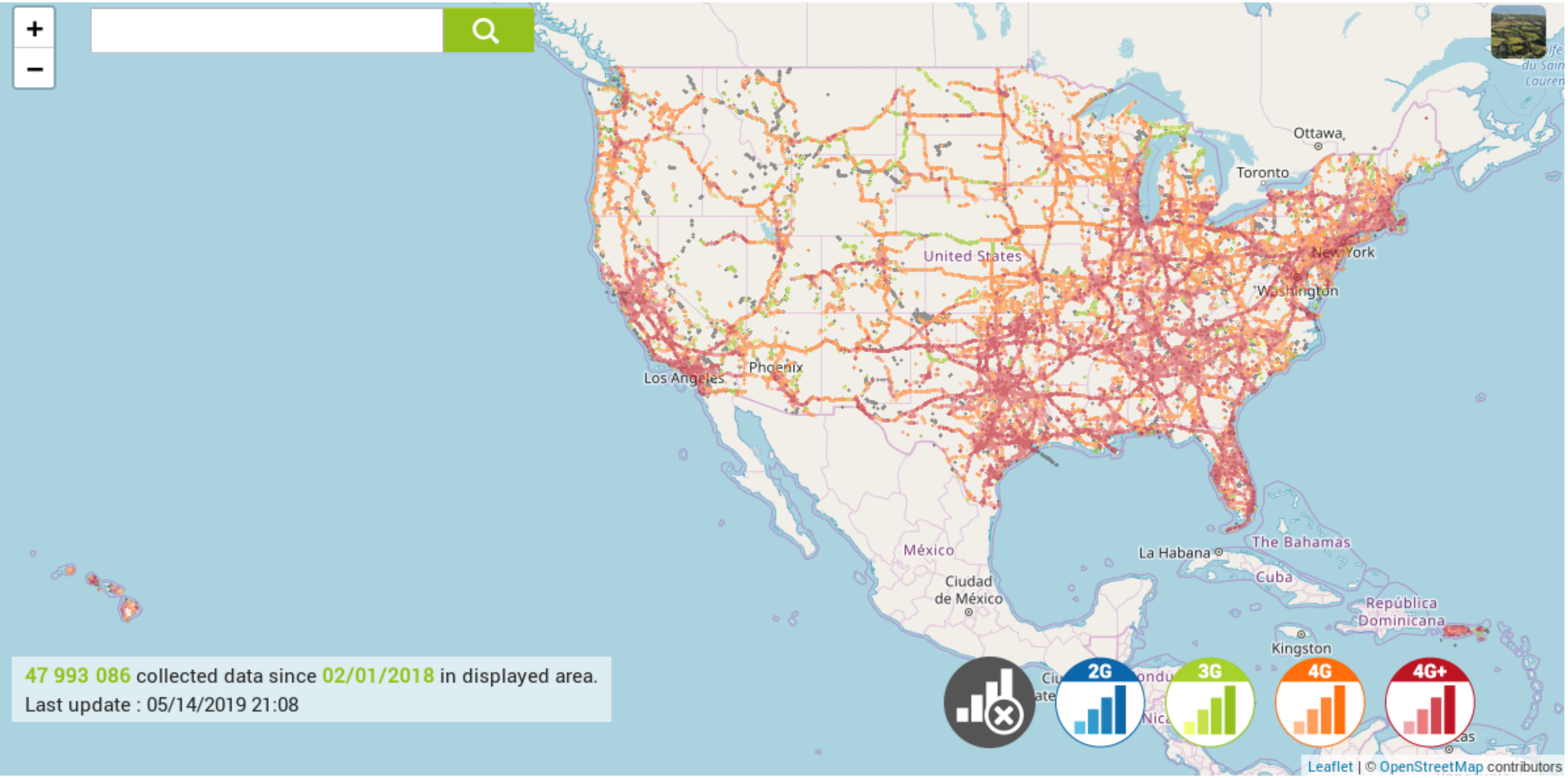
- **Motivation;**
- Aeronautical Ad-Hoc Networking (AANET) scenarios;
- AANET applications;
- AANET specifications and challenges;
- AANET enabling techniques and futures;

- **The Motivation...**

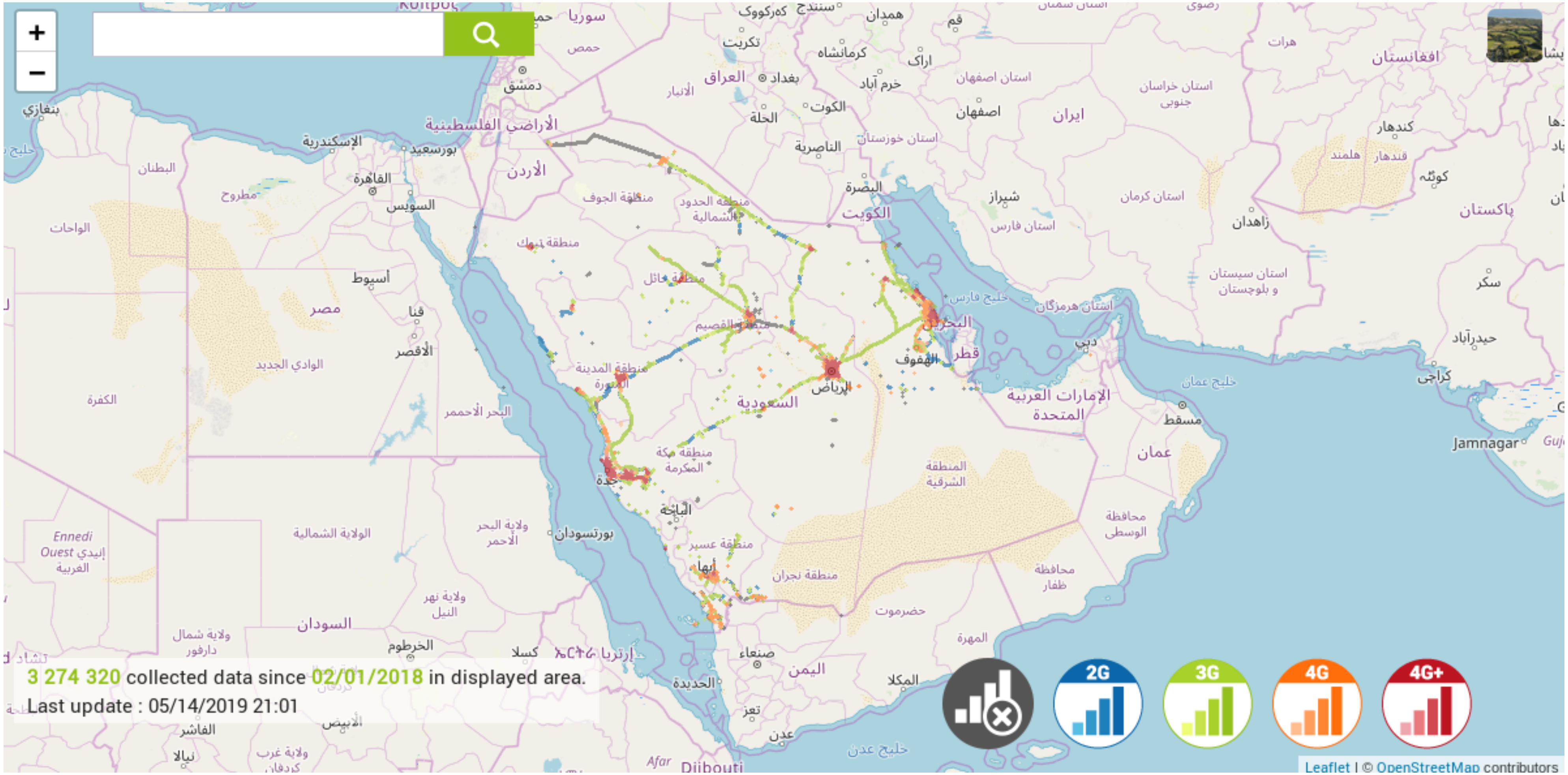
2G, 3G & 4G Coverage Maps



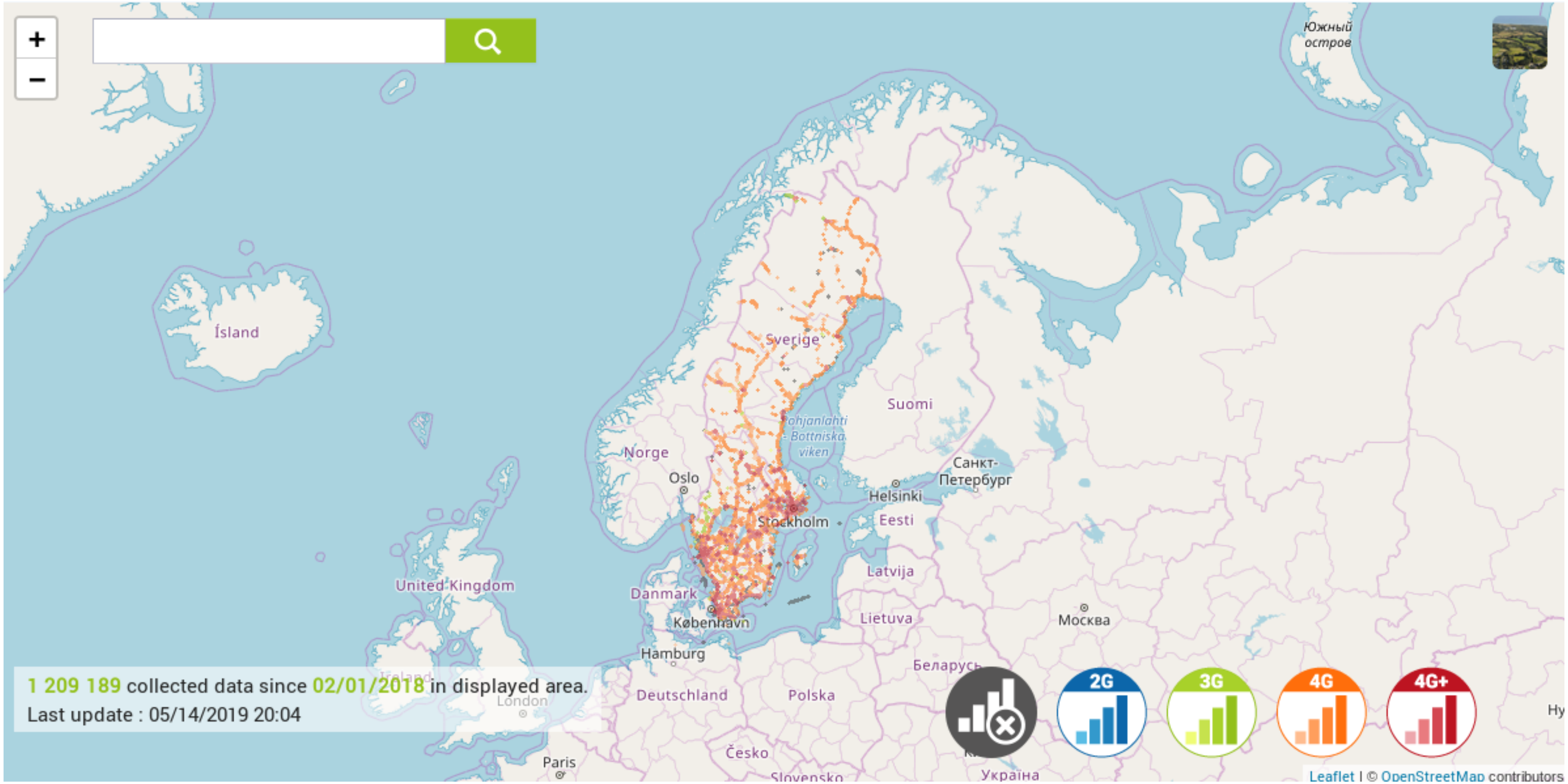
2G, 3G & 4G Coverage Maps



2G, 3G & 4G Coverage Maps



2G, 3G & 4G Coverage Maps



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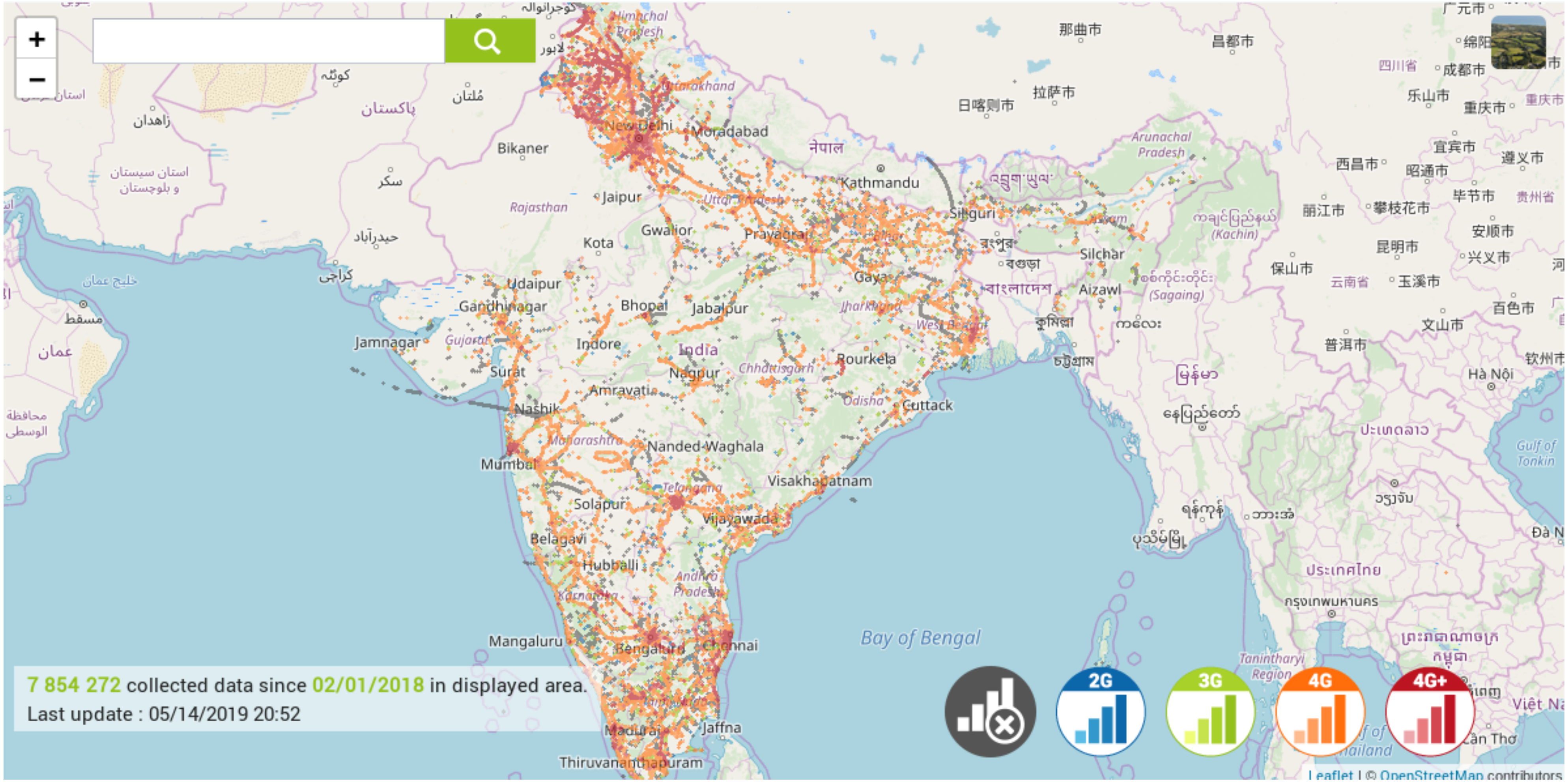

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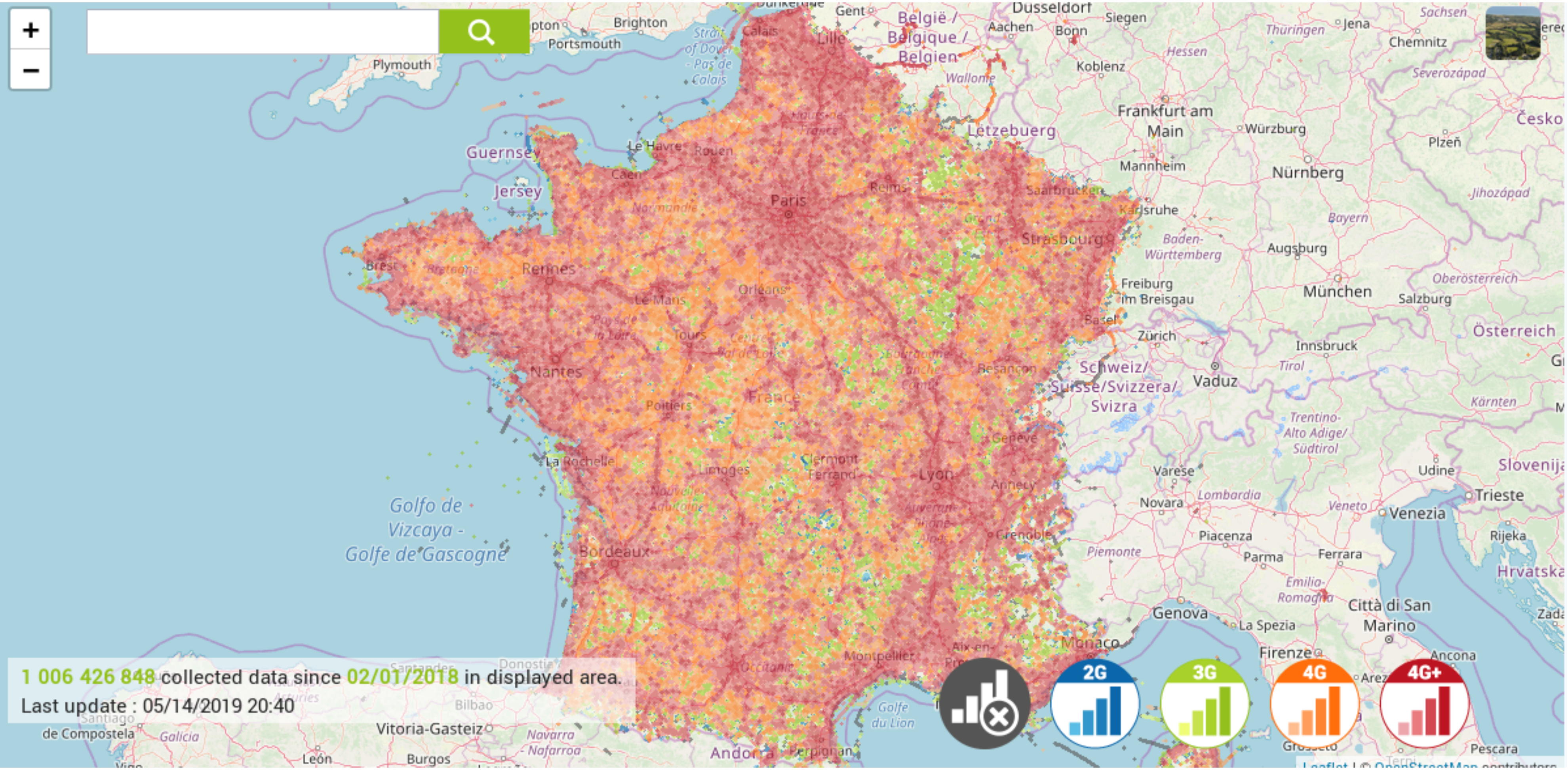
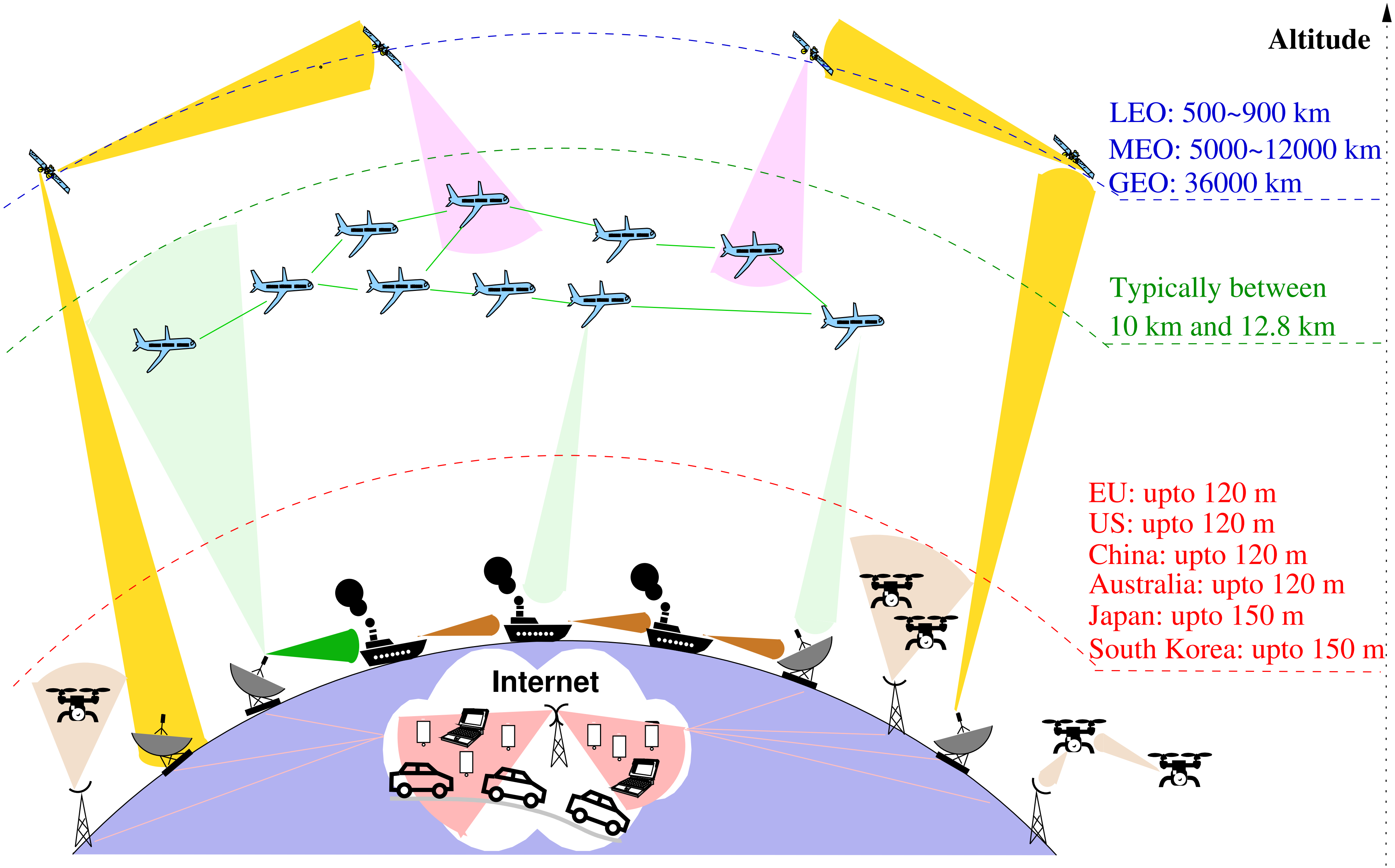
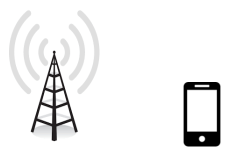
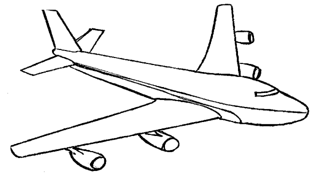
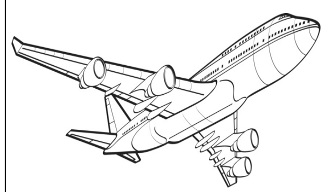


A Next-Generation Vision

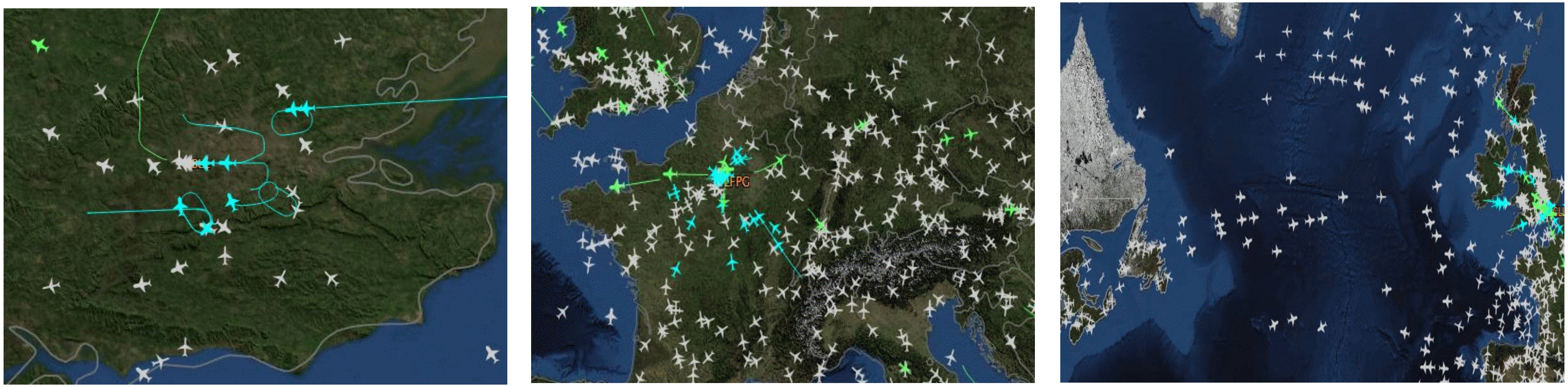


The 3D Global Wireless System

	Currently Upgrading 5G Wireless Network	← Unmanned Aircraft Systems →			Currently Upgrading Air Traffic Management
					
	Terrestrial cellular	Balloon/Airship	Rotary–wing quadcopter	Fixed–wing glider/aircraft	Civil Aviation
Altitude	Ground–level	Low/High (e.g. below 1200 ft/365 m or above 59000 ft/18 km)	Low (e.g. up to 400 ft/120 m without licensing)	Low → High (e.g. from near–ground to stratospace)	High (e.g. up to 59000 ft/18 km below stratospace)
Speed	Low (e.g. up to 310 mph/500 kmh for high–speed train)	Low (near static)	Low (e.g. up to 100 mph/160 kmh)	Low → High (e.g. may even exceed speed of sound 741 mph/1192 kmh)	High (e.g. generally under speed of sound 741 mph/1192 kmh)
Dynamic Maneuver	Low	Low	High	High	High
LOS Strength	Low	High	High	High	High
Terrain Shadowing	High	Low	High for near–ground	High for near–ground	Low
Multipath fading	High	Low	High for near–ground	High for near–ground	High during taxiing, taking–off, landing
Airframe Shadowing (During Maneuver)	None	None	High for maneuver	High for maneuver	Low for gentle maneuver
Doppler Frequency (Normalized by Symbol Rate)	Low	Low	High for control link	High for control link	High

- Xu, Bai, Zhang, Rajashekar, Maunder, Wang & Hanzo: Adaptive Coherent/Non-Coherent Spatial Modulation Aided Unmanned Aircraft Systems, ResearchGate, 2019

Solar-Charged UAV ©CCBY

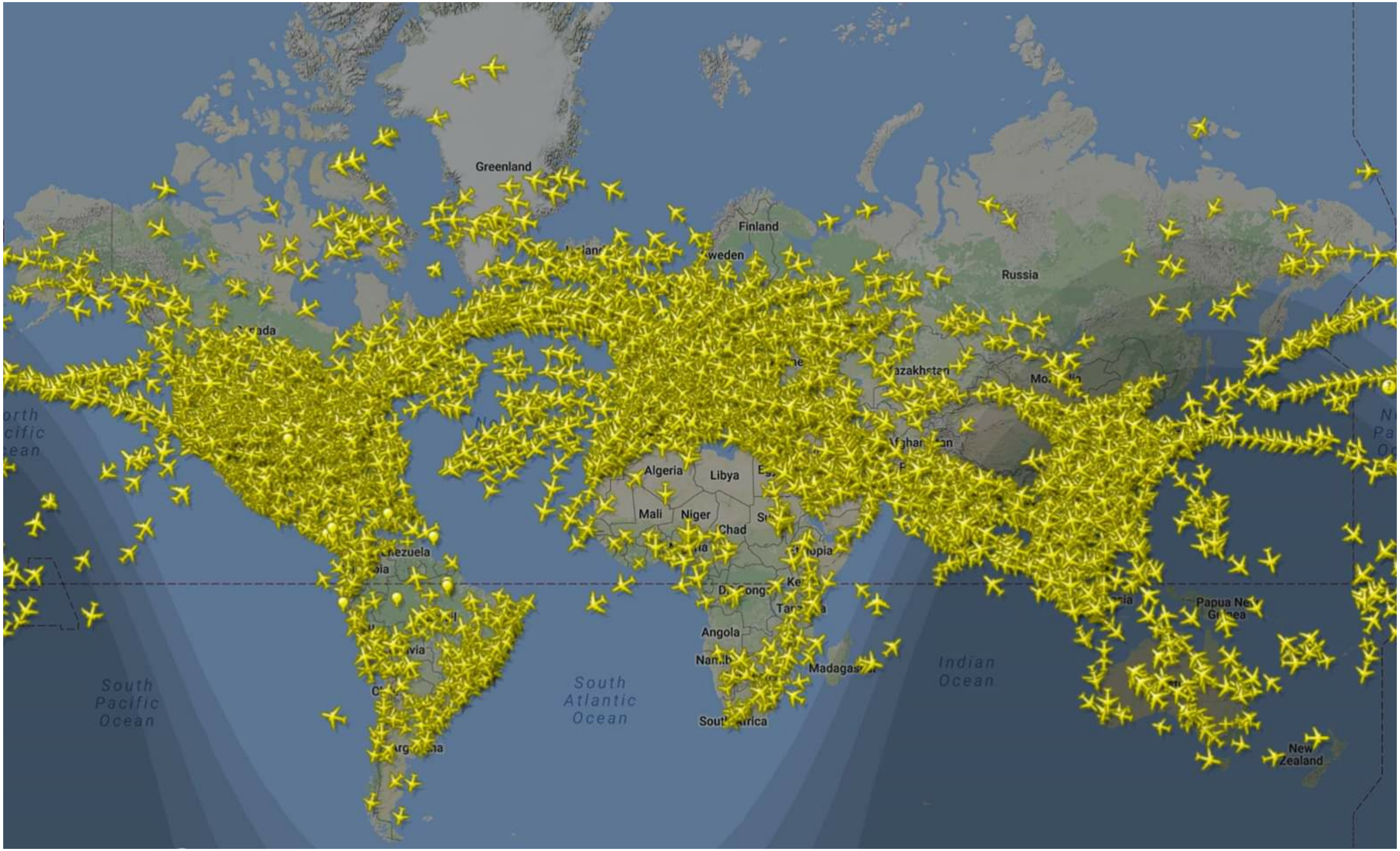


Heathrow Airport | European Airspace | North Atlantic

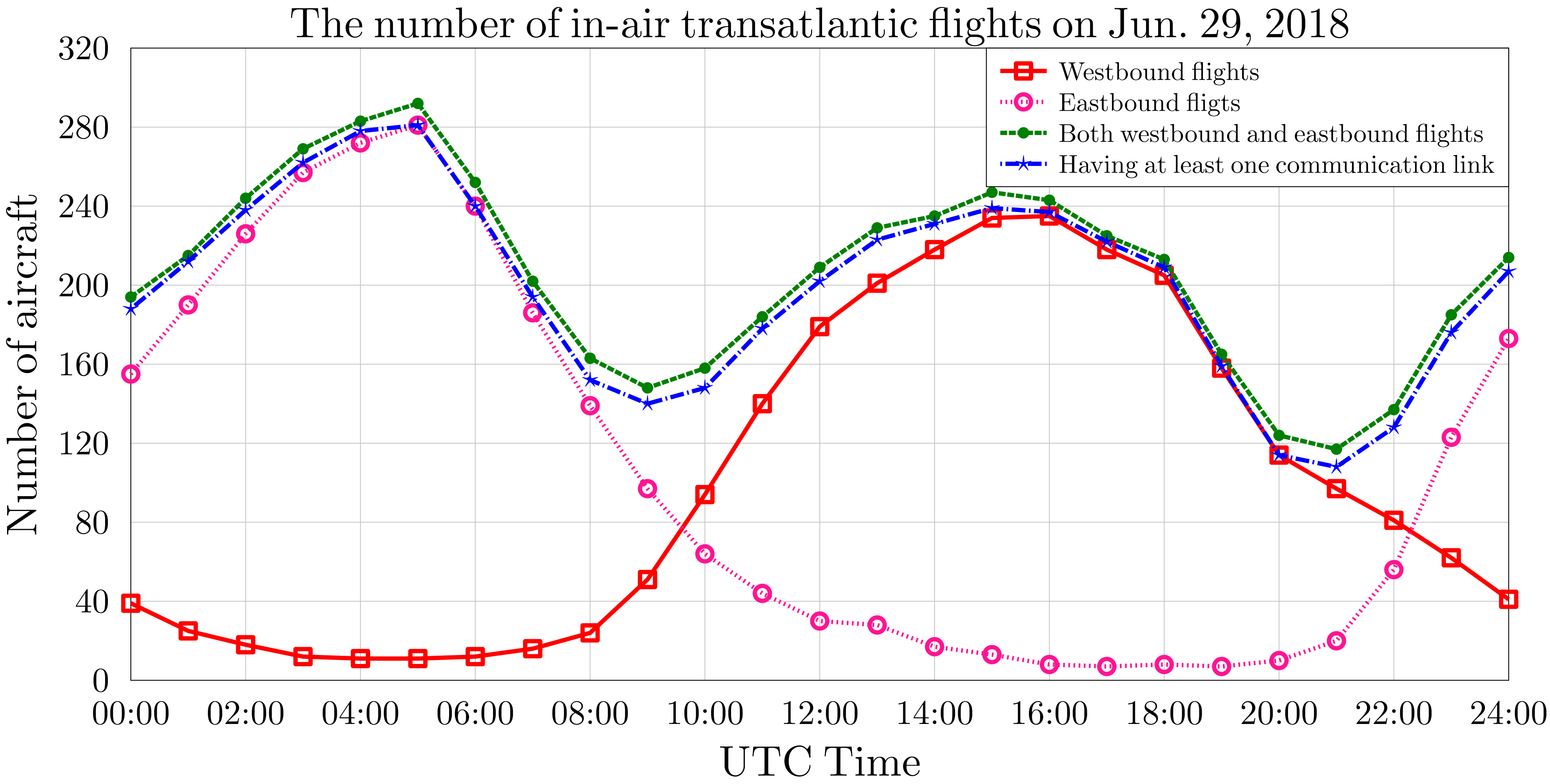
Figure 1: Aircraft mobility pattern for London Heathrow airport, from a populated area selected in the European airspace and in an unpopulated area over the North Atlantic captured from flight-aware.

- https://uk.flightaware.com/live/airport/EGLL
- Aeronautical Ad Hoc Networking for the Internet-Above-the-Clouds, Zhang, Chen, Zhong, Wang, Zhang, Zuo, Maunder & Hanzo, Proc. of the IEEE'19

A Global Snap-Shot



Number of Trans-Atlantic Flights - 29th of June 2018



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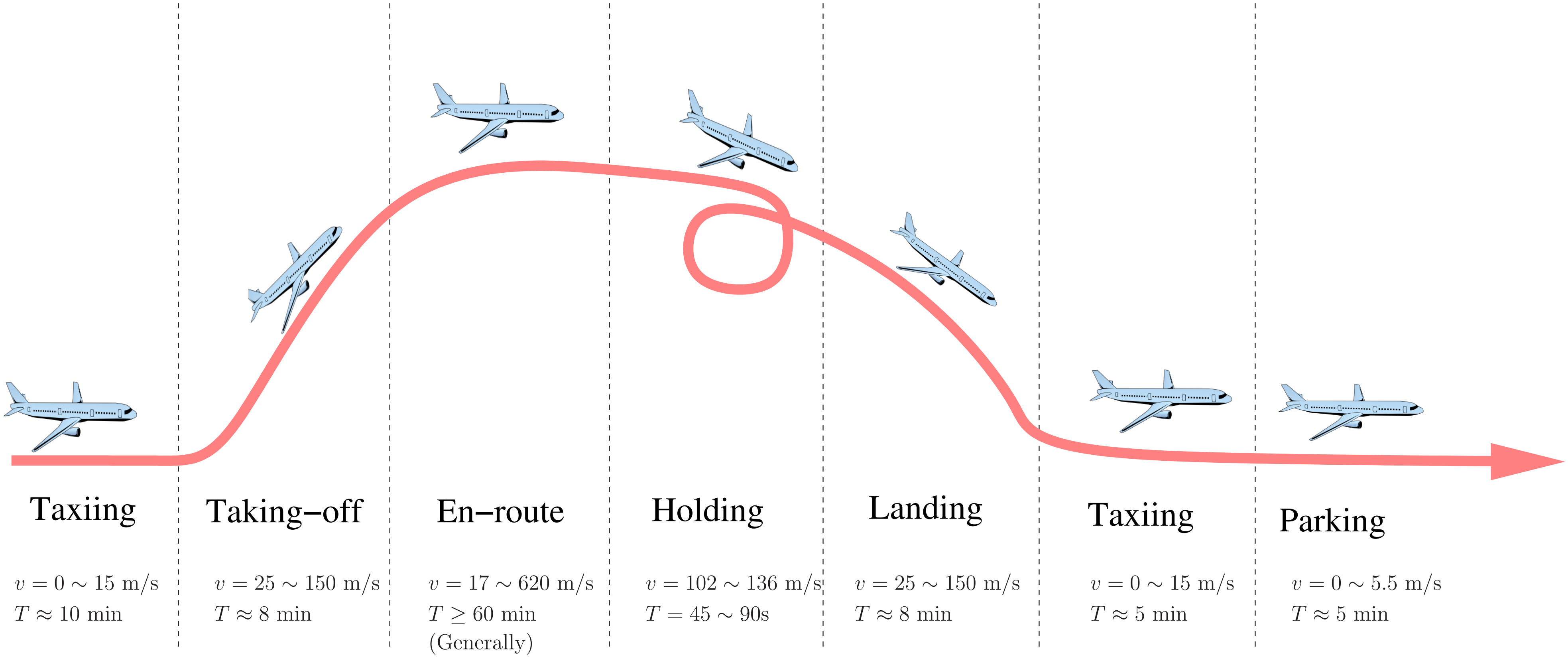

Figure 2: Different aircraft scenarios

- Aeronautical Ad Hoc Networking for the Internet-Above-the-Clouds, Zhang, Chen, Zhong, Wang, Zhang, Zuo, Maunder & Hanzo, Proc. of the IEEE'19

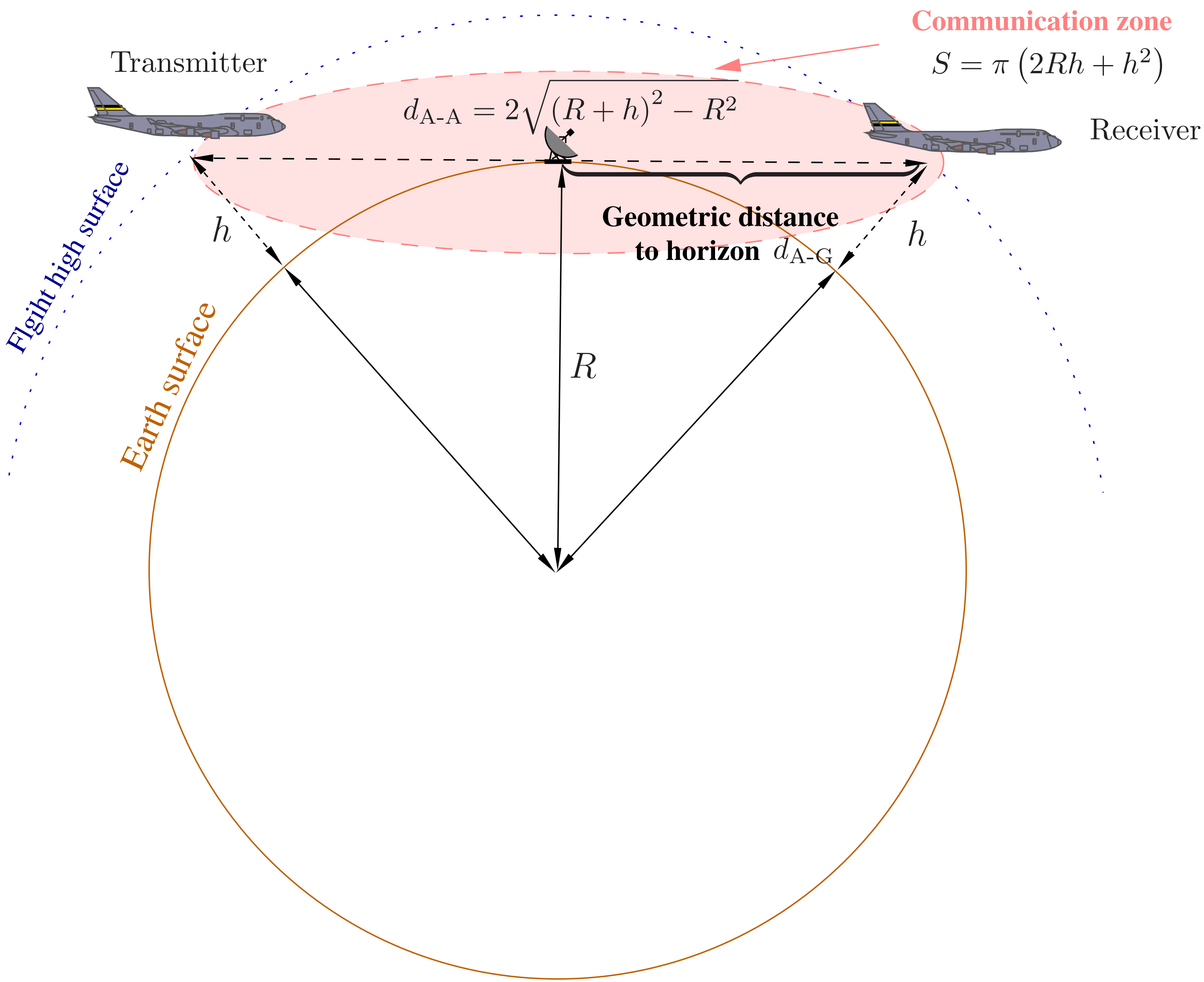

Figure 3: Over-the-horizon zone S for LOS, when flying at altitude h.

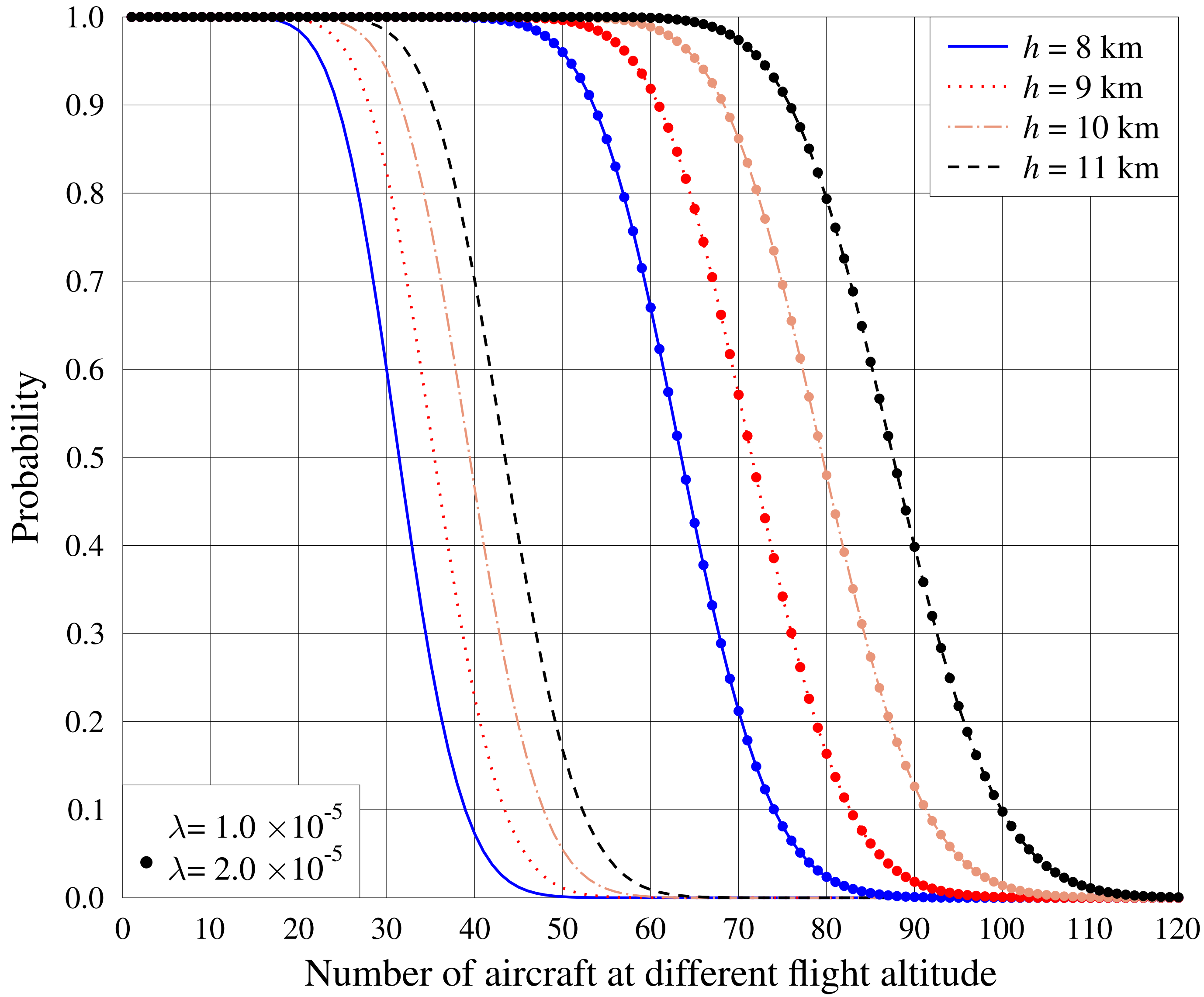

Figure 4: Probability of over-the-horizon communication with n planes at an altitude h, provided that P_{TX} is high enough, where λ is 900/1800 planes in the 9 000 000 km^2 Atlantic Ocean.

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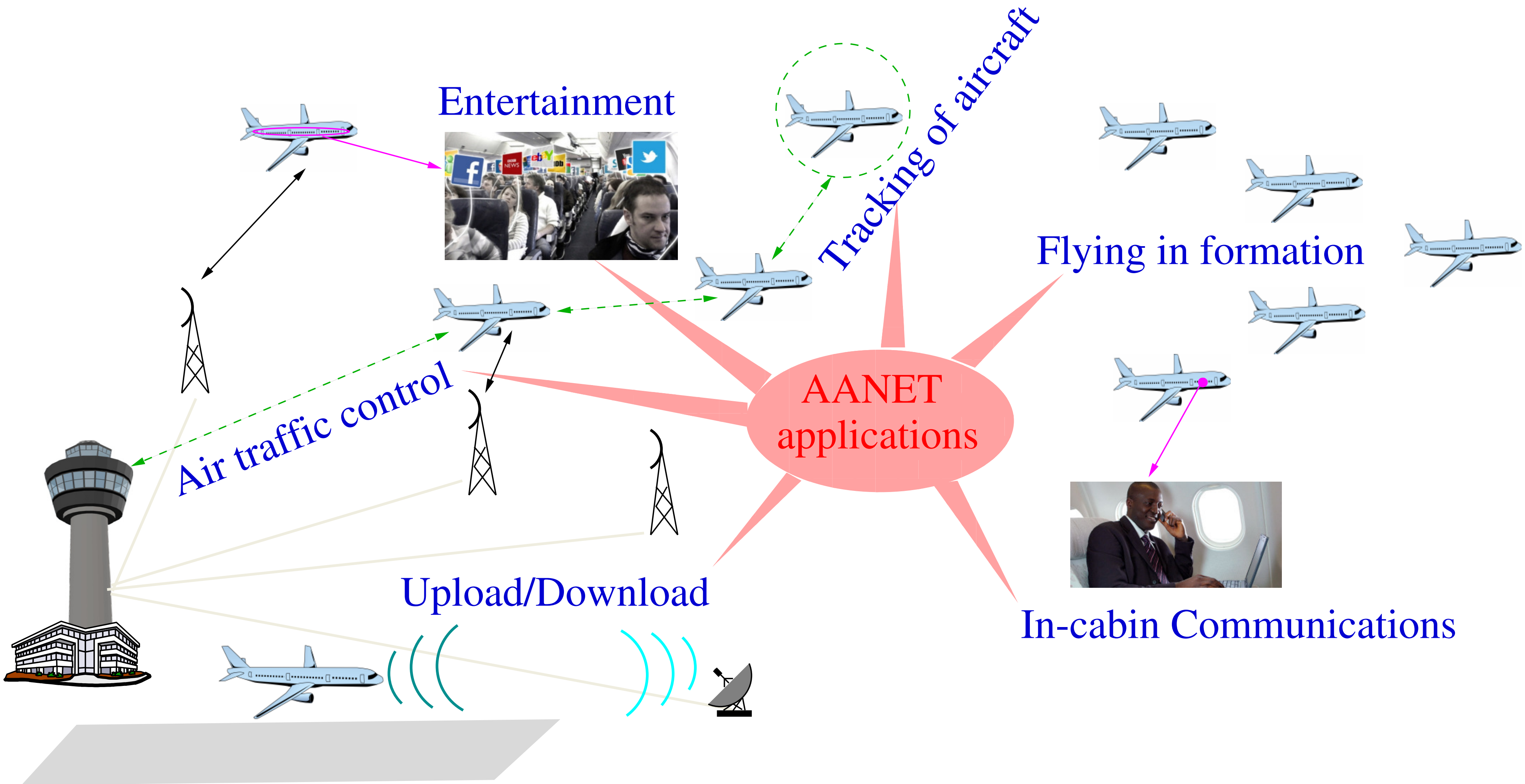

Figure 5: Potential applications of AANETs

- Aeronautical Ad Hoc Networking for the Internet-Above-the-Clouds, Zhang, Chen, Zhong, Wang, Zhang, Zuo, Maunder & Hanzo, Proc. of the IEEE'19

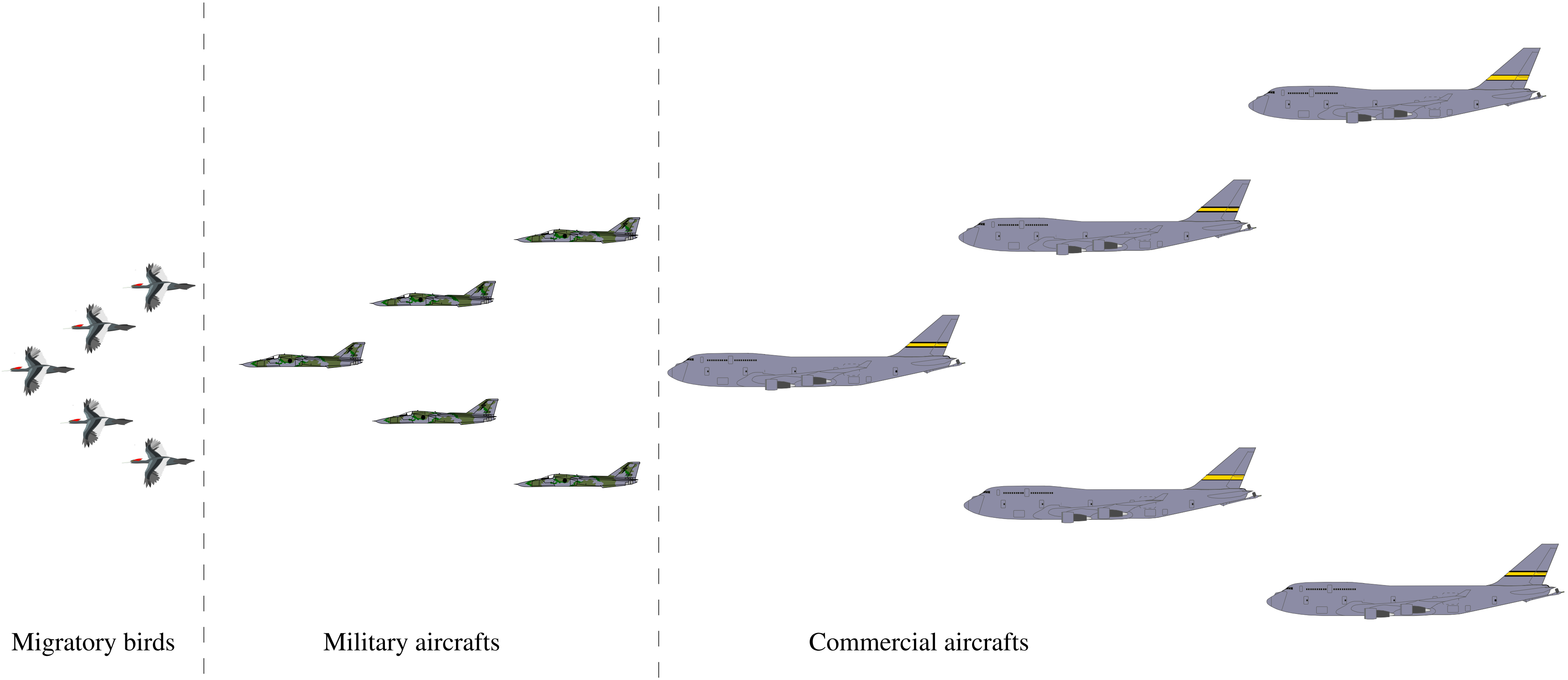

Figure 6: Flying in formation

- Aeronautical Ad Hoc Networking for the Internet-Above-the-Clouds, Zhang, Chen, Zhong, Wang, Zhang, Zuo, Maunder & Hanzo, Proc. of the IEEE'19

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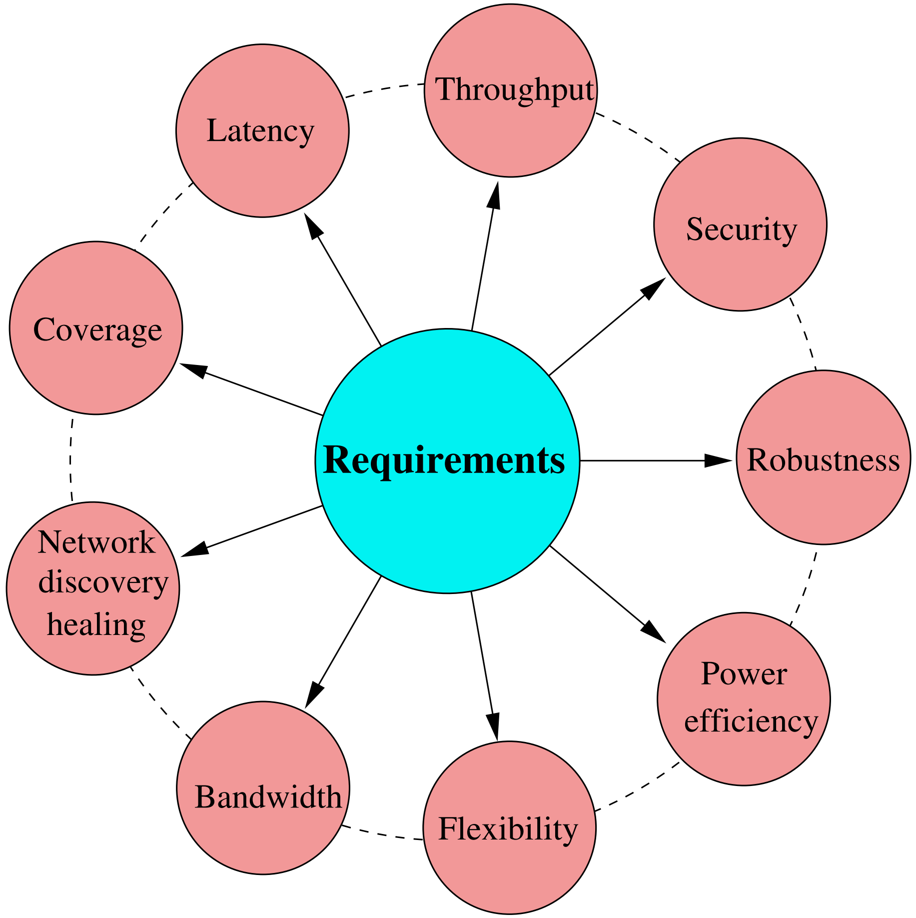

Figure 7: Multi-Component OF=[BER, Throughput, Power, Delay, Complexity, ...]

• Huge opportunities for optimization and machine-learning enthusiasts to find the optimum Pareto front

- Aeronautical Ad Hoc Networking for the Internet-Above-the-Clouds, Zhang, Chen, Zhong, Wang, Zhang, Zuo, Maunder & Hanzo, Proc. of the IEEE'19

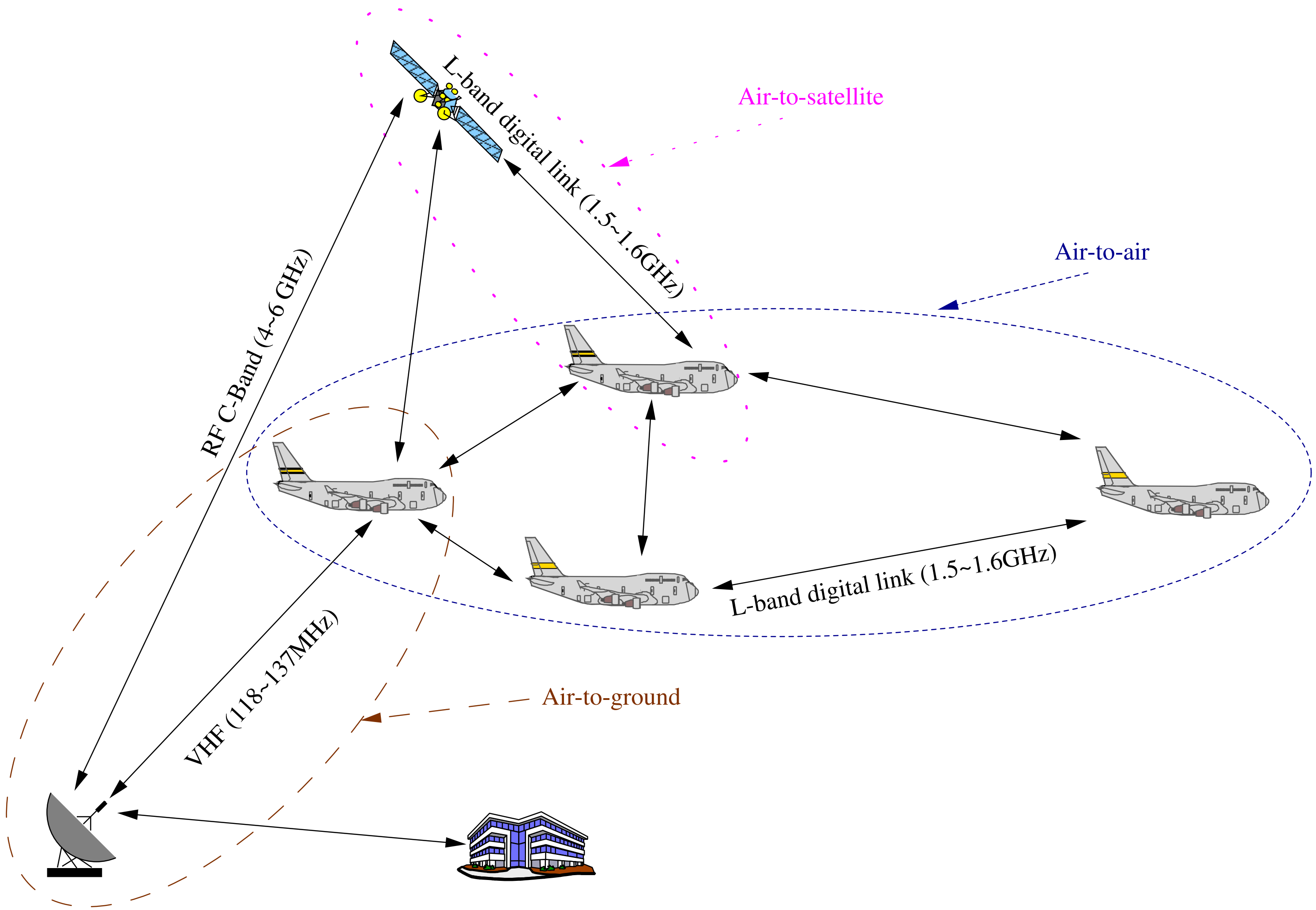

Figure 8: The spectrum used for various aircraft communication systems

- Aeronautical Ad Hoc Networking for the Internet-Above-the-Clouds, Zhang, Chen, Zhong, Wang, Zhang, Zuo, Maunder & Hanzo, Proc. of the IEEE'19

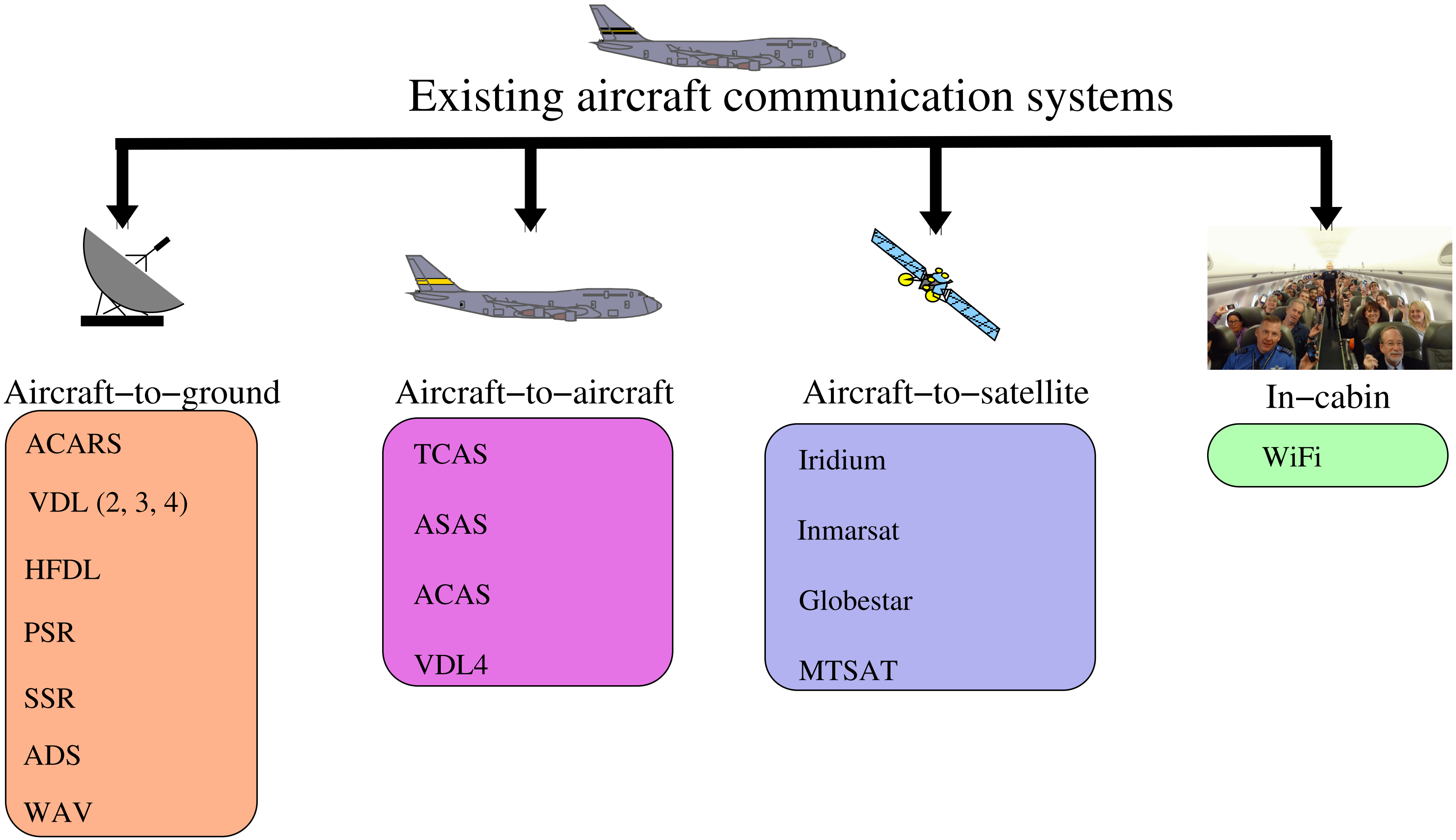

Figure 9: Existing aircraft communication systems

- Aeronautical Ad Hoc Networking for the Internet-Above-the-Clouds, Zhang, Chen, Zhong, Wang, Zhang, Zuo, Maunder & Hanzo, Proc. of the IEEE'19

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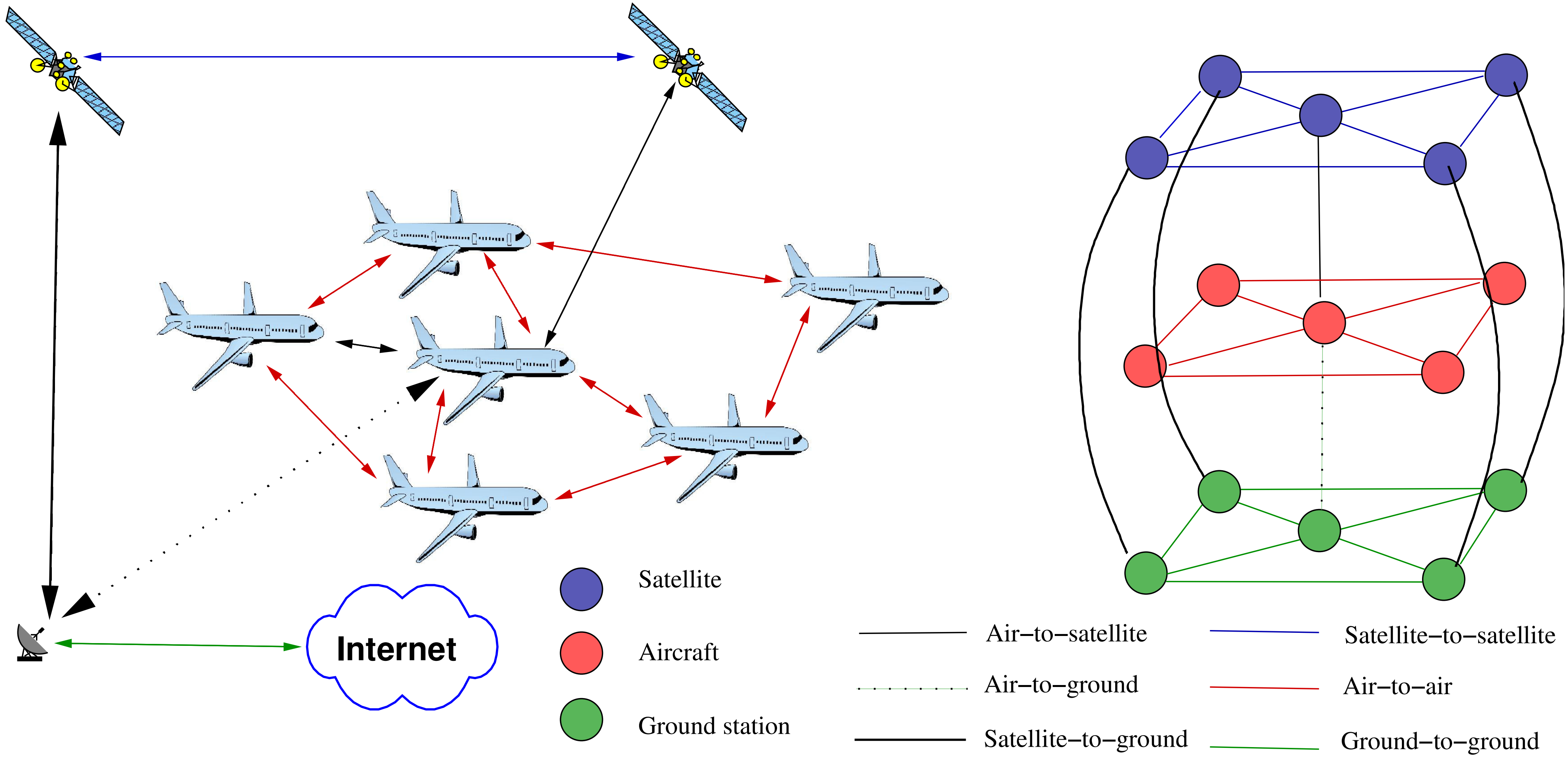
A Stroll with Shannon...

$$C = M_t \cdot B/N_f \cdot \log(1 + SINR)$$

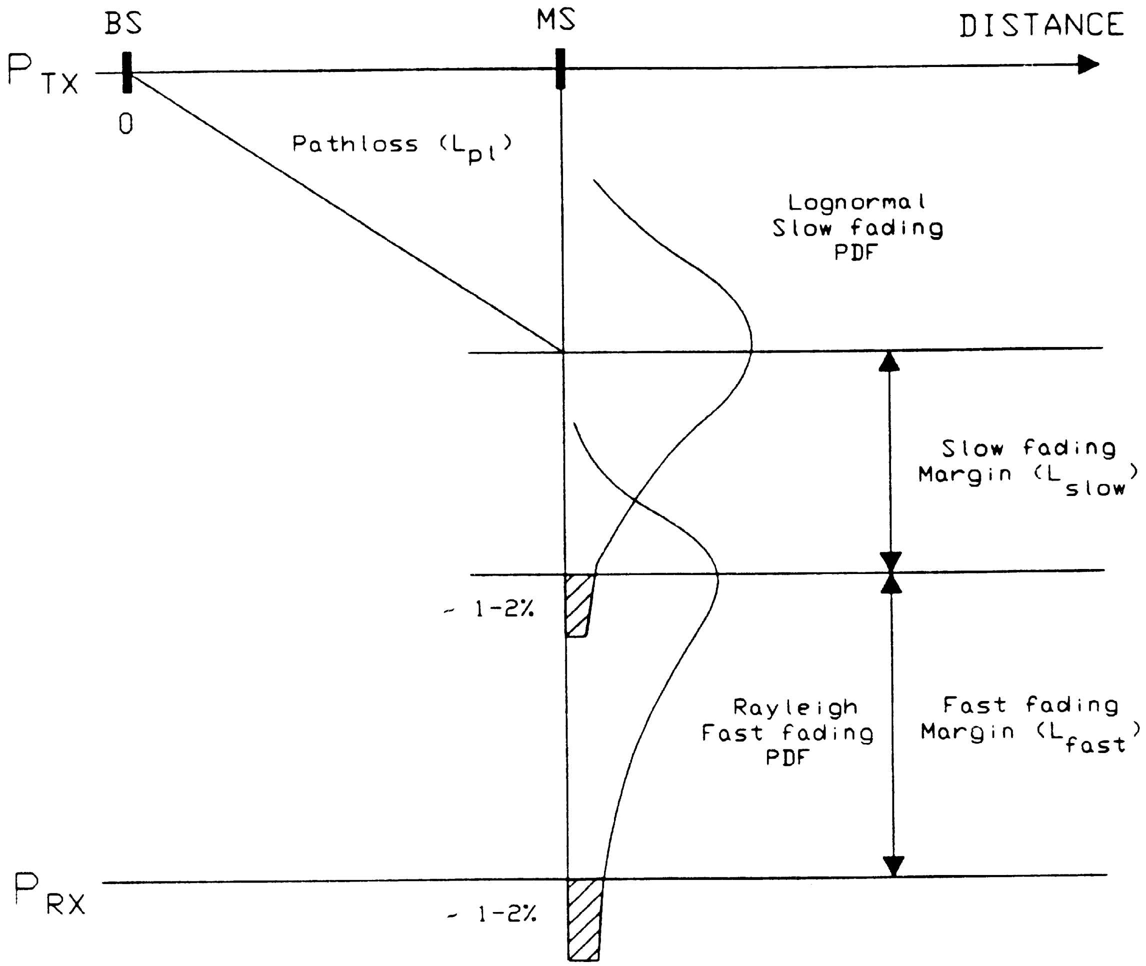
1. Shannon's Lesson # 1 B: Bandwidth - **mm-Wave & Free-Space Optical Wireless**
2. Shannon's Lesson # 2 N_f: Frequency-reuse & Cell-Size - **Terrestrial Small Cell BSs, UAV/AANET Mobile BSs, Satellites & HO-Rate, ASE**
3. Shannon's Lesson # 3 $SINR$: No. of RX antennas (M_r) - **Large-Scale MIMOs for RX-diversity, Beamforming & Interference Alignment**
4. Shannon's Lesson # 4 M_t: No. of TX antennas - **Large-scale MIMOs for BLAST and Spatial Modulation**
5. *L. Hanzo, M. El-Hajjar, O. Alamri: Near-Capacity Wireless Transceivers and Cooperative Communications in the MIMO Era: Evolution of Standards, Waveform Design, and Future Perspectives Proceedings of the IEEE Volume 99, Issue 8, 2011, pp 1343 - 1385*

A 6G Vision & Shannon's Lesson # 2



- With Optional UL/DL and Data/Control Plane Decoupling and latency/integrity classes
- Aeronautical Ad Hoc Networking for the Internet-Above-the-Clouds, Zhang, Chen, Zhong, Wang, Zhang, Zuo, Maunder & Hanzo, Proc. of the IEEE'19

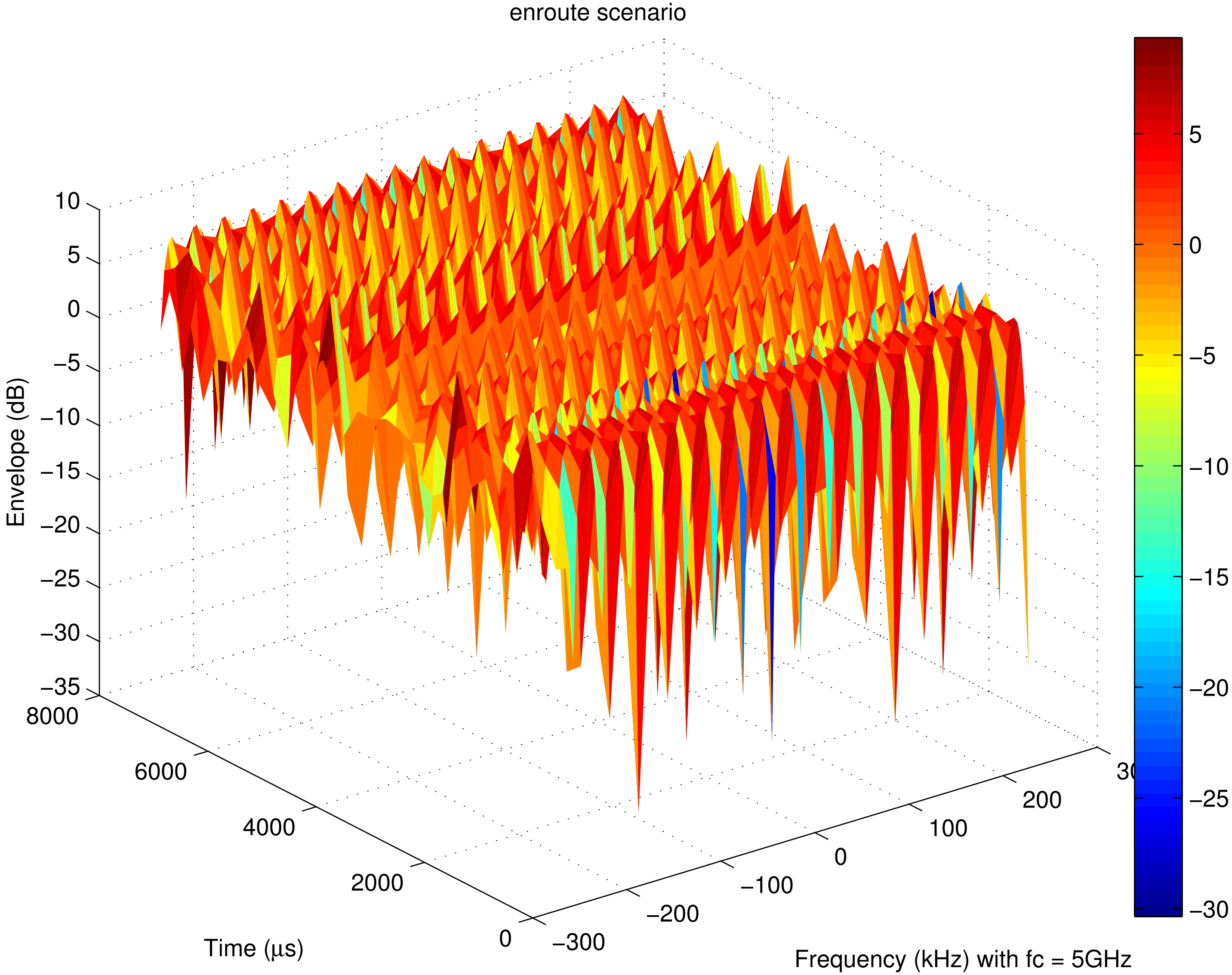
Shannon's Lesson # 3 - The SINR Depends on the Pathloss & Fading of Both the Signal & Interference



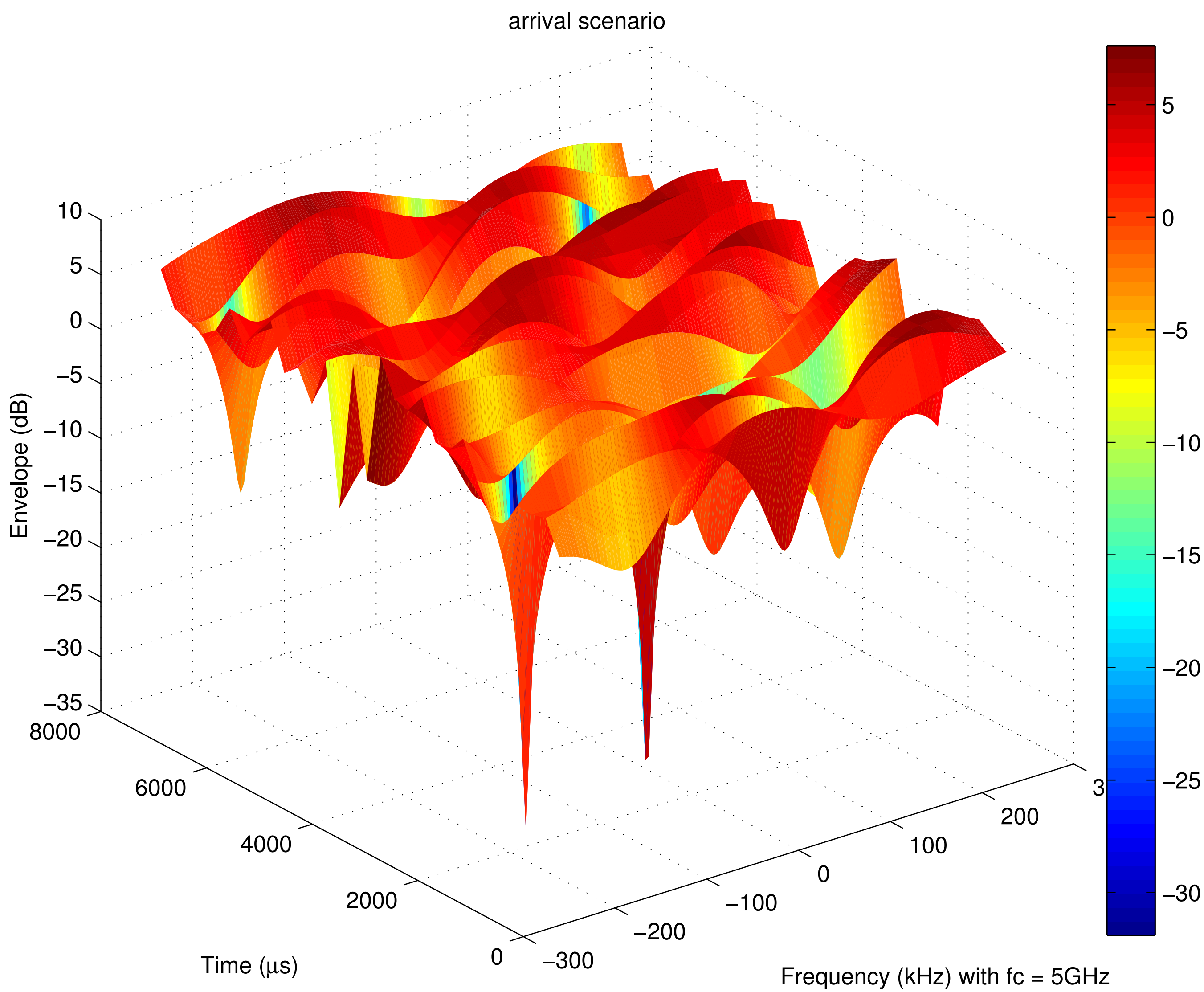
Shannon's Lesson # 3 - The SINR Depends on the Pathloss & Fading of Both the Signal & Interference

- En route
- Arrival
- Taxiing
- Parking

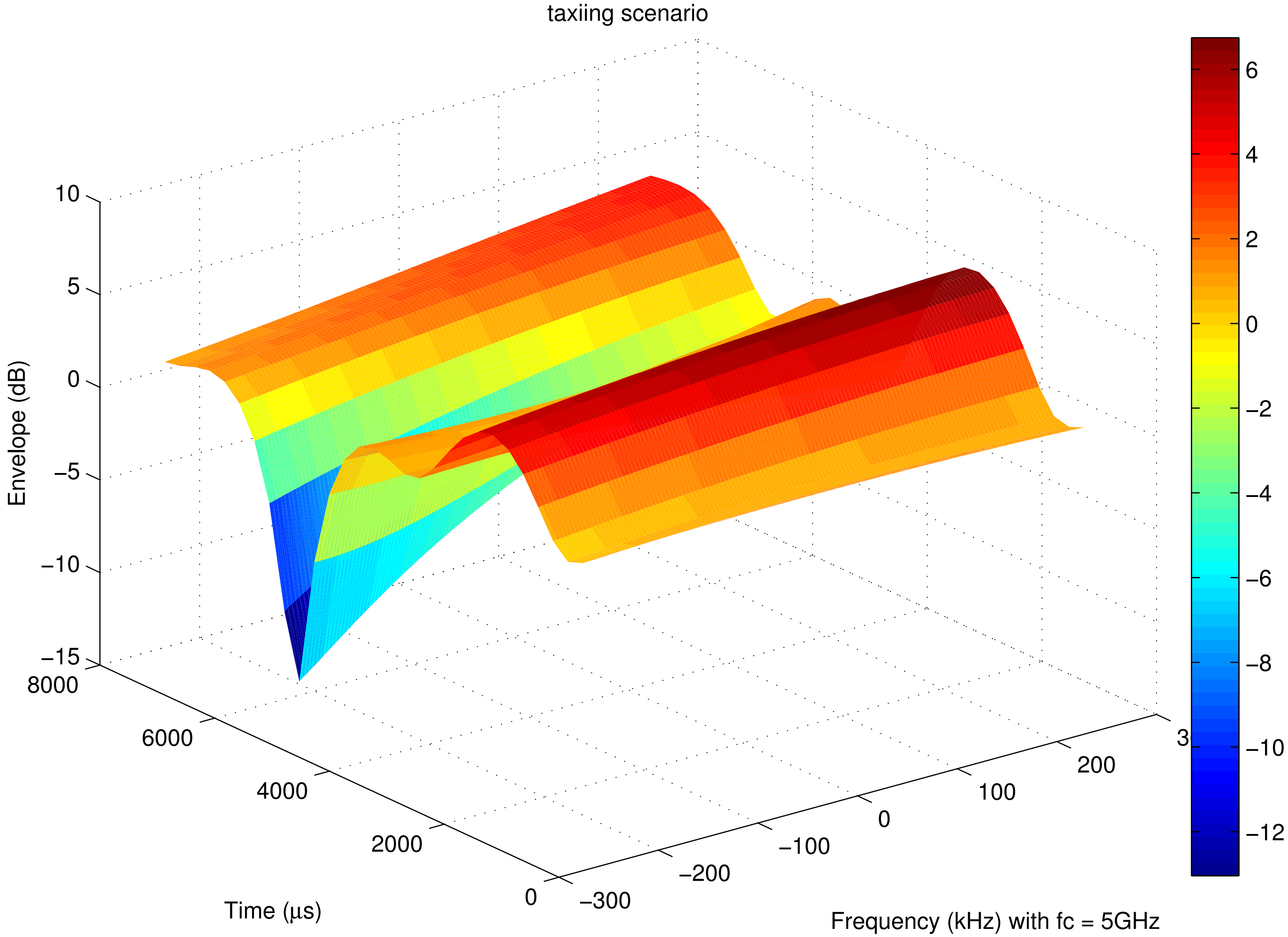
Shannon's Lesson # 3 - Enroute Scenario



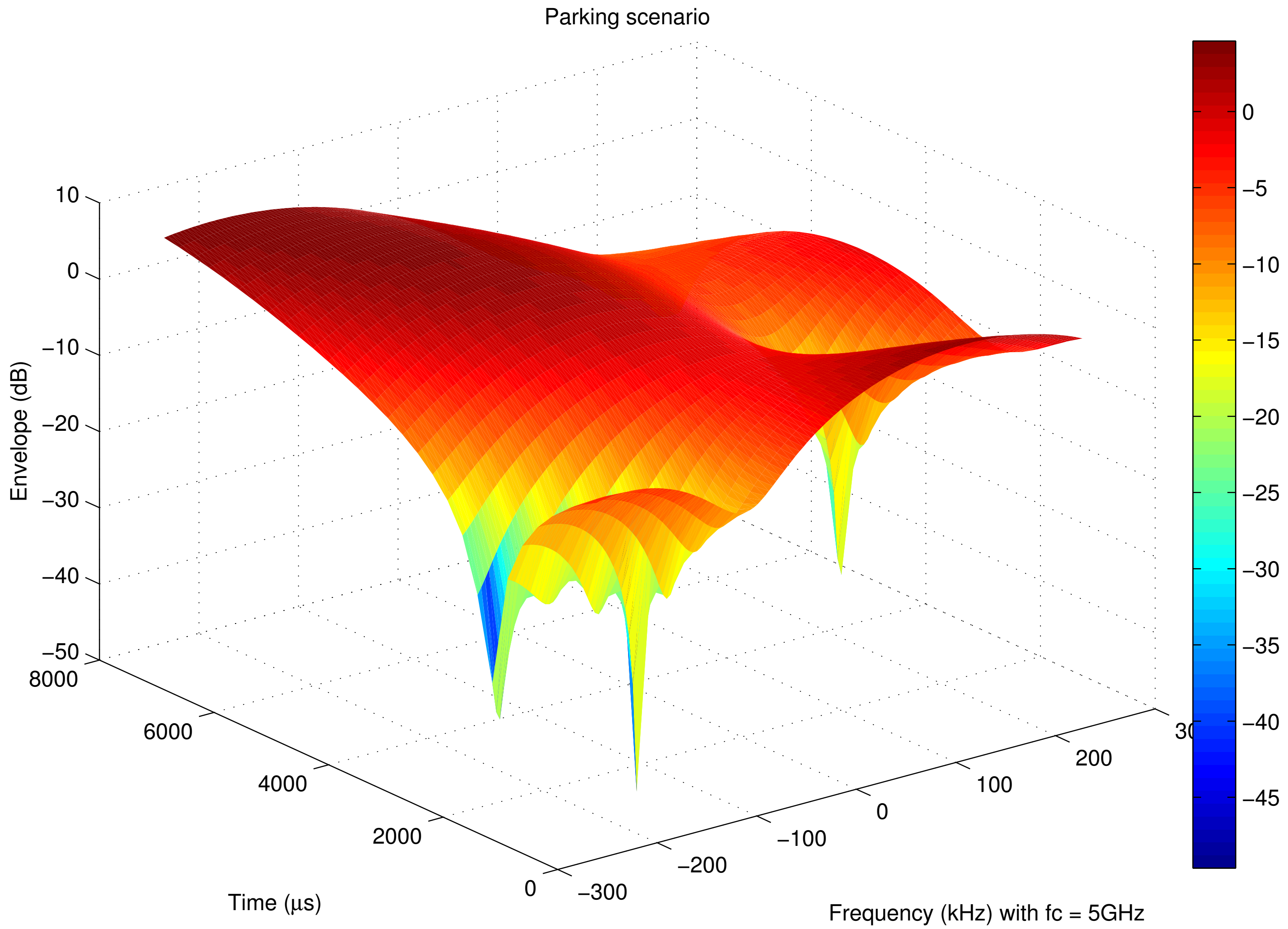
Shannon's Lesson # 3 - Arrival Scenario



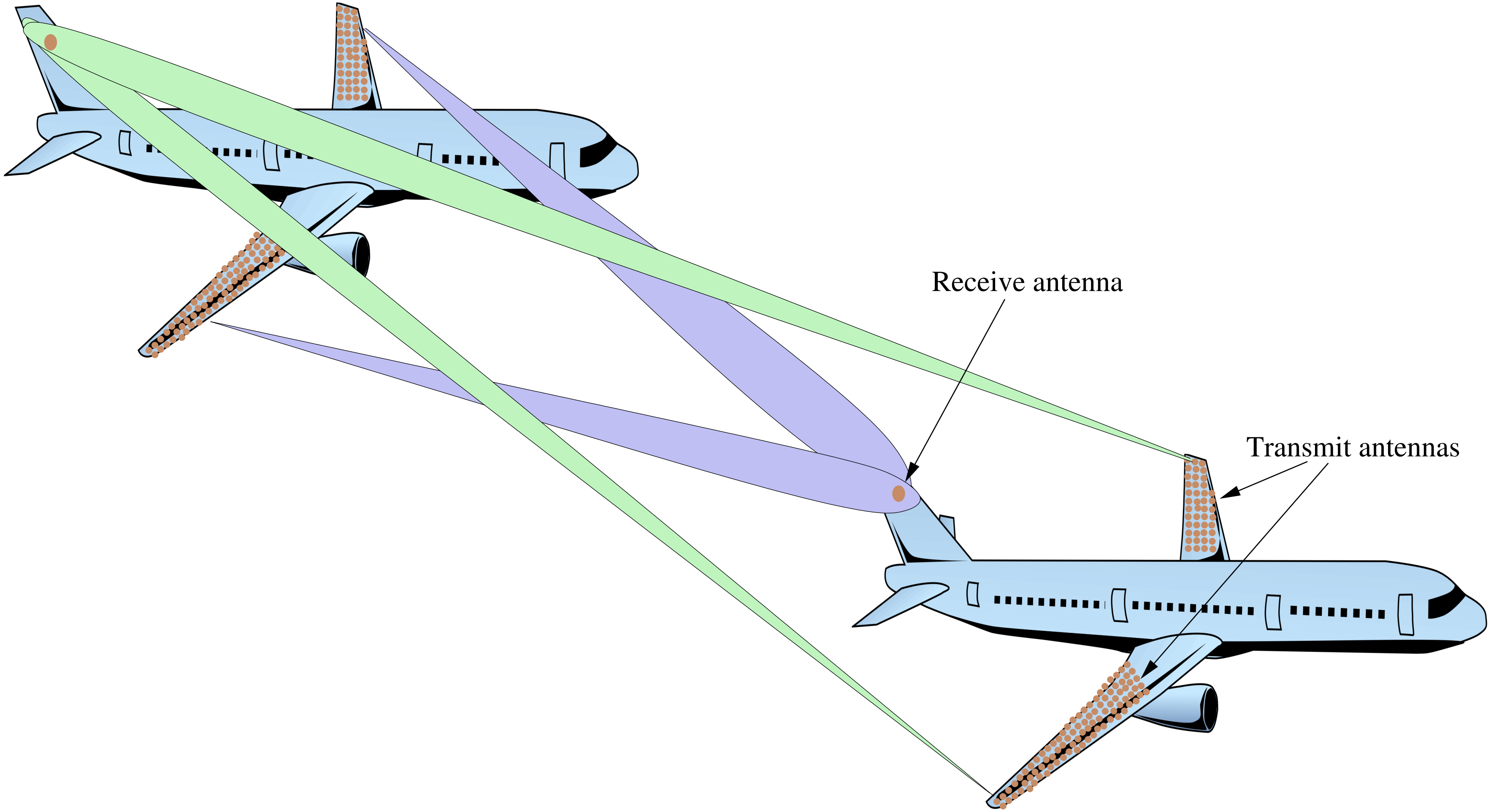
Shannon's Lesson # 3 - Taxiing Scenario



Shannon's Lesson # 3 - Parking Scenario

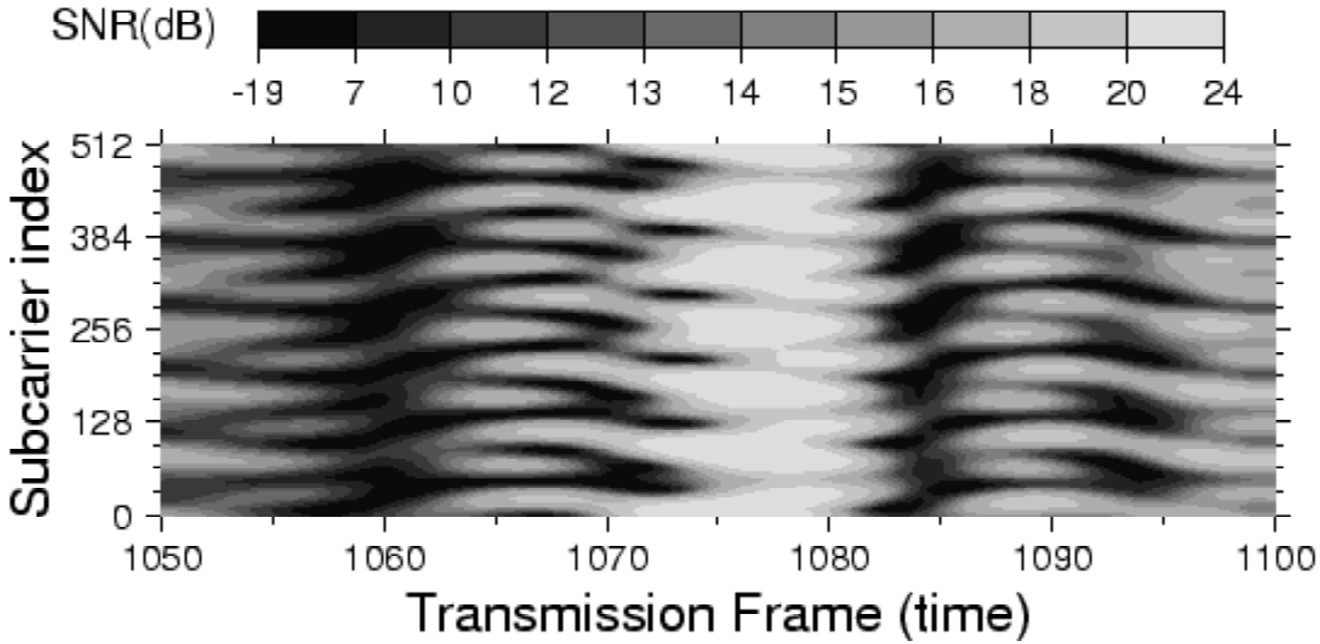


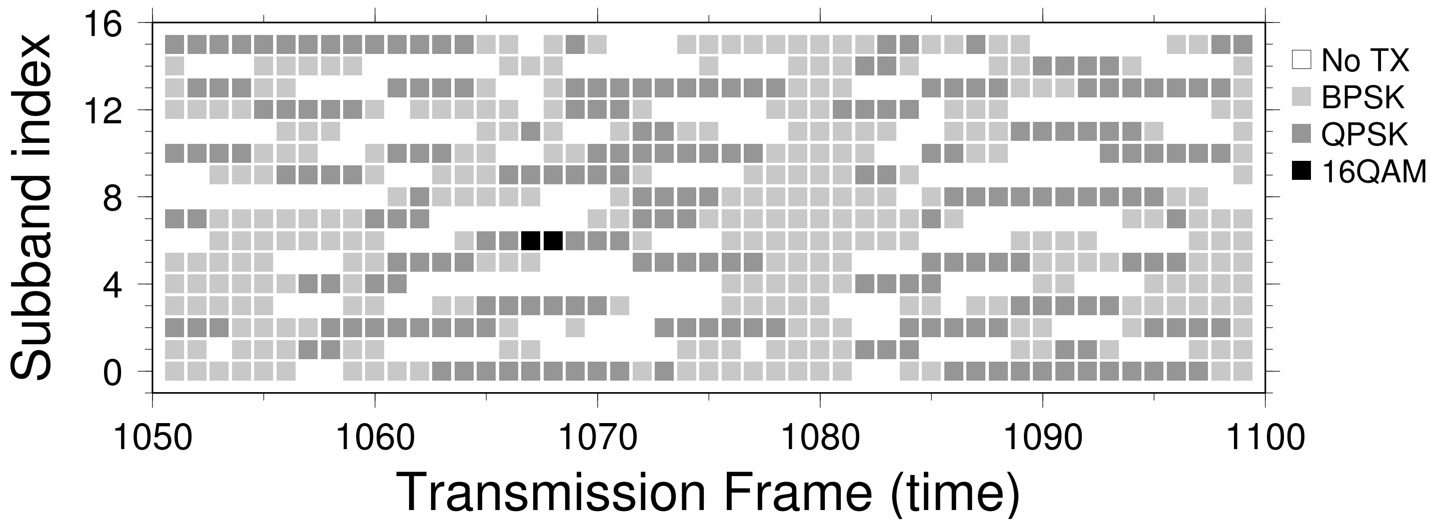
Shannon's Lesson # 3 & 4 - Large-Scale MIMO-aided AANET



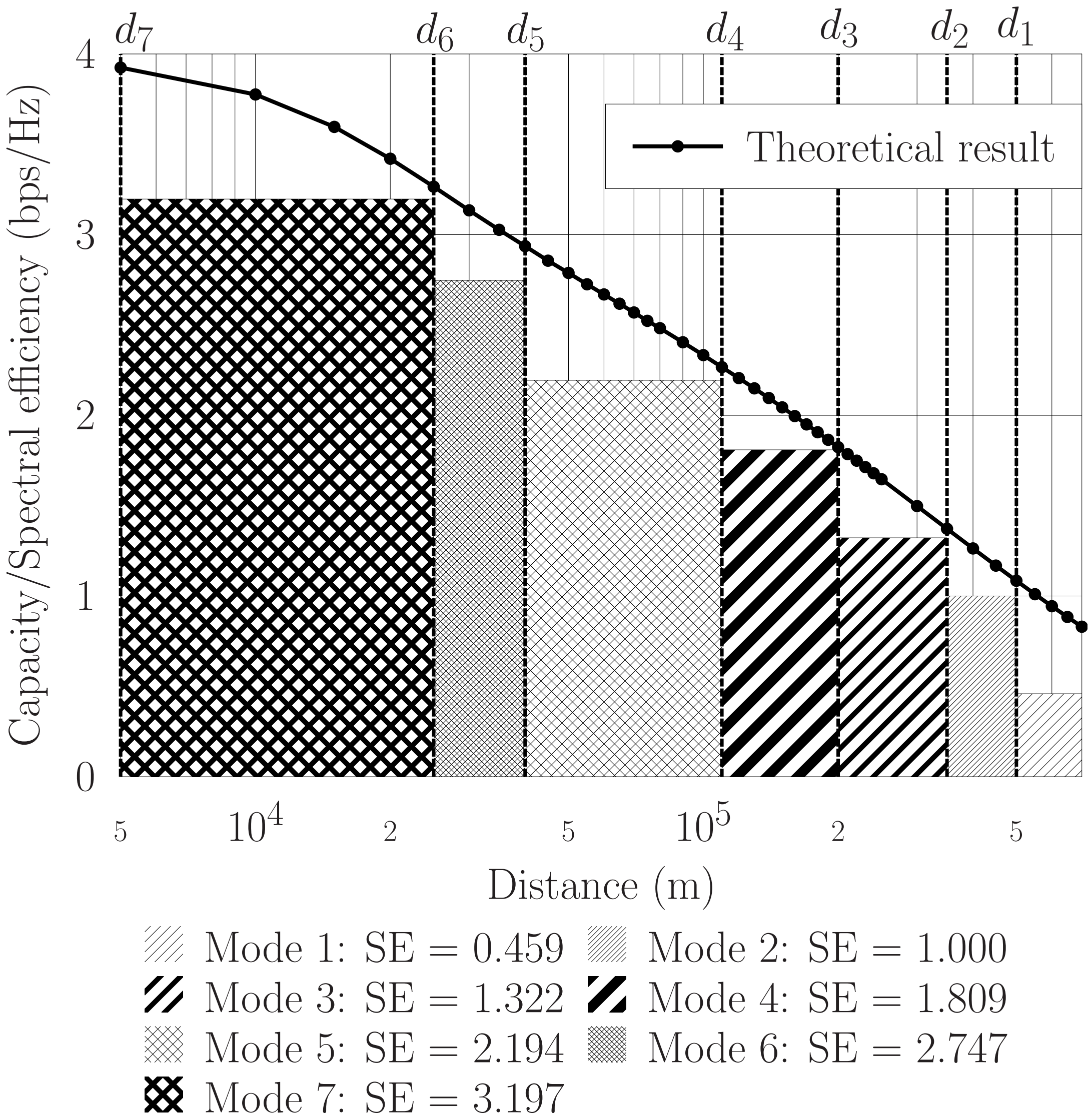
• **L. Hanzo, O. Alamri, M. El-Hajjar, N. Wu**: Near-Capacity Multi-Functional MIMO Systems; *John Wiley and IEEE PRESS*, 2009

Shannon's Lesson # 3 Adaptive OFDM





Lesson # 3 - Adaptive MIMO-OFDM

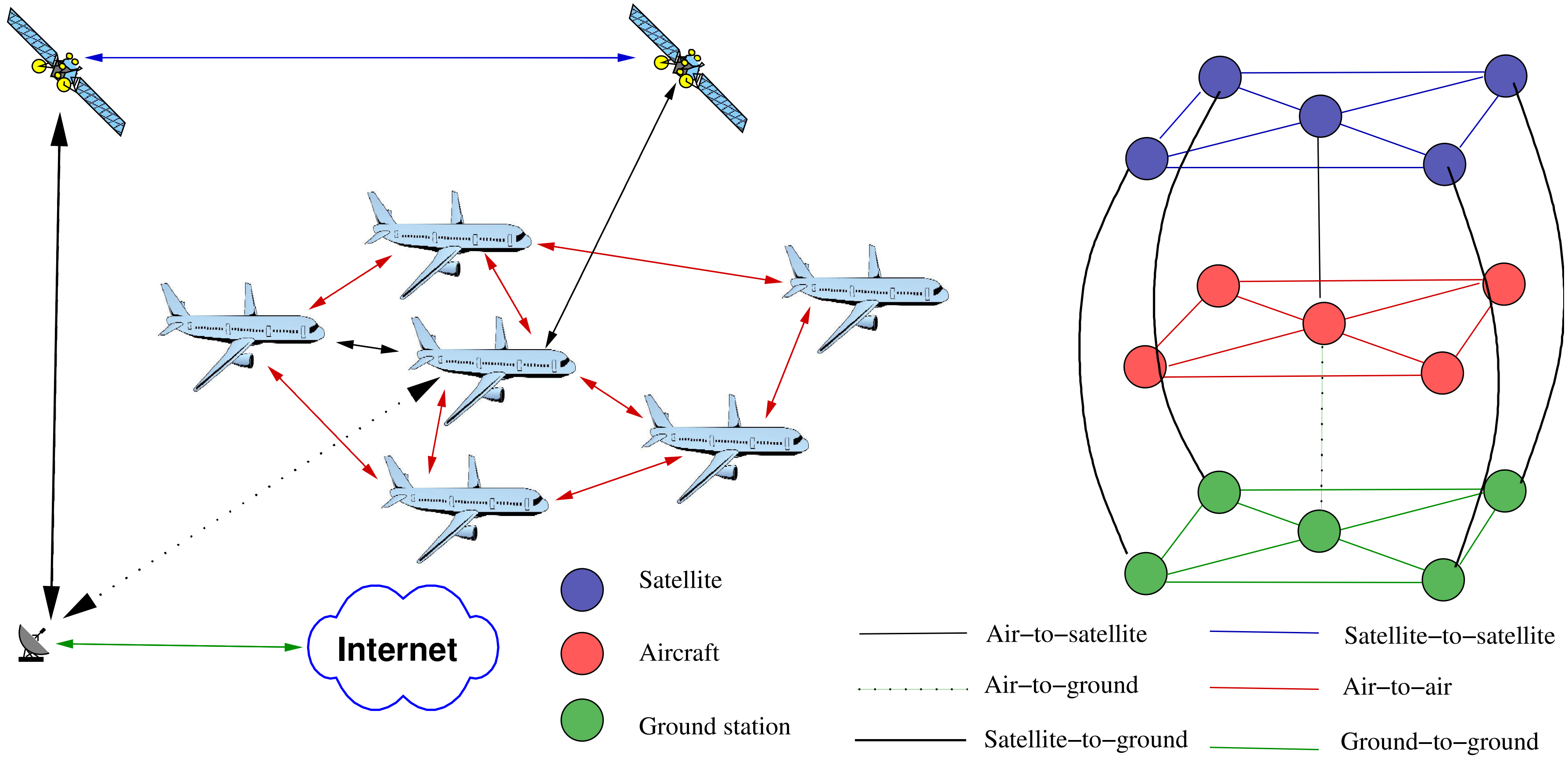


Pareto-Optimal Networking

Multi-Component Pareto Optimization OF[THROUGHPUT, BER, DELAY, POWER & COMPLEXITY]

- Alanis, D.; Botsinis, P.; Babar, Z.; Ng, S.X.; Hanzo, L.: Non-Dominated Quantum Iterative Routing Optimization for Wireless Multihop Networks, IEEE Access
- Alanis, D. ; Botsinis, P. ; Soon Xin Ng ; Hanzo, L.: Quantum-Assisted Routing Optimization for Self-Organizing Networks: IEEE Access, Volume: 2, 2014, pp 614 - 632

A 6G Vision & Shannon's Lesson # 2 Pareto-Optimization



- With Optional UL/DL and Data/Control Plane Decoupling
  The Number of QOS-Classes is Vast - Reduced-Search ML Is Beneficial!
- Aeronautical Ad Hoc Networking for the Internet-Above-the-Clouds, Zhang, Chen, Zhong, Wang, Zhang, Zuo, Maunder & Hanzo, Proc. of the IEEE'19

I Haven't Even Touched Upon...

- So, how do we design an optimum AANET, Dr. Shannon?
- Networking Information Theory, Machine Learning & Gupta-Kumar Law...
- ...and an FEC?
- ...and a modem...
- ...and an ARQ...
- ...and the seven OSI layers...
- ...what about network-information theory & networks...
- ...what about the optimum multiple access...
- ...what is optimum anyway, in what sense? MMSE, BER, FER, QoE?
- ...what is the price of approaching capacity?
- ...and how to optimize the holistic objective function - with ML?

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NEVER CONCOMMITANTLY,
BUT IN THE PARETO-SENSE...