15th BroadSky Workshop: One More Asset for the 5th Generation
October 17, 2017

Role and expectations of satellite communication in 5G

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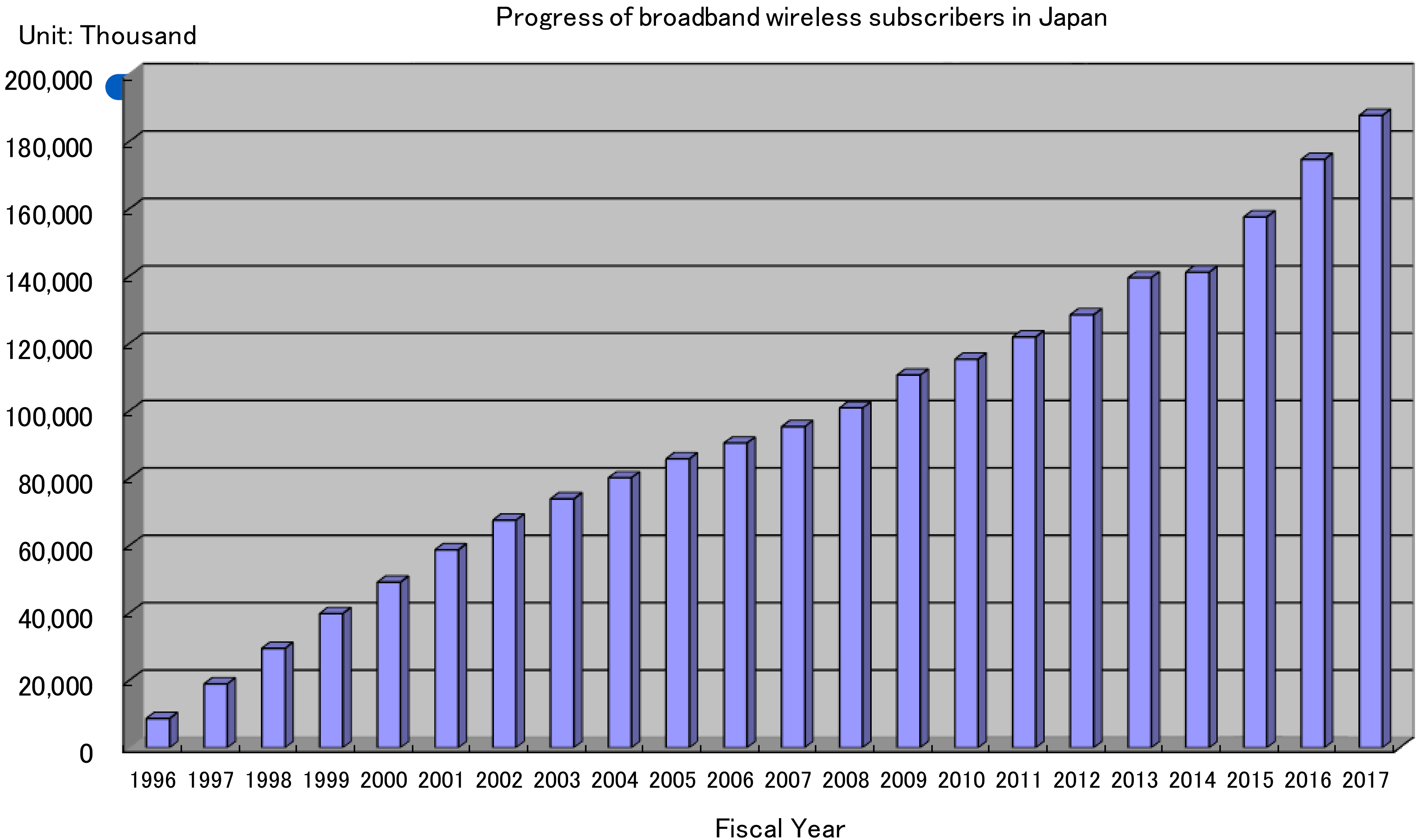
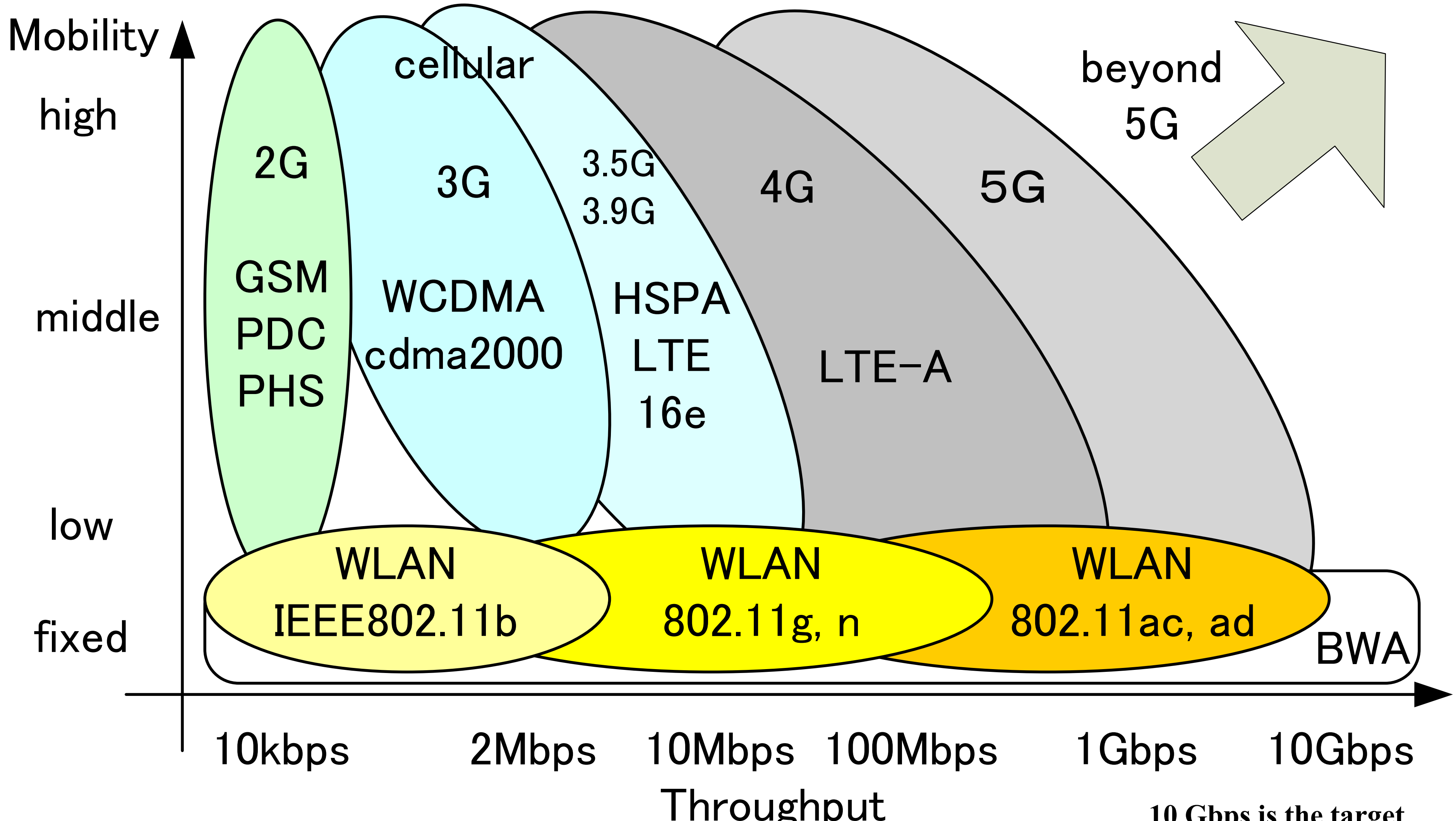
Number of broadband wireless subscribers in Japan



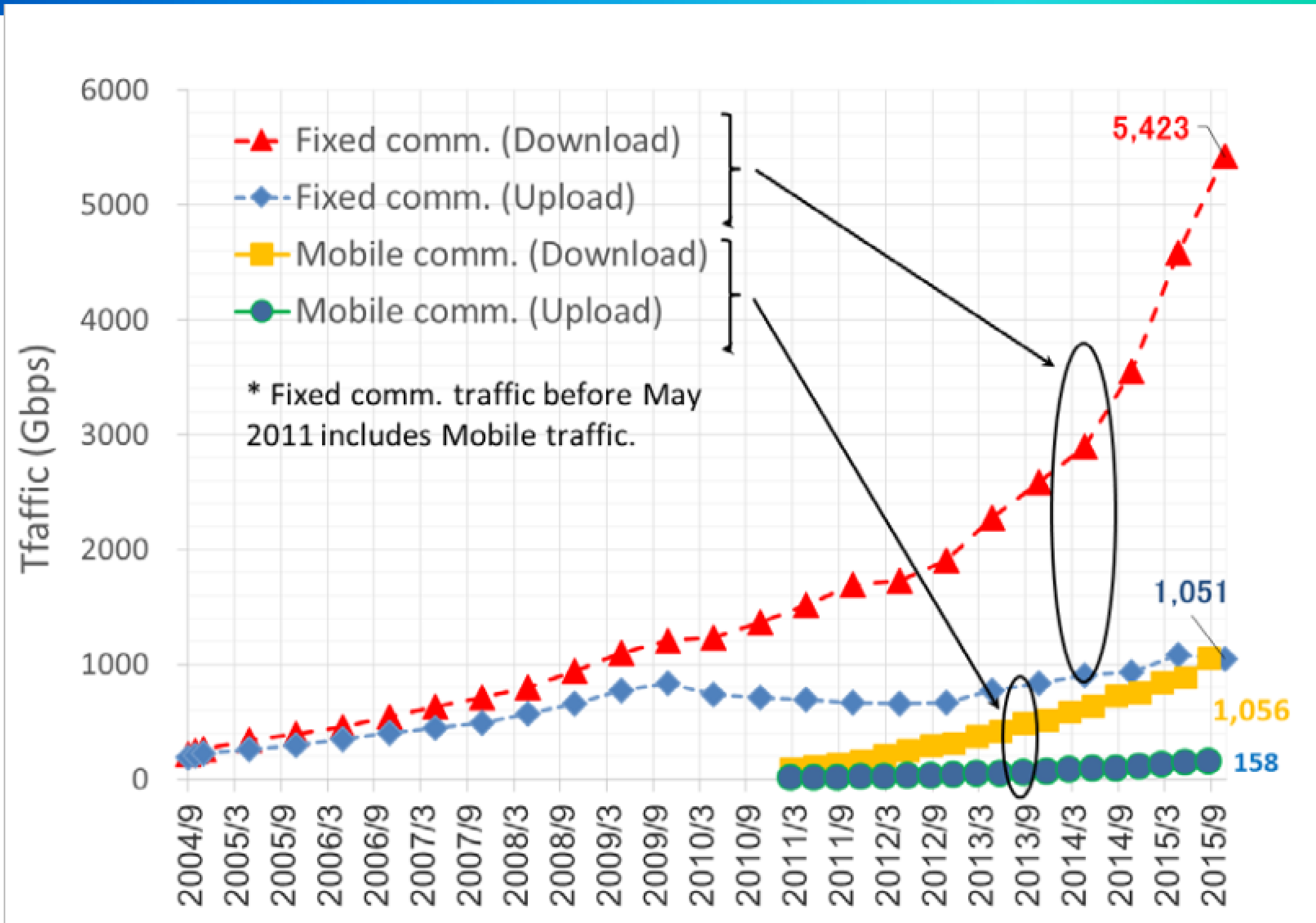
- March 2017: Cellular, PHS, WiMAX -> 187,661,100
- March 2017: Japan population -> 126,760,000
- Adoption rate: 148.0 %

Demands for mobility and throughput in mobile communications



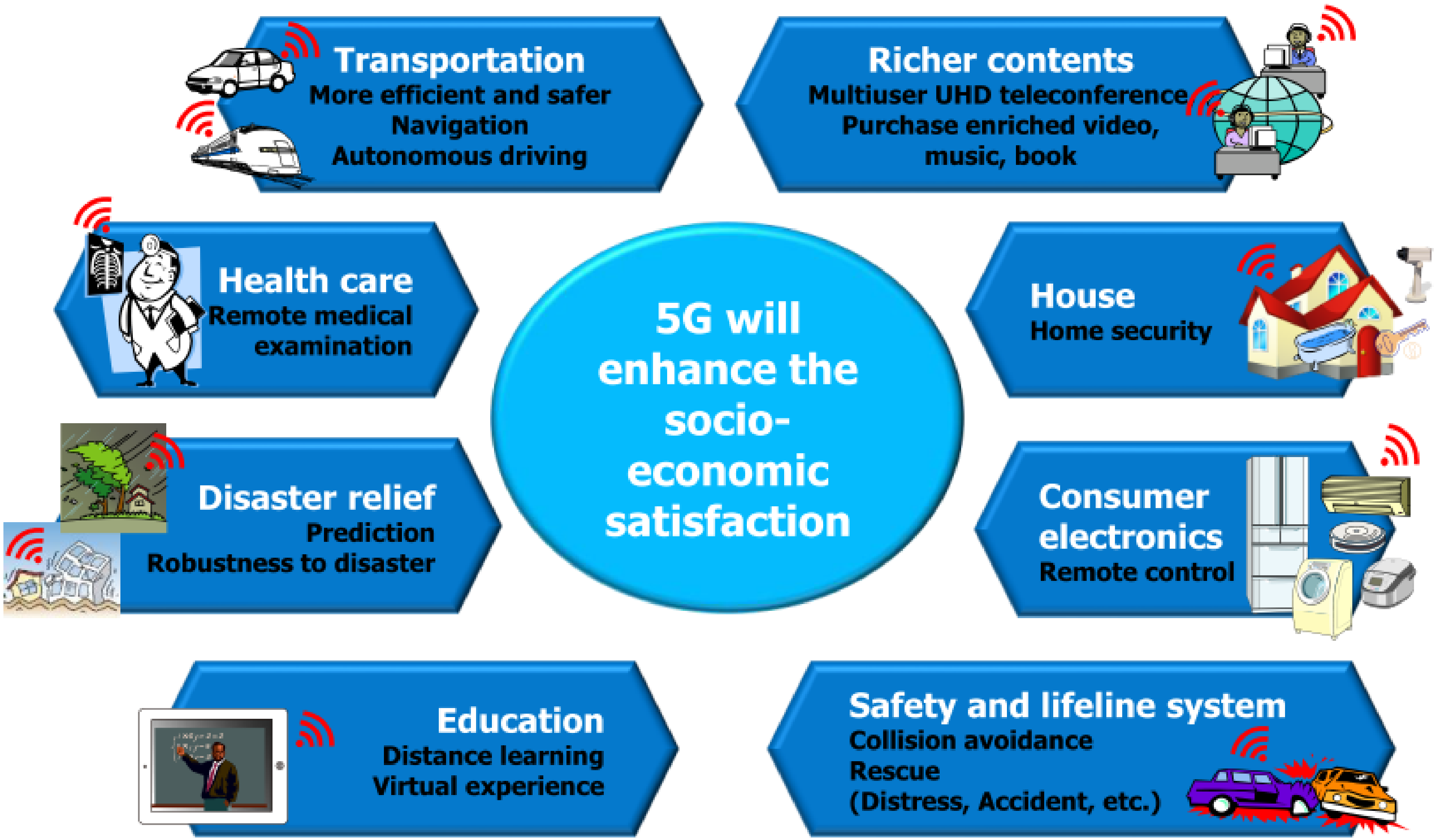
10 Gbps is the target of 5G mobile broadband

Aggregation and Provisional Calculation of Internet Traffic in Japan



[1] The Ministry of Internal Affairs and Communications, "Aggregation and Provisional Calculation of Internet Traffic in Japan," Oct. 2015.

Usage scenarios of 5G from socio-economic perspective



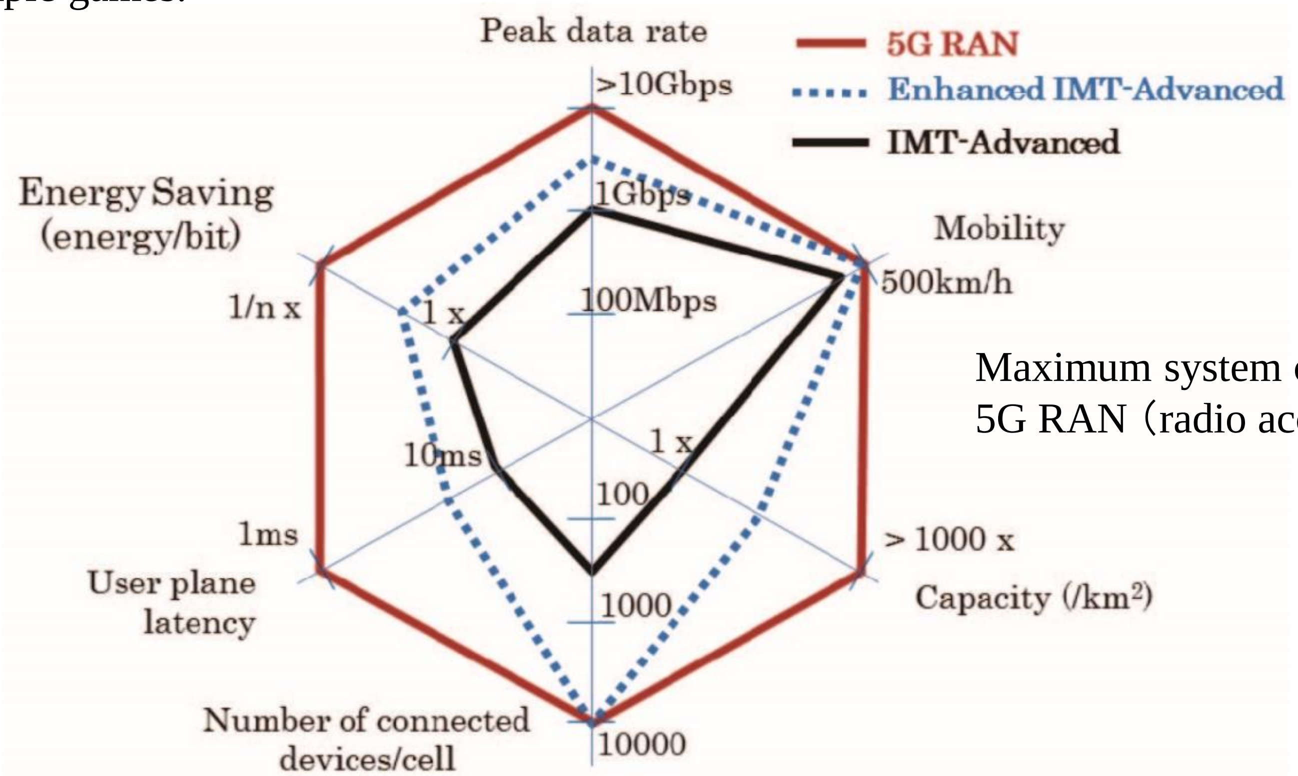
- 5G system will accommodate many use-cases.

[2] "ARIB 2020 and Beyond Ad Hoc Group, Mobile Communications Systems for 2020 and beyond," White Paper, [Online] http://www.arib.or.jp/ADWICS/20bah-wp-100.pdf, Oct. 2014.

Required system capabilities of 5G radio access network

- The maximum system capabilities such as the peak data rate, mobility, capacity, number of connected devices, air latency, and energy saving will be greatly improved compared to IMT-Advanced (4G) system.

- In Japan, a part of 5G services (phase I) is planned to start in 2020 according to Tokyo 2020 Olympic and Paralympic games.

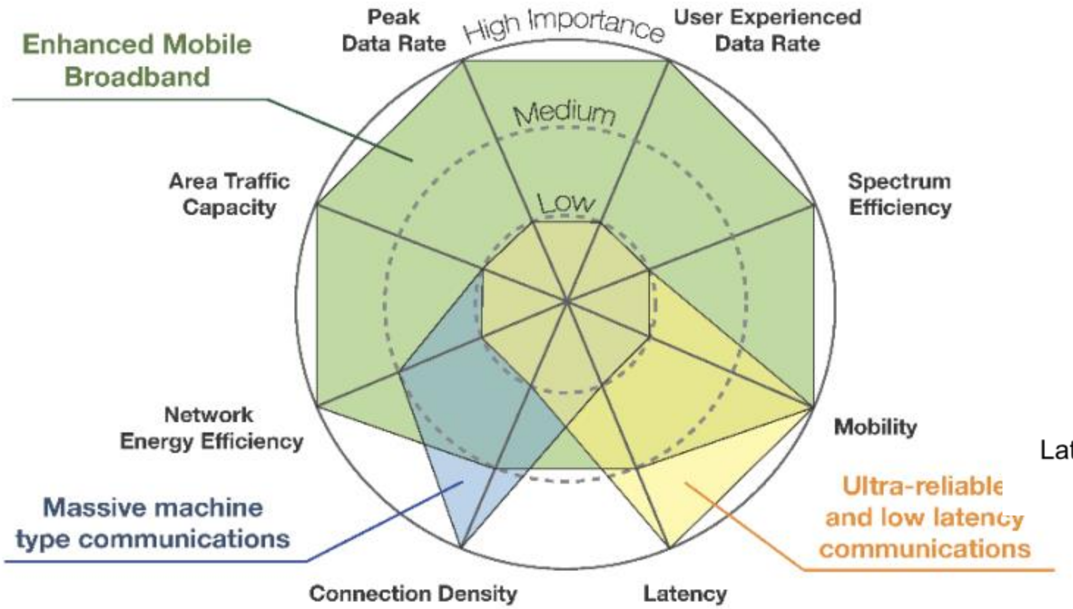


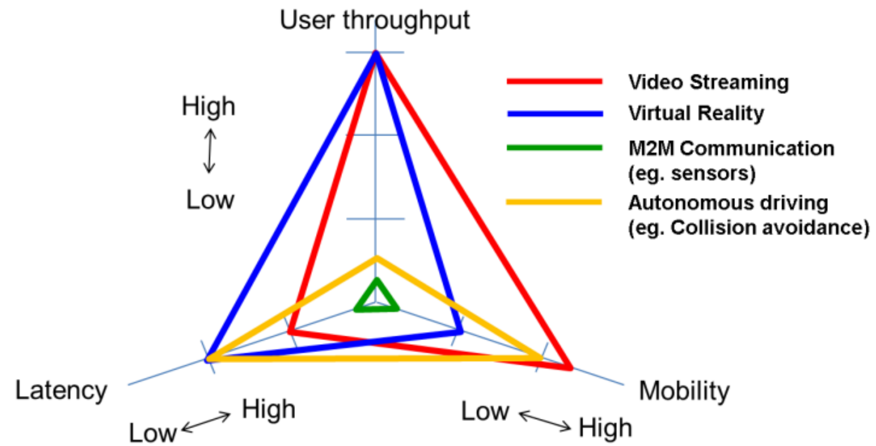
Maximum system capabilities of 5G RAN（radio access network)

[2] ARIB 2020 and Beyond Ad Hoc Group, “Mobile Communications Systems for 2020 and beyond,” White Paper, [Online] http://www.arib.or.jp/ADWICS/20bah-wp-100.pdf, Oct. 2014.

Three major usage scenarios and their requirements

Enhanced mobile broadband (eMBB)





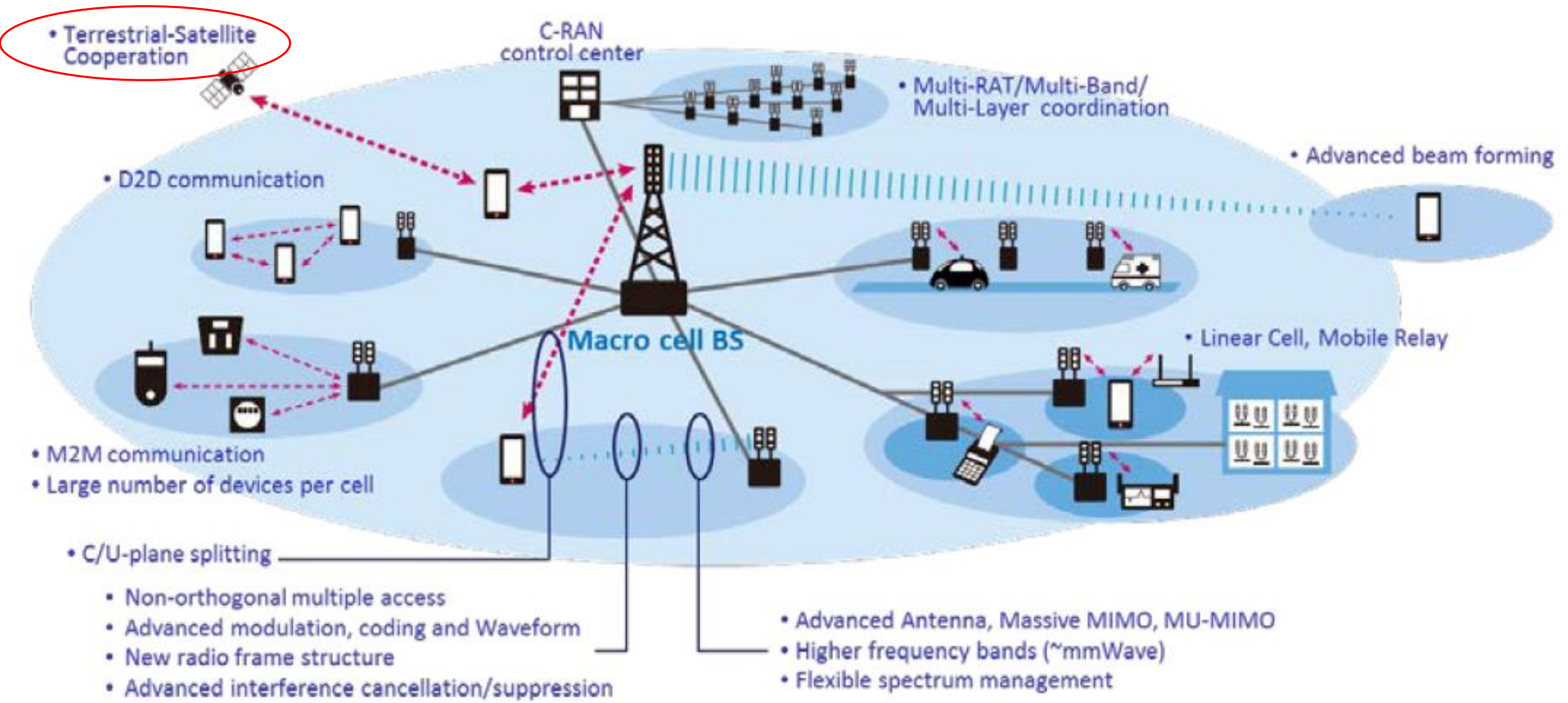
massive machine type communications (mMTC)

ultra-reliable and low-latency communications (URLLC)

[3] 5GMF White Paper, "5G Mobile Communications Systems for 2020 and beyond, " ver. 1.0.1, July 2016. [Online] http://5gmf.jp/wp/wp-content/uploads/2016/07/5GMF_WP101_All.pdf

[2] ARIB 2020 and Beyond Ad Hoc Group, "Mobile Communications Systems for 2020 and beyond," White Paper, [Online] http://www.arib.or.jp/ADWICS/20bah-wp-100.pdf, Oct. 2014.

5G radio access network (RAN) technologies



[3] 5GMF White Paper, "5G Mobile Communications Systems for 2020 and beyond, " ver. 1.0.1, July 2016. [Online] http://5gmf.jp/wp/wp-content/uploads/2016/07/5GMF_WP101_All.pdf

Challenges in beyond 5G systems

- Vanishing the wireless throughput selectivites in terms of time, space, and frequency.
- Providing a stable throughput anytime and anywhere.

↓

- Evolution from 'best-effort service' to 'guaranteed service' in 6G or beyond.

Pros and Cons of satellite communications

■ Pros:

- Cost-effective earth-scale coverage that enables new concept "out-of-range free"
- Cost-effective construction of cyber physical systems (outdoor)
- Stable connection

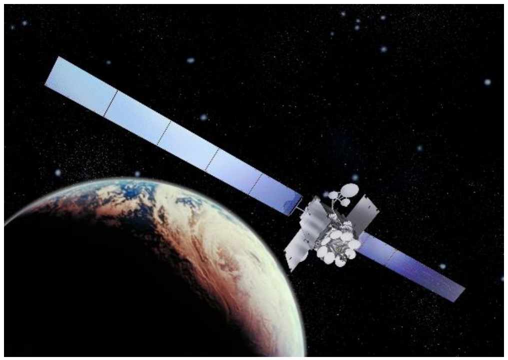
■ Cons:

- Capacity limitation
- Relatively high latency

- User demands are based on terrestrial 5G

Satellite communication systems

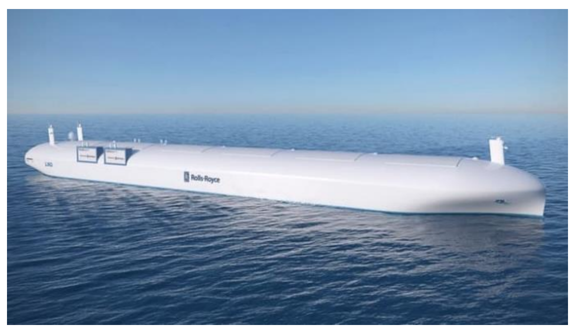
- Advantages and new services using satellite communications



inmarsat
Global Xpress®
uplink 5Mbps/ downlink 50 Mbps
at maximum using Ka-band

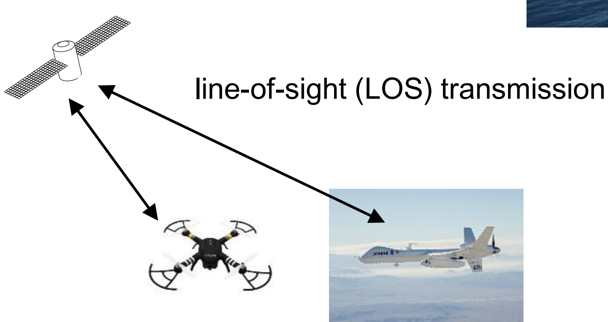
- Global Positioning System (GPS)

- Global broadband services including mountainous and oceanic areas



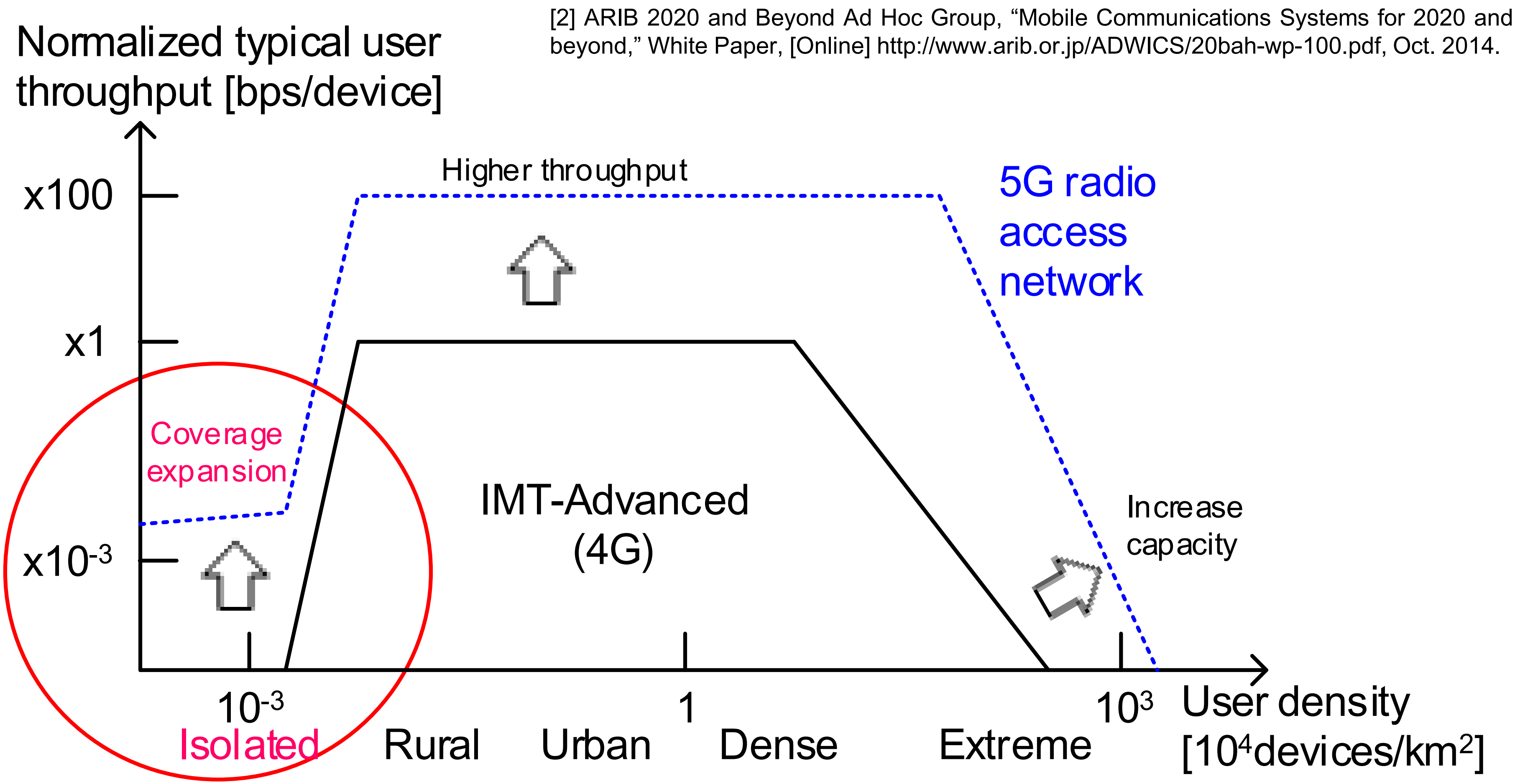
- Autonomous ship controlled by satellites

Rolls Royce
Autonomous Ship



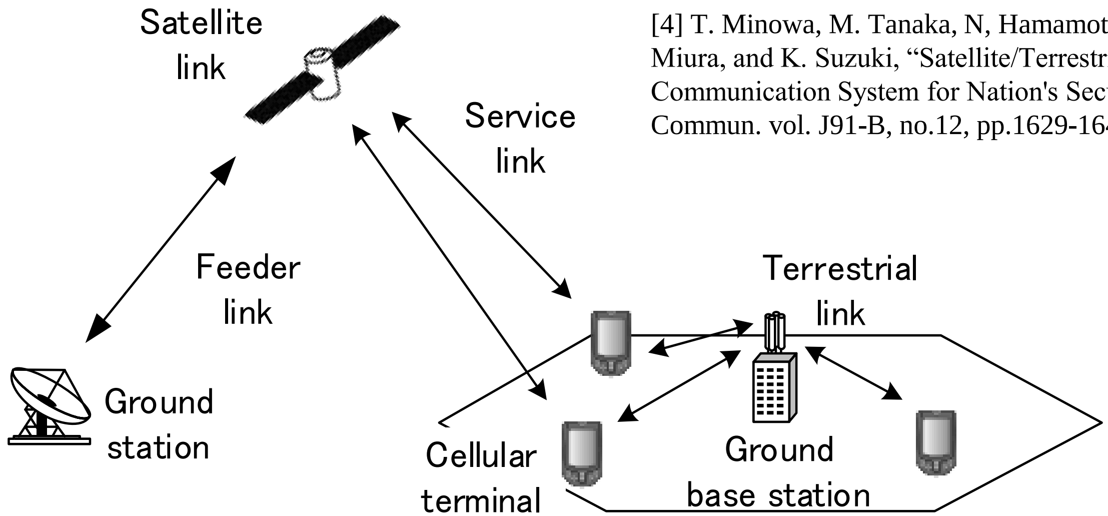
- Autonomous unmanned aerial vehicle (UAV) controlled by satellites

Satellite communication in 5G



- Relationship between user density and target user throughput in 5G mobile communication systems.

Satellite/terrestrial integrated mobile communication system (STICS)



[4] T. Minowa, M. Tanaka, N, Hamamoto, Y. Fujino, N. Nishinaga, R. Miura, and K. Suzuki, "Satellite/Terrestrial Integrated Mobile Communication System for Nation's Security and Safety," IEICE Trans. Commun. vol. J91-B, no.12, pp.1629-1640, Dec. 2008.

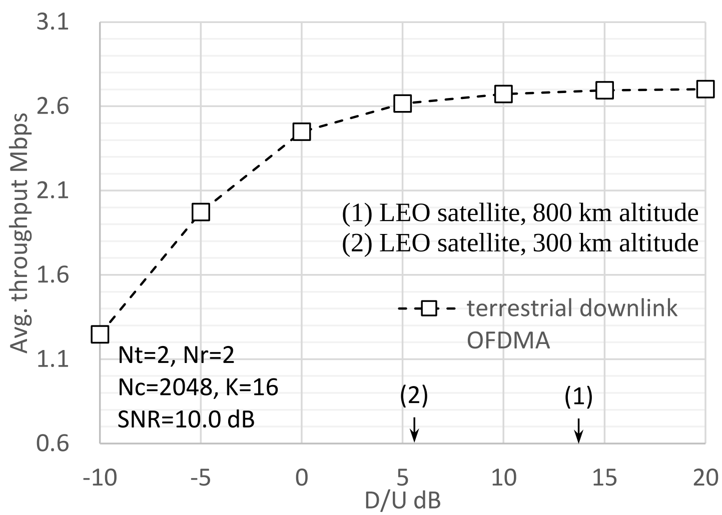
- In satellite/terrestrial integrated mobile communication system (STICS) [4]
  - A mobile terminal can connect both the terrestrial cellular base station and the satellite station.
  - Robust connectivity in emergency cases and wide-area connectivity in mountainous and oceanic areas with low population density are provided.
  - "out-of-range free" cell-phone is realized.
- Similar concepts are given as
  - Ancillary terrestrial component (ATC) technology in US
  - Complementary ground component (CGC) in Europe
  - Enhanced Geostationary Air Link (EGAL) by Qualcomm
  - Recommendation M.2047, "Detailed specifications of the satellite radio interfaces of International Mobile Telecommunications-Advanced (IMT-Advanced)," by ITU-R

[5] E. Okamoto, A. Tanaka, H. Tsuji, and A. Miura, "Throughput Performance Improvement by Dual-Directional Resource Allocation in Satellite/Terrestrial Integrated Mobile Communication System," IEICE Trans. on Commun., vol. J97-B, no. 11, pp. 1009-1021, Nov. 2014.

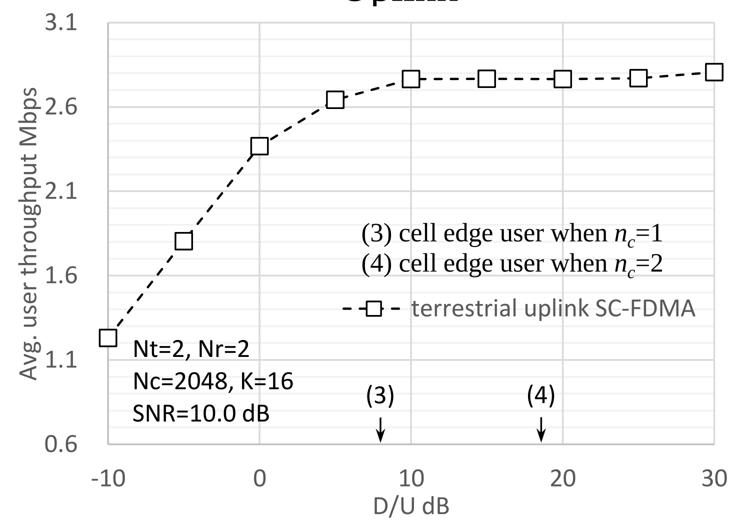
Throughput performance of STICS [5]

Terr. links
max 3.750 Mbps

Downlink

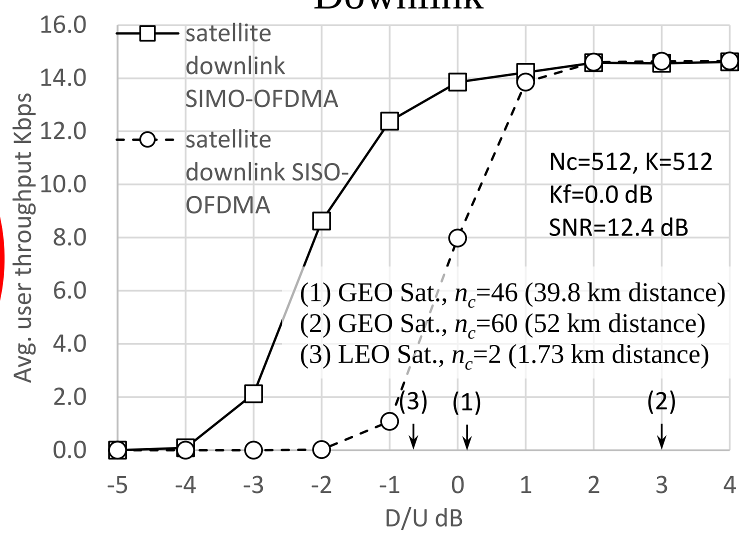


Uplink

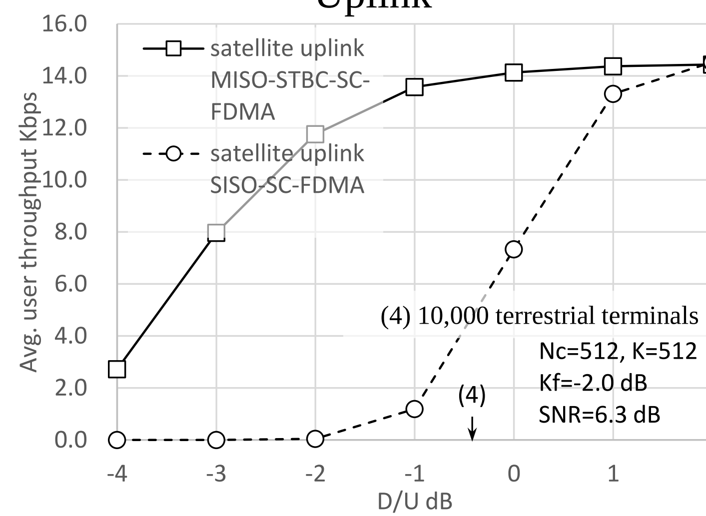


Sat. links
max 14.65 Kbps

Downlink



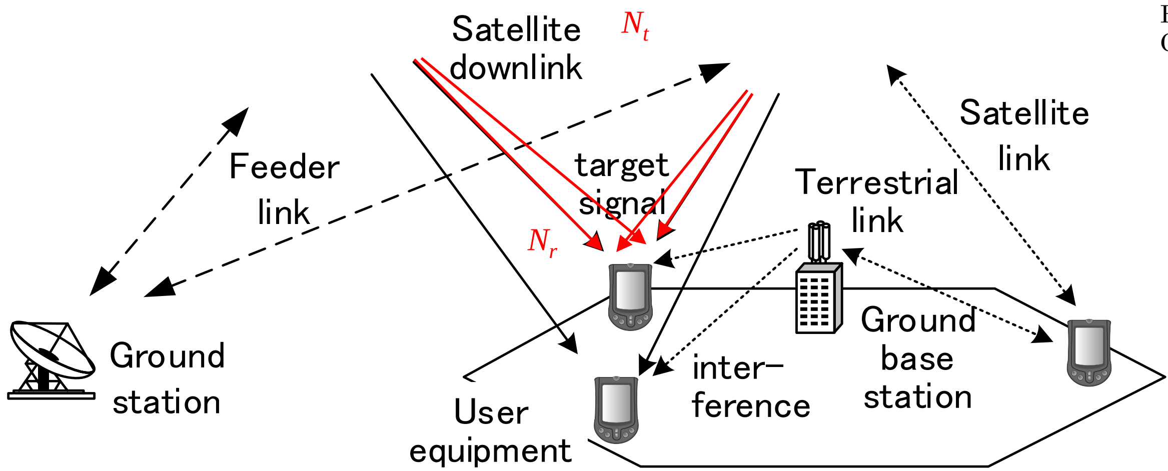
Uplink



- Due to the long-distance propagation and large cell size, the user throughput in satellite cell is ten kbps range.
- The performance of satellite links needs to be improved.

Multi-satellite transmission (satellite MIMO)

[6] D. Goto, F. Yamashita, T. Sugiyama, and K. Kobayashi, "Broadband Multi-Satellite/Multi-Beam System with Single Frequency Reuse," Proc. IEEE Vehicular Technology Conference (VTC-2015S), pp. 1-5, May 2015.



N_t: no. of satellites (total transmit antennas)

N_r: no. of receive antennas at UE

- Channel capacity of multiple-input multiple-output (MIMO) channel

$$N_{\min} = \min(N_t, N_r)$$

$$C = \sum_{k=1}^{N_{\min}} \log_2(1+\lambda_k \gamma) \quad \text{bit/sec/Hz}$$

λ_k : eigenvalue of channel matrix

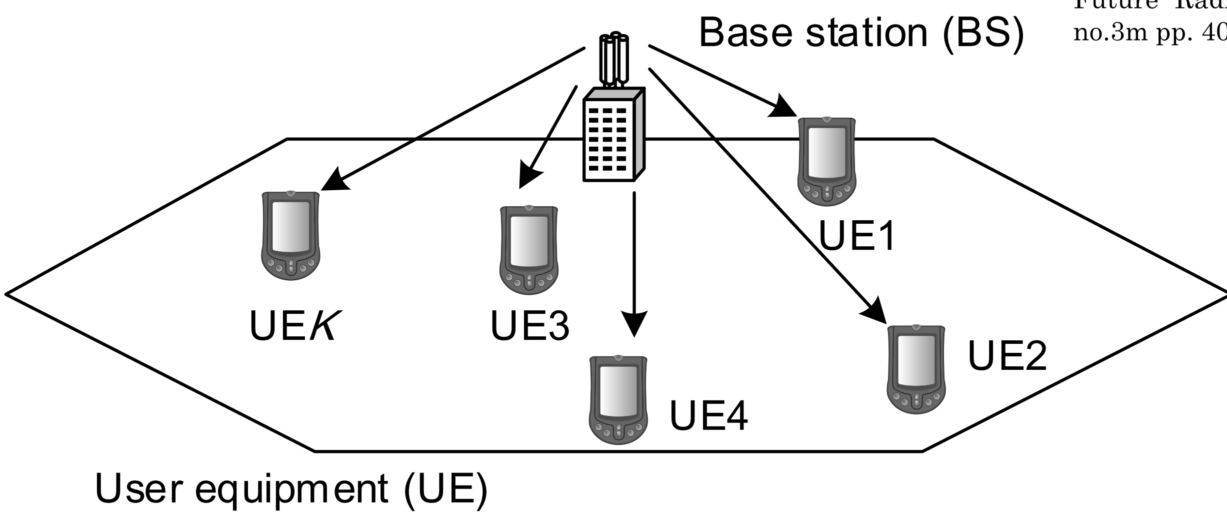
γ : receive SNR

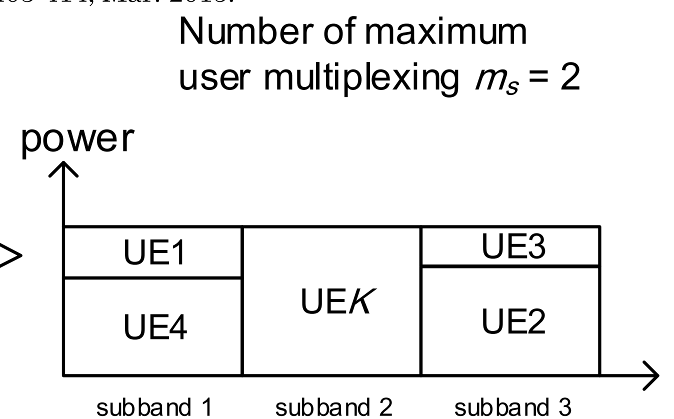
  - C is increased in proportion to number of antennas (rank of channel matrix).

- It is assumed that the synchronization between geostationary (GEO) satellites is perfectly obtained in the multi-satellite case, and that the distance between a user and a GEO satellite is the same at any positions in the satellite cell.

Non-orthogonal multiple access with SIC (SIC-NOMA)

[7] K. Higuchi and A. Benjebbour, “Non-orthogonal Multiple Access (NOMA) with Successive Interference Cancellation for Future Radio Access,” IEICE Trans. on Commun., vol. E98-B, no.3m pp. 403-414, Mar. 2015.





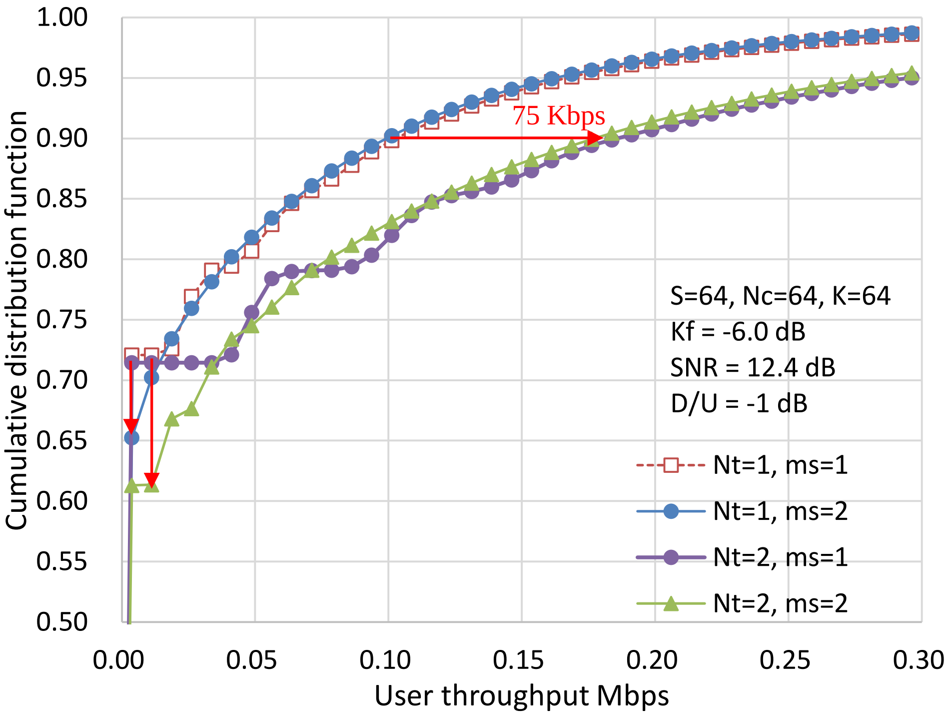
- Different from orthogonal frequency division multiple access (OFDMA), in the figure, the superposition allocation is conducted in subbands 1 and 3 for UE1 and UE4, and UE2 and UE3, respectively.

- System throughputs can be enhanced compared to OFDMA (4G).

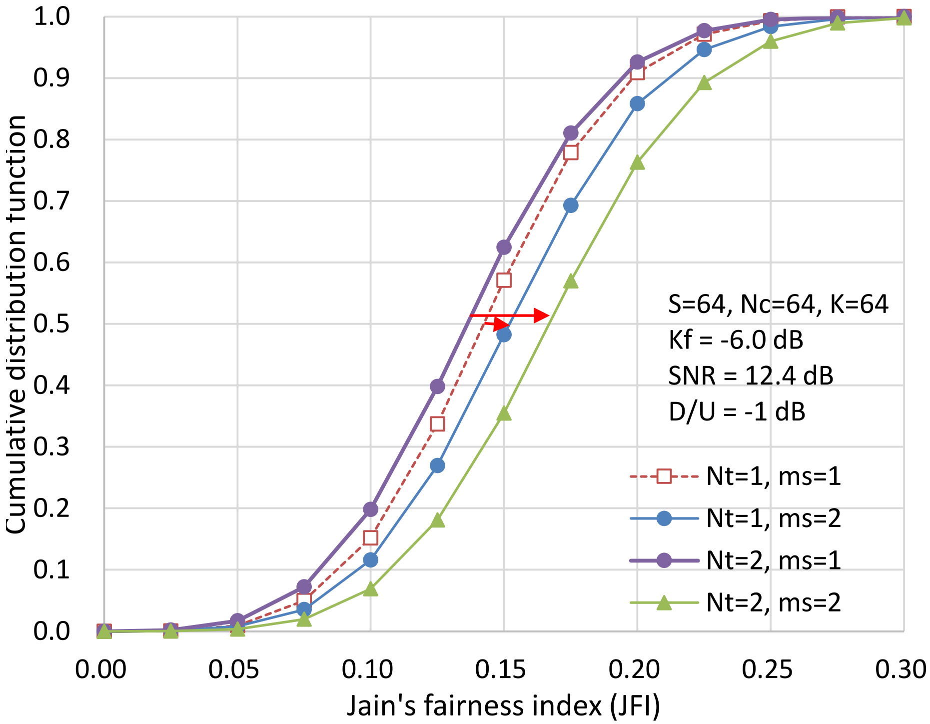
- We proposed an satellite MIMO-NOMA scheme for satellite/terrestrial integrated mobile communication system (STICS) [8].

[8] E. Okamoto and H. Tsuji, "Application of non-orthogonal multiple access scheme for satellite downlink in satellite/terrestrial integrated mobile communication system with dual satellites," IEICE Trans. Commun., vol. E99-B, no. 10, pp. 2146-2155, Oct. 2016.

Performance at Rice factor $K_f = -6$ dB



CDF of user capacity



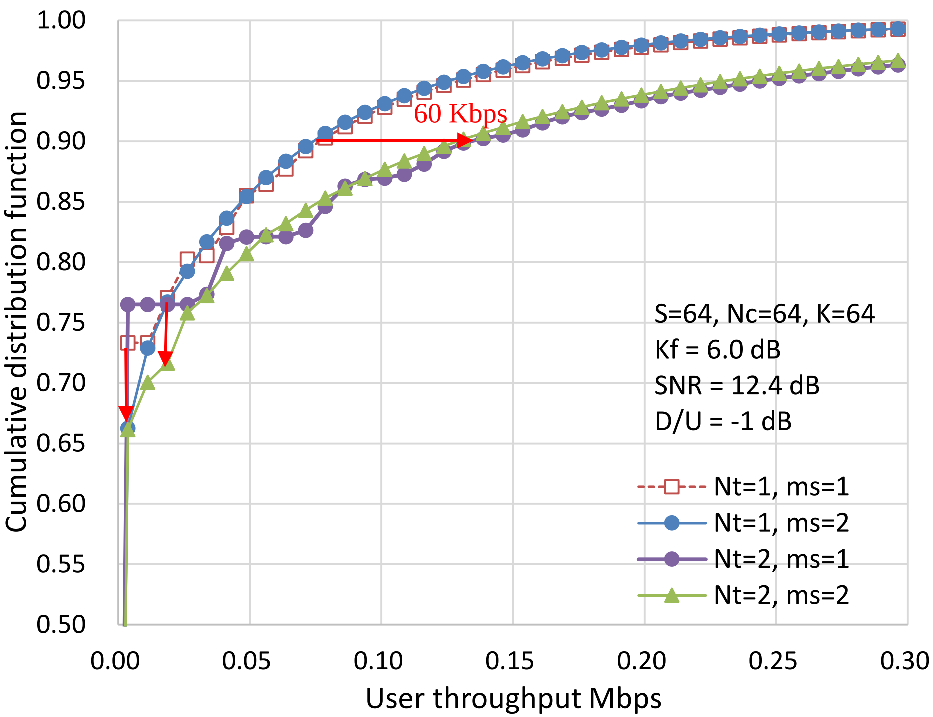
CDF of Jain's fairness index

CDF: cumulative distribution function

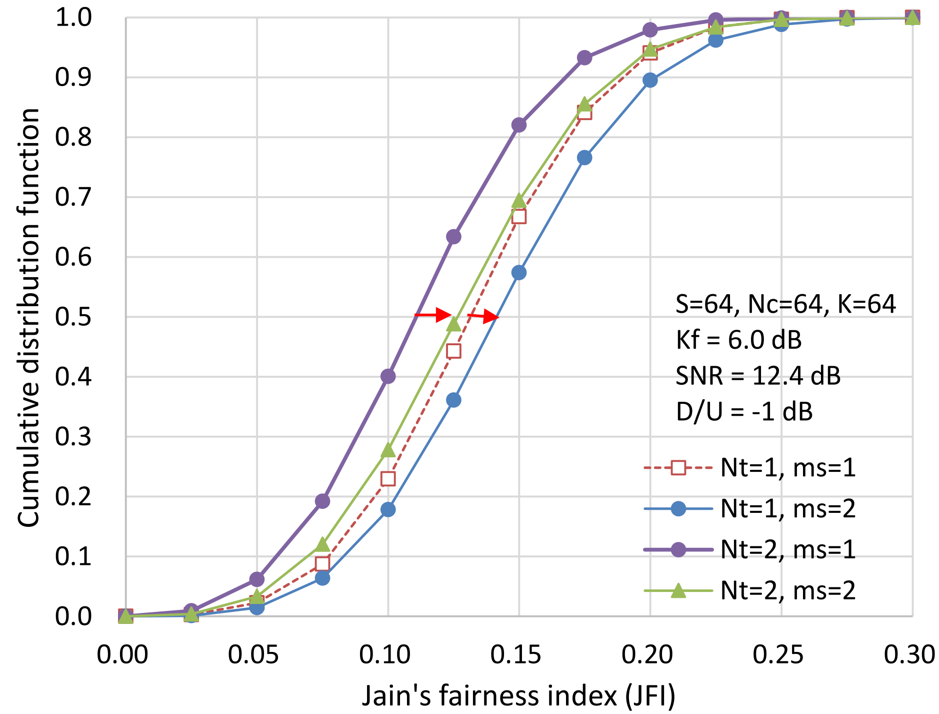
- The performances are improved in both figures compared to K_f = 6 dB, because of the space diversity effect of MIMO channel, i.e., the second eigenvalue is increased.
- JFI is also improved because the channel variance is increased due to the blockage of direct wave, and the PF allocation works well.
- The performance of JFI with $N_t = 2$ and $m_s = 2$ is the best.

- The application of multi-satellite and NOMA is effective.

Performance at Rice factor K_f = 6 dB



CDF of user capacity

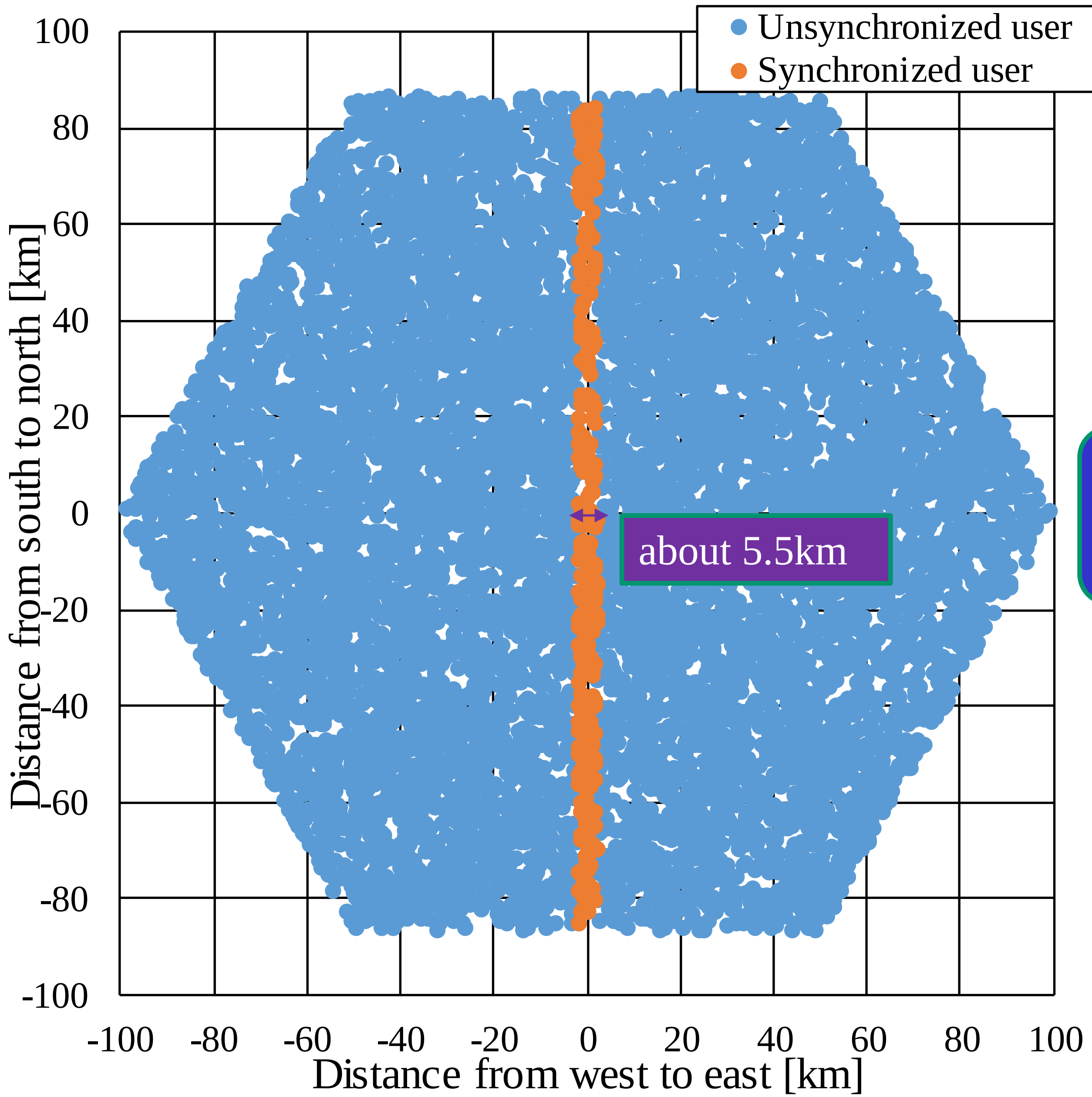


CDF of Jain's fairness index

CDF: cumulative distribution function

- User variance is relatively small and the CDF at minimum throughput is over 0.5 in all configurations, because the 64 subbands (subcarriers) are allocated to 64 users.
- 6 Kbps improvement is obtained at CDF of 90% regardless of m_s when multi-satellites are used.
- The performances at lower throughput below 3 Kbps are improved by applying NOMA of m_s = 2.
- The fairness is improved by applying NOMA, that is, 0.15 and 0.2 point of JFI at CDF of 50% are increased for N_t = 1 and 2, respectively, by applying m_s = 2.

MIMO synchronization in satellite cell



274 users out of 10000 users (2.7%)

Problems and solutions of STICS

■ Problems:

- Capacity limitation
- Narrow area of satellite MIMO synchronization
- Relatively high latency of GEO

■ Solutions:

- Super-constellation using low-earth orbit (LEO) satellites
- High-throughput satellite (HTS)

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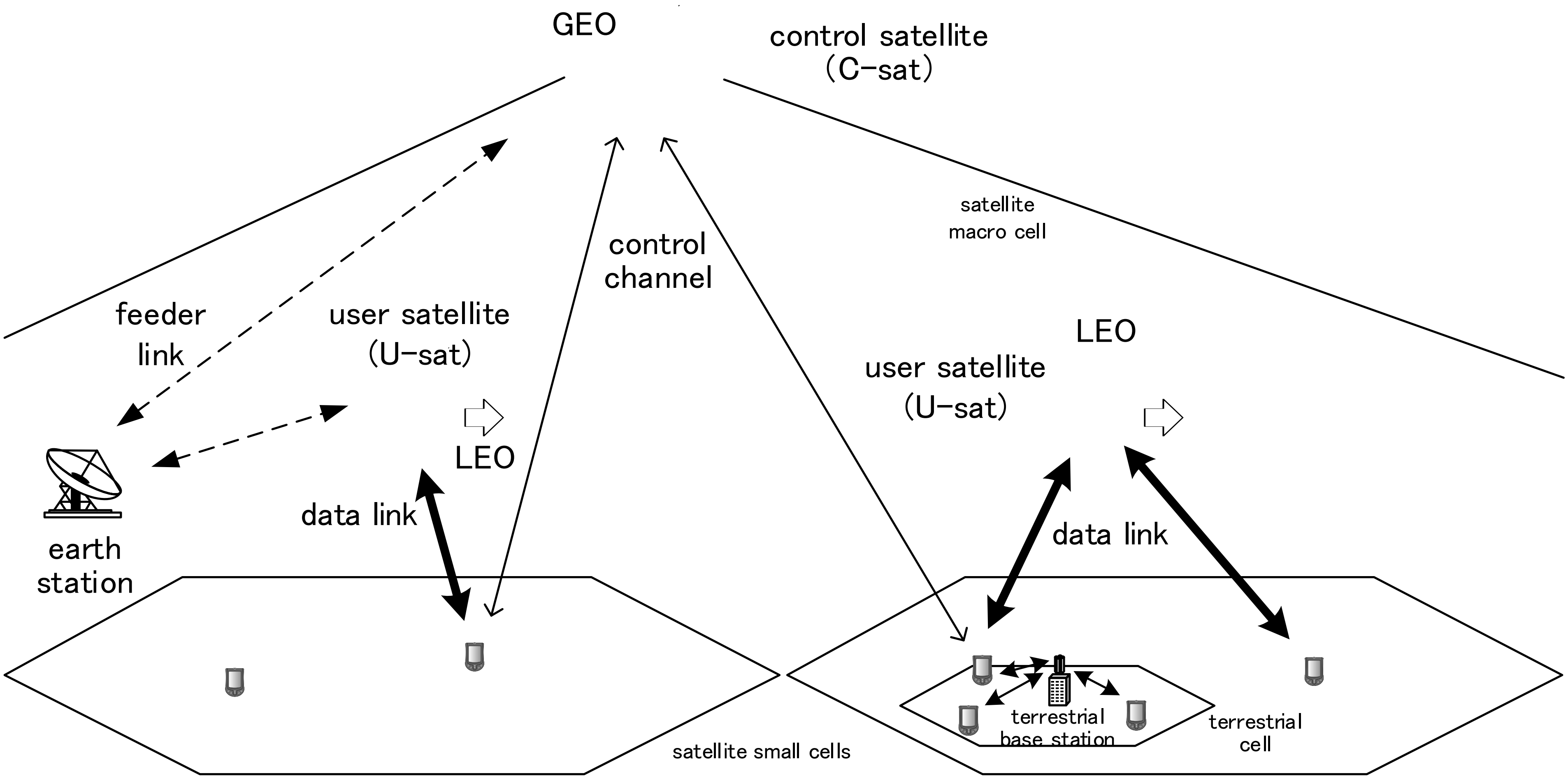
- channel fluctuation of many non-line-of sight LEO satellites may be utilized for good MIMO transmission

Control and user plane separation in satellite communication



- System capacity enhancement is obtained.
- Low latency transmission
- Different from terrestrial 5G, the latency of C-Plane is a problem to be solved.

Summary

- 5G enables variety of scenarios for socio-economic satisfaction.
- Satellite communications enhances 5G system.
- Satellite systems will enable "out-of-range free" and "guaranteed service" in 5G or beyond.