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Multi-Shell Space Data Centers in the Sun-Synchronous Orbit-assisted LEO Mega-Constellation

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ABSTRACT

Space data centers (SDCs), which offer space-based computing solutions, have recently drawn wide attention due to their potential to substitute energy-intensive terrestrial cloud data centers (CDCs). With the rapid development of artificial intelligence (AI) technologies, the increasing number of satellites, and the improved durability of computing devices, the implementation of SDCs has become even more feasible. However, architecture of SDCs has rarely been addressed in previous works. **In this position paper, we propose a multi-shell SDC architecture composed of a Low Earth Orbit (LEO) mega-constellation and a single sun-synchronous orbit (SSO) shell.** Combined with RIC-assisted control, the proposed architecture can support efficient resource allocation, path selection and computation offloading decision while reducing dependence on traditional terrestrial CDCs. **This position paper provides an initial, scalable architecture toward future orbital SDCs.**

Proposal of Space Data Center Architecture

Motivation

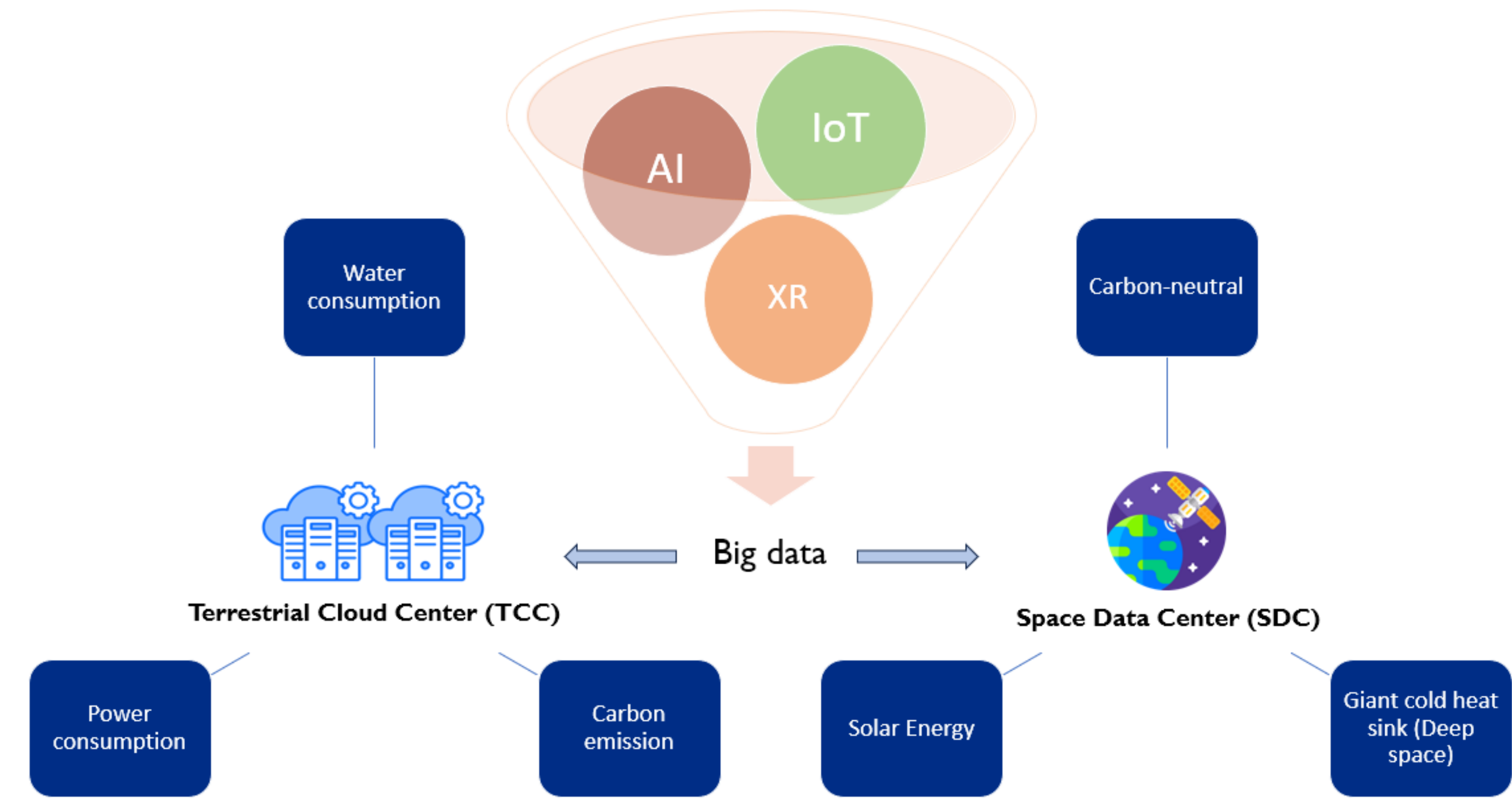


Fig. 1. Terrestrial vs. Space Data Centers

- Explosive data growth in 6G Era and the increasing importance of data centers.
- Carbon- and energy intensive TCCs drive the need for solar-powered and carbon-neutral SDC.
- The architecture of SDCs was hardly suggested in prior works.

Prior Network Architecture

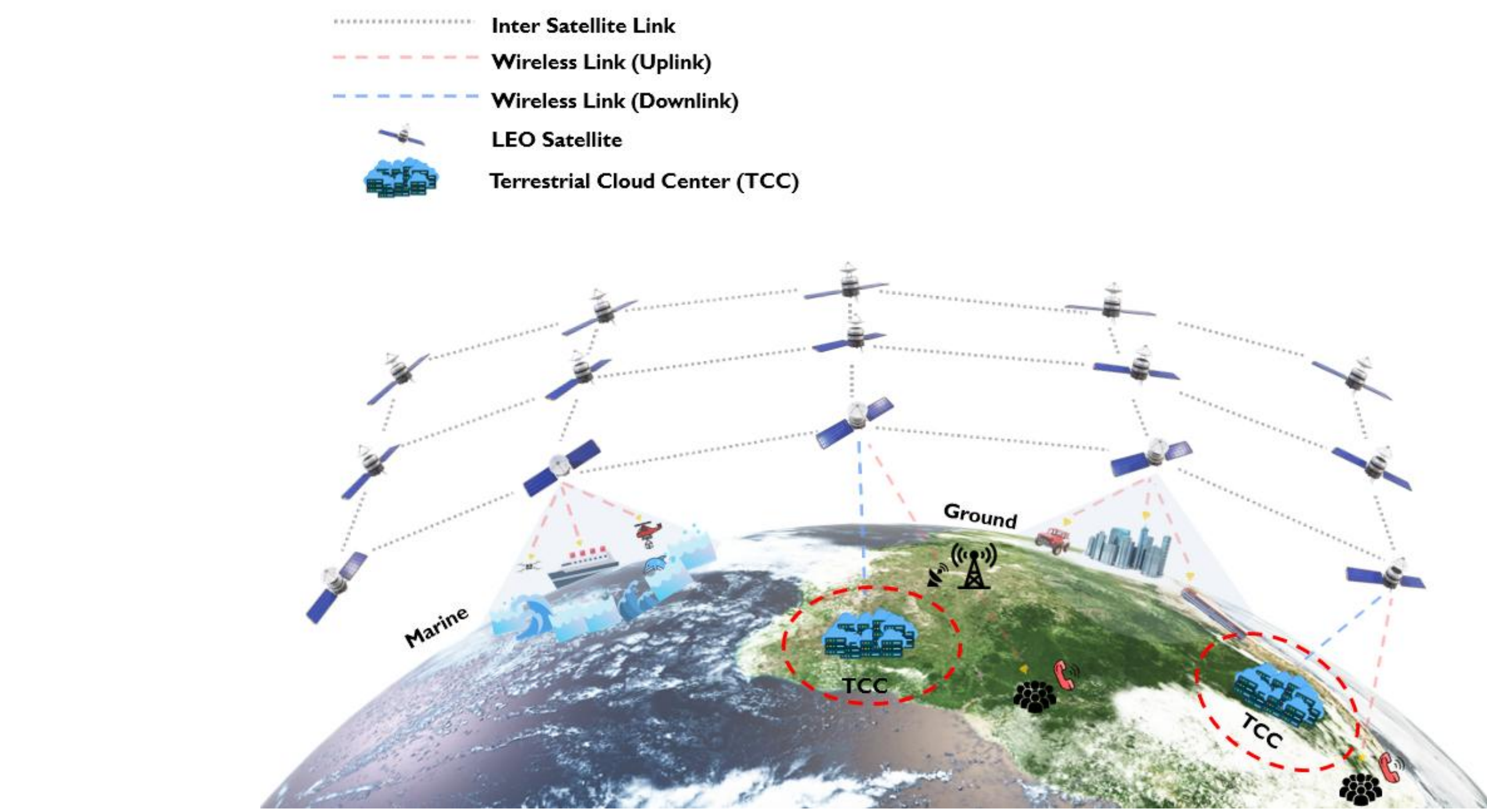


Fig. 2. Conventional ISTN architecture

- Satellites in conventional satellite-terrestrial network also have provided computation ability.
- Prior networks have been highly dependent on TCCs.

Sun-Synchronous Orbit

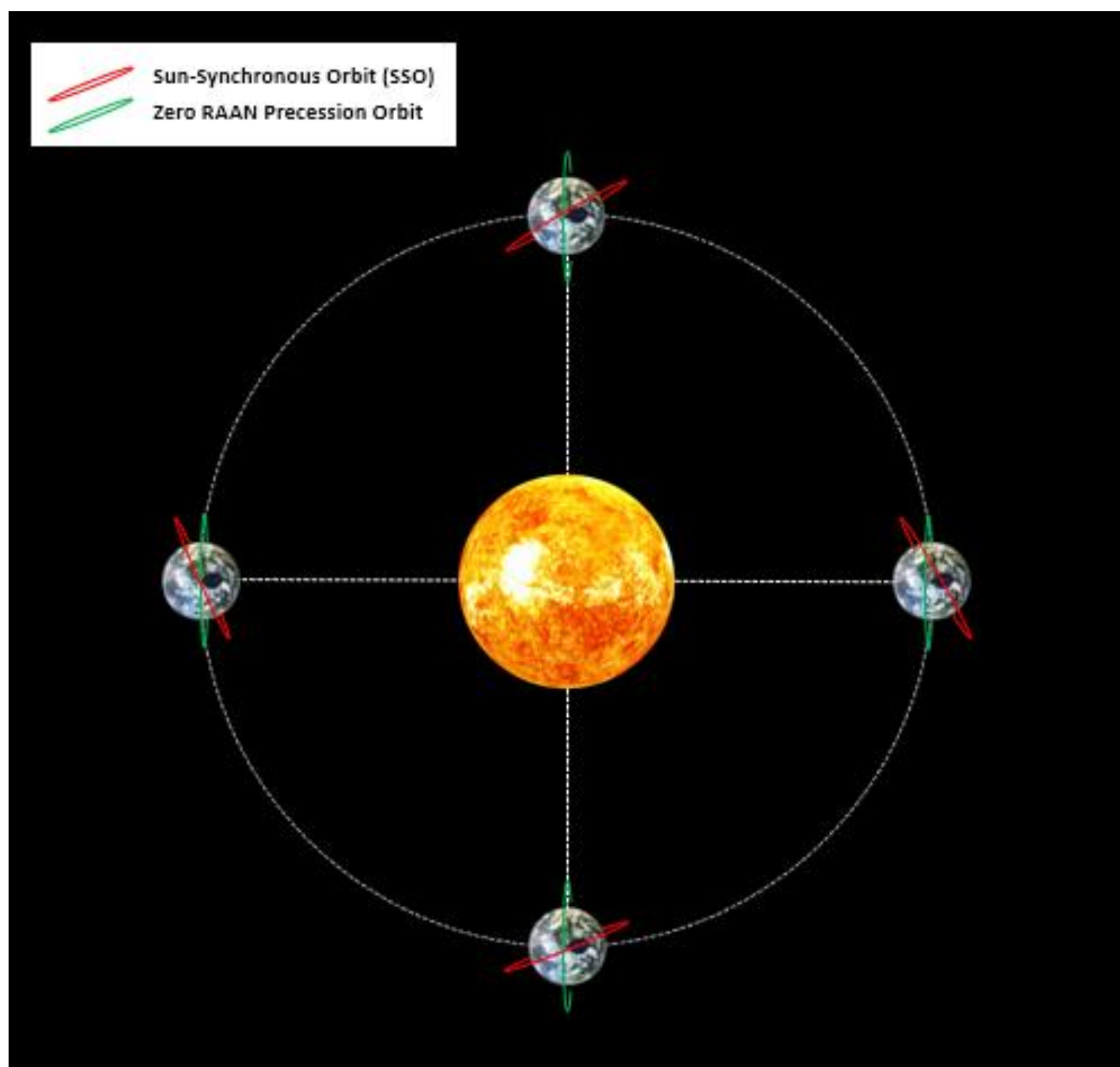


Fig. 3. Schematic illustration of the SSO

<Key Features>

- Fixed Sun-orbit geometry
- Periodic solar illumination
- Predictable battery charging
- Energy-stable computing frequency
- RAAN changes 360 degrees per year

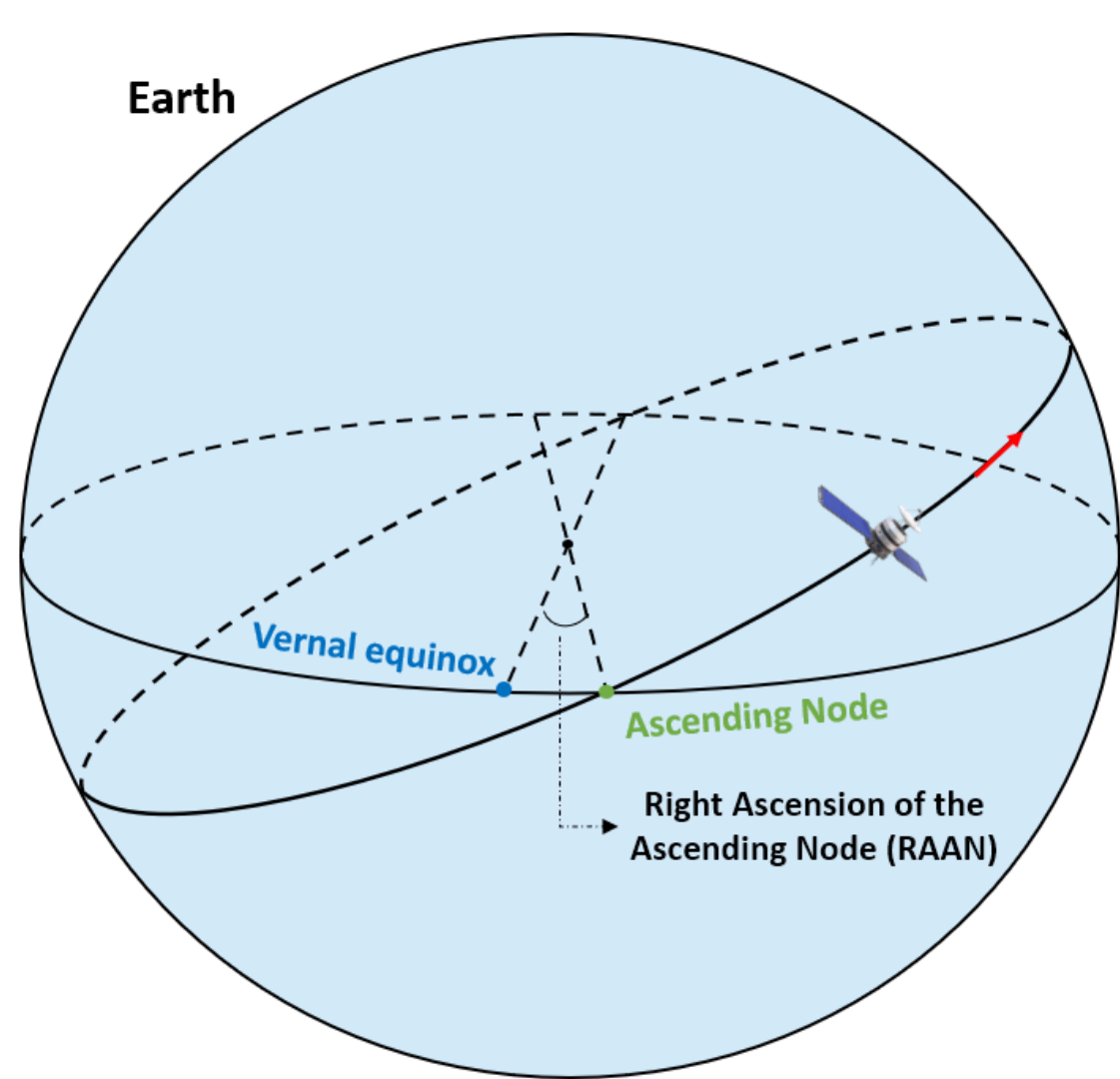


Fig. 4. RAAN definition illustration

Proposed Network Architecture

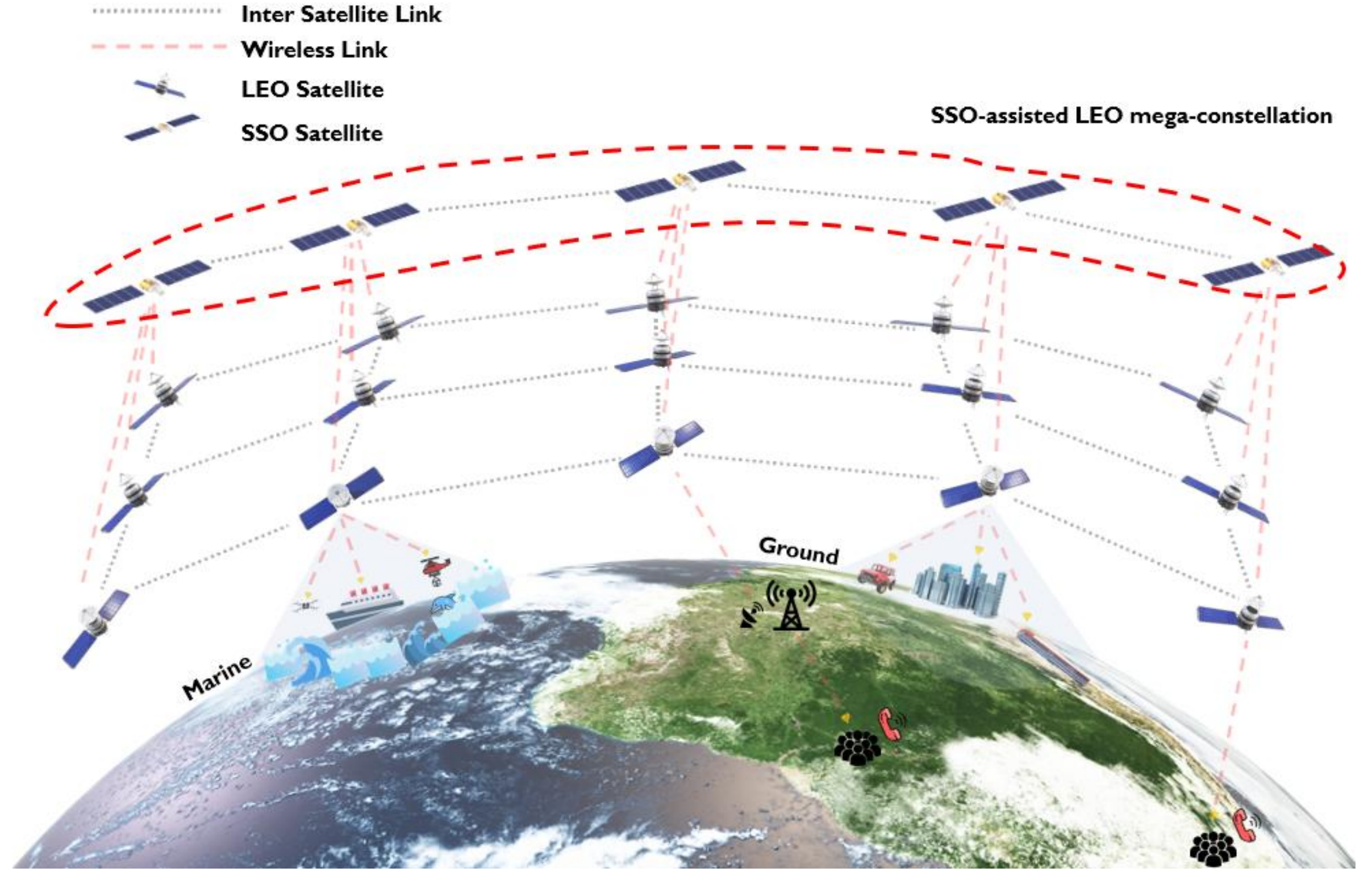
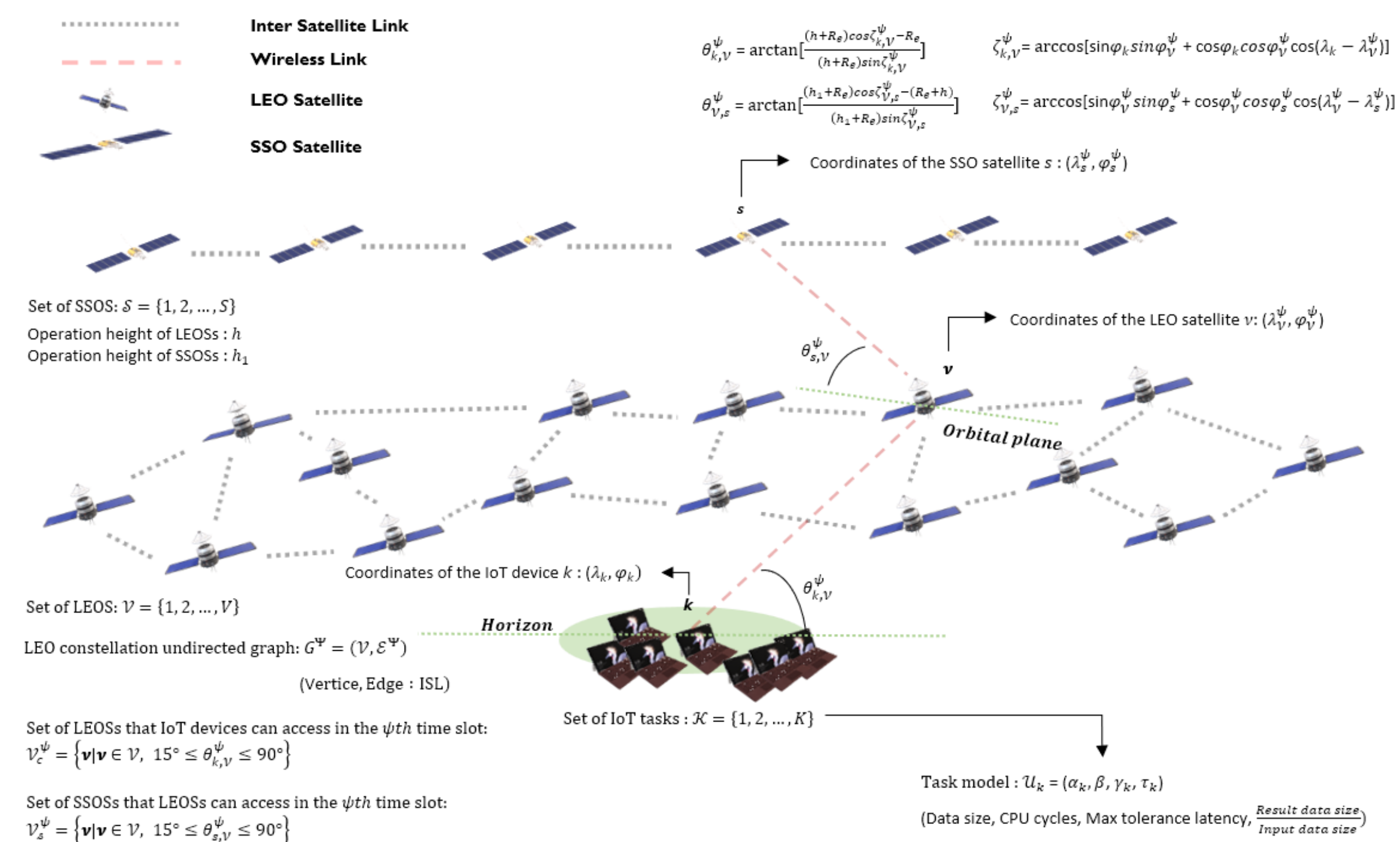


Fig. 5. The Sun-Synchronous Orbit-assisted LEO Mega-Constellation

- Relying solely on solar-powered satellites for computation without dependence on TCCs.
- By introducing an SSO shell with predictable daily solar illumination, the proposed architecture establishes stable and reliable computing support, mitigating short-term and irregular variability in battery power and computing resources inherent in LEO-only SDCs and enhancing overall system robustness.
- By taking orbital characteristics and energy constraints into account, the architecture enables energy-aware computing decisions that are not addressed in conventional SDC architectures.

System Operation and Control



- A near-RT RIC operates over the LEO satellites as a control plane, jointly coordinating computation offloading, routing, and resource allocation between LEO and SSO shells.
- The task is offloaded to the contact satellite and relayed to the processing satellite through ISL.
- Selection of satellites is based on their locations and computing capabilities at each time slot.
- Satellites in different shells cannot be connected through ISL.
- Joint minimization of latency and carbon emission.

Limitations and Future Work

- Inter-layer ISLs remain challenging to deploy, introducing communication and latency constraints between satellites in different shells.
- Path selection in a multi-shell architecture requires topology-aware optimization, due to high mobility of satellites in each shell.
- The characteristics of an SSO vary with its orbital elements, such as altitude, inclination, and eccentricity, and the careful selection of these elements is required.
- Quantitative analysis and comparison of SDC and TCC performance, with respect to latency and carbon emissions, are necessary to demonstrate the practical need for SDCs.

CONCLUSION

In this position paper, we proposed an MSSDC architecture for satellite-centric SDCs without reliance on terrestrial CDCs. The proposed architecture has the potential to mitigate global challenges related to energy consumption and carbon emissions and serves as an initial step toward the architectural development of future scalable SDCs for next-generation networks.