Space Data Centers – Future Development and Application Perspectives

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***Abstract*— The exponential growth of digital data presents escalating challenges for terrestrial data centers, including energy consumption, ecological impact, and cybersecurity risks. Deploying data centers in space emerges as a compelling alternative, leveraging microgravity, extreme temperatures, and isolation to enhance computational efficiency and environmental sustainability. This study explores the technological foundations and feasibility of emerging Space Data Center concepts. It also highlights the environmental burden imposed by terrestrial data centers, particularly their high water and land usage for hosting web services. In response, a space-based architecture is proposed to support low-cost, eco-friendly web development and content delivery. The research underscores space data centers as a forward-looking strategy for sustainable digital infrastructure.**

Keywords – Data centers; satellite; space Integrated; computing networks; photonics.

I. INTRODUCTION

Data centers are vital for hosting digital content accessed over the Internet, supporting key applications such as social media and data storage. Terrestrial data centers consist of multiple servers requiring substantial power and cooling, often leading to high water and land footprints. Water-intensive cooling systems, such as chillers and indirect evaporative cooling, contribute significantly to environmental strain [1], [2], while power demands escalate with data center scale [3], [4]. These constraints limit deployment in water-scarce, landlocked, or densely populated regions, resulting in content latency and power strain, especially in developing areas. Solutions to mitigate these challenges have been proposed in [5], [6]. The discussion in [5], and [6] also shows that future trends in the continued use of terrestrial data centers aim to address challenges in ensuring that data centers deploy their own power sources and systems. However, it is recognized that these approaches do not eliminate the competition for natural resources between terrestrial data center operators and other entities seeking to deploy power systems for other applications.

Terrestrial centers process space-based data [7], but the growing volume from small satellites and the latency in downlinking such data hinder timely decision-making. To address these limitations, there is a need for alternative infrastructure with lower environmental impact and reduced latency, the Space Data Center (SDC). SDCs eliminate dependence on Earth's land and water resources and are positioned to process satellite data in orbit, enabling rapid access and decision-making for latency-sensitive applications. They also host caches to support low-latency content delivery in landlocked regions, offering advantages over terrestrial centers for satellite-based communications.

The concept of SDCs is gaining global attention, with initiatives such as the European Union's ASCEND (Advanced Space Cloud for European Net Zero Emission and Data Sovereignty) project [8], [9] exploring large-scale orbital data centers powered by solar energy to reduce the carbon footprint of information technology. This paper explores the feasibility, technological underpinnings, and environmental implications of deploying data centers in space. It also investigates the role of SDCs in supporting web development tasks, where the reliance on cloud-based tools typically hosted on terrestrial infrastructure incurs significant environmental costs. By shifting such workloads to SDCs, the potential exists to achieve more sustainable computing.

The research being presented focuses on the design and application of SDCs in the area of web development. The motivation for the consideration of the web development application is that web development utilizes a significant proportion of existing computing resources. It is proposed that web development be migrated to SDCs. This has the benefit of reducing the environmental toll due to the use of existing terrestrial data centers for executing web development. The research presents a network architecture i.e., entity identification and describing entity relations. This is done to achieve the goal of executing web development aboard SDCs. In addition, the research recognizes the SDC

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as the new computational workhorse for future execution of web development. It also presents the subsystems and components alongside space related elements for the realization of SDCs to be used in the proposed application. The use of SDCs is expected to be beneficial from an operational perspective. This is because of the abundance of solar power in space, which is accessible by SDC's onboard solar panels during the SDC's lifetime. The SDC does not need to incur high costs in comparison to terrestrial data center operation.

The remainder of this paper is structured as follows: Section II presents background work on data centers; Section III introduces the SDC technology concept; Section IV outlines potential advantages; Section V explores use cases and applications; Section VI discusses enabling hardware and software; and Section VII concludes the study.

II. Limitations and Challenges of Terrestrial Data Centers

Terrestrial data centers are centralized infrastructures that host computing and networking resources, including servers, storage systems, and communication hardware. They form the digital backbone for a broad spectrum of services, such as website hosting, cloud applications, enterprise IT operations, and content delivery. In particular, they are vital for web hosting and online enterprises, providing the essential computational support required for digital content accessibility across the globe. Currently, approximately 4,798 data centers are operating worldwide, with over 500 categorized as hyperscale facilities. These hyperscale data centers, typically operated by global technology firms, such as Amazon, Microsoft, Google, and Meta, are characterized by their immense capacity, architectural scalability, and advanced energy and infrastructure management capabilities [10]. In Africa, South Africa leads in terrestrial data center deployment, with major installations in Cape Town and Johannesburg [15]. These facilities support national and regional digital services but face significant operational constraints.

One of the most pressing challenges is the immense energy demand required to power servers and cooling systems. Data centers globally account for roughly 1–2% of electricity consumption, and this figure is expected to rise as digital services expand [11]. Maintaining an optimal thermal environment for servers further exacerbates energy consumption. Conventional cooling techniques, such as chilled water systems, are especially energy intensive. Even with improved methods like indirect evaporative cooling, the overall environmental toll remains significant, particularly due to high water usage [12].

The spatial requirements of large-scale data centers also contribute to broader urban planning and environmental challenges. These facilities often occupy large tracts of land, including prime real estate in urban areas, thereby competing with residential, agricultural, and infrastructural developments. In regions with high population densities or limited land availability, allocating space for new data centers becomes increasingly problematic. From an environmental standpoint, terrestrial data centers contribute significantly to global carbon emissions. Their high electricity consumption, coupled with reliance on water-intensive cooling systems, has led to increased scrutiny amid growing concerns about climate change and ecological degradation [16]. The environmental cost is especially acute in water-stressed and landlocked regions, where freshwater and land resources are either unavailable or severely constrained. This geographical limitation also leads to latency issues for users located far from major data center hubs.

Security and data privacy represent additional concerns. Data centers manage and store vast quantities of sensitive information, including personal, financial, and corporate data. As a result, they are frequent targets of cyberattacks. Breaches can result in severe financial and reputational damage, prompting constant investment in advanced cybersecurity infrastructure and regulatory compliance mechanisms [17].

Meanwhile, as the Internet of Things (IoT) continues to grow, the volume of data requiring real-time processing has increased significantly. This rise presents new latency and bandwidth challenges for conventional centralized data centers, which often struggle to efficiently support the responsiveness demanded by distributed IoT networks. Although architectural solutions, such as edge computing and fog computing address these issues, they add additional layers of complexity and cost [11].

In addition to supporting digital consumer services, terrestrial data centers process vast volumes of space-derived data, including imagery and telemetry from satellites. The transmission of such data from orbit to ground stations and then to terrestrial data centers introduces latency and relies on limited spectrum availability. As the number of small satellites and Earth observation missions increases, this bottleneck becomes more pronounced, hindering timely data analysis and decision-making [18]. These challenges, ranging from high energy and water consumption to land constraints, environmental impact, and latency, underscore the limitations of traditional terrestrial data center architectures. As demand for data processing escalates and the environmental and infrastructural costs of terrestrial data centers rise, the exploration of alternative solutions becomes increasingly justified.

III. The Concept of Space-based Data centers

The prospect of deploying data centers in space is increasingly gaining traction as a feasible future alternative to terrestrial infrastructures. Several leading technology corporations and governmental bodies, including the European Union through its ASCEND project, are actively exploring this alternative. The ASCEND initiative envisions the deployment of orbital data center stations powered by high-capacity solar power plants, potentially generating several hundred megawatts. The primary objective is to significantly reduce the environmental impact of information technology infrastructure by harnessing solar energy in the space environment, thereby mitigating the carbon footprint associated with traditional, Earth-based data centers.

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One potential solution is the utilization of a satellite networking system. This approach would entail the collection of data from Earth, followed by its transmission to space for processing and storage. The system would employ photonics and optical technology, thereby reduce energy consumption and increase in the data transmission speed. Such a system would be immune to the effects of adverse weather conditions or natural disasters, ensuring uninterrupted communication. In a collaborative effort, Japan's NTT has joined forces with SKY Perfect JSAT to develop a satellite network system, designated as the Space Integrated Computing Network. As stated in [13], the Space Integrated Computing Network is a novel infrastructure to be constructed by combining NTT's network and computing infrastructure with SKY Perfect JSAT's space assets and business. The system will integrate multiple orbits from the ground to High-Altitude Platform Stations (HAPSs) flying at high-altitude, Low Earth Orbit (LEO) satellites and Geostationary orbit (GEO) satellites. The constituent components will be connected to the ground via an optical wireless communication network, thereby forming a constellation that will enhance the processing of various data sets through distributed computing. Furthermore, it will facilitate access to terrestrial mobile devices, thereby extending the service coverage to an ultra-wide range. Each satellite will be equipped with computing functions that can process data, connecting to a network of satellites that perform the function of an optical communications data center. This eliminates the necessity for data to be transmitted back to the Earth for processing and analysis, which impedes data traffic and consumes a considerable amount of power. Here is a description of each potential satellite orbit: (i) Low Earth Orbit: It is located at an altitude of between 200 and 2000 km above the earth, and is characterized by low latency time, better performance for real-time communications, LEO satellites move quickly around the Earth, requiring satellite constellation networks to ensure continuous coverage, (ii) Medium Orbits (MEO–Medium Earth Orbit) Approximately located at 2000 to 35786 km: fewer satellites needed for global coverage compared to LEO, MEO satellites can operate at similar efficiencies to fibre optics, even in remote areas of the world, and they are most often used for GPS, (iii) Geostationary Earth Orbit (GEO): It is located about 5000 km above the earth. GEO has the following characteristics: (i) A single satellite can cover a large part of the Earth's surface, (ii) Satellites remain stationary concerning a fixed point on Earth, and (iii) GEO satellites yield high ROI thanks to their high reliability and long life spans.

The scenario of a space-integrated computing network showing the role of the space data center in the context of a space application is shown in Figure 1. The application context of the SDC presented in Figure 1 is that of enabling low latency via free space optical networks for a space-based IoT (Space IoT) application. The SDC executes IoT data storage and Artificial Intelligence (AI) related processing. In this case, it is identified that computing platform-related applications using SDCs do not experience service interruptions from natural disasters. This provides an additional layer of physical level protection against the occurrence of natural disasters. Hence, the use of SDC is beneficial for use in regions with high susceptibility to natural disaster occurrence. The realization of the SDC in the scenario presented in Figure 1 recognizes the capability of SDCs to integrate with other non-terrestrial network entities such as HAPSs.

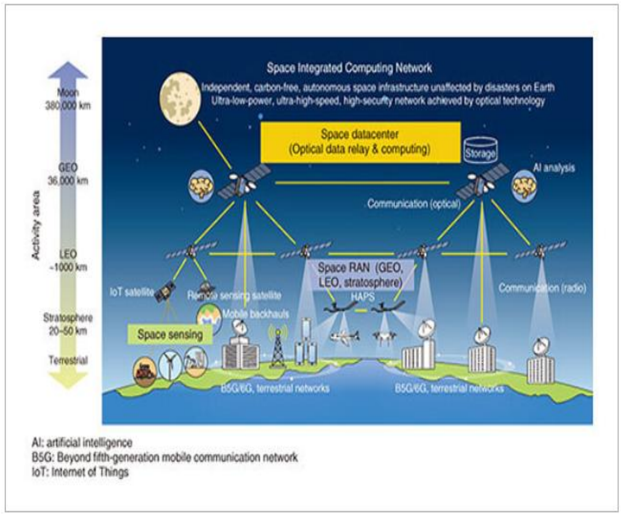

Figure 1. Space Integrated Computing Network.

The application context presented in Figure 1 is of enables the SDCs or a constellation of SDCs to accept, store, and process data from multiple Earth observation satellites. This is crucial considering the large number of in-orbit remote sensing satellites. The hosting of satellite systems enabling SDC functionality requires the derivation of global continuous coverage. This requires the specification of important orbital parameters such as: (i) Satellite orbital parameters, (ii) Orbital inclination, (iii) Number of orbital planes, and (iv) Satellite spacing. In the case of satellite orbital parameters, it is important to have global coverage with low latency. This requires ensuring proper organization of orbiting satellites. The important factors to consider are the orbital altitude. The orbital altitude influences: (i) Field of View: The higher the altitude, the wider the field of view of each satellite, but this can increase communication latency, (ii) Exposure to Space Debris: Lower altitudes may have a higher density of space debris, which increases the risk of collision, (iii) Lifespan: Satellites in lower orbit undergo greater atmospheric drag, which can reduce their lifespan unless regular orbit correction manoeuvres are performed.

The orbital inclination’s related parameters are associated with latitudinal coverage and population access. The relevant parameters in this case are the latitudinal coverage and associated population access. The inclination determines the latitudes covered by the satellite. For example, an inclination of 90 degrees allows coverage up to the poles. The number of orbital planes also describes satellite distribution and influences the coverage density. Distributing satellites across multiple orbital planes allows for uniform coverage of the

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Earth's surface, and Coverage Density. The more orbital planes there are, the denser the coverage, thus reducing poorly covered or uncovered areas. The use of multiple orbital planes also reduces interference between satellites. This is because it enables increased satellite spatial separation. In addition, the satellite spacing is an important orbital parameter as it influences : (i) Intervals: Satellites should be spaced evenly in each orbital plane to avoid interference and ensure uniform coverage, (ii) Revisit Time: Spacing affects the time it takes for a satellite to return above the same region (orbital period) in a given orbital altitude i.e., LEO, MEO and GEO, and (iii) Load Balancing. Proper spacing balances the communication load across the satellite network, ensuring optimal performance and reliability.

Besides the orbital aspects, the use of SDCs should consider their role in future network architectures alongside the evolution of crucial networking protocols. These aspects are crucial for describing the supported and realized data transmission. The data transmission protocol aspects are: (i) Photonics: These data centers will use photonics through Innovative Optical Wireless Network (IOWN) technology. This technology reduces satellite power consumption and allows satellites to withstand radiation better. (ii) TCP/IP over Satellite: The TCP/IP protocol, which forms the basis of the Internet, can be adapted for satellite communications. However, adjustments are necessary to accommodate latency and higher packet losses, and (iii) DTN (Delay-Tolerant Networking): This protocol is designed for environments where delays and interruptions are frequent, such as space. DTN stores and retransmits data until it can be delivered, ensuring reliable communication despite difficult conditions. The realization of low-latency and high data rate communications in SDC networks requires the use of optical communications. This is because optical communications offer higher data rates and better security. It is used for communications between satellites and between satellites and ground stations.

The realization of meaningful application-based communications with SDCs requires data exchange with ground stations. The required network architecture elements enabling this capability are: (i) ground stations, and (ii) relay (forwarding) satellites. Ground stations enable the establishment of a connection between higher-capacity terrestrial data centers and orbiting SDCs. This is useful in establishing uplink, and downlink connections. Relay satellites enable the execution of forwarding communications between orbiting SDCs and ground stations. This can include SDC satellites in low Earth orbit (LEO), medium Earth orbit (MEO), and geostationary Earth orbit (GEO), thereby ensuring global coverage, and reducing latency. In this case, the relations of SDCs with satellites in this context are presented in Figure 2.

The benefits and advantages of using SDCs are identified as: (i) Global coverage: The potential exists for SDCs to provide more equitable access to data services across the globe, (ii) Enhanced security: The physical isolation of SDCs offers additional protection against certain security threats, due to the reduced risk of external interference, (iii) Abundant solar energy. In the absence of atmospheric interference, solar panels in space could harness uninterrupted sunlight, thereby providing a constant and renewable energy source. The utilization of SDCs would not constitute an additional burden to the grid. In addition, the use of SDCs has a reduced environmental impact. By moving data centers off-planet, their direct impact on terrestrial ecosystems could be minimized.

Furthermore, SDCs benefit from natural cooling. The cold vacuum of certain locations in space may offer an optimal environment for cooling heat-generating SDC.

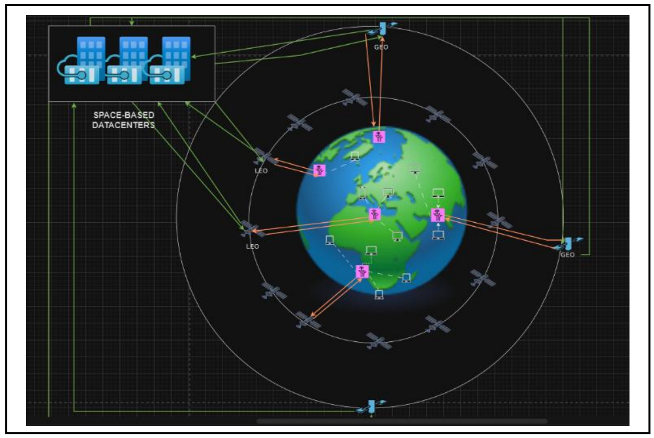

Figure 2. Space-based data center communications with satellites across the altitudes of LEO, MEO, and GEO.

Although the establishment of general-purpose large-scale SDCs (with power consumption more than 5.5 GW) may not be a realistic proposition soon, there are specific applications where large-scale SDCs could prove beneficial. Smaller SDCs with power consumption in the range of tens of MWs can be beneficial in (i) Scientific Research: The processing of data from space-based sources could prove advantageous for the analysis of extensive datasets generated by space telescopes, Earth observation satellites, and other scientific instruments in orbit, (ii) Disaster Recovery and Backup: Space-based data storage has the potential to serve as an ultra-secure backup solution for critical data, protected from terrestrial disasters, (iii) Edge Computing for Space Operations: As human activities in space increase, having computing resources in orbit could support various space operations, from satellite management to future lunar or Mars missions, and (iv) Global Communications Infrastructure: Although not yet at the level of full-scale data centres, satellite constellations providing Internet services are already exhibiting some of the principles that could lead to more sophisticated space-data processing capabilities.

IV. TECHNICAL CHALLENGES AND CONSIDERATIONS

The discussion in this section has two aspects. The first focuses on the SDC's components. The second focuses on the discussion of the application architecture for the SDCs in this case. The architecture is designed for SDC-anchored web development.

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A. SDCs – Components and Enablers

SDCs present a promising alternative to traditional terrestrial facilities, particularly in addressing challenges related to energy consumption, environmental sustainability, and data latency. The development and deployment of SDCs involve a range of complex technical and operational challenges that must be addressed to realize their full potential.

One of the challenges is the launch and deployment of SDC infrastructure into orbit. Despite the significant reduction in launch costs in recent years, driven by advancements in aerospace technology and the increased availability of commercial launch vehicles [14], the expense associated with transporting sophisticated computing equipment to space remains substantial. In addition to cost, the physical design of these systems must account for the harsh launch conditions and the extreme space environment. Equipment must be robust enough to withstand vibrations and temperature fluctuations, while being resilient to radiation exposure, necessitating the use of radiation-hardened components.

The implementation of SDCs introduces complex regulatory considerations. The operation of such systems raises issues related to orbital rights, space debris mitigation, and international jurisdiction over data and communications. These challenges are compounded by the current lack of comprehensive global regulatory frameworks governing commercial data infrastructure in orbit. Effective policy will be essential in ensuring the responsible and sustainable use of orbital space for data storage and processing.

Energy management represents another critical aspect of SDC deployment. Although solar energy is abundant in space, the practical realization of a continuous and efficient power supply requires careful consideration. Energy systems must be designed to capture solar radiation effectively while accounting for panel degradation caused by radiation over time. Moreover, during eclipse periods, when solar power is temporarily unavailable, sufficient energy storage must be ensured through the integration of high-capacity batteries and intelligent power control systems.

Scalability is also a key consideration in SDC design. Unlike terrestrial data centers, which can expand horizontally by adding more physical infrastructure, orbital deployment is constrained by launch vehicle capacity and spaceborne volume limits. However, the relative abundance of orbital slots offers opportunities for distributed deployment. A constellation-based approach to SDCs could provide a scalable solution by enabling the deployment of multiple units across various orbital positions. This approach would also enhance redundancy and reduce latency by placing processing units closer to data sources in space.

Cost-effectiveness remains one of the most significant barriers to widespread adoption of SDCs. The high capital expenditure required for research, development, fabrication, launch, and maintenance must be weighed against long-term operational savings and environmental benefits. These benefits include a substantial reduction in terrestrial resource consumption, particularly water and land, and a minimized carbon footprint, especially when powered entirely by space-based solar energy systems. Nonetheless, whether SDCs can achieve economic competitiveness with terrestrial data centers in the near future remains an open question.

B. Proposed Low-Scale SDC Configuration

In this study, a low-scale SDC configuration is proposed as a viable and scalable architecture for orbital data processing. The model envisions a compact system with fewer than twenty servers, denoted as $N_s < 20$, optimized to minimize total mass and reduce launch costs. The overall system mass, M_{total}, is a summation of contributions from the servers, power subsystem, communication components, and thermal management infrastructure. The total SDC launch mass SDC is denoted M_{total} and given as:

$$M_{total} = M_s \cdot N_s + M_p + M_c + M_t \quad (1)$$

M_s is the mass of a single server, M_p corresponds to the power system mass, M_c is the mass of the communication subsystem, and M_t is the mass of the thermal management system.

The SDC's power budget is driven by the total average power consumption P_{avg} , which aggregates the power requirements of the computing, communication, and control electronics. This is expressed as:

$$P_{avg} = N_s \cdot P_s + P_{comm} + P_{control} \quad (2)$$

P_s denotes the power consumed per server, P_{comm} is the power consumption of the communication system. and $P_{control}$ is the power consumption of the operational control units.

Energy generation is handled through photovoltaic solar arrays. The total daily energy produced in orbit and accessible for SDC operation is denoted E_{day}, and given as:

$$E_{day} = \eta_{solar} \cdot A_{panel} \cdot G_{orbital} \cdot t_{illum} \quad (3)$$

where η_{solar} represents solar conversion efficiency, A_{panel} is the area of the solar panels, $G_{orbital}$ is the solar irradiance in orbit (approximately $1361\ W/m^2$), and t_{illum} is the duration of sunlight exposure per orbit.

During eclipse phases, the system relies on onboard batteries with energy storage capacity E_{bat} to maintain operations. This requires that $E_{bat} \geq P_{avg} \cdot t_{eclipse}$, ensuring sufficient energy availability when solar input is absent. Efficient thermal management is a critical design consideration, especially in the vacuum of space. Instead of traditional fluid-based cooling, the SDC relies on radiative heat dissipation, governed by the Stefan–Boltzmann law. The total radiated thermal power , Q_{rad} is modeled as

$$Q_{rad} = \epsilon \cdot \sigma \cdot A_{rad} \cdot \left(T^4 - T_{space}^4\right) \quad (4)$$

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where ϵ is the emissivity of the radiator surface, σ is the Stefan–Boltzmann constant, A_{rad} is the surface area of the radiators, T is the radiator surface temperature, and T_{space}, approximately 3K, is the ambient temperature of space.

The relation in (4) serves to identify that the proposed SDC will be cooled via the radiation. In this case, heat pipes from the server interior will be connected to SDC exterior radiators. This ensures that server electronics are maintained at the requisite operational temperature.

Communication between the SDC and terrestrial stations is achieved through high-gain directional antennas, operating in the X or Ka bands. The link budget is constrained by the signal-to-noise ratio (SNR), given by the equation:

$$SNR = \frac{P_t \cdot G_t \cdot G_r \cdot \lambda^2}{(4\pi d)^2 \cdot k \cdot T_{sys} \cdot B} \quad (5)$$

P_t is the transmit power, G_t and G_r are the gains of the transmit and receive antennas respectively, λ is the operating SDC wavelength, d is the distance from the SDC to Earth, k is Boltzmann's constant, T_{sys} is the system noise temperature, and B is the communication bandwidth.

Through the coordinated integration of these subsystems into a cohesive and space-resilient design, the low-scale SDC illustrates the feasibility of deploying efficient and environmentally sustainable data processing infrastructure in orbit. This approach reduces reliance on land and water, and introduces new paradigms in distributed computing and remote sensing data processing, setting the stage for more ambitious deployments in the future.

C. SDC – Application Architecture

The proposed SDC architecture enables the remote development and hosting of websites using space-based computational infrastructure. Situated in LEO, the SDC is configured to support interactive web development tasks by Earth-based developers who access hosted tools, libraries, and development environments through satellite Internet connections.

A typical SDC pass over a ground station provides a communication window of approximately 7 minutes, or $T_w = 420$ seconds. Given the average round-trip latency of $L = 0.12$ seconds, the maximum number of potential bidirectional communication epochs per pass is $N_e = \frac{T_w}{L} \approx 3500$. This suggests that despite inherent latency, a significant number of interactions can be supported during each orbital pass, allowing developers to upload scripts, receive feedback, and test website functionality.

To manage this interaction efficiently, the SDC integrates interconnected logical entities. Commands issued by a developer from Earth are first received by the Script Receiver Entity (SSRE), which acts as the primary interface for incoming web development instructions. These commands, denoted $C_d(t)$, are passed to the Web Rendering Entity (WRE), responsible for executing them and rendering the resulting webpage. The rendered webpage state $R(t)$ evolves based on the input command as $R(t + \Delta t) = f\big(C_d(t)\big)$, where $f(\cdot)$ is a function that maps developer input to the updated state of the web interface.

Given the latency sensitivity of space-based communication, the architecture includes a Render Pause Entity (RPE), which temporarily halts script execution when latency levels exceed tolerable thresholds. This behavior is informed by the Communication Profile Entity (CPE), which continuously monitors communication latency. Suppose the current latency measurements over a window of n epochs are $\{L_1, L_2, \dots, L_n\}$; the moving average latency $\bar{L}$ is computed as $\bar{L} = \frac{1}{n}\sum_{i=1}^{n} L_i$. If the current latency L_c exceeds the average by a defined margin δ such that $L_c > \bar{L} + \delta$, then the CPE signals the RPE to activate, resulting in a temporary suspension of script execution, effectively setting a script execution flag $S_{exec} = 0$. This mechanism prevents unstable page rendering due to excessive delay.

In parallel, web content that has already been developed and is ready for access is managed by the Web Access Entity (WAE). When user requests are received, either from developers or end-users, the CPE determines whether the request pertains to command execution or content retrieval. If it concerns access, the request is routed to the WAE, which retrieves and prepares the corresponding webpage $P(t)$ for downlink. These components interact bidirectionally: the uplink allows for script transmission and page development, while the downlink returns rendered output and user-facing web pages. All data exchanges between users and the SDC are routed through an Internet Exchange Point (IXP), which connects the orbital system to terrestrial Internet infrastructure. The final content delivery process can be modeled as $P_{out}(t) = g\big(P(t), U(t)\big)$, where $U(t)$ is the user request and $g(\cdot)$ denotes the IXP routing function.

Through this architecture, the SDC demonstrates the feasibility of low-latency, interactive web development and hosting in orbit. It addresses key latency challenges through computational buffering, latency-aware pausing, and an intelligent routing scheme. The resulting system not only serves as a viable complement to terrestrial web services but also establishes the foundation for scalable, environmentally responsible orbital computing platforms.

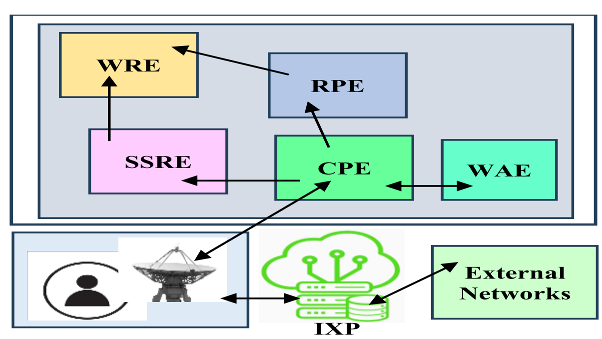

Figure 3. Architecture showing the relations between the entities WRE, SSRE, RPE, CPE, and the WAE.

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V. CONCLUSION

The concept of Space Data Centers (SDCs) represents a convergence of data technology and space exploration. The miniaturization of electronics and a reduction in launch costs could render aspects of this concept feasible. From the perspective of near-term prospects, it is probable that there will be more advances in the processing capabilities of data in space rather than the establishment of comprehensive orbital data centres. Such developments could encompass the implementation of enhanced onboard computing for satellites and the utilization of limited-scale experimental platforms. SDC use in the medium term presents opportunities that should be further analyzed. From this perspective, we might see the deployment of small, specialized data centers in Low Earth Orbit (LEO). The discussion presents an application context for the LEO based SDC. The application is one in which the SDC enables web development and accessing developed web pages. Such an application is considered to have a significant role due to the pervasive deployment and use of web portals on existing data centers (with a high environmental toll). The research presents an architecture enabling subscribers to access the web page developed via rendering and execution aboard the SDC. Future work will focus on enabling additional functionalities for the SDCs. Advances in autonomous maintenance and space-based power generation will be key to making SDCs feasible, setting the stage for larger future projects. In the long term, as human space exploration and application development improves, the development of a space-based data infrastructure may become a necessity. Future work will address how the use of the medium earth orbit by the SDC can be sustainably realized. In addition, future work will address the need to design web development protocols that are suited to the space-based data center as a precursor to the conduct of performance analysis.

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